TTI: 0-6954

MASH TL-3 EVALUATION OF GUARDRAIL TO RIGID BARRIER TRANSITION ATTACHED TO BRIDGE OR CULVERT STRUCTURE

ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01
Crash testing performed at:
TTI Proving Ground
3100 SH 47, Building 7091
Bryan, TX 77807

Test Report 0-6954-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE

COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
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16. Abstract

TTI researchers performed an extensive literature review of bridge railing transitions crash tested to *MASH* TL-3, and incorporated the information obtained from this review into the design and details for the new transition testing developed for this project. TTI researchers developed concepts for the new transition anchored to a concrete wing wall.

TTI researchers developed a full-scale, three-dimensional finite element model of the guardrail transition. The modeling effort included developing and validating a subcomponent level model of the post installed on concrete.

Upon completion of the simulations, TTI researchers processed the results and assessed the likelihood of the transition system passing the required *MASH* crash tests. TTI researchers noted the design deficiencies and recommended design modifications to the system to mitigate those deficiencies.

TTI researchers developed full-scale test installation drawings of the design after the finite element model simulations were completed and all the results were reviewed with favorable results. After approval of the test installation drawings by TxDOT, construction of a full-scale test installation for crash testing commenced, and crash tests were performed on the full-scale test installation. The Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure, used on the upstream and downstream ends, performed acceptably for *MASH* TL-3 transitions.

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and the
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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The researcher in charge of the project was William F. Williams, P.E. #71898.

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TTI PROVING GROUND DISCLAIMER

The results of the crash testing reported herein apply only to the article tested.

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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 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 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	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. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

CHAPTER 1: INTRODUCTION

1.1 PROBLEM

The current Texas Department of Transportation (TxDOT) high-speed transition is approximately 19 ft long and the approximate length of metal beam guard fence end treatment is 50 ft long, for a total 69 ft in length. In situations where it was appropriate, if there was a transition from flexible rail to rigid rail that attached to the top of a culvert, wing wall, or bridge deck, the rigid rail would end on the bridge before the end of the bridge, and start the transition on the culvert, wing wall, or bridge deck. This would allow TxDOT to reduce the required distance between the end of the bridge and the intersecting roadway or driveway to a maximum length of 50 ft. The purpose of this project was to develop a transition that could be anchored on top of a concrete deck or wingwall and thus reduce the length of transition needed off the bridge structure.

1.2 BACKGROUND

In the continued advancement and evolution of roadside safety testing and evaluation, a research effort completed in 2009 resulted in a document published by the American Association of State Highway and Transportation Officials (AASHTO), entitled *Manual for Assessing Safety Hardware* (*MASH*), which supersedes the previous crash test and evaluation guidelines (*1*). This document was updated in 2016 and is the current standard used to evaluate crash tests (*2*). Changes incorporated into the guidelines include new design test vehicles, revised test matrices, and revised impact conditions.

1.3 OBJECTIVE/SCOPE OF RESEARCH

Five tasks were undertaken to develop a crashworthy transition design that reduces the required distance between the end of the bridge and an intersecting roadway or driveway and meet the crash requirements of *MASH* TL-3.

1.3.1 Task 1. Project Management and Research Coordination

Working in conjunction with the project team, TTI researchers conducted a Value of Research (VoR) assessment. In developing the VoR, TTI researchers identified sources for both qualitative and economic data, such as TxDOT construction bids (economic), material price lists from vendors (economic), pavement performance data (economic), and district personnel (qualitative). Table 1.1 illustrates the qualitative and economic benefit areas designated by TxDOT for this project.

TTI researchers completed the VoR Template, including the economic based calculations, the description of economic variables used within the calculations, and the qualitative values of the selected benefit areas.

Table 1.1. Qualitative and Economic Benefit Areas.

Selected	Functional Area	QUAL	ECON	Both	TxDOT	State	Both
X	Level of Knowledge	X			X		
X	Reduced User Cost		X			X	
X	Reduced Construction, Operations, and Maintenance Cost		X			X	
X	Engineering Design Improvement			X			X
X	Safety			X			X

TTI researchers evaluated the initial submission of the VoR Template and revised as needed as TTI researchers continued to identify qualitative and economic VoR data during the course of the research project.

1.3.2 Task 2. Literature Review

TTI researchers performed an extensive literature review of bridge railing transitions crash tested to *MASH* TL-3 and documented the findings of this review in a brief technical memorandum for this task. TTI researchers incorporated the information obtained from this review into the design and details for the new transition testing developed for this project. Results from this task are presented in Chapter 2.

1.3.3 Task 3. Develop Concepts, Engineering Design, and Component Testing

TTI researchers developed four concepts for the new transition. The design would anchor the transition posts on a concrete slab and a concrete wingwall. Posts were located in the transition onto the concrete slab or wall. TTI researchers performed engineering analyses on the new post designs, and in addition, developed engineering drawings of the new transition designs considered for this project. TTI researchers recommended four post designs to TxDOT for review. TxDOT selected two post designs for full-scale component testing. TTI researchers performed pendulum testing of posts (three posts per design [six tests total]) and compared them to strength tests performed on embedded posts in soil. Once all the available testing data were reviewed, TTI researchers with input TxDOT, selected an anchored post design for finite element modeling simulations performed in Task 4. Task 3 was performed in conjunction with the simulation effort in Task 4. Chapter 3 presents the results of Task 3.

1.3.4 Task 4. Finite Element Model Simulations

TTI researchers developed a full-scale three-dimensional finite element model of the guardrail transition. The modeling effort incorporated developing and validating a subcomponent-level model of the post installed on concrete, which TTI researchers validated using the results of the dynamic pendulum testing from Task 3.

Once the subcomponent-level model was validated, TTI researchers used it in the system-level finite element model to develop a full-system model of the guardrail to concrete barrier transition. Previously validated component models including, but not limited to, the metal guardrail model and soil-and-post model were included into the system model to achieve sufficient reliability of the full-system model.

TTI researchers performed dynamic vehicle impact analysis of the transition design to evaluate the expected performance of the system in full-scale crash testing once the full-system model was developed.

MASH TL-3 requires at least two crash tests of the transition system at the location where the stiffness or shape of the system changes. The transition system has two locations where such changes take place. One location is the upstream transition, where the W-beam guardrail in soil transitions to the guardrail on concrete. The other location is the downstream transition, where the guardrail on concrete transitions or attaches to the concrete barrier.

Due to the presence of two clear transition locations (upstream and downstream), TTI researchers performed dynamic vehicle impact simulations for both locations. The four simulation cases were:

1. Upstream End, *MASH* Test 3-20 Condition.
2. Upstream End, *MASH* Test 3-21 Condition.
3. Downstream End, *MASH* Test 3-20 Condition.
4. Downstream End, *MASH* Test 3-21 Condition.

Tests 3-20 and 3-21 involve small passenger car and pickup truck vehicle impacts, respectively. The impact speed and angle for both tests are 62 mi/h and 25°, respectively.

TTI researchers processed the results and assessed the likelihood of the transition system passing all four *MASH* crash tests upon completion of the simulations. TTI researchers noted the design deficiencies and recommended design modifications to the system to mitigate those deficiencies. Chapter 4 presents the results of Task 4.

1.3.5 Construction of Full-Scale Test Installation and Crash Testing

TTI researchers developed full-scale test installation drawings of the design after the finite element model simulations were completed, and all the results had been reviewed with favorable results. TTI researchers submitted these drawings to the TxDOT project team for review and approval. After approval of the test installation drawings was received, construction of a full-scale test installation for crash testing commenced. Similar to the simulation effort, the following four full-scale crash tests were to be performed on the full-scale test installation:

1. *MASH* Test 3-20, 1100C Small Car, 62 mi/h at 25° impact angle on the Upstream End of the Transition Design.
2. *MASH* Test 3-21, 2270P Pickup Truck, 62 mi/h at 25° impact angle on the Upstream End of the Transition Design.

3. *MASH* Test 3-20, 1100C Small Car, 62 mi/h at 25° impact angle on the Downstream End of the Transition Design.
4. *MASH* Test 3-21, 2270P Pickup Truck, 62 mi/h at 25° impact angle on the Downstream End of the Transition Design.

However, based on the final design details developed for this project, *MASH* Test 3-20 impacting the downstream end of the transition (Item 3 below) was optional, and therefore not performed.

After the completion of the crash testing, TTI researchers prepared this technical report that summarizes the crash test results performed on the transition design. TTI researchers documented and summarized all the crash tests results and fully documented material specifications used to construct the test installation. In addition, TTI researchers included all final drawings and details used to construct the test installation in this technical report.

CHAPTER 2: LITERATURE REVIEW*

2.1 INTRODUCTION

A literature review was performed and completed for this project. The literature review satisfies the requirement of Task 2. A brief summary of the projects that were reviewed for this study follows.

2.2 DEVELOPMENT AND IMPLEMENTATION OF THE SIMPLIFIED MGS STIFFNESS TRANSITION

Report No. TRP-03-210-10/TRB 2012 Paper No. 12-3367

The finding in Report No. TRP-03-210-10/TRB 2012 Paper No. 12-3367 was considered for this project (*3*). The Midwest Roadside Safety Facility (MwRSF) researchers developed a simplified version of the original MGS stiffness transition by utilizing two common sizes of steel posts, and it was full-scale crash tested according to *MASH* TL-3.

The design of the stiffness transition for this project included a standard Midwest Guardrail System (MGS), a previously accepted thrie beam approach guardrail transition (AGT) system, and an asymmetrical W-beam to thrie beam transition element. The thrie beam AGT consisted of a nested 12-gauge thrie beam attached to W6×15 steel posts at half-post or 37½-inch spacings, which represented a critical configuration (one of the stiffest AGT) after researchers reviewed the previously accepted FHWA AGT systems.

Test Nos. MWTSP-2 and MWTSP-3 were performed on this stiffness transition design. Test No. MWTSP-2 was performed according to test designation *MASH* Test No. 3-21 with a 2270P pickup truck. Test no. MWTSP-3 was performed according to test designation *MASH* Test No. 3-20 with an 1100C small car. Figures 2.1 and 2.2 show the test impact drawings for Test Nos. MWTSP-2 and MWTSP-3, respectively.

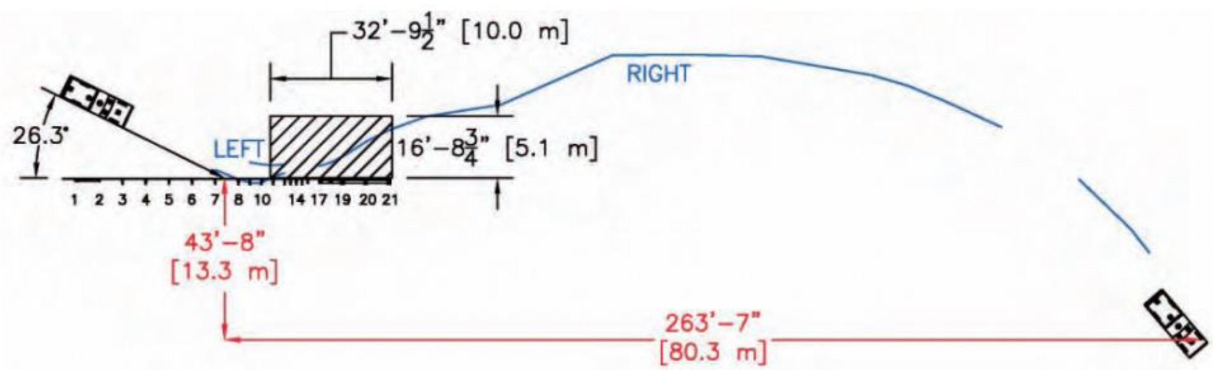


Figure 2.1. Test Impact Drawings for Test No. MWTSP-2.

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

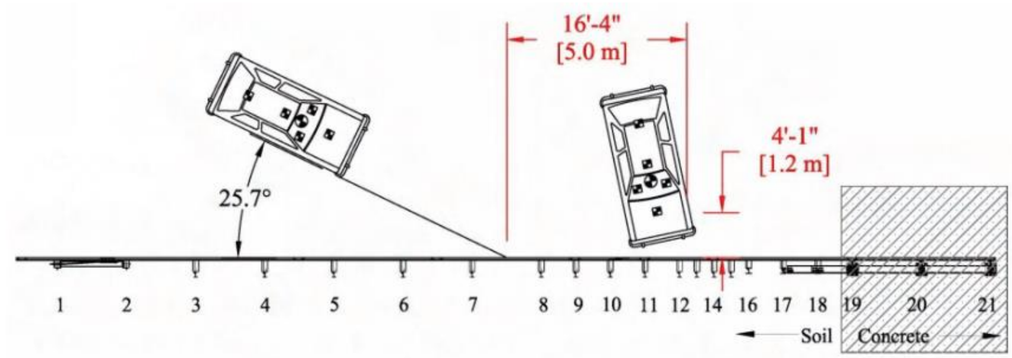


Figure 2.2. Test Impact Drawings for Test No. MWTSP-3.

A new, simplified steel-post stiffness transition between the MGS and a thrie beam AGT previously accepted by FHWA was developed and tested for this project. This system consists of standard steel posts and an asymmetric W-to-thrie transition element. A very stiff thrie beam guardrail transition was used during the full-scale crash test. This new system satisfied all *MASH* TL-3 criteria. Figure 2.3 shows the details of the recommended transition design for the MGS system to thrie beam and tube bridge railing using steel posts.

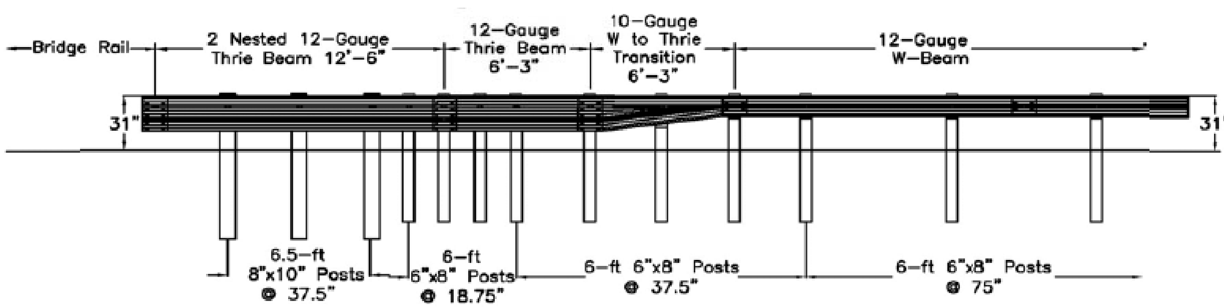


Figure 2.3. Adapted Simplified Steel-Post Stiffness Transition (Transition to Thrie Beam and Tube Bridge Railing Steel Post Version).

2.3 EVALUATION OF THE MIDWEST GUARDRAIL SYSTEM STIFFNESS TRANSITION WITH CURB

Report No. TRP-03-291-14/TRB 2015 Paper No. 15-4502/Journal of Transportation Safety and Security Paper No. 105-121

MwRSF researchers developed a W-beam to thrie beam stiffness transition with a 4-inch tall concrete curb to connect a 31-inch tall W-beam guardrail, commonly known as the MGS, to a previously developed thrie beam approach guardrail system (*4*). Standard steel posts commonly used by state departments of transportation were used for the upstream stiffness configuration.

The full-scale crash test installation used a 12 ft-6 inch long thrie beam and channel bridge railing system, a 12 ft-6 inch nested thrie beam guardrail, a 6 ft-3 inch standard 12 gauge thrie beam guardrail, a 6 ft-3 inch long asymmetrical 10 gauge W-beam to thrie beam transition segment, and a 50 ft standard 12 gauge W-beam rail attached to a simulated anchorage device. The lap-splice connections between adjacent rail sections were configured to reduce vehicle snag at the splices. The guardrail components were supported by two BCT timber posts (posts nos. 1 and 2), 16 steel guardrail posts (post nos. 3 through 15 are W6×8.5 members and posts nos. 16 through 18 are W6×15 members), and three steel bridge posts (W6×20 member, post nos. 19 through 21).

Three tests were performed for this project: Test Nos. MWTC-1, MWTC-2, and MWTC-3. Test Nos. MWTC-1 and MWTC-2 were performed according to test designation *MASH* Test No. 3-20 with an 1100C small car. Test No. MWTC-3 was performed according to test designation *MASH* Test No. 3-21 with a 2270P pickup truck. Figures 2.4 through 2.6 show the test impact drawings for Test Nos. MWTC-1, MWTC-2, and MWTC-3, respectively.

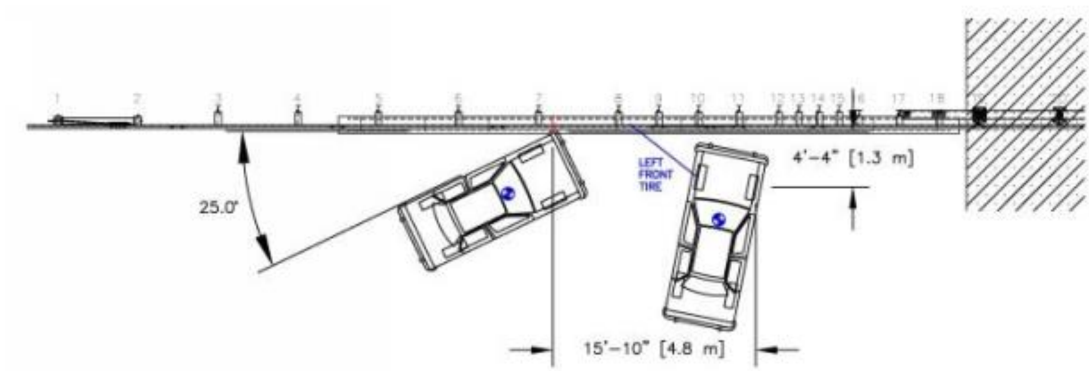


Figure 2.4. Test Impact Drawings for Test No. MWTC-1.

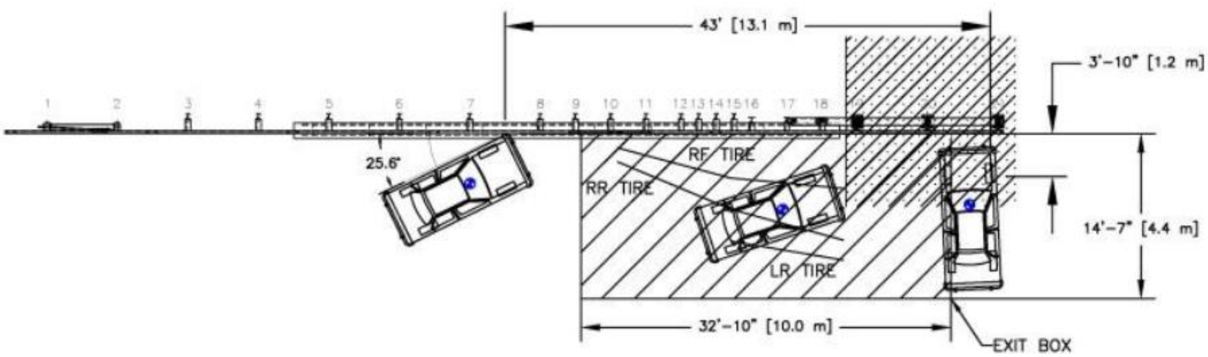


Figure 2.5. Test Impact Drawings for Test No. MWTC-2.

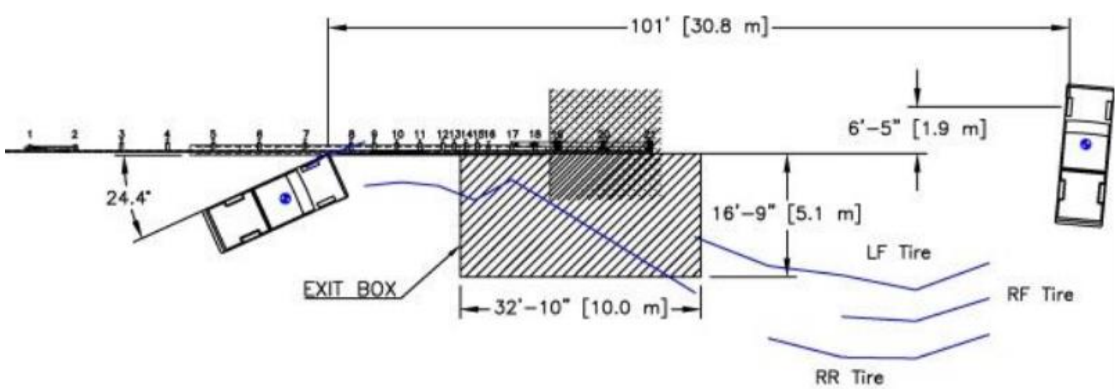
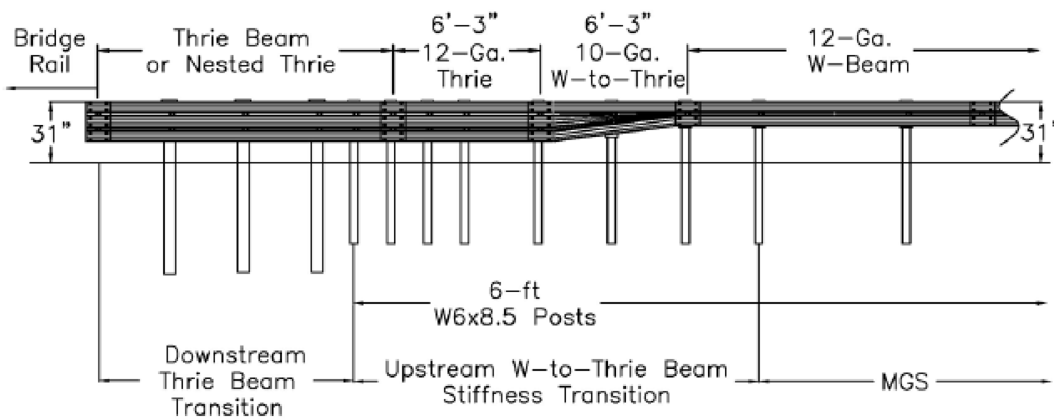


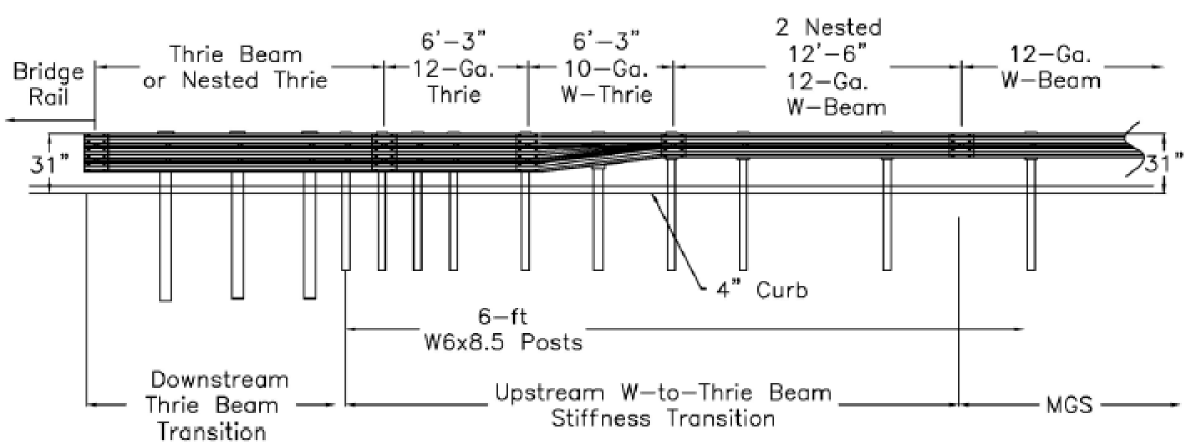
Figure 2.6. Test Impact Drawings for Test No. MWTC-3.

The initial crash test (Test No. MWTC-1) was performed according to test designation *MASH* Test No. 3-20 with an 1100C small car. The MGS Stiffness Transition with Curb did not perform acceptably for the initial *MASH* 3-20 test according to *MASH* TL-3 requirements. The front end of the 1100C vehicle penetrated under the W-beam rail while the wheel climbed up and overrode the curb. The combination of these events caused the W-beam rail to rupture at the splice adjacent to the rail elements, which eventually caused the W-beam rail to rupture at the splice adjacent to the W-beam to thrie beam transition element.

After the failed crash test, the design was modified to incorporate an additional 12 gauge W-beam segment such that 12.5 ft of nested guardrail preceded the asymmetric W-beam to thrie beam transition element. After this modification was incorporated in the stiffness transition system, Test Nos. MWTC-2 and MWTC-3 were performed with an 1100C small car and 2270P pickup truck, respectively. This modified upstream stiffness transition between the MGS and thrie beam approach guardrail transition with curb resulted in a successful completion of the *MASH* TL-3 testing matrix. Therefore, this modified system was found to satisfy current safety standards. Figure 2.7 presents the details of the recommended transition system with and without a curb tested for this project.



(a)



(b)

Figure 2.7. MGS to Thrie Beam Stiffness Transition Details (a) without a Curb and (b) with a Curb, 4-Inch Maximum Curb Height.

2.4 *MASH* TEST 3-21 ON TL-3 THRIE BEAM TRANSITION WITHOUT CURB

Report No. 9-1002-12-3

TTI researchers evaluated the impact performance of a modified transition design for approach W-beam guardrail to a rigid concrete bridge rail without a curb element beneath the transition rail (*5*). The test was performed in accordance with *MASH* guidelines following the impact conditions for Test Designation 3-21.

The surrogate bridge rail parapet was constructed according to TxDOT 36-inch single slope traffic rail (SSTR) bridge rail standards found on the TxDOT standards. The metal beam guard fence was constructed using 19 posts. Posts 1 and 2 were installed as part of the standard 31-inch ET-2000 Terminal. Posts 3 through 11 were installed as part of a standard 12 gauge W-Beam Guardrail (RWM04a). Each post in this section is a 72-inch long W6x8.5 SLP (PEW01) attached to the 12 gauge rail element using an 8-inch wood blockout. The posts in this section were placed at the mid-span of the guardrail. Between posts 11 and 13, a 10 gauge thrie beam to W-beam non-symmetric transition segment is used and is supported by a 72-inch long W6×8.5 SLP. Between post 13 and the end of the bridge parapet, a nested 12 gauge thrie beam (RTM02a) configuration is used and is supported by 84-inch long W6×8.5 posts with 6×8×18-inch wood blockouts. A 10 gauge thrie beam end shoe (RTE01b) was used to connect the nested thrie beam to the ¼-inch thick adapter plate.

The TxDOT TL-3 Transition did not perform acceptably for *MASH* Test 3-21 due to vehicle rollover. Indications of wheel snagging on the end of the concrete parapet may have contributed to the destabilization of the vehicle.

Three design changes were proposed by researchers to possibly improve the performance of the system. A short curb may be placed at the end of the parapet under the rail to help prevent wheel snagging. The steel blockout at the end of the parapet could be increased in depth to offset the rail to decrease the amount of snagging. Also, the posts in the nested section of the guardrail could be strengthened by using a larger size post and increasing the embedment depth to overall stiffen the transition and ultimately reduce the dynamic deflections. Some previous studies suggest that excessive deflection in the transition region can induce vehicle instability, but if the system becomes too stiff the upstream end of the transition section may need to be redesigned and evaluated. Figure 2.8 shows a photograph of the installation.

Figure 2.8. Thrie Beam Transition without Curb.

2.5 *MASH* TL-3 TESTING AND EVALUATION OF THE TXDOT T131RC BRIDGE RAIL TRANSITION

Project 9-1002-12; Report No. 9-1002-12-4; March 2014

TTI researchers designed and crash tested a transition design for the TxDOT T131RC Bridge Rail that would meet the strength and safety performance criteria for AASHTO *MASH* TL-3 (*6*).

The TxDOT T131RC Bridge Rail Transition consists of two nested 12 gauge thrie beam sections supported by six W6×8.5 posts spaced at 37 ½ inches on centers. The nested thrie beams connect to a 10 gauge asymmetric transition piece on the upstream end. The nested thrie beam transition was connected to a 10 gauge end shoe on the downstream end. This end shoe was anchored to the end of the T131RC Bridge Rail. The height from the finished grade to the top of the W-beam guardrail and transition was 31 inches.

The TxDOT T131RC Bridge Rail Transition contained and redirected both the 1100C vehicle and the 2270P vehicle. Overall, all *MASH* TL-3 requirements were met, therefore the TxDOT T131RC Bridge Rail Transition performed acceptably as a *MASH* TL-3 transition. Figures 2.9 through 2.11 show photographs of the test installation.

Figure 2.9. T131RC Bridge Rail Transition Impact View.

Figure 2.10. T131RC Bridge Rail Transition Connection.

Figure 2.11. T131RC Bridge Rail Transition Connection Field View.

2.6 SUMMARY AND CONCLUSIONS FROM LITERATURE SEARCH

Based on the review of this information, the following is beneficial for this project:

1. 4-inch maximum curb height.
2. 31-inch transition height with nested thrie beam elements.
3. 10 gauge asymmetric transition section supported with steel posts similar to that shown in Figure 2.2 and Figure 2.4.
4. Crash testing should be performed on the nested thrie beam area and the asymmetric transition section to confirm *MASH* acceptance.

CHAPTER 3: DEVELOP CONCEPTS, ENGINEERING DESIGN, AND COMPONENT TESTING*

3.1 INTRODUCTION

Task 3 considered the transition anchored to the top of a concrete wing wall. For this task, several post concepts were considered for the transition. Based on the information provided in the kickoff meeting held at the TxDOT Office on September 28, 2017, anchoring the new transition on top of a 12-inch wide wing wall was preferred over anchoring the posts on top of a reinforced concrete deck. As part of this task, TTI developed a general concept for the transition anchored on top of the wing wall. Figure 3.1 shows the general details of this concept.

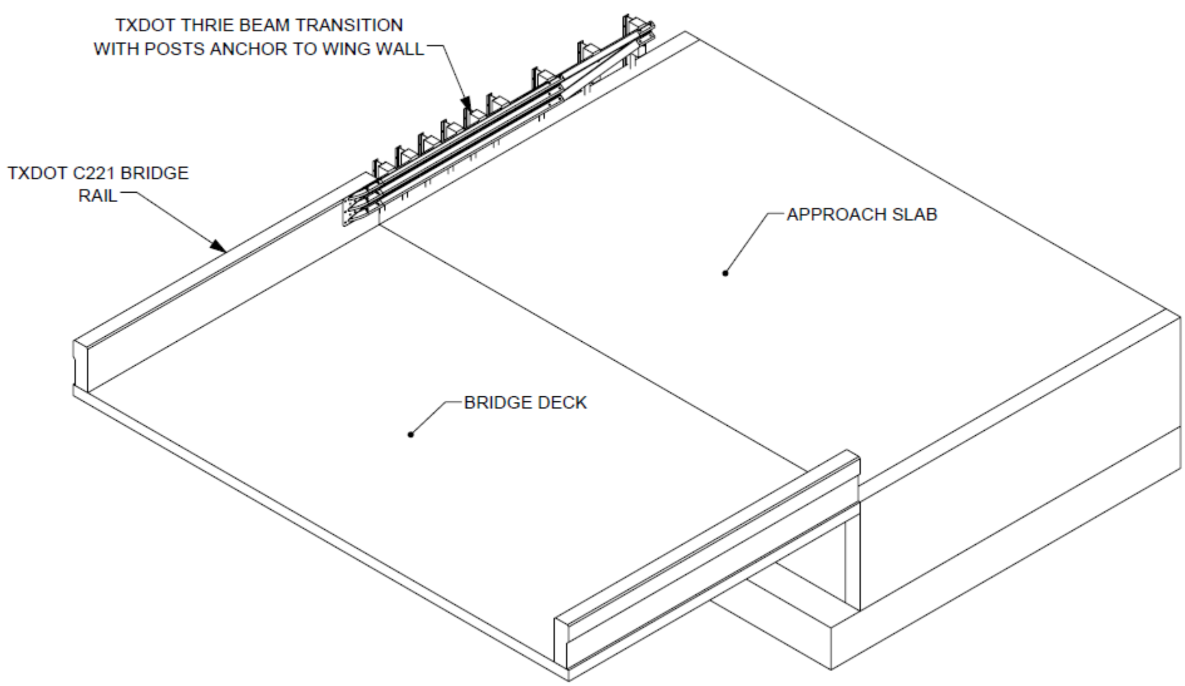


Figure 3.1. TxDOT Transition Anchored on Top of 12-Inch Wide Wing Wall.

As part of this task, TTI considered several post anchoring concepts for the new transition anchored to the top of the concrete wing wall. For the concepts presented herein, engineering analyses were performed to adequately anchor the posts to the concrete. Developing the full ultimate plastic moment capacity of the posts was the goal in the analyses. Engineering details were developed for the two options developed for Task 3 of this project. These designs

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

are presented below. The 2-bolt design anchoring to the top of the wing wall was selected for full-scale testing and Task 4 LS-DYNA Simulation.

3.2 OPTION 1. BASEPLATED POST TRANSITION DESIGN WITH RUB RAIL

Option 1 incorporates W6×8.5 steel base-plated posts anchored to the top of the wing wall using in-line Hilti Adhesive anchoring system. This design incorporates the use of a C6×8.2 steel rub rail in place of the concrete curb. This design uses the full plastic strength of the steel posts. Figures 3.2 and 3.3 present details of Option 1.

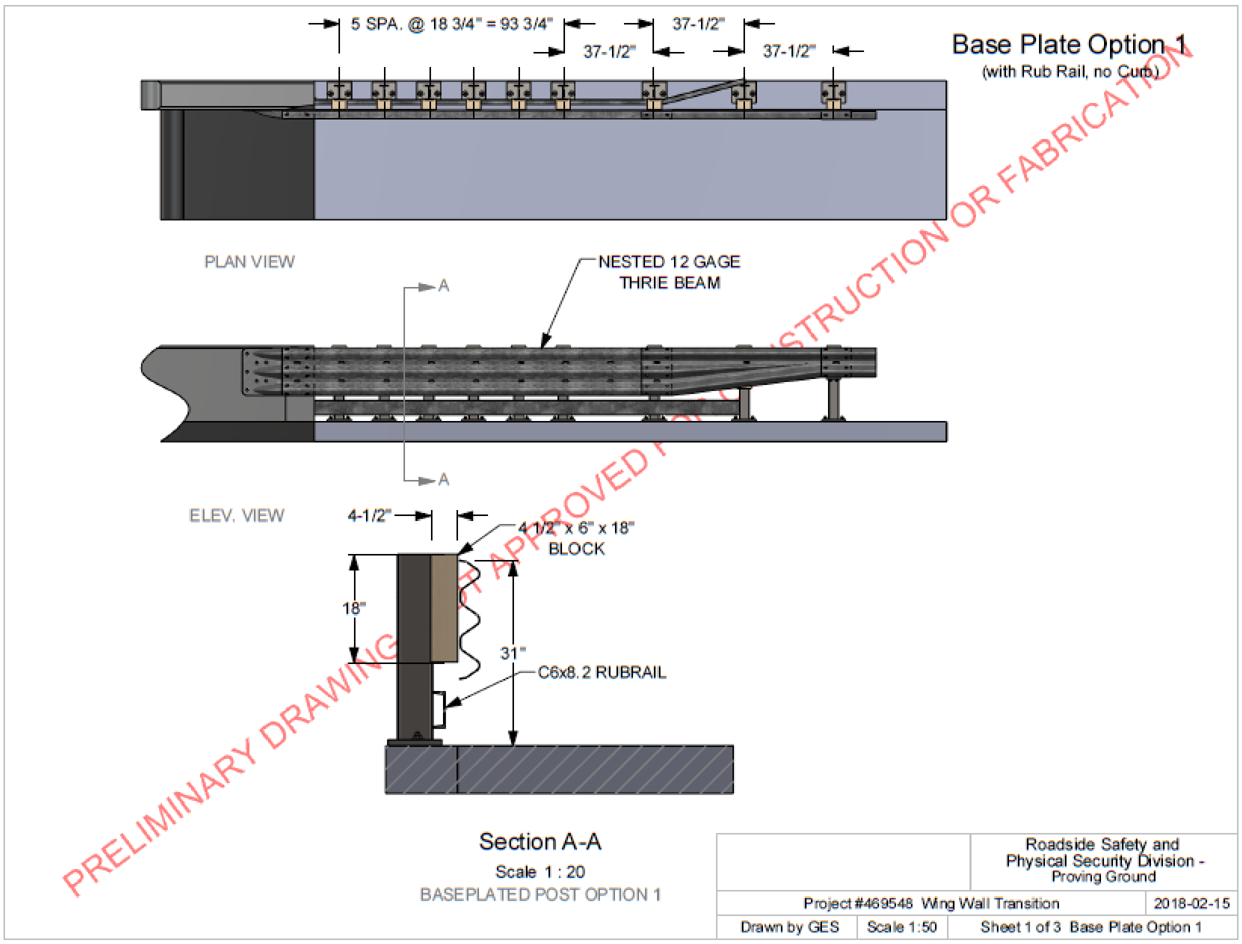


Figure 3.2. Option 1 Installation Details.

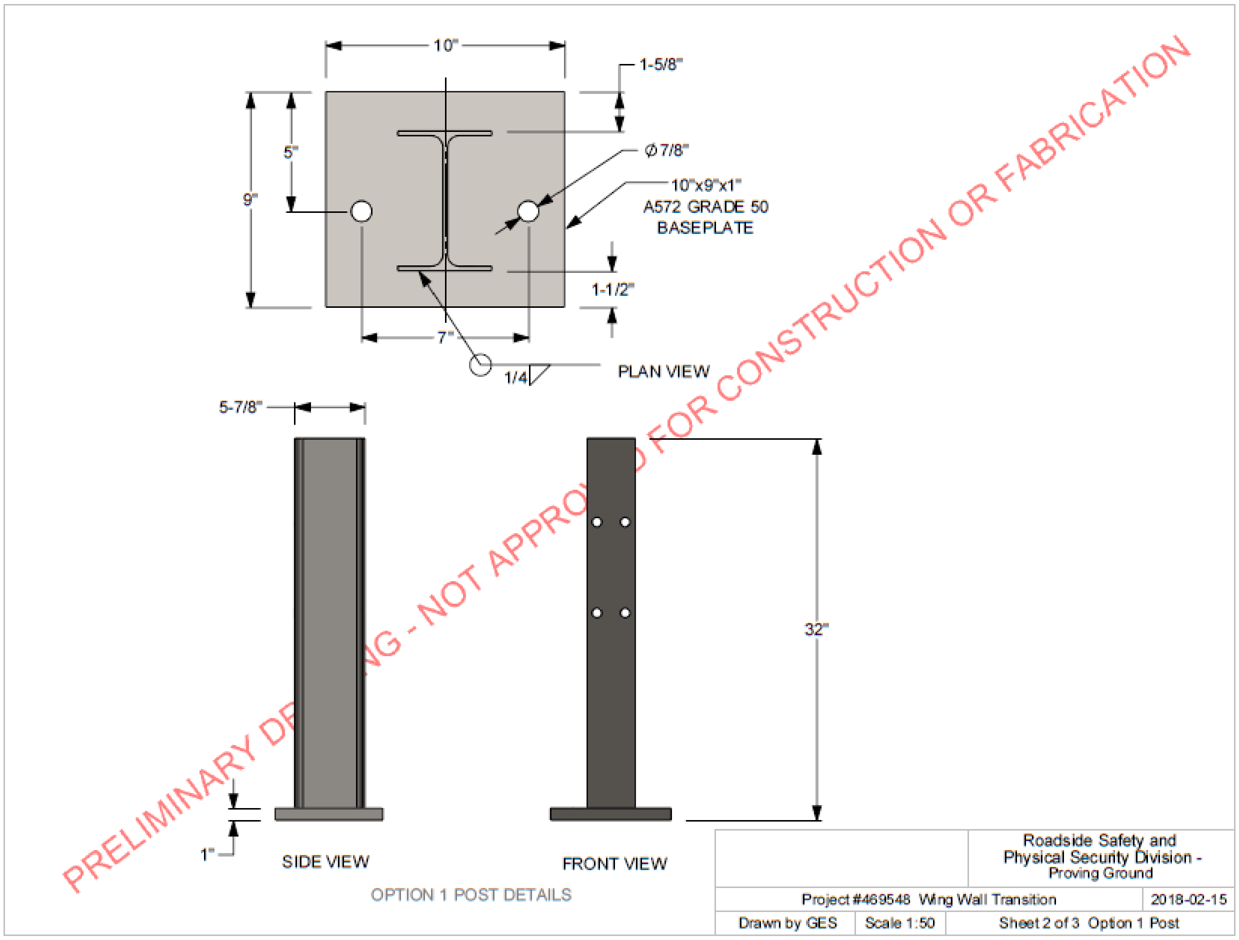


Figure 3.3. Option 1 Post Details.

3.3 OPTION 2. SIDE MOUNTED POST OPTION WITH CONCRETE CURB (NO RUB RAIL)

Option 2 incorporates a W6×8.5 steel side mounted anchored with a concrete curb. These posts are anchored to the field side of the concrete wing wall using Hilti Adhesive anchoring system. This design incorporates the use of a 6-inch high concrete curb cast flush with the traffic face of the concrete parapet. A steel rub rail is not necessary with the use of the concrete curb. This design uses the full plastic strength of the steel posts. Figure 3.4 presents the details of Option 2.

3.4 SUMMARY AND CONCLUSIONS

The side mount option was not selected for further study. The 2-bolt option shown in Figure 3.3 was selected for full-scale testing as part of this task and for LS-DYNA simulation Task 4.

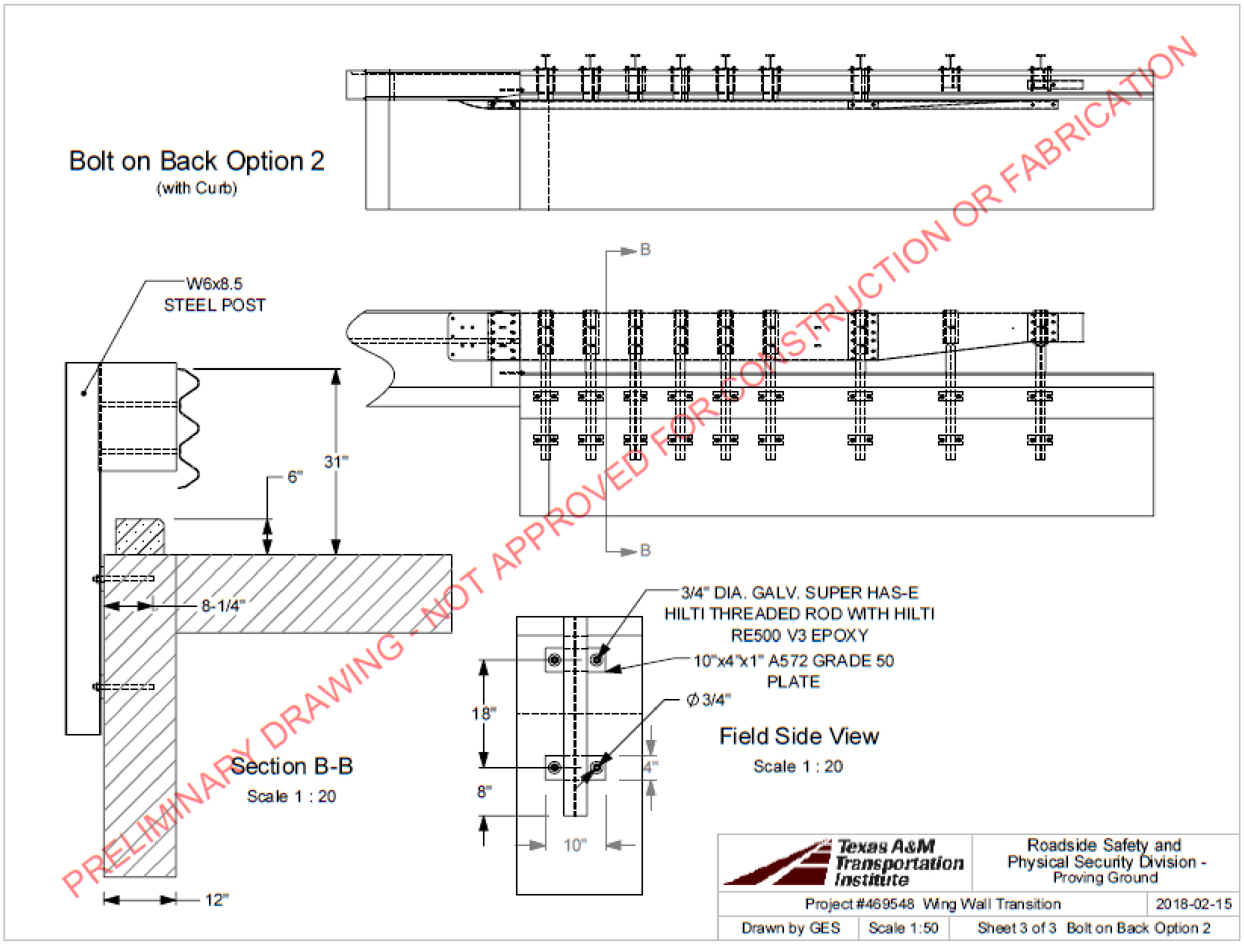


Figure 3.4. Option 2 Installation Details.

CHAPTER 4:
FINITE ELEMENT MODEL SIMULATIONS*

4.1 INTRODUCTION

Finite element modeling simulations were performed on the initial transition design as part of Task 4. The computer simulations were performed using LS-DYNA. The following summarizes the simulation effort performed for this task.

4.2 SYSTEM DESIGN

The 65 ft-5 inch installation consists of four sections: A 16-ft parapet, an 18 ft-¾ inch Wingwall transition, a 21 ft-11¾ inch length of need, and a 9 ft-4½ inch Downstream Anchor Terminal (DAT). The wing wall shown here was made rigid (no movement or rotation) in the simulation efforts. The 16 ft parapet is 12 inches wide and 31 inches tall. Between the system and the existing apron, a rigid moment slab was used, at a 10 degree angle from the system and transitions from 38 inches to 72 inches. Figure 4.1 shows the overall details of the installation.

Figure 4.2 shows a detailed drawing of the wingwall used in the simulations. The reinforcement used in the wingwall was not considered or modeled in the simulations since the wigwall was simulated as rigid. The 20-ft long wingwall was 24 inches tall, 12 inches wide, and had reinforcement every 6 inches starting at 3¼ inch from the edge. Figures 4.3 and 4.4 show details of the transition design used in the initial simulation effort.

4.3 DETAILED MODELING

An explicit finite element model of the transition system with wingwall was modeled using detailed geometrical and material properties. Figures 4.5 and 4.6 show the different views of the system modeled, including parapet, wingwall, transition posts, nested thrie section, rub rail, and approaching W-beam guardrail.

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

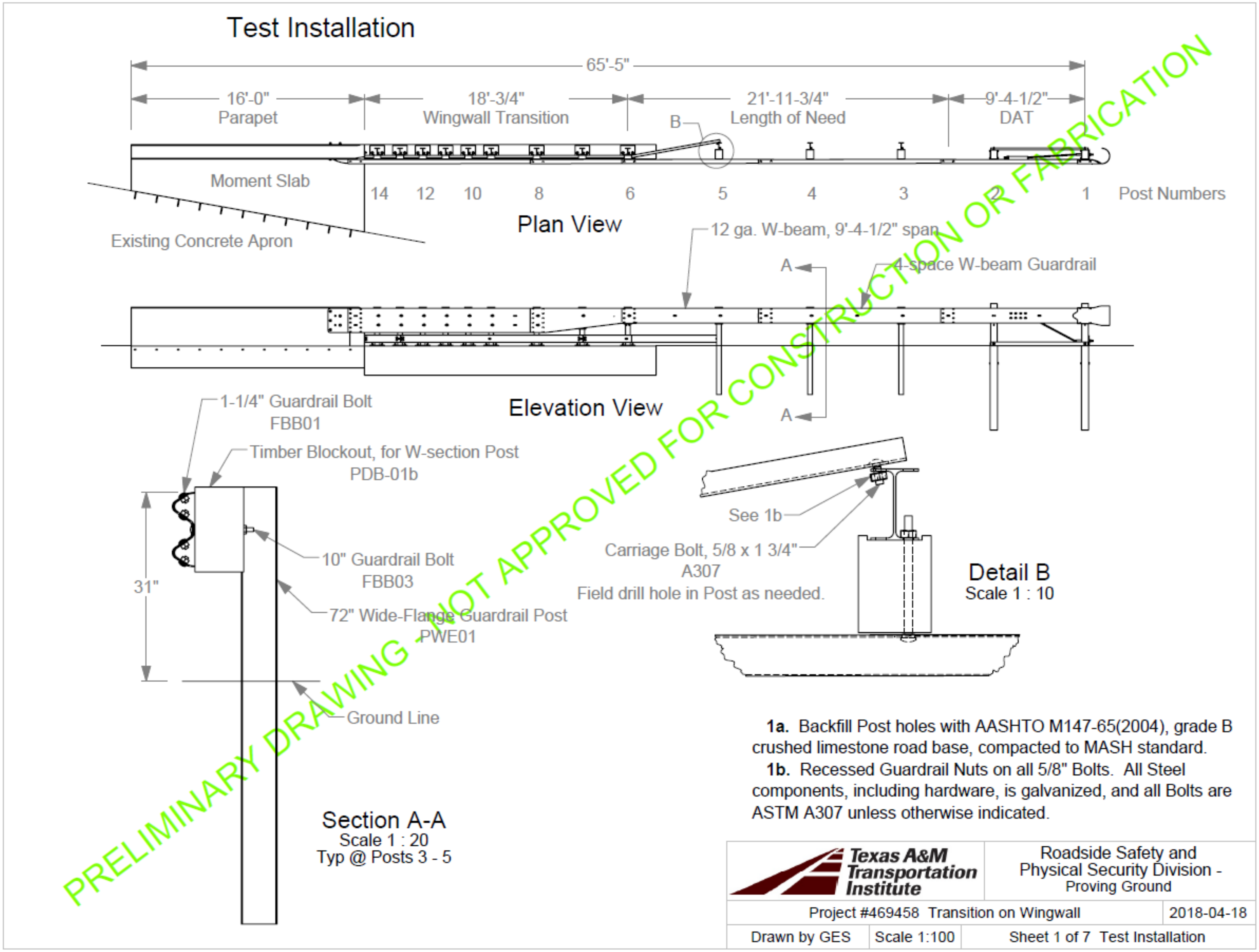


Figure 4.1. Plan View and Elevation of Installation.

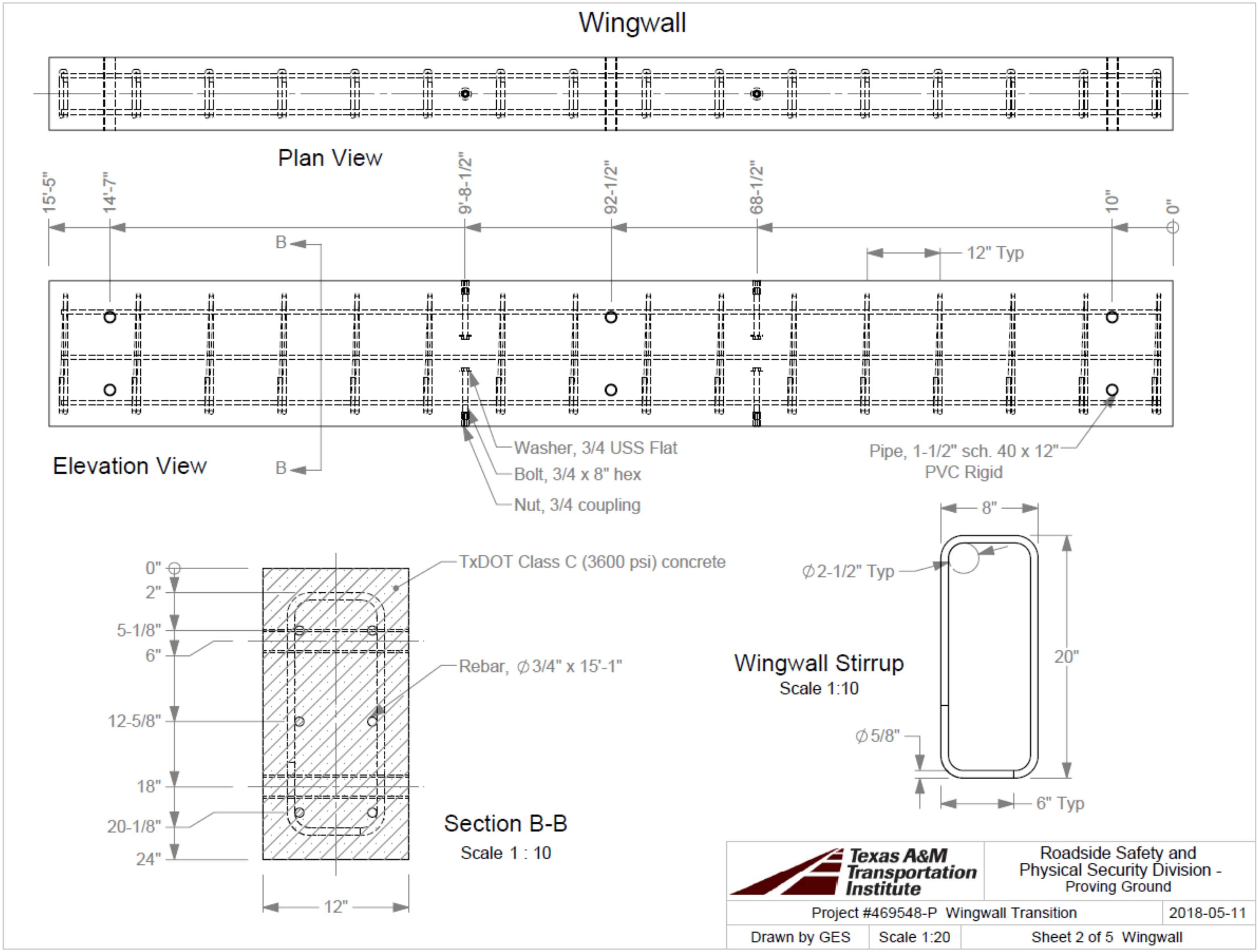


Figure 4.2. Wingwall Details.

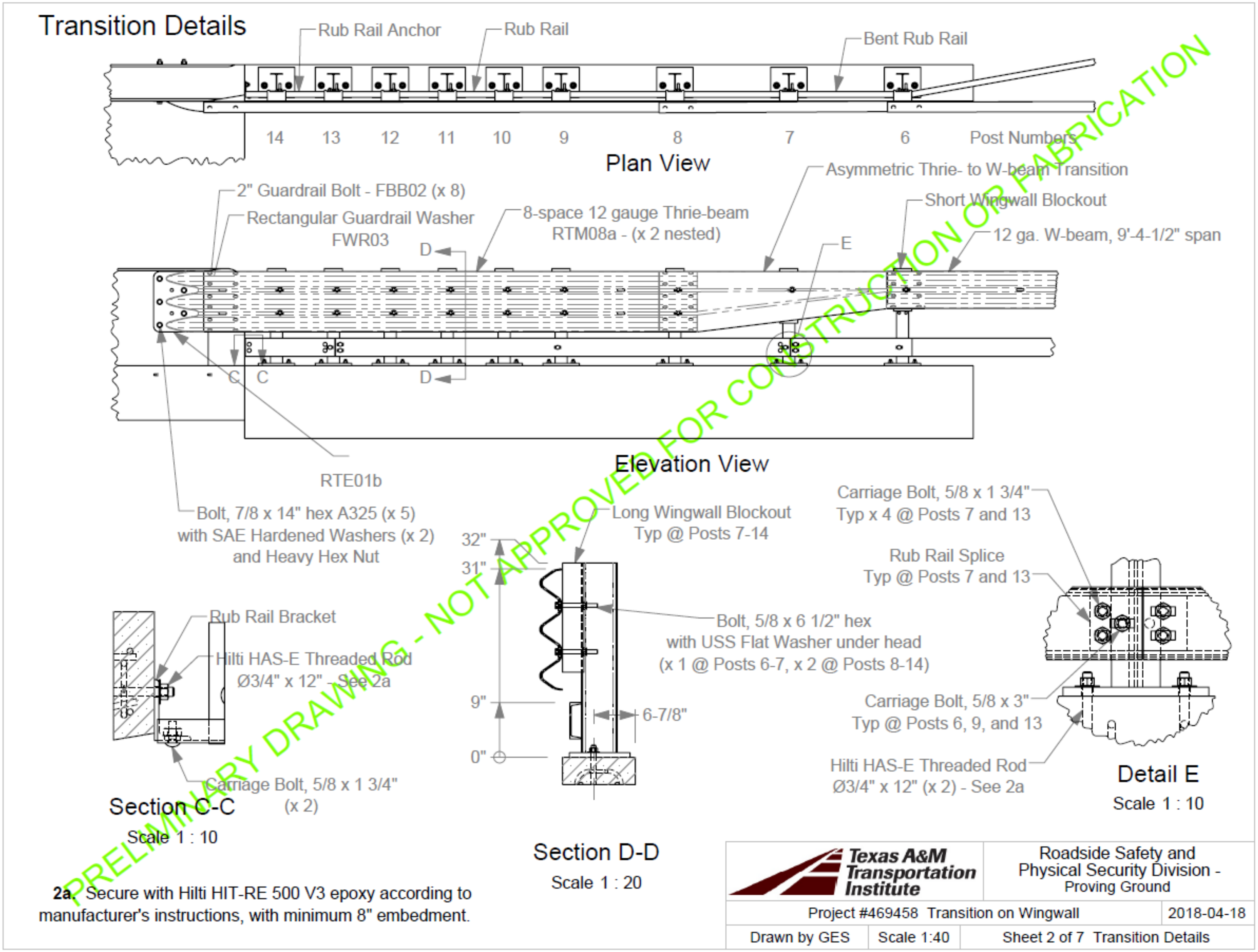


Figure 4.3. Wingwall Transition.

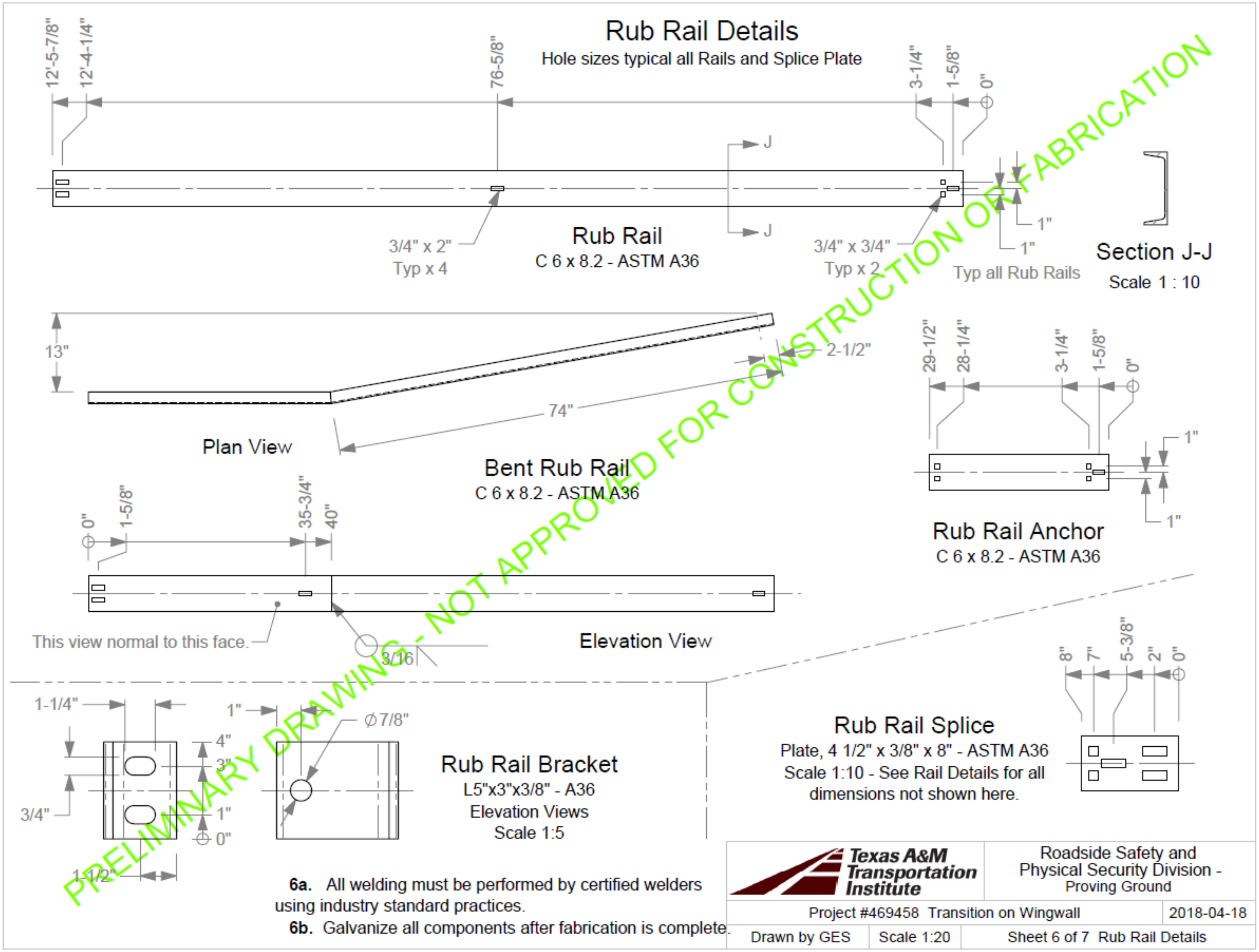


Figure 4.4. Details of Rub Rail.

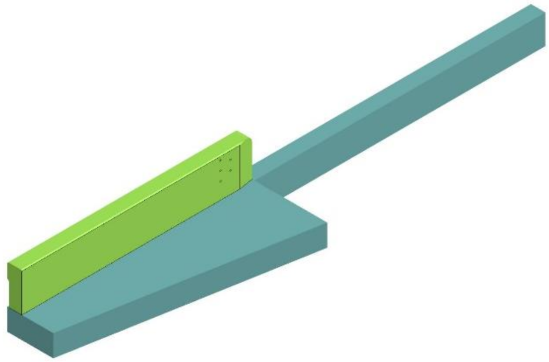


Figure 4.5. Parapet, Moment Slab, and Wingwall.

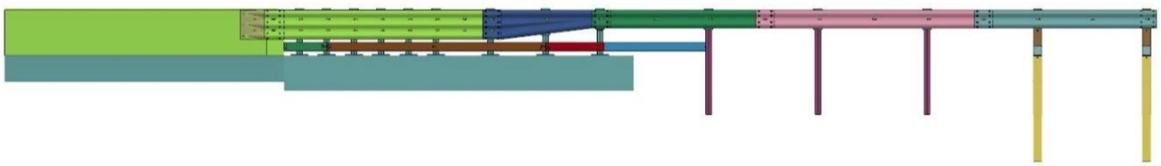


Figure 4.6. Front View of System.

Figure 4.7 shows the moment slab and wingwall. The transition shown here would attach to a vertical concrete parapet. The 16-ft parapet is 12 inches wide and 24 inches tall. In between the system and the existing apron, there is a moment slab. It is at a 10° angle from the system and transitions from 38 inches to 72 inches. The 20-ft long wingwall is 24 inches tall, 12 inches wide, and has reinforcement every 6 inches starting at 3¼ inch from the edge.

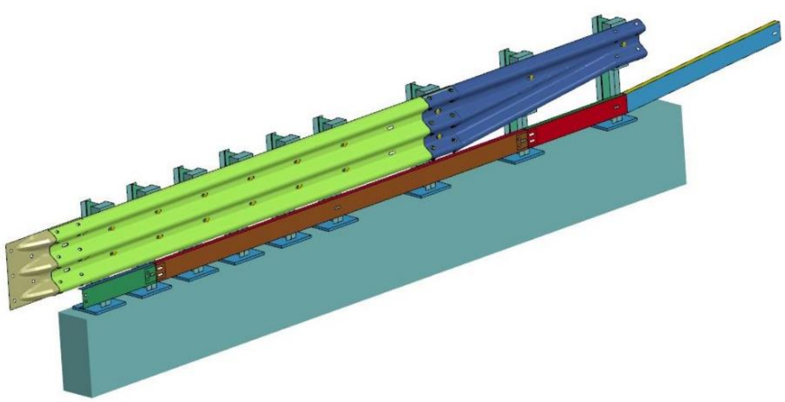


Figure 4.7. Wingwall Transition.

Figure 4.8 shows a front view the wingwall transition. The wingwall used in the simulations measured 20 ft long, 24 inches tall, and 12 inches wide. This wingwall was modeled as rigid and did not consider any concrete failure from vehicle impact loads. Nine steel posts that are 31 inches tall and bolted onto the wingwall were also used. The wingwall is made of concrete with rebar stirrups. The wingwall transition used in the simulations was bolted onto the parapet with ¾ inch diameter anchor bolts. The wingwall transition consists of an 8-space 12 gauge thrie-beam followed by an asymmetric thrie to W-beam transition. The rub rail is bolted onto the posts below the beam. The rub rail consists of the rub rail anchor, the rub rail splice, the rub rail bracket, the rub rail, and the bent rub rail. The rub rail is a C6×8.2- ASTM A36 steel. Figures 4.9 and 4.10 show views of the *MASH* 1100C and the 2270P vehicle models, respectively.

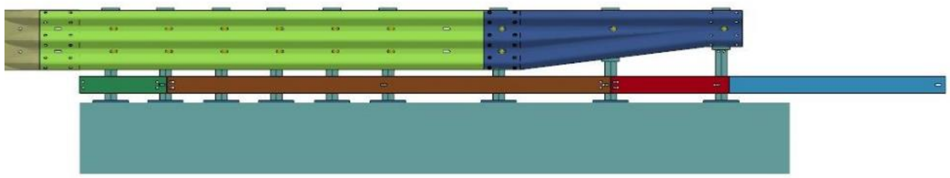


Figure 4.8. Front View of Wingwall Transition.

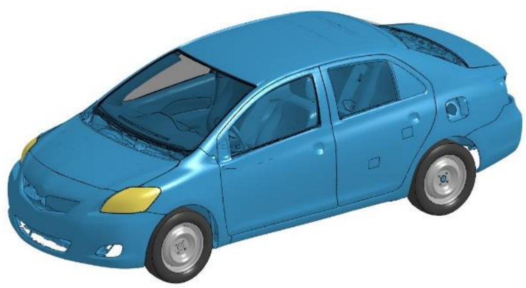


Figure 4.9. *MASH* 1100C Test Vehicle Model.

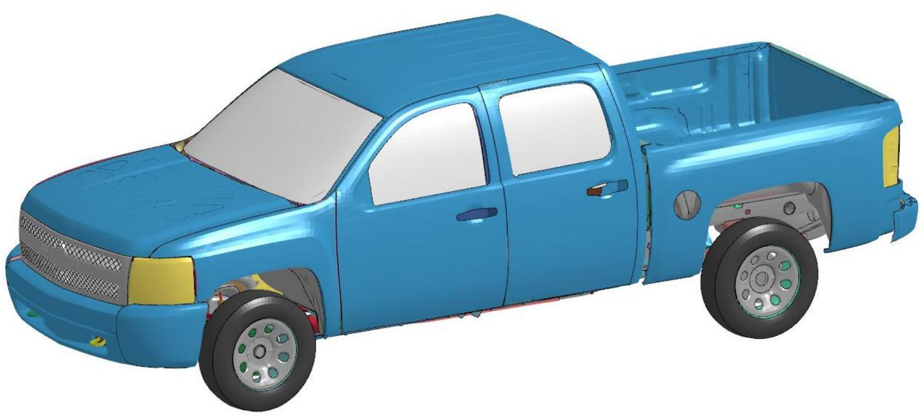


Figure 4.10. *MASH* 2270P Test Vehicle Model.

4.4 SIMULATION OF *MASH* TEST 3-21: TRUCK IMPACTING NEW BARRIER TRANSITION

Figures 4.11 through 4.14 show images of the vehicle setup for this impact simulation. The vehicle used in this simulation is a 2270P vehicle weighing 5000 lb and impacting the barrier at a speed of 62.2 mph and an angle of 25°. The target impact point is the centerline of the vehicle with the flared rub rail span at post 8 (numbered from the end of the concrete parapet). Post 8 is bolted onto the wingwall and is a part of the wingwall transition.

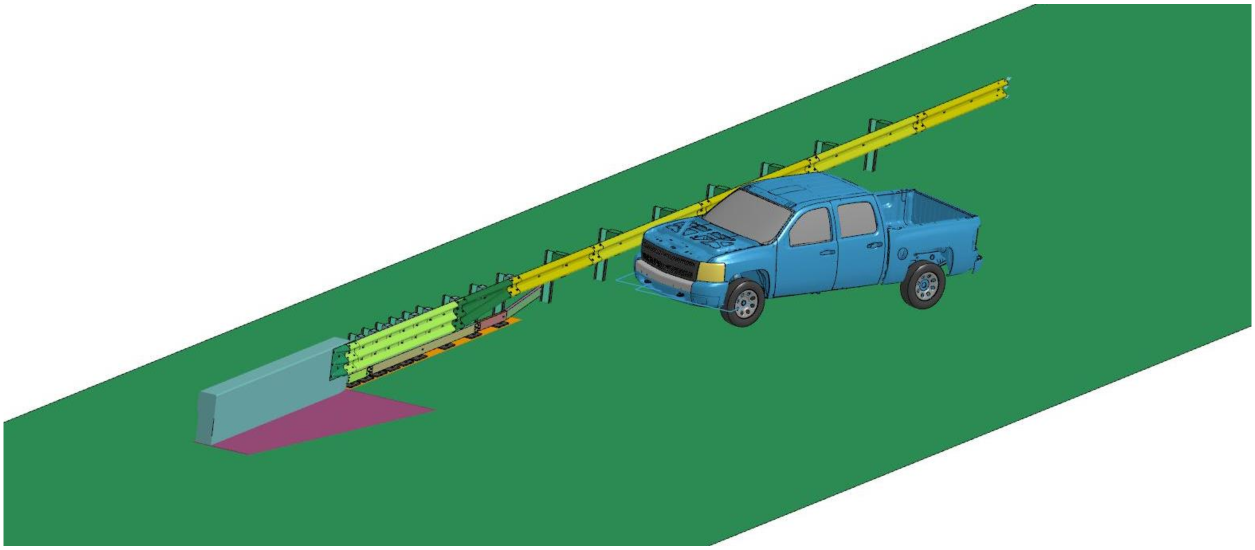


Figure 4.11. ***MASH*** **2270P Vehicle/Installation Setup – Isometric View.**

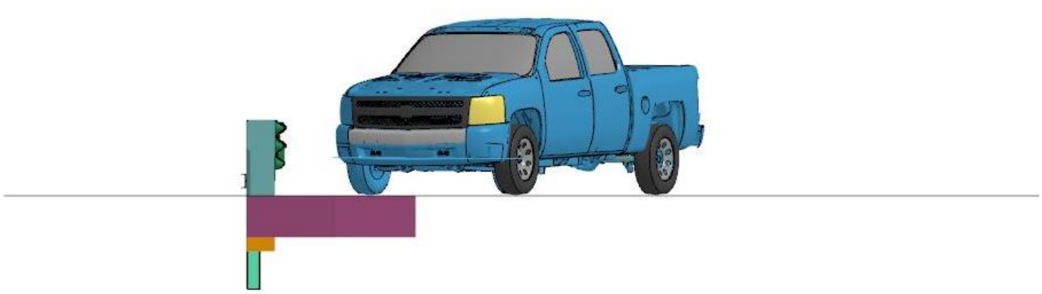


Figure 4.12. ***MASH*** **2270P Vehicle/Installation Setup – Front View.**

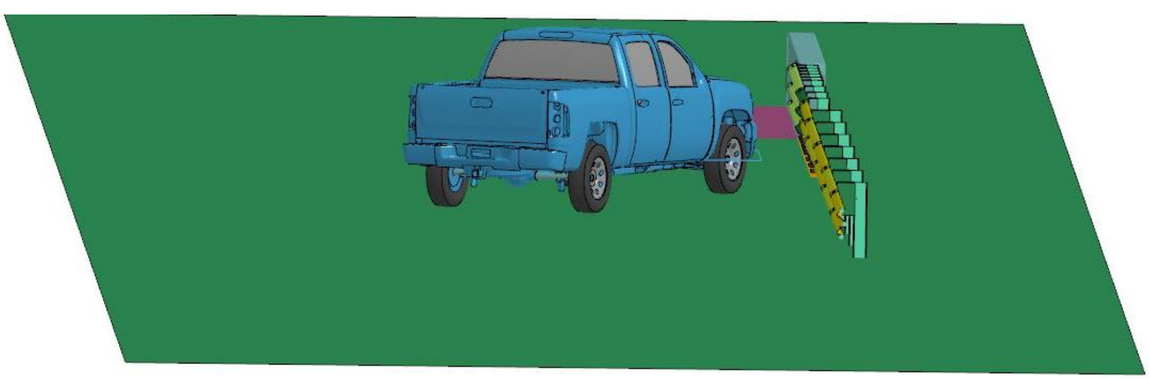


Figure 4.13. ***MASH*** **2270P Vehicle/Installation Setup – Rear View.**

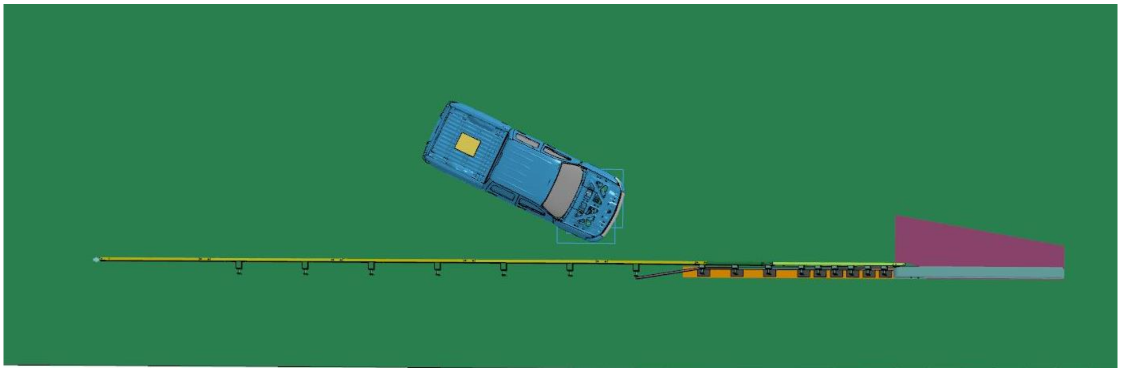


Figure 4.14. *MASH* 2270P Vehicle/Installation Setup – Top View.

4.5 SIMULATION OF *MASH* TEST 3-21: SMALL CAR IMPACTING GUARDRAIL SYSTEM WITH RIGID BARRIER TRANSITION

Figures 4.15 through 4.17 show images of the vehicle setup for this test installation. The vehicle used in this simulation is a 1100C vehicle impacting the barrier at a speed of 62.2 mph and an angle of 25°. The target impact point is the centerline of the vehicle with Post 8. Post 8 is bolted onto the wingwall and is a part of the wingwall transition.

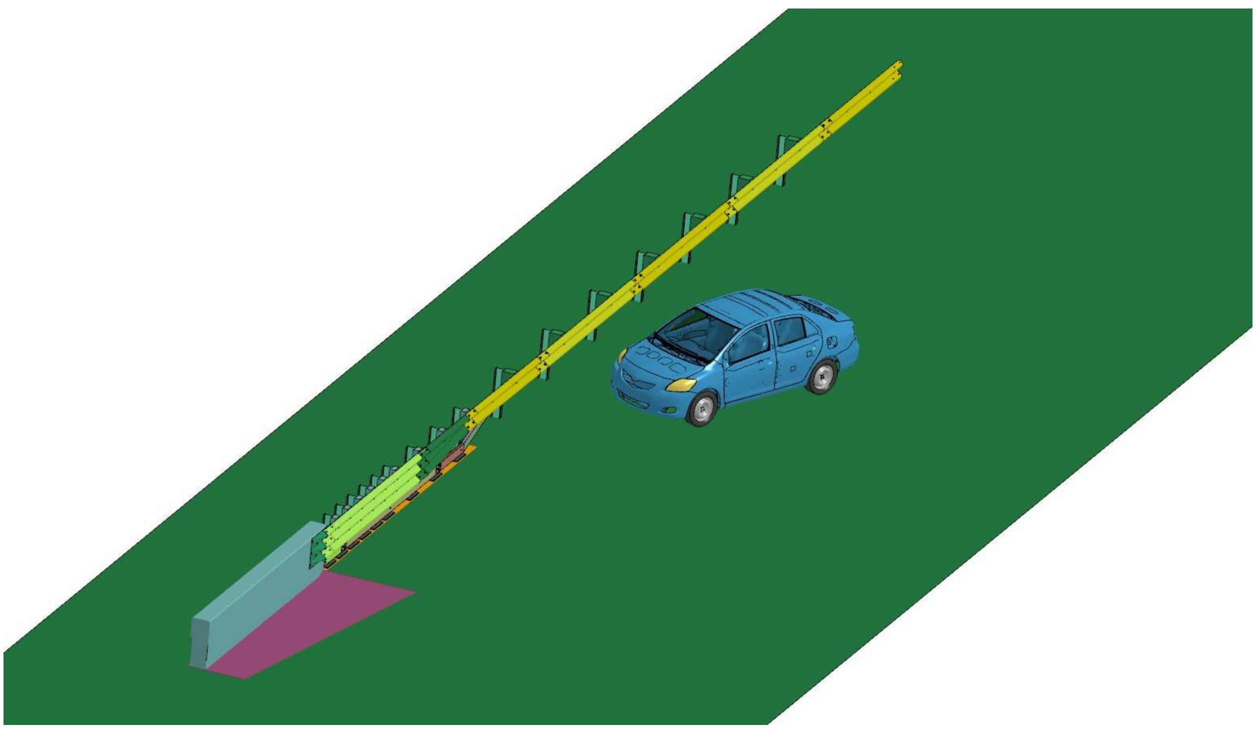


Figure 4.15. *MASH* 1100C Vehicle/Installation Setup – Isometric View.

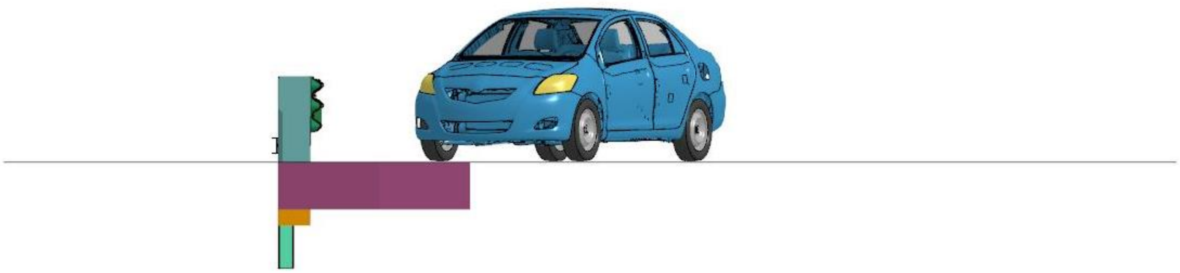


Figure 4.16. ***MASH*** **1100C Vehicle/Installation Setup – Front View.**

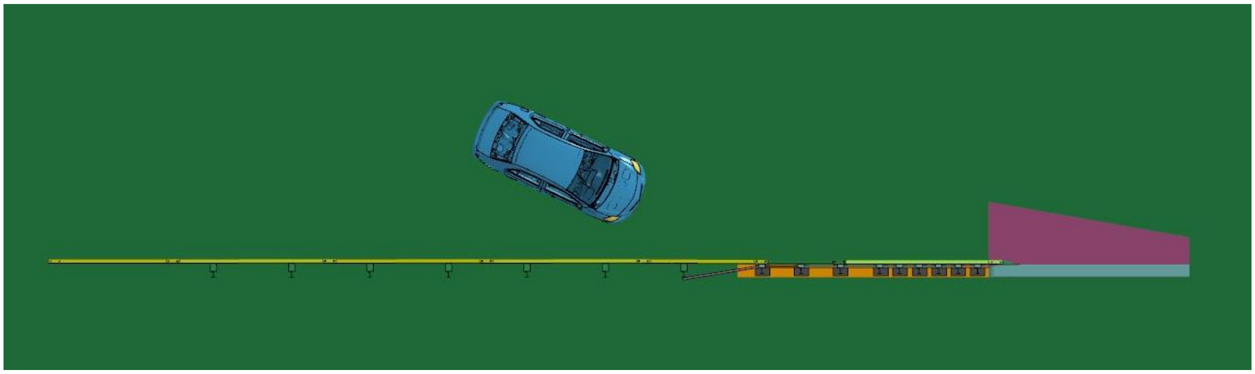


Figure 4.17. ***MASH*** **1100C Vehicle/Installation Setup – Top View.**

The small car experienced pocking (snagging) due to front right tire being pushed between the W-beam and the flared rub rail span as shown in Figures 4.18 and 4.19. The pickup truck experienced vehicular instability as it engaged the flared rub rail section as shown in Figures 4.20 and 4.21.

4.6. SUMMARY AND CONCLUSIONS

The recommended system for evaluation would have one or more of these options:

- Add an additional thrie beam 12-ft section (NOT nested) upstream from the nested thrie and then the asymmetric piece.
- Add a longer rub rail along with the additional thrie beam section and then flare the rub rail back.

These design modifications are expected to reduce the pocketing and vehicular instability as observed in the simulation and improve the crash performance of the transition design.

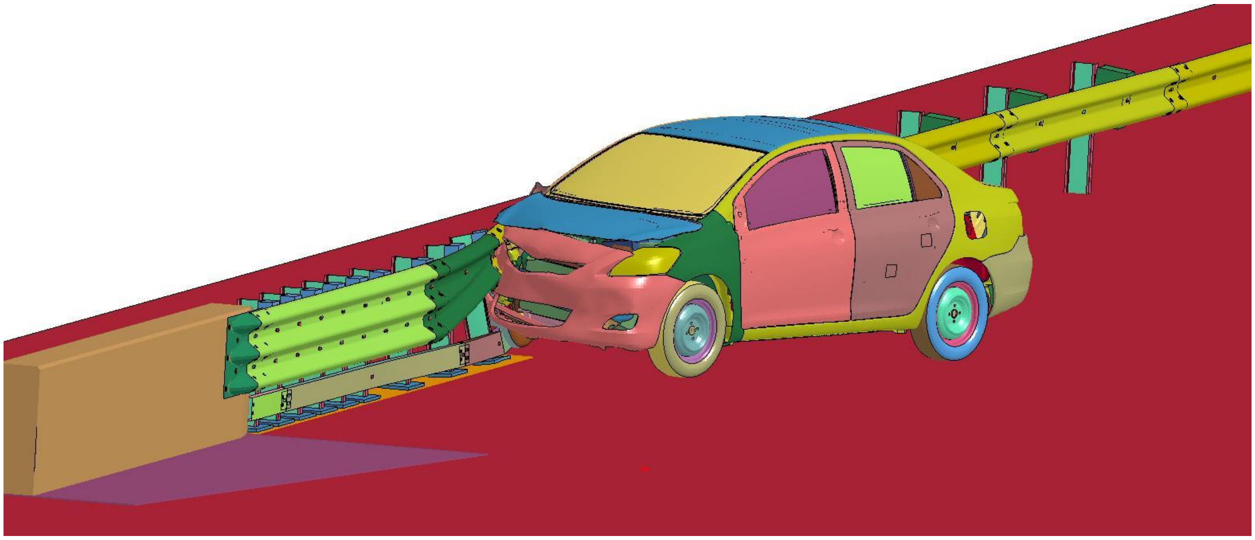


Figure 4.18. ***MASH*** **1100C Vehicle Pocketing into Opening Above Flared Rube Rail Span.**

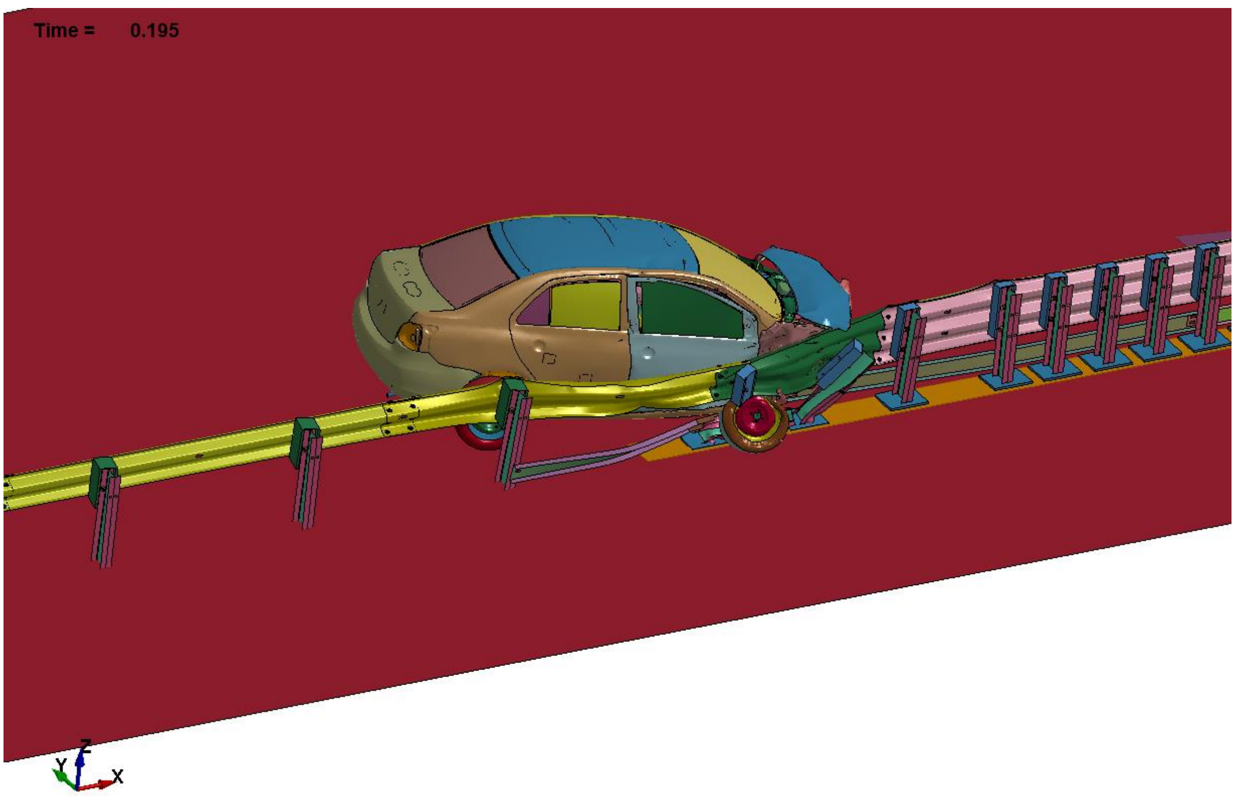


Figure 4.19. ***MASH*** **1100C Vehicle Pocketing into Opening Above Flared Rub Rail.**

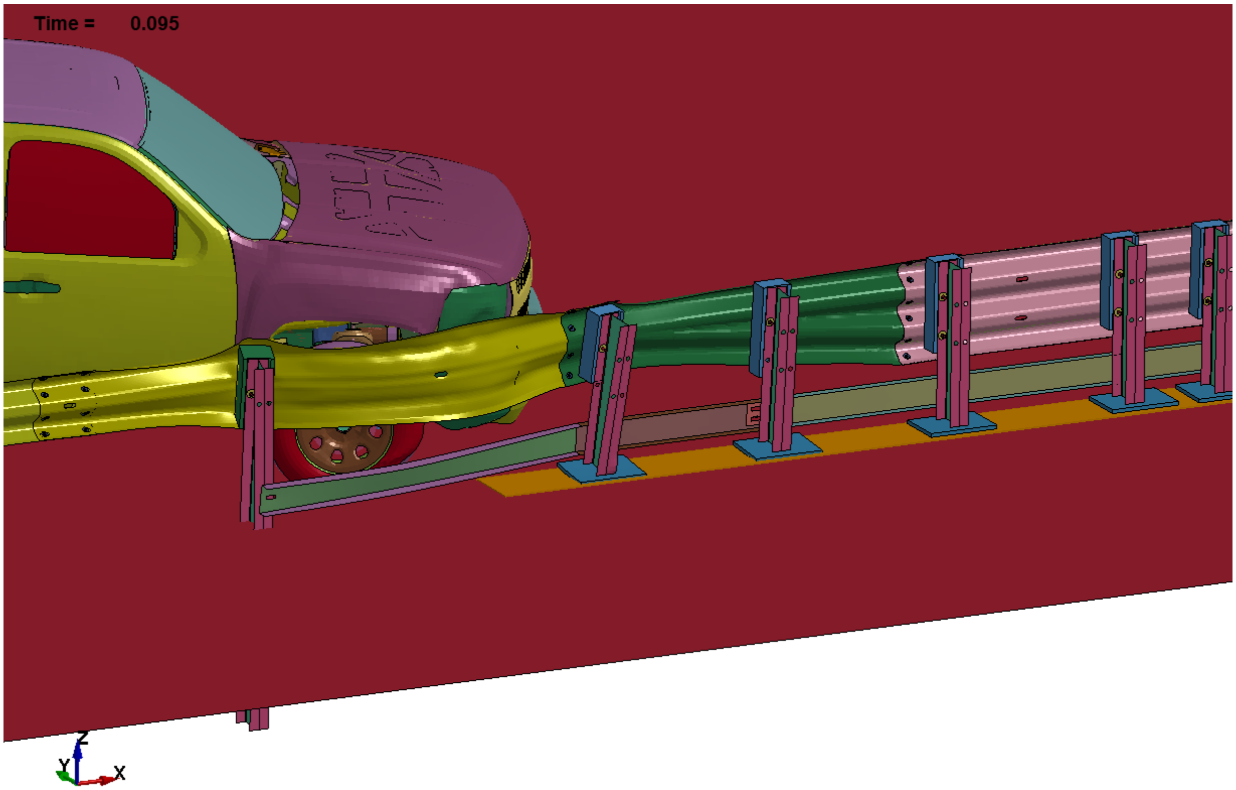


Figure 4.20. *MASH* 2270P Vehicle Interacting with W-Beam and Flared Rub Rail.

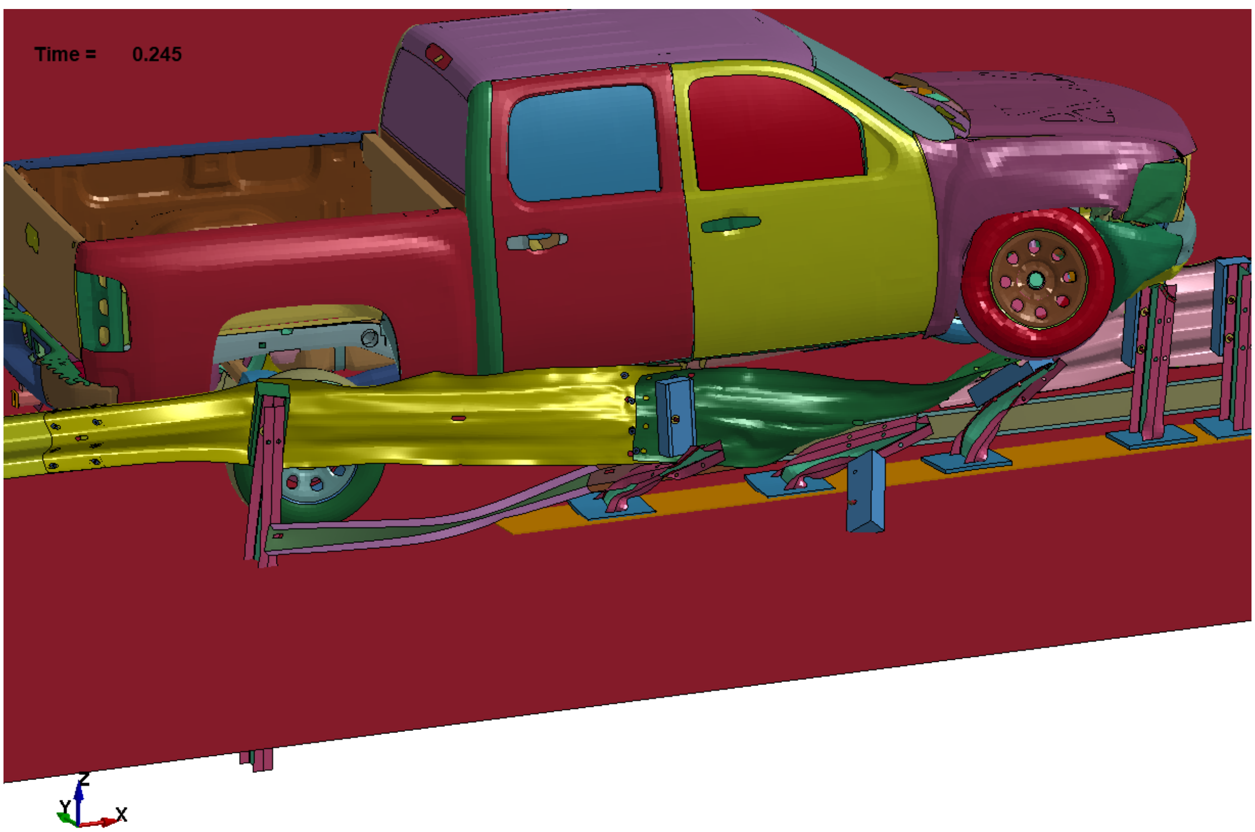


Figure 4.21. *MASH* 2270P Vehicle Overriding System.

CHAPTER 5:
TEST REQUIREMENTS AND EVALUATION CRITERIA

5.1 CRASH TEST MATRIX

Table 5.1 shows the test conditions and evaluation criteria for *MASH* TL-3 for transitions. Three tests were performed on the Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure. *MASH* Tests 3-20 and 3-21 were performed on the upstream terminal, and MASH Test 3-21 only was performed on the downstream terminal. *MASH* Test 3-20 in the downstream area of the transition is an optional test to evaluate occupant risk and post-impact trajectory. *MASH* states that this test should be performed “if there is reasonable uncertainty regarding the impact performance of the system for impact with small passenger vehicles.” The geometry and profile of the transition in the immediate area upstream of the concrete parapet appeared favorable for MASH Test 3-20, so this test was not performed.

Table 5.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-3 Transitions.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Transitions	3-20	1100C	62 mi/h	25	A, D, F, H, I
	3-21	2270P	62 mi/h	25	A, D, F, H, I

The target critical impact points (CIPs) were determined using simulation. Several impact points were considered. Figure 5.1 shows the target CIP (most critical) for *MASH* Test 3-20 (Test No. 469549-01-1) on the upstream transition, which was the centerline of post 3 at the connection to the rail. Based on LS-DYNA simulations for the other impact conditions, the other critical impacts points for the other crash tests are presented as follows.

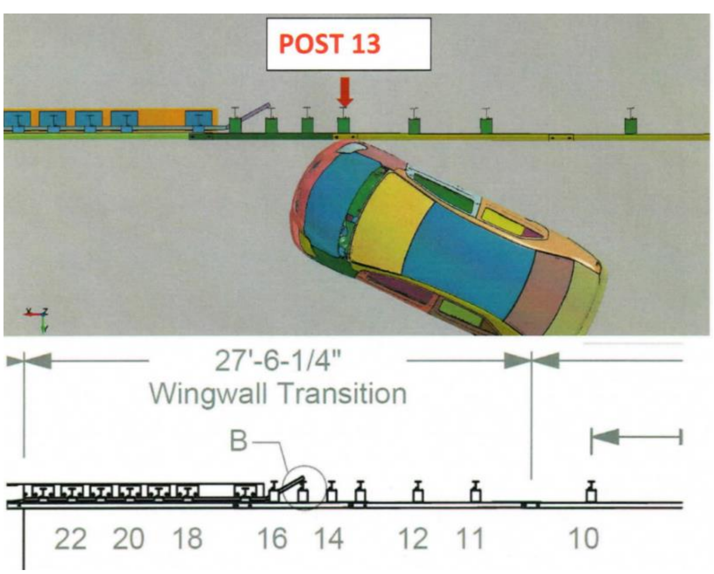


Figure 5.1. Target CIP for *MASH* Test 3-20 on the Upstream Transition.

Figure 5.2 shows the target CIP for *MASH* Test 3-21 (Test No. 469549-01-2) on the upstream transition, which was the centerline of post 14 at the connection with the rail.

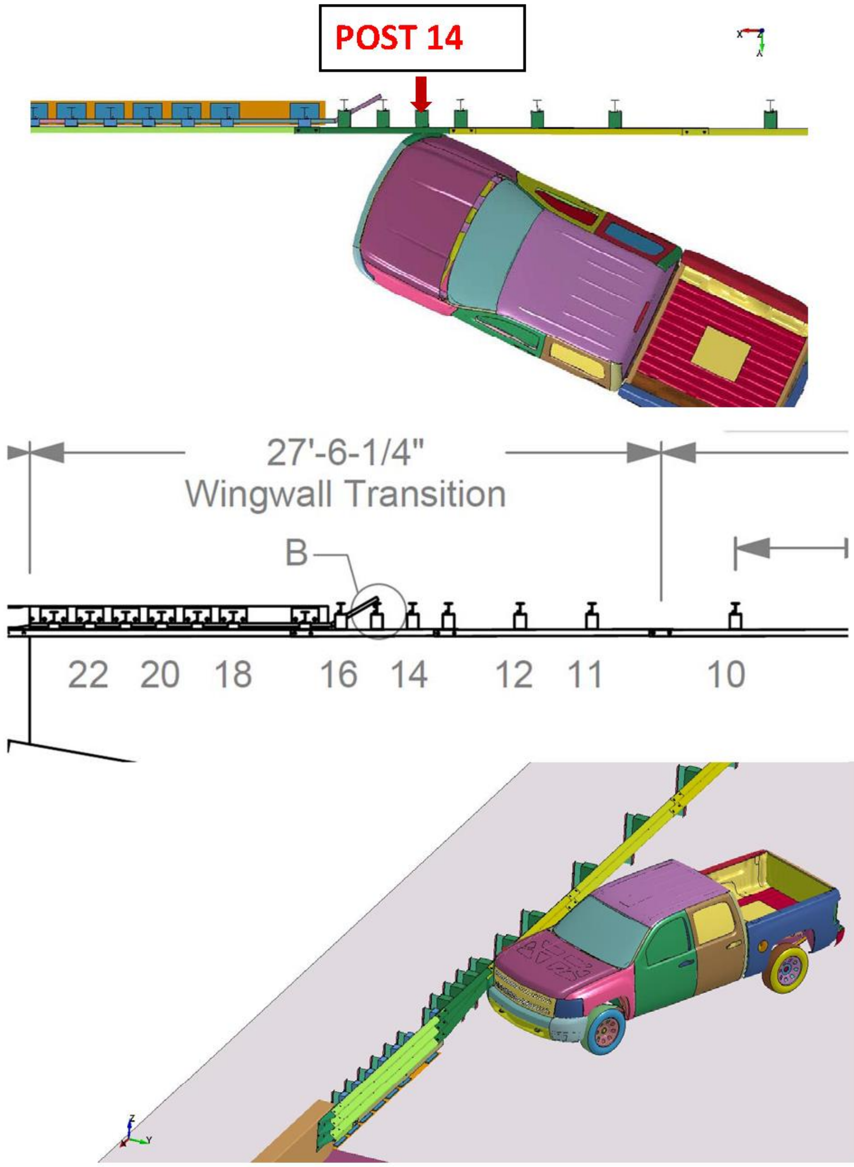


Figure 5.2. Target CIP for *MASH* Test 3-21 on the Upstream Transition.

Figure 5.3 shows the target CIP for *MASH* Test 3-21 (Test No. 469549-01-4) on the upstream transition, which was 5 inches downstream of the centerline of post 19 at the connection with the rail.

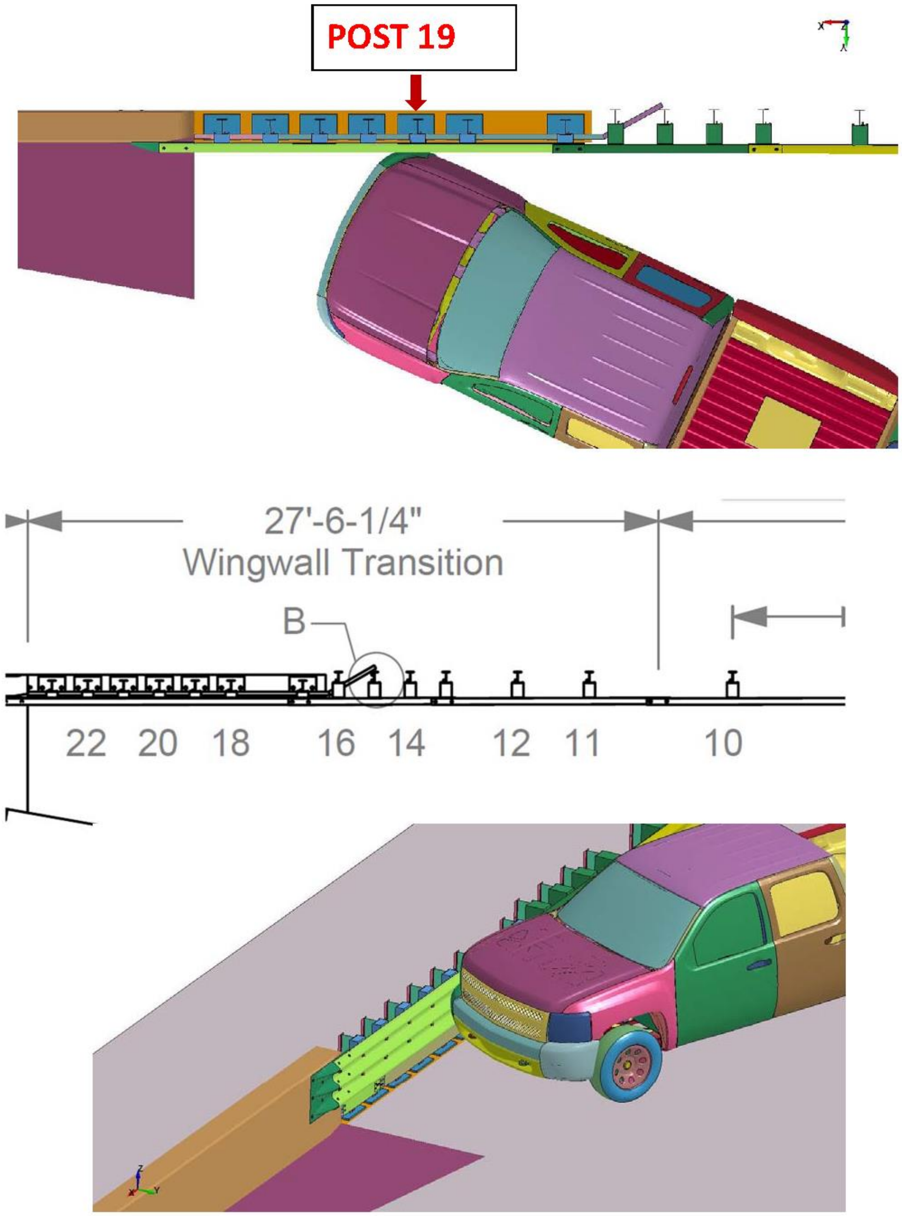


Figure 5.3. Target CIP for *MASH* Test 3-21 on the Downstream Transition.

The crash tests and data analysis procedures were in accordance with the guidelines presented in *MASH*. Chapter 4 presents brief descriptions of these procedures.

5.2 EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2 and 5-1 of *MASH* were used to evaluate the crash tests reported herein. Table 5.1 lists the test conditions and evaluation criteria required for *MASH* Test TL-3 transitions, and Table 5.2 provides the substance of the evaluation criteria. Evaluation of the crash test results is presented in detail under the section Assessment of Test Results.

Table 5.2. Evaluation Criteria Required for *MASH* TL-3 Transitions.

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.*
	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 velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.
	I. The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.

CHAPTER 6: TEST CONDITIONS

6.1 TEST FACILITY

The full-scale crash tests reported herein were 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 tests were 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 transition was along the edge of an out-of-service runway. The runway consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches deep. The runway was built in 1942, and the joints have some displacement, but are otherwise flat and level.

6.2 VEHICLE TOW AND GUIDANCE SYSTEM

Each 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, if needed, to bring the test vehicle to a safe and controlled stop.

6.3 DATA ACQUISITION SYSTEMS

6.3.1 Vehicle Instrumentation and Data Processing

Each 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 and 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 factory 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 are 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 SAE Class 180 low-pass filters, 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).

6.3.2 Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the front seat on the impact side (side opposite of impact for sign supports) of the 1100C vehicle. The dummy was not instrumented.

According to *MASH*, use of a dummy in the 2270P vehicle is optional, and no dummy was used in the tests with the 2270P.

6.3.3 Photographic Instrumentation and Data Processing

Photographic coverage of each 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 transitions. 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.

CHAPTER 7:
MASH TL-3 TESTS ON UPSTREAM TRANSITION

7.1 TEST ARTICLE AND INSTALLATION DETAILS

The Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure installation was approximately 102 ft-10¾ inches long. It consisted of a 16-ft long reinforced concrete parapet and moment slab, a 27 ft-6¼ inch long W-beam to thrie-beam to parapet transition section that was anchored to the parapet, 50 ft of W-beam guardrail, and a Downstream Anchor Terminal (DAT). The posts in the thrie-beam portion of the installation were anchored to a reinforced concrete wingwall that was embedded in the soil with the top at grade, and the rest of the posts were embedded directly into the soil. The top edge of the thrie-beam and W-beam rails were at 31 inches above grade. The wingwall was 13 ft long, 12 inches thick, and 5 ft deep. A C6×8.2 rub rail was positioned below the thrie-beam section of the transition.

Figure 7.1 presents overall information on the transition, and Figure 7.2 provides photographs of the installation. Appendix A provides further details of the transition.

7.2 MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to install/construct the transition.

The specified minimum unconfined compressive strength of the concrete for the working slab (used on previous test), the support wall, and the barrier was 4000 psi. The average unconfined compressive strengths of the batches of concrete used in the construction of the test installation were as follows with locations of the different batches shown in Figure 2.3:

- Wingwall: 5245 psi on 2019-03-04, 28 days from pour date.
- Parapet: 4590 psi on 2019-03-04, 17 days from pour date.
- Deck: 4010 psi on 2019-03-04, 14 days from pour date.

Steel reinforcement of the bridge deck and wall was comprised of epoxy coated ASTM A615 Grade 60 rebar with specified minimum yield strength of 60 ksi.

7.3 SOIL CONDITIONS

The test installation was installed in standard soil meeting AASHTO standard specifications for “Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses,” designated M147-65(2004), grading B.

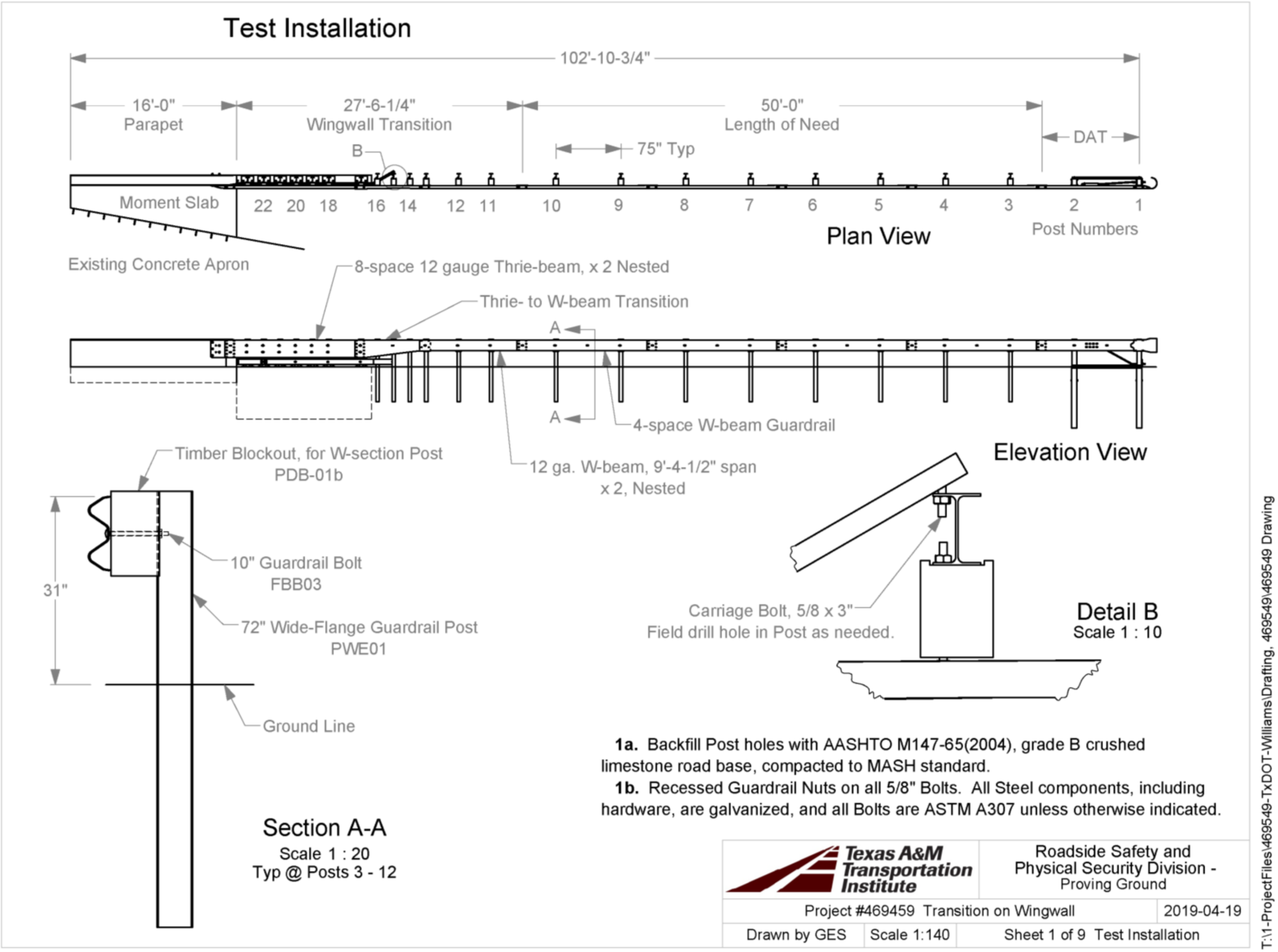


Figure 7.1. Installation Details for Upstream Transition.

Figure 7.2. Upstream Transition prior to Testing.

In accordance with Appendix B of *MASH*, soil strength was measured on the day of the crash test. During installation of the transition for full-scale crash testing, two standard W6×16 posts were installed in the immediate vicinity of the transition, using the same fill materials and installation procedures used in the standard dynamic test (see Table C.1 in Appendix C for establishment minimum soil strength properties in the dynamic test performed in accordance with *MASH* Appendix B).

As determined in the tests shown in Appendix C, Table C.1, the minimum post load required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, is 3940 lb, 5500 lb, and 6540 lb, respectively (90 percent of static load for the initial standard installation). On the day of Test No. 469549-01-1, March 4, 2019, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 7525 lbf, 8131 lbf, and 9040 lbf, respectively. On the day of Test No. 469549-01-2, March 6, 2019, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 7777 lbf, 8838 lbf, and 9292 lbf, respectively. Tables C.2 and C.3 in Appendix C show the strength of the backfill material in which the transition was installed met minimum requirements.

7.4 *MASH* TEST 3-20 (CRASH TEST NO. 469549-01-1)

7.4.1 Test Designation and Actual Impact Conditions

MASH Test 3-20 involves an 1100C vehicle weighing 2420 lb ±55 lb impacting the CIP of the test article at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. The CIP for *MASH* Test 3-20 on the upstream transition was the centerline of post 13 at the connection with the rail ±1 ft.

The 2007 Kia Rio* used in the test weighed 2444 lb, and the actual impact speed and angle were 62.7 mi/h and 24.8°, respectively. The actual impact point was the right front corner of the vehicle bumper at the centerline of post 13 at the connection with the rail. Minimum target impact severity (IS) was 51 kip-ft, and actual IS was 57 kip-ft.

7.4.2 Weather Conditions

The test was performed on the morning of March 4, 2019. Weather conditions at the time of testing were as follows: wind speed: 7 mi/h; wind direction: 355° (vehicle was traveling in a northwesterly direction); temperature: 31°F; relative humidity: 77 percent.

7.4.3 Test Vehicle

Figures 7.3 and 7.4 show the 2007 Kia Rio used for the crash test. The vehicle's test inertia weight was 2444 lb, and its gross static weight was 2609 lb. The height to the lower edge of the vehicle bumper was 7.75 inches, and height to the upper edge of the bumper was 21.5 inches. Table D.1 in Appendix D1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

* The 2007 model vehicle used is older than the 6-year age noted in *MASH*, and was selected based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2007 model vehicle met the *MASH* requirements.

Figure 7.3. Upstream Transition/Test Vehicle Geometrics for Test No. 469549-01-1.

Figure 7.4. Test Vehicle before Test No. 469549-01-1.

7.3.4 Test Description

The test vehicle was traveling at an impact speed of 62.7 mi/h when it contacted the upstream transition. The right front corner of the vehicle bumper contacted the centerline of post 13 at the connection with the rail at an impact angle of 24.8°. Table 7.1 lists events that occurred during Test No. 469549-01-1. Figures D.1 and D.2 in Appendix D2 present sequential photographs during the test.

Table 7.1. Events during Test No. 469549-01-1.

TIME (s)	EVENTS
0.0000	Vehicle contacts transition
0.0420	Vehicle begins to redirect
0.1140	Right rear tire leaves pavement surface
0.1810	Vehicle parallel with transition
0.2320	Right rear bumper contacts transition
0.3460	Vehicle loses contact with transition while traveling at 40.2 mi/h, trajectory of 8.6°, and heading of 18.6°
0.8080	Right rear tire contacts pavement surface

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle came to rest 185 ft downstream of the impact and 56 ft toward traffic lanes.

7.4.5 Damage to Test Installation

Figure 7.5 shows the damage to the upstream transition. The soil was disturbed around posts 12 through 16, the guardrail was released from post 15, and the rub rail was released from post 17. Post 15 showed evidence of significant contact with the vehicle, and it was leaning back and downstream approximately 10 inches. The base plate of post 17 was buckled. Working width was 26.2 inches, and height of working width was 31.0 inches. Maximum dynamic deflection during the test was 7.1 inches, and maximum permanent deformation was 3.4 inches (at post 15).

7.4.6 Damage to Test Vehicle

Figure 7.6 shows the damage sustained by the vehicle. The front bumper, hood, radiator and support, right front fender, right front tire and rim, right front strut and tower, right front lower A-arm, right outer CV joint, right front door and glass, right rear door, right rear quarter panel, and right front floor pan were damaged. Maximum exterior crush to the vehicle was 10.0 inches in the side plane at the right front corner at bumper height. Maximum occupant compartment deformation was 1.25 inches in the kick panel across the floor pan. Figure 7.7 shows the interior of the vehicle. Tables D.2 and D.3 in Appendix D1 provide exterior crush and occupant compartment measurements.

7.4.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and results are shown in Table 7.2. Figure 7.8 summarizes these data and other pertinent information from the test. Figure D.3 in Appendix D3 shows the vehicle angular displacements, and Figures D.4 through D.9 in Appendix D4 show acceleration versus time traces.

Figure 7.5. Upstream Transition after Test No. 469549-01-1.

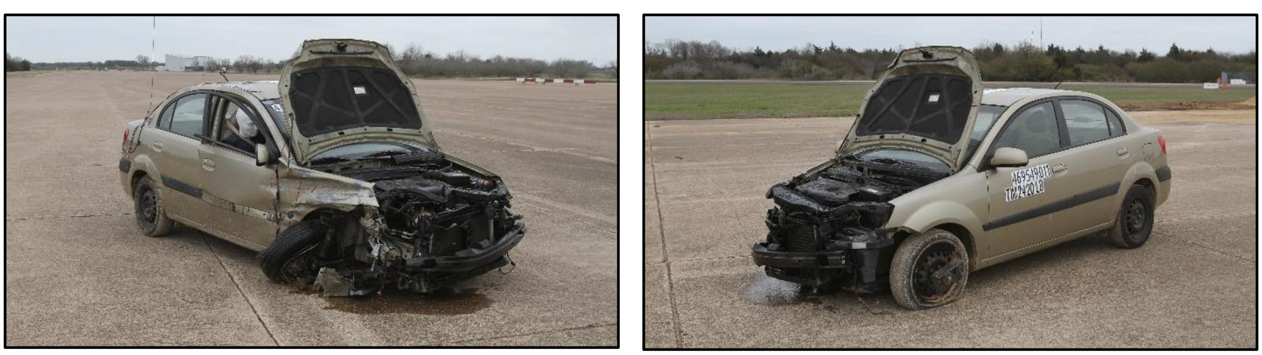


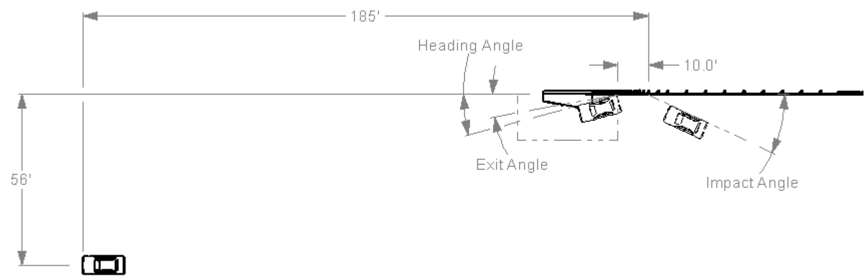
Figure 7.6. Test Vehicle after Test No. 469549-01-1.

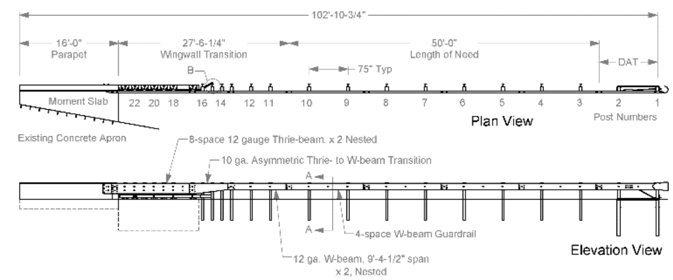
Figure 7.7. Interior of Test Vehicle after Test No. 469549-01-1.

Table 7.2. Occupant Risk Factors for Test No. 469549-01-1.

Occupant Risk Factor	Value	Time
Impact Velocity		
Longitudinal	27.3 ft/s	At 0.0849 s on right side of interior
Lateral	30.5 ft/s	
Ridedown Accelerations		
Longitudinal	19.4 g	0.0878–0.0978 s
Lateral	14.6 g	0.0849–0.0949 s
THIV	43.4 km/h 12.0 m/s	At 0.0827 s on right side of interior
PHD	24.9 g	0.0837–0.0937 s
ASI	2.42	0.0570–0.1070 s
Maximum 50-ms Moving Average		
Longitudinal	−16.9 g	0.0501–0.1001 s
Lateral	−16.2 g	0.0433–0.0933 s
Vertical	7.1 g	0.0288–0.0788 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	19°	0.4940 s
Pitch	10°	0.4556 s
Yaw	67°	0.9658 s

0.000 s | 0.100 s | 0.200 s | 0.400 s





General Information
- Test Agency .... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ...... *MASH* Test 3-20
- TTI Test No. 469549-01-1
- Test Date 2019-03-04

Test Article
- Type .... Transition
- Name .... Thrie Beam Transition
- Installation Length .... 102 ft-10¾ inches
- Material or Key Elements ... 16-ft long parapet/moment slab, a 27 ft-6¼ inch long W-beam to thrie-beam to parapet transition section, 50 ft of W-beam guardrail, and DAT terminal; top of metal rail height 31 inches

Soil Type and Condition ..... AASHTO M147-65(2004), grading B Soil (crushed limestone)

Test Vehicle
- Type/Designation 1100C
- Make and Model .... 2007 Kia Rio
- Curb .... 2483 lb
- Test Inertial .... 2444 lb
- Dummy .... 165 lb
- Gross Static .... 2609 lb

Impact Conditions
- Speed .... 62.7 mi/h
- Angle .... 24.8°
- Location/Orientation .... Post 13

Impact Severity .... 57 kip/ft

Exit Conditions
- Speed .... 40.2 mi/h
- Trajectory/Heading Angle ... 8.6°/18.6°

Occupant Risk Values
- Longitudinal OIV .... 27.3 ft/s
- Lateral OIV .... 30.5 mi/h
- Longitudinal Ridedown .... 19.4 g
- Lateral Ridedown .... 14.6 g
- THIV .... 43.4 km/h
- PHD .... 24.9 g
- ASI 2.42
- Max. 0.050-s Average
  - Longitudinal .... −16.9 g
  - Lateral .... −16.2 g
  - Vertical .... 7.1 g

Post-Impact Trajectory
- Stopping Distance .... 185 ft downstream 56 ft toward traffic

Vehicle Stability
- Maximum Yaw Angle .... 67°
- Maximum Pitch Angle .... 10°
- Maximum Roll Angle .... 19°
- Vehicle Snagging .... No
- Vehicle Pocketing .... No

Test Article Deflections
- Dynamic .... 7.1 inches
- Permanent .... 3.4 inches
- Working Width .... 26.2 inches
- Height of Working Width .... 31.0 inches

Vehicle Damage
- VDS 01RFQ5
- CDC 01FREW3
- Max. Exterior Deformation .... 10.0 inches
- OCDI RF0120000
- Max. Occupant Compartment Deformation .... 1.25 inches

Figure 7.8. Summary of Results for *MASH* Test 3-20 on Upstream Transition.

7.5 *MASH* TEST 3-21 (CRASH TEST NO. 469549-01-2)

7.5.1 Test Designation and Actual Impact Conditions

MASH Test 3-21 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the CIP of the transition at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. The CIP for *MASH* Test 3-21 on the upstream transition was centerline of post 14 at the connection with the rail ±1 ft.

The 2013 RAM 1500 pickup truck used in the test weighed 5034 lb, and the actual impact speed and angle were 62.2 mi/h and 23.8°, respectively. The actual impact point was centerline of post 14 at the connection with the rail. Minimum target IS was 106 kip-ft, and actual IS was 106 kip-ft.

7.5.2 Weather Conditions

The test was performed on the morning of March 6, 2019. Weather conditions at the time of testing were as follows: wind speed: 4 mi/h; wind direction: 178° (vehicle was traveling in a northwesterly direction); temperature: 49°F; relative humidity: 38 percent.

7.5.3 Test Vehicle

Figures 7.9 and 7.10 show the 2013 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5034 lb, and its gross static weight was 5034 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 29.0 inches. Tables E.1 and E.2 in Appendix E1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 7.9. Upstream Transition/Test Vehicle Geometrics for Test No. 469549-01-2.

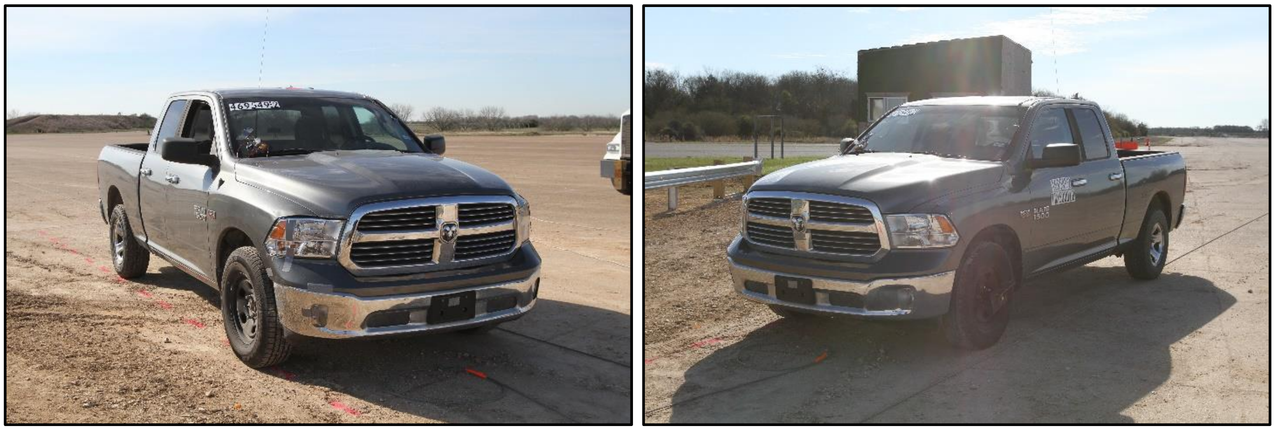


Figure 7.10. Test Vehicle before Test No. 469549-01-2.

7.5.4 Test Description

The test vehicle was traveling at an impact speed of 62.2 mi/h when it contacted the upstream transition. The right front corner of the vehicle bumper contacted the centerline of post 14 at the connection with the rail at an impact angle of 23.8°. Table 7.3 lists events that occurred during Test No. 469549-01-2. Figures E.1 and E.2 in Appendix E2 present sequential photographs during the test.

Table 7.3. Events during Test No. 469549-01-2.

TIME (s)	EVENTS
0.0000	Vehicle contacts transition
0.0410	Vehicle begins to redirect
0.1160	Left front tire leaves pavement surface
0.1280	Left rear tire leaves pavement surface
0.1980	Vehicle is parallel with transition
0.2030	Right rear bumper impacts transition
0.3460	Vehicle loses contact with transition while traveling at 49.1 mi/h, with a trajectory of 9.0 degrees and heading of 8.4 degrees.
0.5400	Left front tire contacts pavement surface

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle came to rest 250 ft downstream of the impact and 18 ft toward traffic lanes.

7.5.5 Damage to Test Installation

Figure 7.11 shows the damage to the transition. The soil was disturbed around posts 13 through 15. The base plate of post 17 was deformed. The concrete wing wall was cracked at post 17, and between posts 17 and 18. Working width was 22.7 inches, and height of working width was 50.5 inches. Maximum dynamic deflection during the test was 6.3 inches, and maximum permanent deformation was 2.75 inches at post 16.

Figure 7.11. Upstream Transition after Test No. 469549-01-2.

7.5.6 Vehicle Damage

Figure 7.12 shows the damage sustained by the vehicle. The front bumper, radiator and support, grill, right front fender, right front upper and lower A-arms, right front tire and rim, right front door and window glass, right rear door, right rear cab corner, right rear exterior bed, right rear rim, and rear bumper were damaged. The right front wheel (with tire) was completely removed. Maximum exterior crush to the vehicle was 15.0 inches in the front plane at the right front corner at bumper height. Maximum occupant compartment deformation was 2.0 inches in the in the right firewall area and 4.0 inches in the right front kick panel. Figure 7.13 shows the interior of the vehicle. Tables E.3 and E.4 in Appendix E1 provide exterior crush and occupant compartment measurements.

Figure 7.12. Test Vehicle after Test No. 469549-01-2.

Figure 7.13. Interior of Test Vehicle for Test No. 469549-01-2.

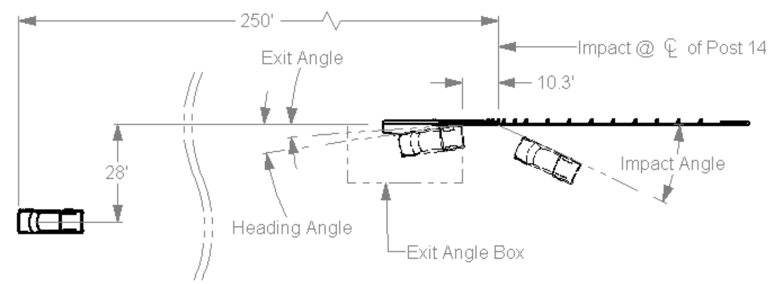
7.5.7 Occupant Risk Factors

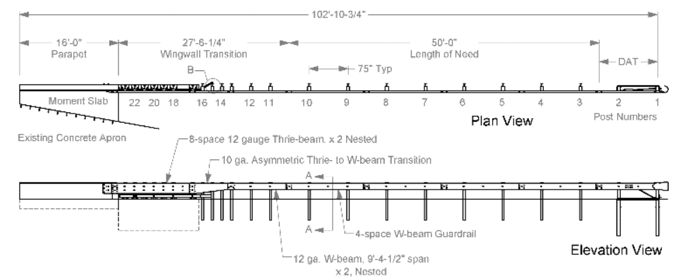
Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and results are shown in Table 7.4. Figure 7.14 summarizes these data and other pertinent information from the test. Figure E.3 in Appendix E3 shows the vehicle angular displacements, and Figures E.4 through E.9 in Appendix E4 show acceleration versus time traces.

Table 7.4. Occupant Risk Factors for Test No. 469549-01-2.

Occupant Risk Factor	Value	Time
OIV Longitudinal Lateral	 18.7 ft/s 24.3 ft/s	at 0.1048 s on right side of interior
Occupant Ridedown Accelerations Longitudinal Lateral	 5.3 g 10.0 g	 0.1104–0.1204 s 0.1395–0.1495 s
THIV	33.3 km/h 9.2 m/s	at 0.1025 s on right side of interior
PHD	10.1 g	0.1396–0.1496 s
ASI	1.68	0.0668–0.1168 s
Maximum 50-ms Moving Average Longitudinal Lateral Vertical	 −9.7 g −12.5 g 4.2 g	 0.0398–0.0898 s 0.0411–0.0911 s 0.0997–0.1497 s
Maximum Roll, Pitch, and Yaw Angles Roll Pitch Yaw	 14° 10° 46°	 1.3533 s 0.6060 s 0.9440 s

0.000 s	0.100 s	0.200 s	0.400 s





General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-21
TTI Test No.	469549-01-2
Test Date	2019-03-06
Test Article	
Type	Transition
Name	Thrie Beam Transition
Installation Length	102 ft-10¾ inches
Material or Key Elements	16-ft long parapet/moment slab, a 27 ft-6¼ inch long W-beam to thrie-beam to parapet transition section, 50 ft of W-beam guardrail, and DAT terminal; top of metal rail height 31 inches
Soil Type and Condition	AASHTO M147-65(2004), grading B Soil (crushed limestone)
Test Vehicle	
Type/Designation	2270P
Make and Model	2013 RAM 1500 Pickup
Curb	5171 lb
Test Inertial	5034 lb
Dummy	No dummy
Gross Static	5034 lb

Impact Conditions	
Speed	62.2 mi/h
Angle	23.8°
Location/Orientation	Centerline of post 14 at connection
Impact Severity	106 kip-ft
Exit Conditions	
Speed	49.2 mi/h
Trajectory/Heading Angle	9.0° / 8.4°
Occupant Risk Values	
Longitudinal OIV	18.7 ft/s
Lateral OIV	24.3 ft/s
Longitudinal Ridedown	5.3 g
Lateral Ridedown	10.0 g
THIV	33.3 km/h
PHD	10.1 g
ASI	1.68
Max. 0.050-s Average	
Longitudinal	-9.7 g
Lateral	-12.5 g
Vertical	4.2 g

Post-Impact Trajectory	
Stopping Distance	250 ft downstream 28 ft toward traffic
Vehicle Stability	
Maximum Yaw Angle	46°
Maximum Pitch Angle	10°
Maximum Roll Angle	14°
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	6.3 inches
Permanent	2.75 inches
Working Width	22.7 inches
Height of Working Width	50.5 inches
Vehicle Damage	
VDS	01RFQ5
CDC	01FREW4
Max. Exterior Deformation	15.0 inches
OCDI	FR0100000
Max. Occupant Compartment Deformation	4.0 inches

Figure 7.14. Summary of Results for *MASH* Test 3-21 on Upstream Transition.

CHAPTER 8: *MASH* TEST 3-21 ON DOWNSTREAM TRANSITION

8.1 TEST ARTICLE AND INSTALLATION DETAILS

The Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure installation was the same as used in the previous tests. Figure 7.1 presents overall information on the transition, and Figure 7.2 provides photographs of the installation. Appendix A provides further details of the transition.

8.2 MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to install/construct the downstream transition.

8.3 SOIL CONDITIONS

On the day of Test No. 469549-01-4, March 19, 2019, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 7525 lbf, 8080 lbf, and 8131 lbf, respectively. Tables C.4 in Appendix C shows the strength of the backfill material in which the transition was installed met minimum requirements.

8.4 *MASH* TEST 3-21 (CRASH TEST NO. 469549-01-4)

8.4.1 Test Designation and Actual Impact Conditions

MASH Test 3-21 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the CIP of the test article at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. The CIP for *MASH* Test 3-21 on the downstream transition was 5 inches ±1 ft downstream of the centerline of post 19 at the connection with the rail (82.75 inches from the end of the parapet).

The 2013 RAM 1500 pickup truck used in the test weighed 5052 lb, and the actual impact speed and angle were 62.8 mi/h and 24.8°, respectively. The actual impact point was 4.0 inches downstream of the centerline of post 19 at the connection with the rail. Minimum target IS was 106 kip-ft, and actual IS was 117 kip-ft.

8.4.2 Weather Conditions

The test was performed on the morning of March 19, 2019. Weather conditions at the time of testing were as follows: wind speed: 4 mi/h; wind direction: 80° (vehicle was traveling in a northwesterly direction); temperature: 64°F; relative humidity: 49 percent.

8.4.3 Test Vehicle

Figures 8.1 and 8.2 show the 2013 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5052 lb, and its gross static weight was 5052 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 28.25 inches. Tables F.1 and F.2 in Appendix F1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 8.1. Downstream Transition/Test Vehicle Geometrics for Test No. 469549-01-4.

Figure 8.2. Test Vehicle before Test No. 469549-01-4.

8.4.4 Test Description

The test vehicle was traveling at an impact speed of 62.8 mi/h when it contacted the downstream transition 4.0 inches downstream of the centerline of post 19 at an impact angle of 24.8°. Table 8.1 lists events that occurred during Test No. 469549-01-4. Figures D.1 and D.2 in Appendix D2 present sequential photographs during the test.

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle came to rest 196 ft downstream of the impact and 53 ft toward traffic lanes.

Table 8.1. Events during Test No. 469549-01-4.

TIME (s)	EVENTS
0.0000	Vehicle contacts transition
0.0580	Vehicle begins to redirect
0.1090	Left front tire leaves ground
0.1220	Left rear tire leaves ground
0.2030	Vehicle is parallel with transition
0.2080	Right rear bumper contacts transition
0.3510	Vehicle loses contact with transition while traveling at 54.1 m/h with a trajectory of 5.6°/heading of 13.7°

8.4.5 Damage to Test Installation

Figure 8.3 shows the damage to the downstream transition. The guardrail was deformed from post 19 to post 21. The soil was disturbed on the traffic side of the concrete wing wall. Posts 19 through 22 were leaning toward the field side at 89°. There was superficial scuffing on the upper edge of the concrete parapet. Working width was 25.4 inches, and height of working width was 47.5 inches. Maximum dynamic deflection during the test was 2.2 inches, and maximum permanent deformation was 0.8 inches.

8.4.6 Vehicle Damage

Figure 8.4 shows the damage sustained by the vehicle. The front bumper, radiator and support, grill, right front fender, right upper and lower A-arms, right front tire and rim, right frame rail, right front and rear doors, right cab corner, right rear exterior bed, and right rear tire and rim were damaged. The right front wheel (with tire) was completely removed. The windshield had stress cracks radiating from the right side A-pillar. Maximum exterior crush to the vehicle was 17.0 inches in the front plane at the right front corner at bumper height. Maximum occupant compartment deformation was 6.0 inches in the right side firewall and kickpanel. Figure 8.5 shows the interior of the vehicle. Tables F.3 and F.4 in Appendix F1 provide exterior crush and occupant compartment measurements.

8.4.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and results are shown in Table 8.2. Figure 8.6 summarizes these data and other pertinent information from the test. Figure F.3 in Appendix F3 shows the vehicle angular displacements, and Figures F.4 through F.9 in Appendix D4 show acceleration versus time traces.

Figure 8.3. Downstream Transition after Test No. 469549-01-4.

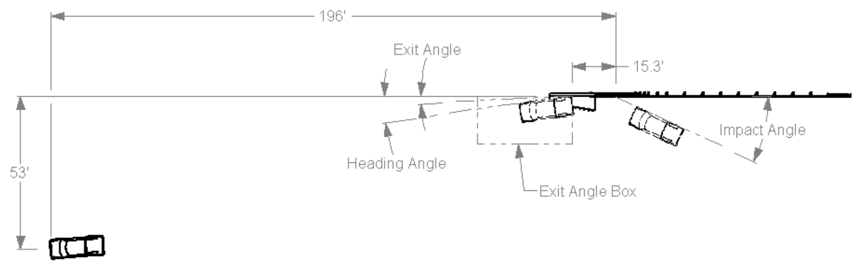
Figure 8.4. Test Vehicle after Test No. 469549-01-4.

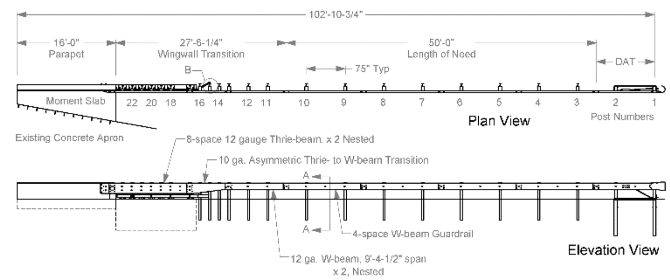
Figure 8.5. Interior of Test Vehicle for Test No. 469549-01-4.

Table 8.2. Occupant Risk Factors for Test No. 469549-01-4.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	19.7 ft/s	at 0.1033 s on right side of interior
Lateral	26.6 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	6.0 g	0.1495–0.1595 s
Lateral	9.1 g	0.1521–0.1621 s
THIV	35.5 km/h 9.9 m/s	at 0.1006 s on right side of interior
PHD	10.3	0.1500–0.1600 s
ASI	1.55	0.0555–0.1055 s
Maximum 50-ms Moving Average		
Longitudinal	−8.6 g	0.0339–0.0839 s
Lateral	−11.5 g	0.0464–0.0964 s
Vertical	−4.8 g	0.1115–0.1615 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	28°	0.9681 s
Pitch	15°	0.5922 s
Yaw	105°	2.0000 s

0.000 s | 0.100 s | 0.200 s | 0.400 s





General Information
Test Agency....................... Texas A&M Transportation Institute (TTI)
Test Standard Test No....... *MASH* Test 3-21
TTI Test No. 469549-01-4
Test Date 2019-03-19

Test Article
Type .... Transition
Name................................. Thrie Beam Transition
Installation Length.............. 102 ft-10¾ inches
Material or Key Elements ... 16-ft long parapet/moment slab, a 27 ft-6¼ inch long W-beam to thrie-beam to parapet transition section, 50 ft of W-beam guardrail, and DAT terminal; top of metal rail height 31 inches

Soil Type and Condition ..... AASHTO M147-65(2004), grading B Soil (crushed limestone)

Test Vehicle
Type/Designation............... 2270P
Make and Model .... 2013 RAM 1500 Pickup
Curb.................................. 4953 lb
Test Inertial........................ 5052 lb
Dummy .... No dummy
Gross Static .... 5052 lb

Impact Conditions
Speed .... 62.8 mi/h
Angle .... 24.8°
Location/Orientation .... 4 inches downstream of post 19

Impact Severity................. 117 kip-ft

Exit Conditions
Speed .... 54.1 mi/h
Trajectory/Heading Angle. 5.6°/13.7°

Occupant Risk Values
Longitudinal OIV .... 19.7 ft/s
Lateral OIV....................... 26.6 ft/s
Longitudinal Ridedown..... 6.0 g
Lateral Ridedown .... 9.1 g
THIV .... 35.5 km/h
PHD .... 10.3 g
ASI.................................. 1.55
Max. 0.050-s Average
Longitudinal .... -8.6 g
Lateral........................... -11.5 g
Vertical.......................... -4.8 g

Post-Impact Trajectory
Stopping Distance.................... 196 ft downstream 53 ft toward traffic

Vehicle Stability
Maximum Yaw Angle .... 105°
Maximum Pitch Angle .... 15°
Maximum Roll Angle .... 28°
Vehicle Snagging ....
Vehicle Pocketing .... No

Test Article Deflections No
Dynamic.................................. 2.2 inches
Permanent .... 0.8 inch
Working Width .... 25.4 inches
Height of Working Width .... 47.5 inches

Vehicle Damage
VDS 01RFQ5
CDC.. 01FREW4
Max. Exterior Deformation......... 17.0 inches
OCDI RF0033000
Max. Occupant Compartment Deformation........................... 6.0 inches

Figure 8.6. Summary of Results for *MASH* Test 3-21 on Downstream Transition.

CHAPTER 9: SUMMARY AND CONCLUSIONS

9.1 SUMMARY OF RESULTS

An assessment of the tests on the Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure based on the applicable safety evaluation criteria for *MASH* TL-3 for transitions is provided in Tables 9.1 through 9.3.

9.2 CONCLUSIONS

The Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure, used on the upstream and downstream ends, performed acceptably for *MASH* TL-3 transitions. Based on the transition design developed for the project, *MASH* Test 3-20 in the immediate area upstream of the concrete parapet did not present reasonable uncertainty of success, so this test was not performed (considered optional for *MASH*). Table 9.4 shows the outcome of the crash tests performed on the transition.

Table 9.1. Performance Evaluation Summary for *MASH* Test 3-20 on Upstream Transition.

Test Agency: Texas A&M Transportation Institute | Test No.: 469549-01-1 | Test Date: 2019-03-04

***MASH* Test 3-20 Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy		
A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure contained and redirected the 1100C vehicle when impacted from the upstream end. Maximum dynamic deflection during the test was 7.1 inches.	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.	No detached elements, fragments, or other debris was present to penetrate or show potential for penetrating 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 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 1.25 inches in the kick panel laterally across the floor pan.	
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 19° and 10°, respectively.	Pass
H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.	Longitudinal OIV was 27.3 ft/s, and lateral OIV was 30.5 ft/s.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.	Maximum longitudinal occupant ridedown acceleration was 19.4 g, and maximum lateral occupant ridedown acceleration was 14.6 g.	Pass
Vehicle Trajectory		
For redirective devices, it is preferable that the vehicle be smoothly redirected and leave the barrier within the exit box criteria (not less than 32.8 ft for the 1100C and 2270P vehicles), and should be documented.	The 1100C vehicle exited within the exit box.	*Documentation only

Table 9.2. Performance Evaluation Summary for *MASH* Test 3-21 on Upstream Transition.

Test Agency: Texas A&M Transportation Institute | Test No.: 469549-01-2 | Test Date: 2019-03-06

***MASH* Test 3-21 Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy		
A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure contained and redirected the 2270P vehicle when impacted on the upstream end. Maximum dynamic deflection during the test was 6.3 inches.	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.	No detached elements, fragments, or other debris was present to penetrate or show potential for penetrating 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 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 4.0 inches in the right front kick panel laterally across the floor pan.	
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 13° and 10°, respectively.	Pass
H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.	Longitudinal OIV was 18.7 ft/s, and lateral OIV was 24.3 ft/s.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.	Maximum longitudinal occupant ridedown acceleration was 5.3 g, and maximum lateral occupant ridedown acceleration was 10.0 g.	Pass
Vehicle Trajectory		
For redirective devices, it is preferable that the vehicle be smoothly redirected and leave the barrier within the exit box criteria (not less than 32.8 ft for the 1100C and 2270P vehicles), and should be documented.	The 2270P vehicle exited within the exit box.	*Documentation only

Table 9.3. Performance Evaluation Summary for *MASH* Test 3-21 on Downstream Transition.

Test Agency: Texas A&M Transportation Institute | Test No.: 469549-01-4 | Test Date: 2019-03-19

MASH Test 3-21 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 Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure contained and redirected the 2270P vehicle when impacted on the downstream end. Maximum dynamic deflection during the test was 2.2 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 was present to penetrate or show potential for penetrating 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 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 6.0 inches in the right side firewall and kickpanel.	
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 28° and 15°, respectively.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.*	Longitudinal OIV was 19.7 ft/s, and lateral OIV was 26.6 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.*	Maximum longitudinal occupant ridedown acceleration was 6.0 g, and maximum lateral occupant ridedown acceleration was 9.1 g.	Pass
<u>Vehicle Trajectory</u> For redirective devices, it is preferable that the vehicle be smoothly redirected and leave the barrier within the exit box criteria (not less than 32.8 ft for the 1100C and 2270P vehicles), and should be documented.	The 2270P vehicle exited within the exit box.	*Documentation only

Table 9.4. Assessment Summary for *MASH* TL-3 Tests on Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure.

Evaluation Factors	Evaluation Criteria	Upstream Transition		Downstream Transition
		Test No. 469549-01-1	**Test No. 469549-01-2**	**Test No. 469549-01-4**
Structural Adequacy	A	S	S	S
Occupant Risk	D	S	S	S
	F	S	S	S
	H	S	S	S
	I	S	S	S
	Test No.	***MASH* Test 3-20**	***MASH* Test 3-21**	***MASH* Test 3-21**
	Pass/Fail	Pass	Pass	Pass

S = Satisfactory
U = Unsatisfactory
N/A = Not Applicable

CHAPTER 10: IMPLEMENTATION[*]

The testing reported herein met all the requirements of *MASH*. However, other impact conditions were discovered that might be critical based on the final design developed for this project. These impact conditions (further testing) will be investigated under a new and separate project at a later date.

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

REFERENCES

1. AASHTO. *Manual for Assessing Roadside Safety Hardware.* American Association of State Highway and Transportation Officials: Washington, DC, 2009.

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

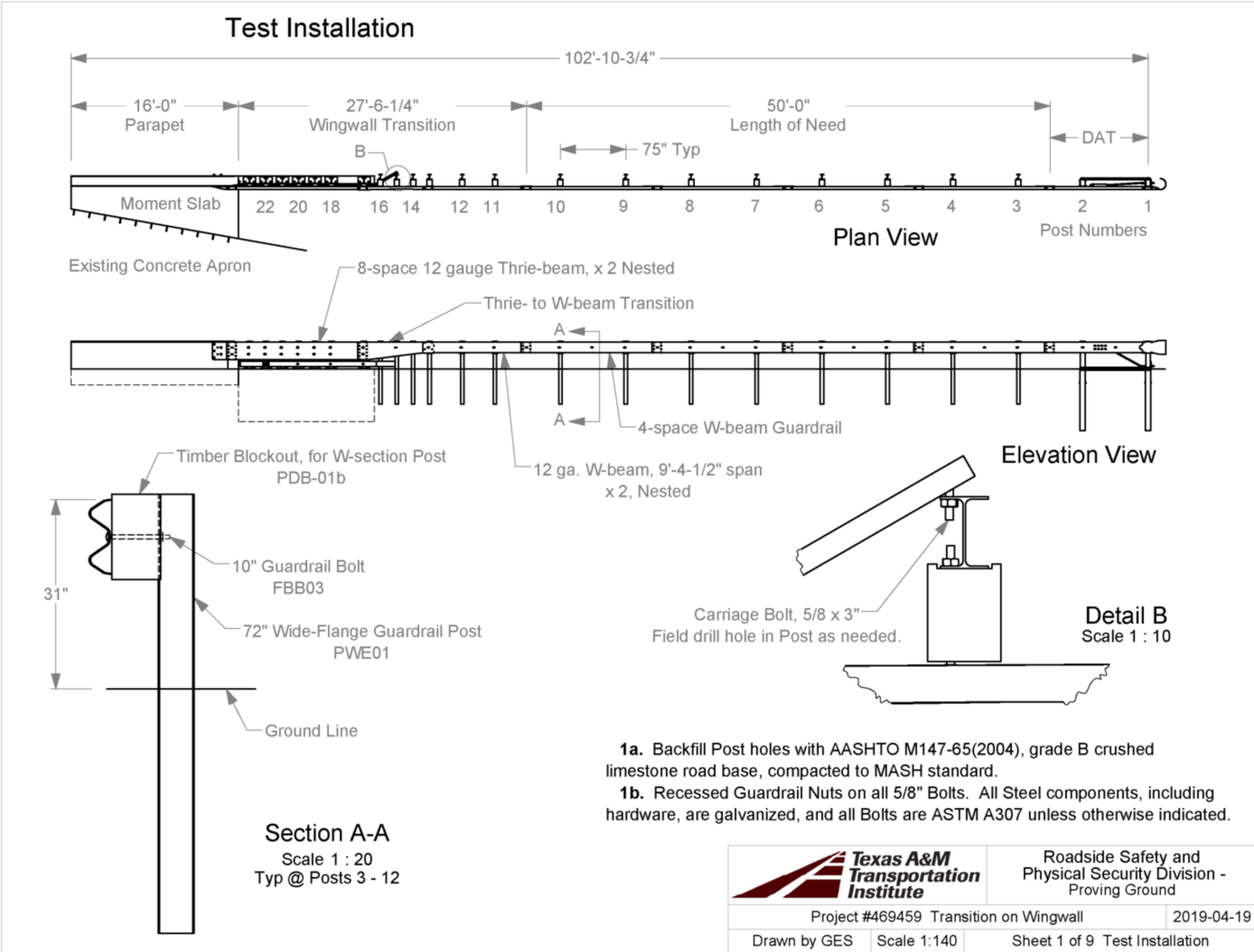
3. S. K. Rosenbaugh, R. K. Faller, R. W. Bielenberg, K. A. Lechtenberg, D. L. Sicking, and J. D. Reid. *Development of the MGS Approach Guardrail Transition using Standardized Steel Posts*. MwRSF Research Report NO. TRP-03-210-10, Midwest Roadside Safety Facility, Lincoln, NE, December 21, 2010.

4. B. J. Winkelbauer, S. K. Rosenbaugh, R. W. Bielenberg, J. G. Putjenter, K. A. Lechtendberg, R. K. Faller. *Dynamic Evaluation of MGS Stiffness Transition with Curb*. MwRSF Research Report TRP-03-291-14. Midwest Roadside Safety Facility, Lincoln, NE, June 30, 2014.

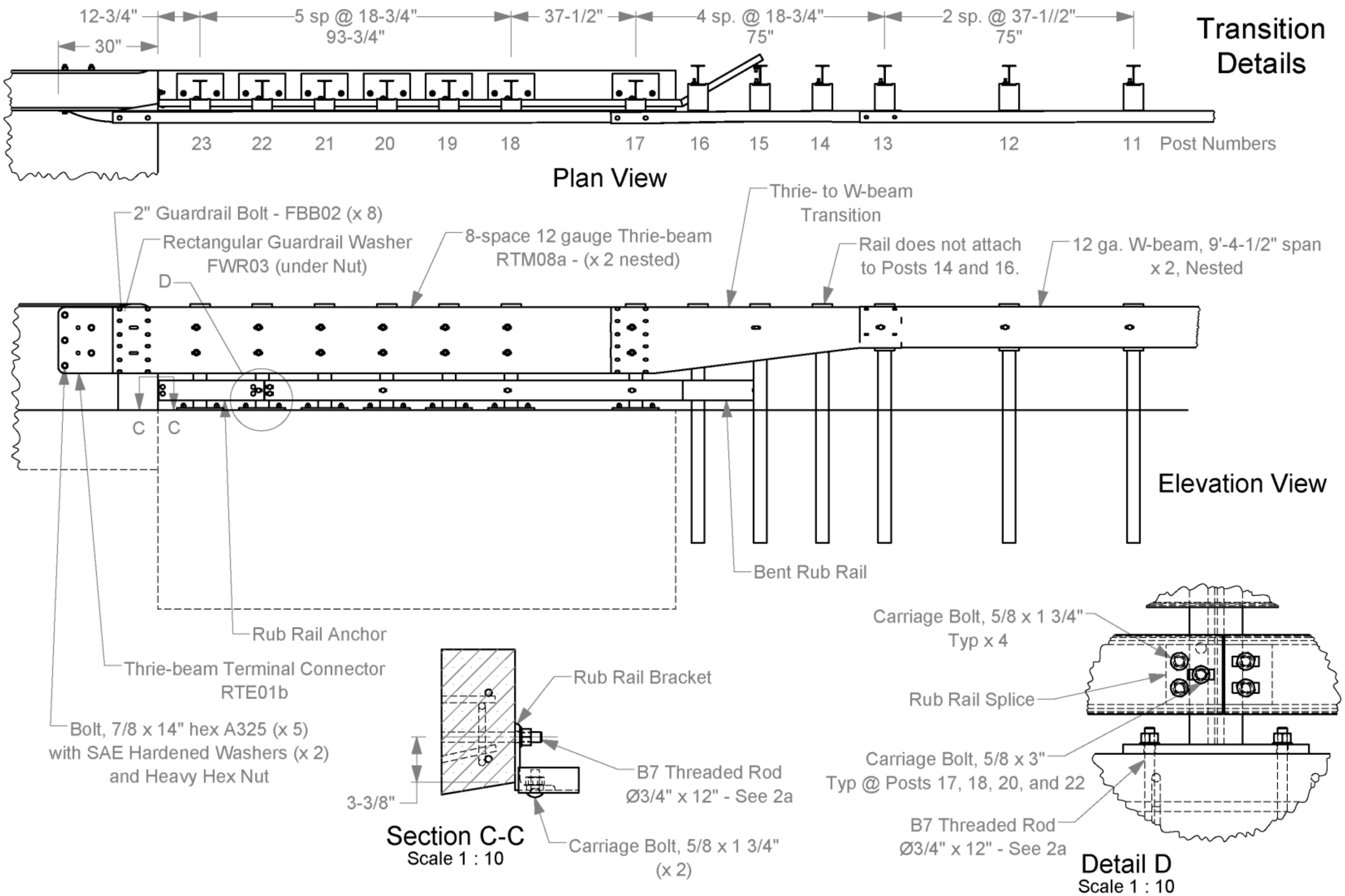
5. D. R. Arrington, R. P. Bligh, and W. L. Menges. *MASH Test 3-21 on TL-3 Thrie Beam Transition without Curb*. TTI Test Report No. 9-1002-12-3. Texas A&M Transportation Institute, College Station, TX, July 2013.

6. W. F. Williams, R. P. Bligh, and W. L. Menges. MASH TL-3 Testing and Evaluation of the TxDOT T131RC Bridge Rail Transition. TTI Test Report No. 9-1002-12-4. Texas A&M Transportation Institute, College Station, TX, March 2013.

APPENDIX A. DETAILS OF THE TRANSITION



Transition Details



2a. Secure with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions, with 10" embedment. SAE Hardened Washer and Heavy Hex Nut on each threaded rod.

2b. Recessed Guardrail Nuts on all 5/8" Bolts. All Steel components, including hardware, are galvanized, and all Bolts are ASTM A307 unless otherwise indicated.

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Project #469459 Transition on Wingwall			2019-04-19
Drawn by GES	Scale 1:40	Sheet 2 of 9 Transition Details	

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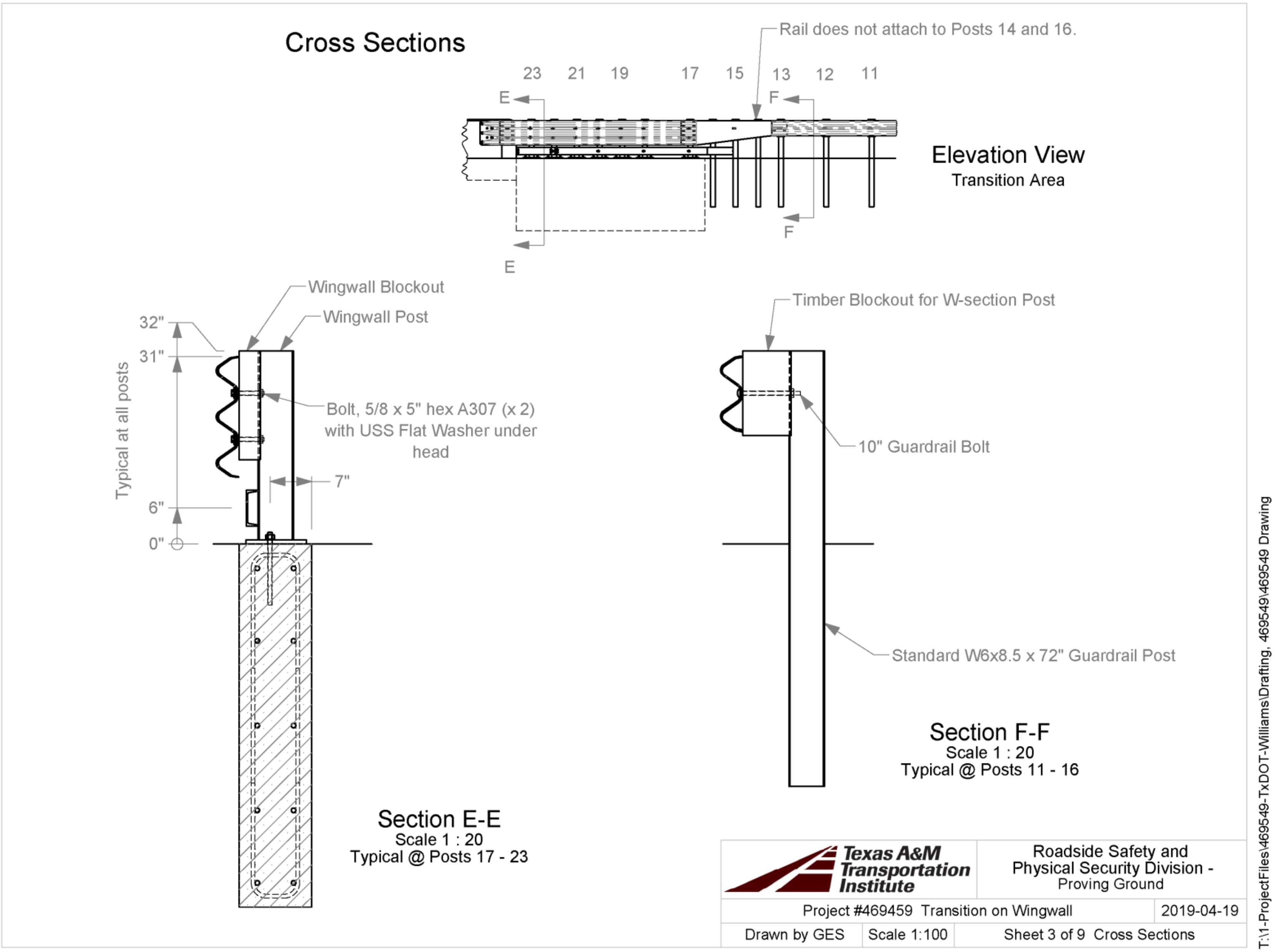
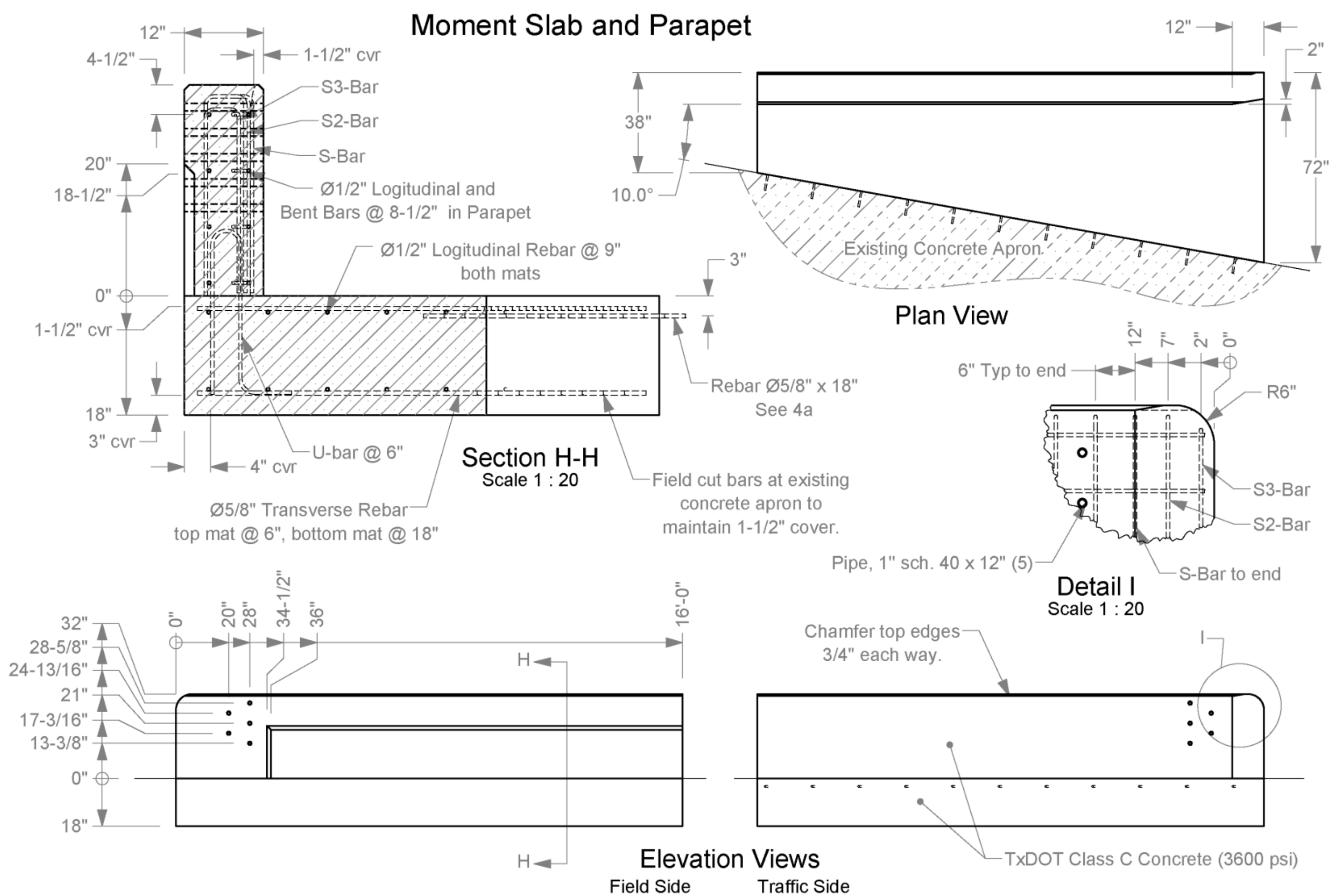

Cross Sections
Rail does not attach to Posts 14 and 16.
23
21
19
17
15
13
12
11
E
F
Elevation View
Transition Area
Wingwall Blockout
Wingwall Post
32"
31"
Typical at all posts
Bolt, 5/8 x 5" hex A307 (x 2) with USS Flat Washer under head
7"
6"
0"
Timber Blockout for W-section Post
10" Guardrail Bolt
Standard W6x8.5 x 72" Guardrail Post
Section F-F
Scale 1 : 20
Typical @ Posts 11 - 16
Section E-E
Scale 1 : 20
Typical @ Posts 17 - 23
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #469459 Transition on Wingwall
2019-04-19
Drawn by GES
Scale 1:100
Sheet 3 of 9 Cross Sections
T:\1-ProjectFiles\469549-TxDOT-Williams\Drafting, 469549\469549 Drawing

Moment Slab and Parapet

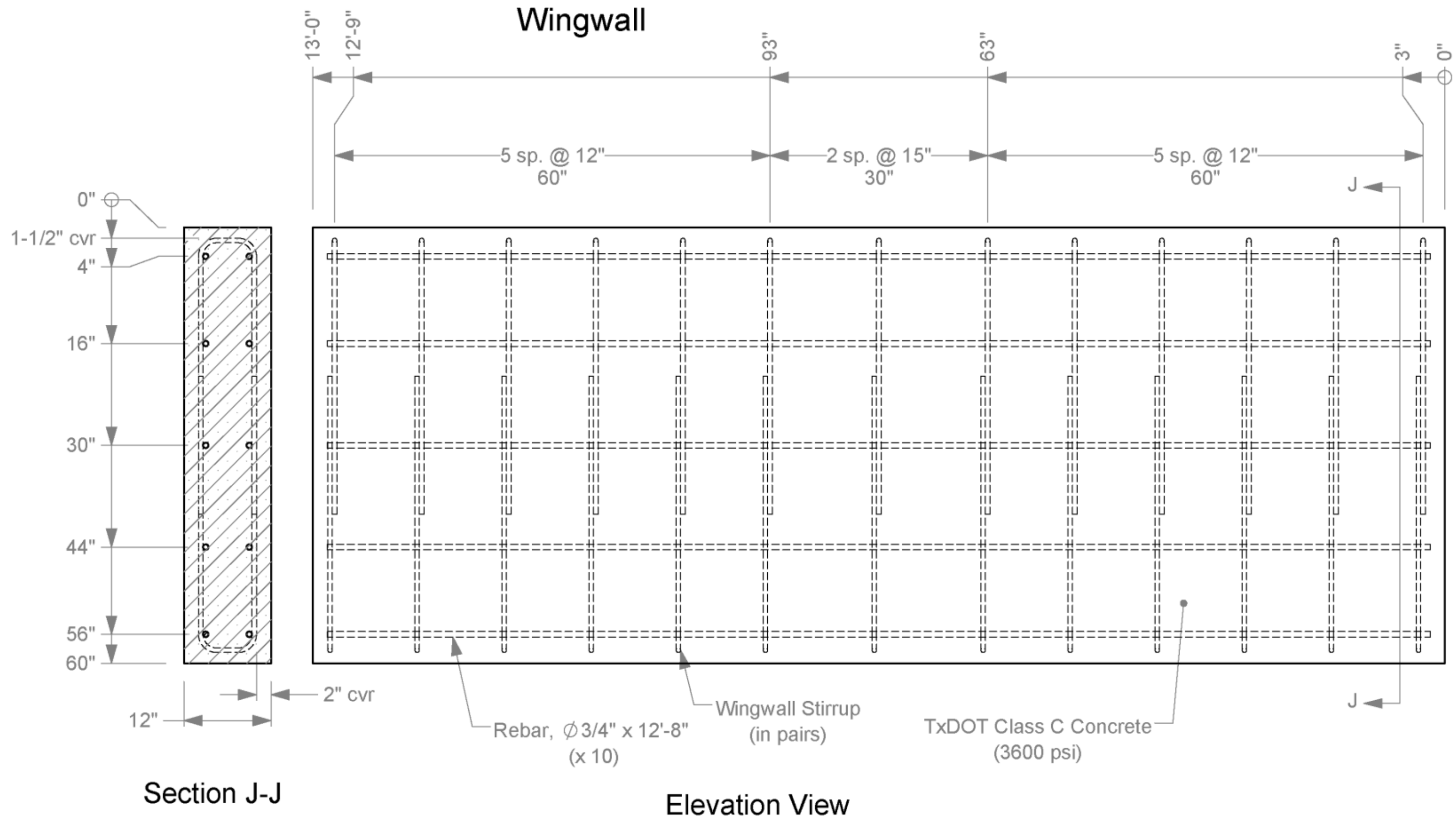


4a. Secure in existing concrete apron with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions, with 6" embedment at 18" spacing.

4b. All rebar dimensions are to center unless otherwise indicated by "cvr" (cover).

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469459 Transition on Wingwall		2019-01-25
Drawn by GES	Scale 1:50	Sheet 4 of 9 Moment Slab and Parapet

Wingwall



5a. All rebar is grade 60.

5b. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover).

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #469459 Transition on Wingwall		2019-01-25
Drawn by GES	Scale 1:20	Sheet 5 of 9 Wingwall

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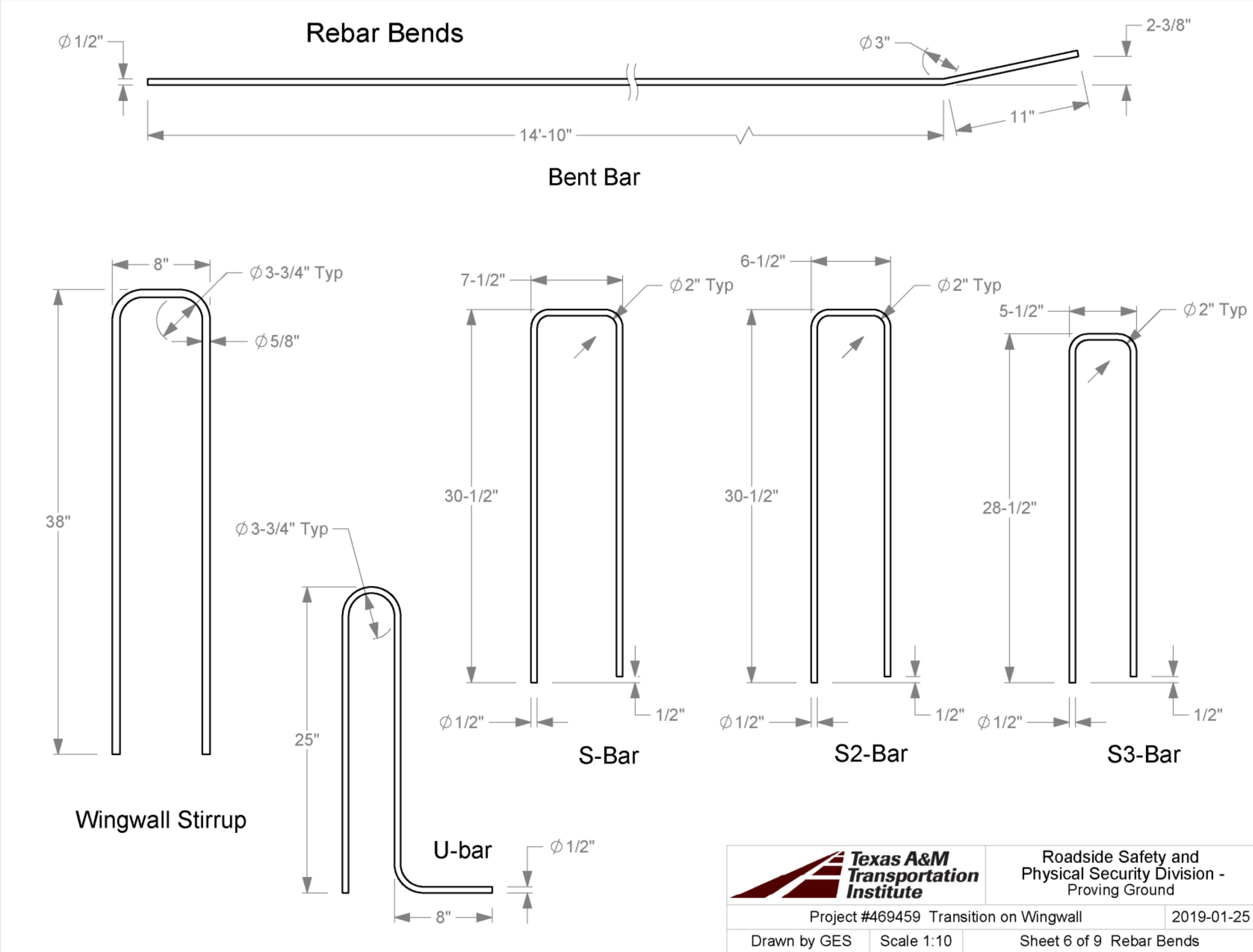

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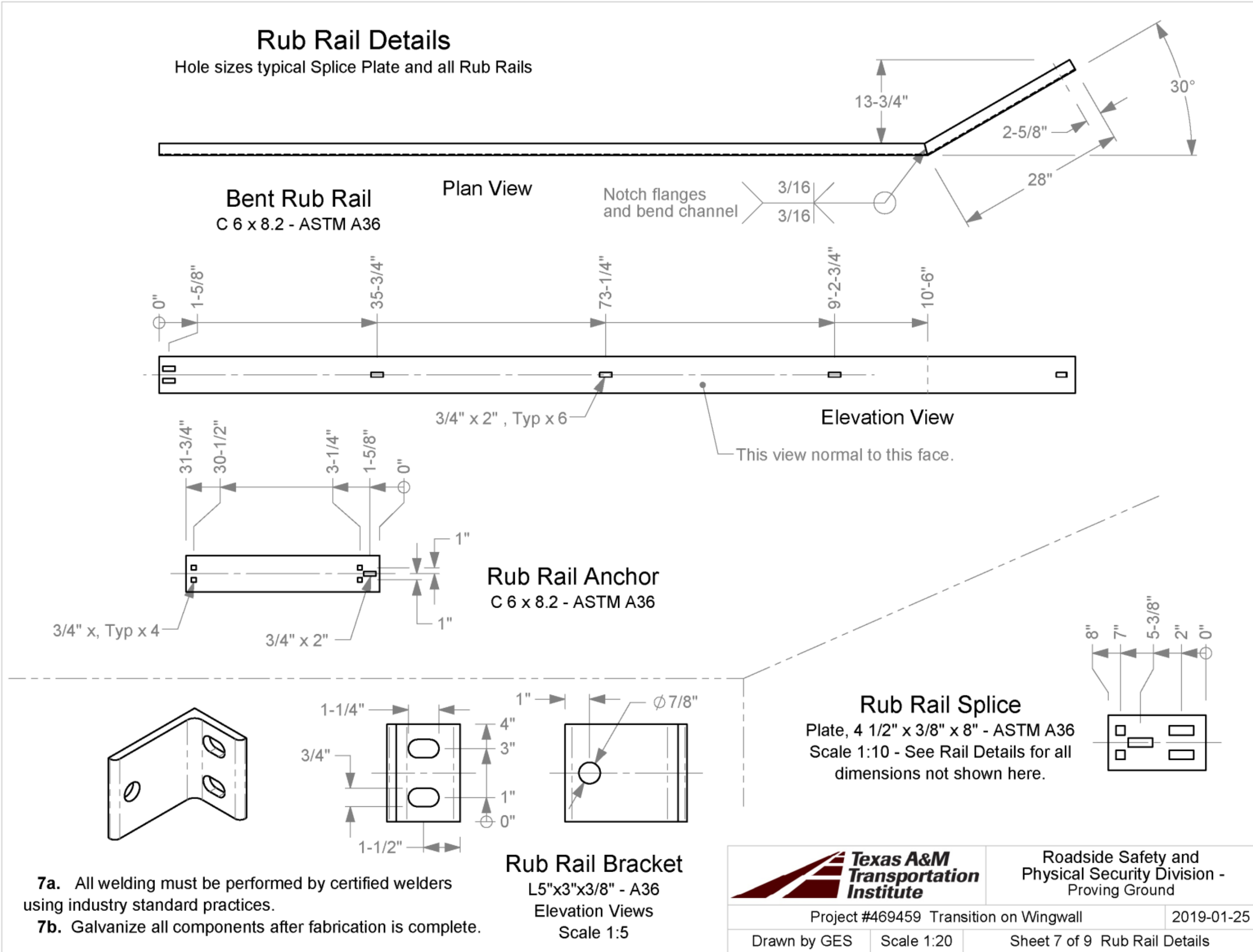
Rub Rail Details
Hole sizes typical Splice Plate and all Rub Rails
13-3/4"
30°
2-5/8"
28"
Bent Rub Rail
C 6 x 8.2 - ASTM A36
Plan View
Notch flanges
and bend channel
3/16
3/16
0"
1-5/8"
35-3/4"
73-1/4"
9'-2-3/4"
10'-6"
3/4" x 2" , Typ x 6
Elevation View
This view normal to this face.
31-3/4"
30-1/2"
3-1/4"
1-5/8"
0"
1"
1"
Rub Rail Anchor
C 6 x 8.2 - ASTM A36
3/4" x, Typ x 4
3/4" x 2"
8"
7"
5-3/8"
2"
0"
Rub Rail Splice
Plate, 4 1/2" x 3/8" x 8" - ASTM A36
Scale 1:10 - See Rail Details for all
dimensions not shown here.
1-1/4"
3/4"
4"
3"
1"
0"
1-1/2"
1"
Ø 7/8"
Rub Rail Bracket
L5"x3"x3/8" - A36
Elevation Views
Scale 1:5
7a. All welding must be performed by certified welders
using industry standard practices.
7b. Galvanize all components after fabrication is complete.
Texas A&M Transportation Institute
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Physical Security Division -
Proving Ground
Project #469459 Transition on Wingwall
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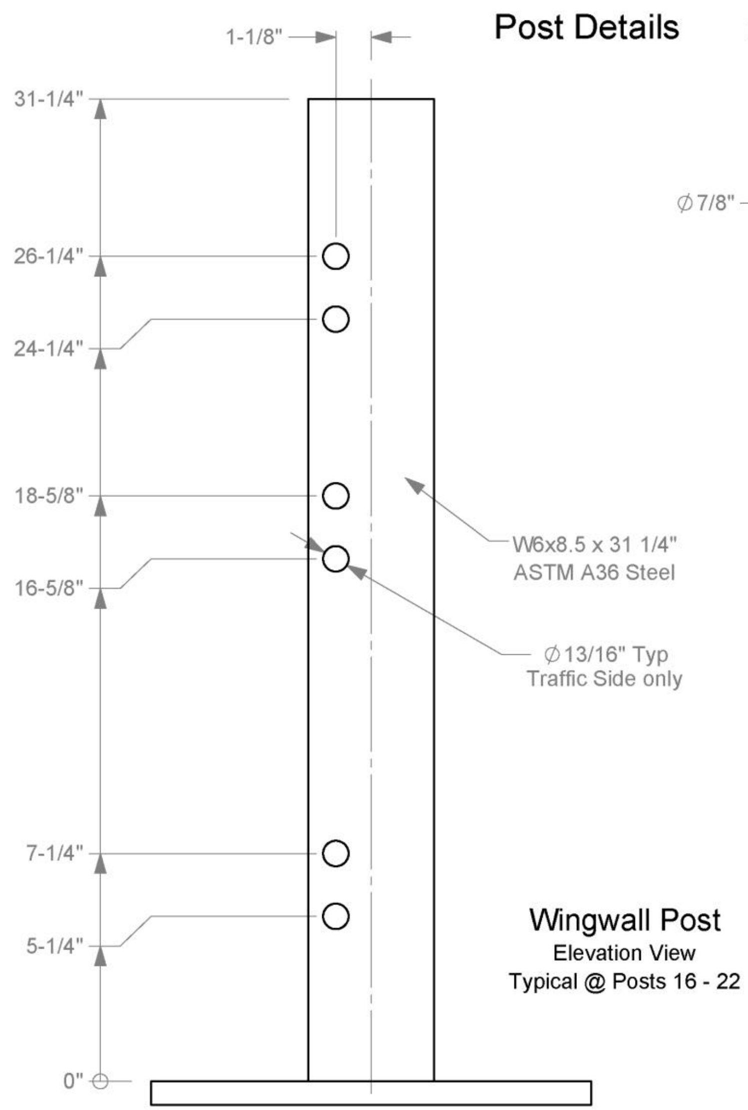
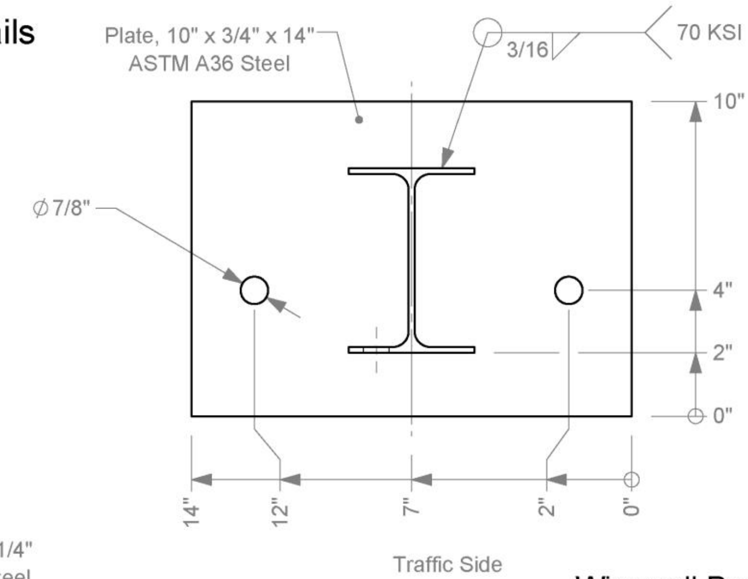
Drawn by GES
Scale 1:20
Sheet 7 of 9 Rub Rail Details

Post Details



Wingwall Post
Elevation View
Typical @ Posts 16 - 22



Wingwall Post
Plan View

8a. All welding must be performed by certified welders using industry standard practices.
8b. Galvanize all components after fabrication is complete.

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Project #469459 Transition on Wingwall		2019-01-25
Drawn by GES	Scale 1:5	Sheet 8 of 9 Post Details

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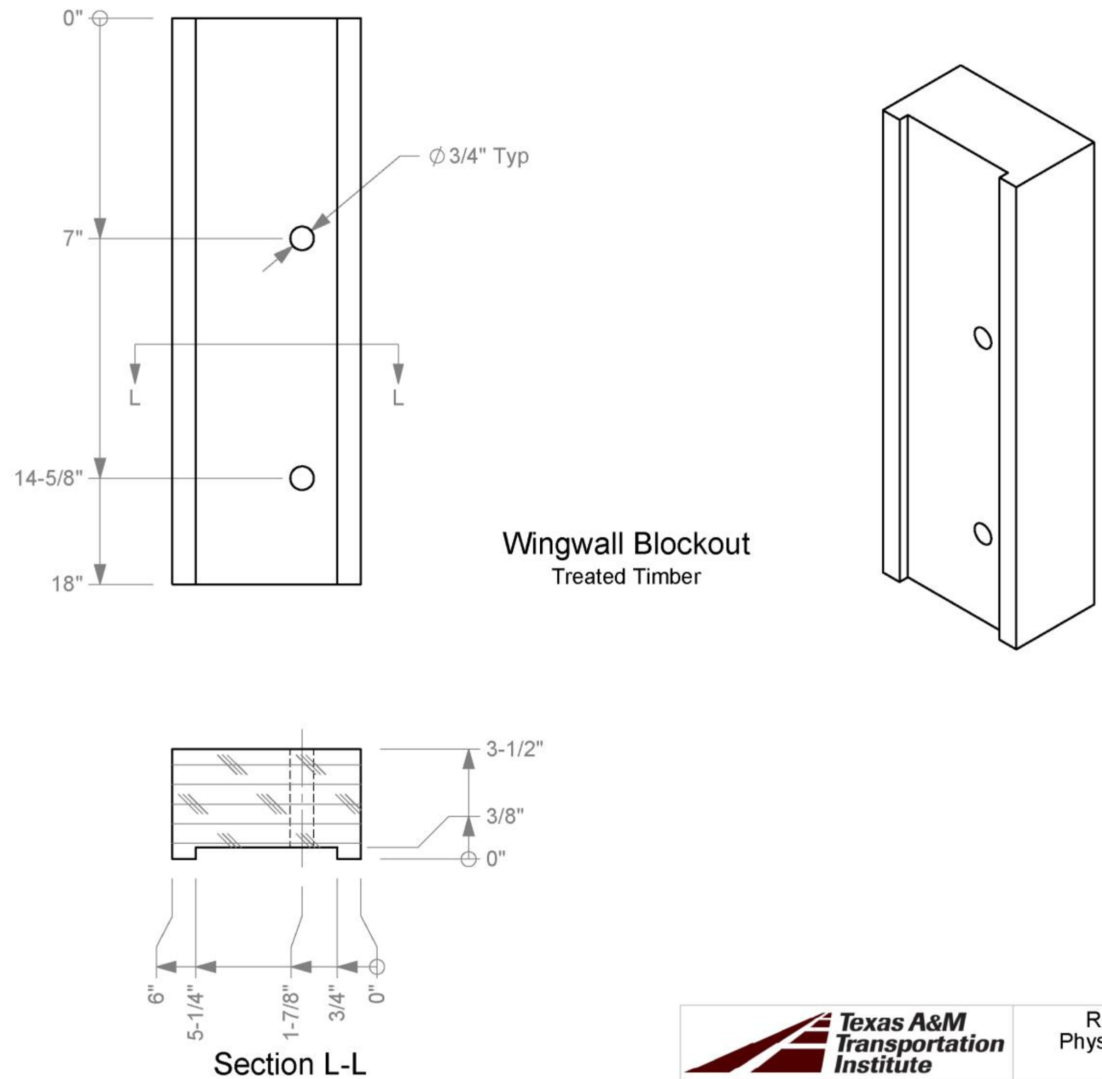


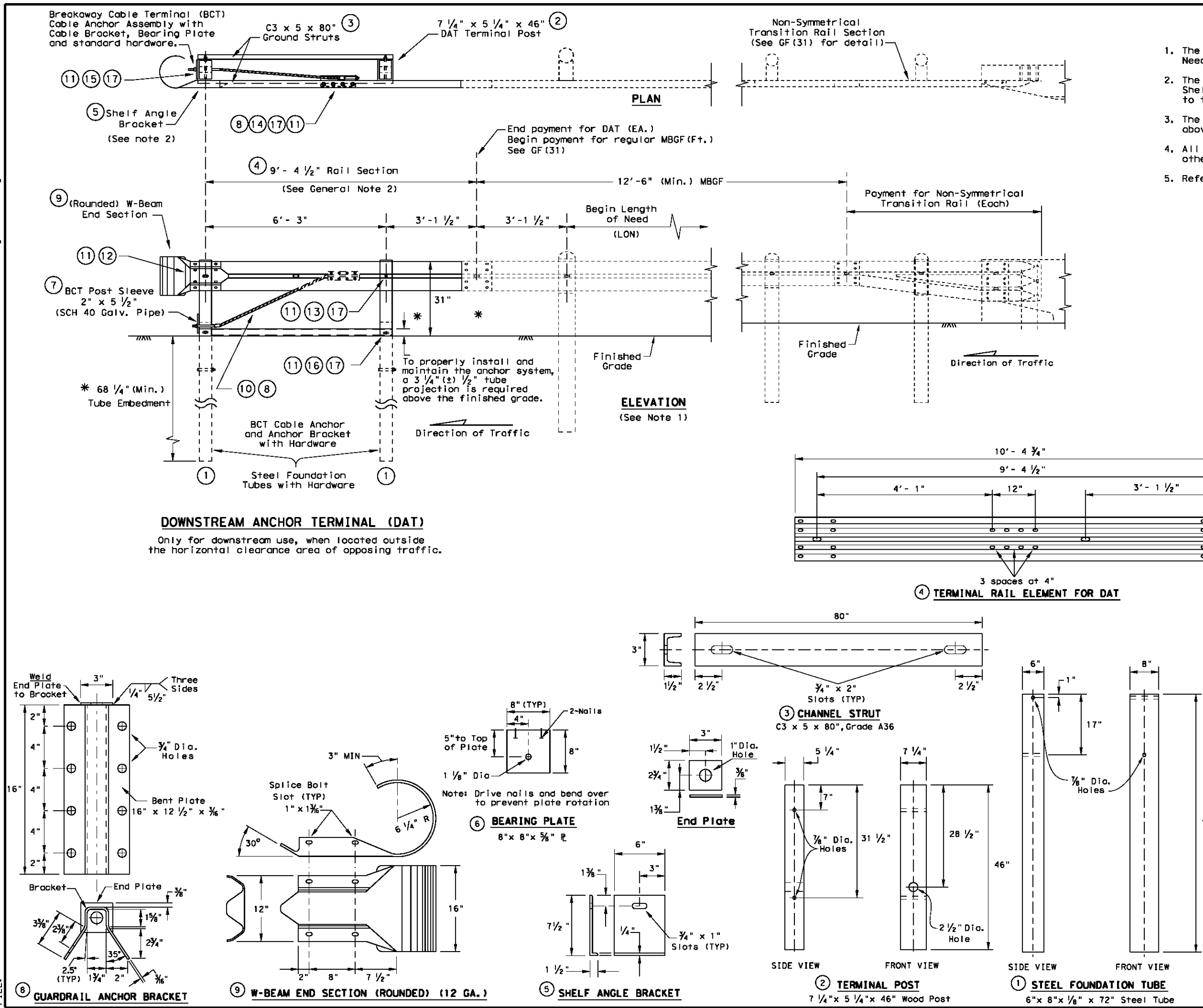
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project #469459 Transition on Wingwall	2019-01-25

Drawn by GES	Scale 1:5	Sheet 9 of 9 Wingwall Blockout

T:\1-ProjectFiles\469549-TxDOT-Williams\Drafting, 469549\469549 Drawing



GENERAL NOTES

1. The detail shown is the minimum Length of Need (LON) for a DAT connected to a concrete rail.
2. The rail section at the end post is supported by the Shelf Angle Bracket. The rail element is not attached to the end post.
3. The foundation tubes shall not project more than 3 3/4" above the finished grade.
4. All hardware for DAT shall be ASTM A307 unless otherwise shown.
5. Refer to GF(31) sheet for terminal connection details.

MOW STRIP INSTALLATION

If a mow strip is required with the DAT installation the leave-out area around the steel foundation tubes and the two channel struts may be omitted. This will require a full pour at the foundation tubes.

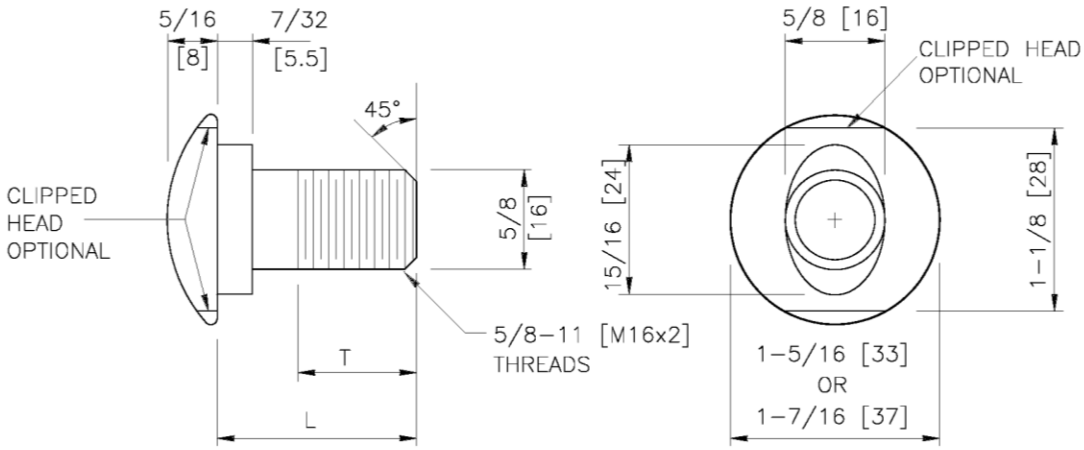
#	(DAT) PARTS LIST	QTY
1	Steel Foundation Tube	2
2	DAT Terminal Post	2
3	Channel Strut	2
4	Terminal Rail Element	1
5	Shelf Angle Bracket	1
6	BCT Bearing Plate	1
7	BCT Post Sleeve	1
8	Guardrail Anchor Bracket	1
9	(Rounded)W-Beam End Section	1
10	BCT Cable Anchor	1
11	Recessed Nut, Guardrail	20
12	1 1/4" Button Head Bolt	4
13	10" Button Head Bolt	2
14	5/8" x 2" Hex Head Bolt	8
15	5/8" x 8" Hex Head Bolt	4
16	5/8" x 10" Hex Head Bolt	2
17	5/8" Flat Washer	18

Texas Department of Transportation — Design Division Standard

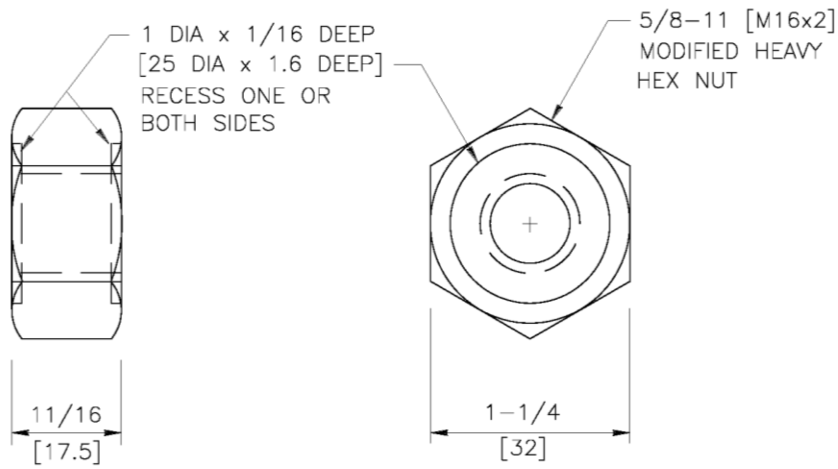
METAL BEAM GUARD FENCE
(Downstream Anchor Terminal)
GF(31)DAT-14

FILE: gf31dt14.dgn	DN: TxDOT	CK: AM	DW: VP	CK: CGL
© TxDOT: December 2011	CONT	SECT	JOB	HIGHWAY
REVISIONS	DIST	COUNTY		SHEET NO.

NOTES: 1. ALL FILLETS SHALL HAVE A MINIMUM RADIUS OF 1/16 [2].
2. IF THE BOLT EXTENDS MORE THAN 1/4 [6] FROM THE NUT THE BOLT SHOULD BE TRIMMED BACK.



DESIGNATOR	L	T (MIN)
FBB01	1-1/4 [32]	1-1/8 [28]
FBB02	2 [51]	1-3/4 [44]
FBB03	10 [254]	4 [102]
FBB04	18 [457]	4 [102]
FBB05	25 [635]	4 [102]



GUARDRAIL BOLT AND RECESSED NUT

FBB01-05

SHEET NO.	DATE:
1 of 2	5/2/2018

SPECIFICATIONS

The geometry and material specifications for this oval shoulder button-headed bolt and hex nut are found in AASHTO M 180. The bolt shall have 5/8-11 [M16x2] threads as defined in ANSI B1.1 [ANSI B1.13M] for Class 2A [6g] tolerances. Bolt material shall conform to ASTM A307 Grade A [ASTM F 568M Class 4.6], with a tensile strength of 60 ksi [400 MPa] and yield strength of 36 ksi [240 MPa]. Material for corrosion-resistant bolts shall conform to ASTM A325 Type 3 [ASTM F 568M Class 8.8.3], with tensile strength of 120 ksi [830 MPa] and yield strength of 92 ksi [660 MPa]. This bolt material has corrosion resistance comparable to ASTM A588 steels. Metric zinc-coated bolt heads shall be marked as specified in ASTM F 568 Section 9 with the symbol "4.6."

Nuts shall have ANSI B1.1 Class 2B [ANSI B1.13M Class 6h] 5/8-11 [M16x2] threads. The geometry of the nuts, with the exception of the recess shown in the drawing, shall conform to ANSI B18.2.2 [ANSI B18.2.4.1M Style 1] for zinc-coated hex nuts (shown in drawing) and ANSI B18.2.2 [ANSI B18.2.4.6M] for heavy hex corrosion-resistant nuts (not shown in drawing). Material for zinc-coated nuts shall conform to the requirements of AASHTO M 291 (ASTM A 563) Grade A [AASHTO M 291M (ASTM A 563M) Class 5], and material for corrosion-resistant nuts shall conform to the requirements of AASHTO M 291 (ASTM A 563) Grade C3 [AASHTO M 291M (ASTM A 563M) Class 8S3].

When zinc-coated bolts and nuts are required, the coating shall conform to either AASHTO M 232 (ASTM A 153/A 153M) for Class C or AASHTO M 298 (ASTM B 695) for Class 50. Zinc-coated nuts shall be tapped over-size as specified in AASHTO M 291 (ASTM A 563) [AASHTO M 291M (ASTM A 563M)], except that a diametrical allowance of 0.020 inch [0.510 mm] shall be used instead of 0.016 inches [0.420 mm].

Designator	Stress Area of Threaded Bolt Shank (in^2 [mm^2])	Min. Bolt Tensile Strength (kips [kN])
FBB01-05	0.226 [157.0]	13.6 [62.8]

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

INTENDED USE

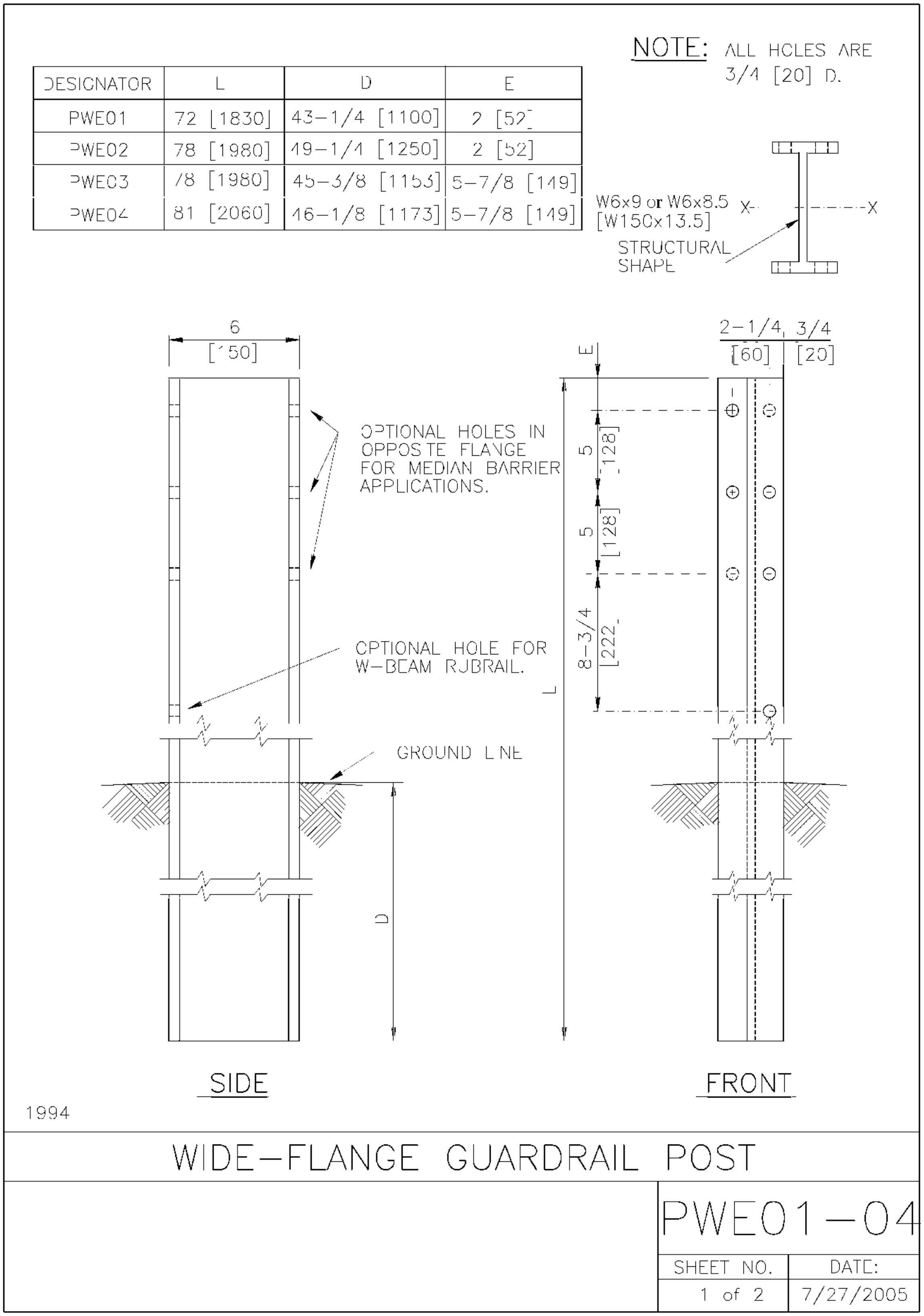
These bolts and nuts are used in numerous guardrail and median barrier designs.

GUARDRAIL BOLT AND RECESSED NUT

FBB01-05	
SHEET NO.	DATE
2 of 2	5/2/2018

TF 13

DESIGNATOR	L	D	E
PWE01	72 [1830]	43-1/4 [1100]	2 [52]
PWE02	78 [1980]	49-1/4 [1250]	2 [52]
PWE03	78 [1980]	45-3/8 [1153]	5-7/8 [149]
PWE04	81 [2060]	46-1/8 [1173]	5-7/8 [149]



SPECIFICATIONS

W-beam and thrie-beam guardrail posts shall be manufactured using AASHTO M 270 / M 270M (ASTM A 709 / A 709M) Grade 36 [250] steel unless corrosion-resistant steel is required, in which case the post shall be manufactured from AASHTO M 270 / M 270M (ASTM A 709 / A 709M) Grade 50W [345W] steel. The dimensions of the cross-section shall conform to a W6x9 [W150x13.5] section as defined in AASHTO M 160 / M 160M (ASTM A 6 / A 6M). [W150x12.6] wide flange posts are an acceptable alternative that is considered equivalent to the [W150x13.5].

After the section is cut and all holes are drilled or punched, the component should be zinc-coated according to AASHTO M 111 (ASTM A 123) unless corrosion-resistant steel is used. When corrosion-resistant steel is used, the portion of the post to be embedded in soil shall be zinc-coated according to AASHTO M 111 (ASTM A 123) and the portion above the soil shall not be zinc-coated, painted or otherwise treated.

Designator	Area in^2 [10^3 mm^2]	I_x in^4 [10^6 mm^4]	I_y in^4 [10^6 mm^4]	S_x in^3 [10^3 mm^3]	S_y in^3 [10^3 mm^3]
PWE01-04	2.63 [1.7]	16.43 [6.84]	2.19 [0.91]	5.57 [91.2]	1.11 [18.2]

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

INTENDED USE

Posts PWE01 and PWE02 are used with the SGR04a and SGR04c guardrails and the SGM04a median barrier. Blockouts like PWB01 (steel) or PDB01 (wood) are attached to each post.

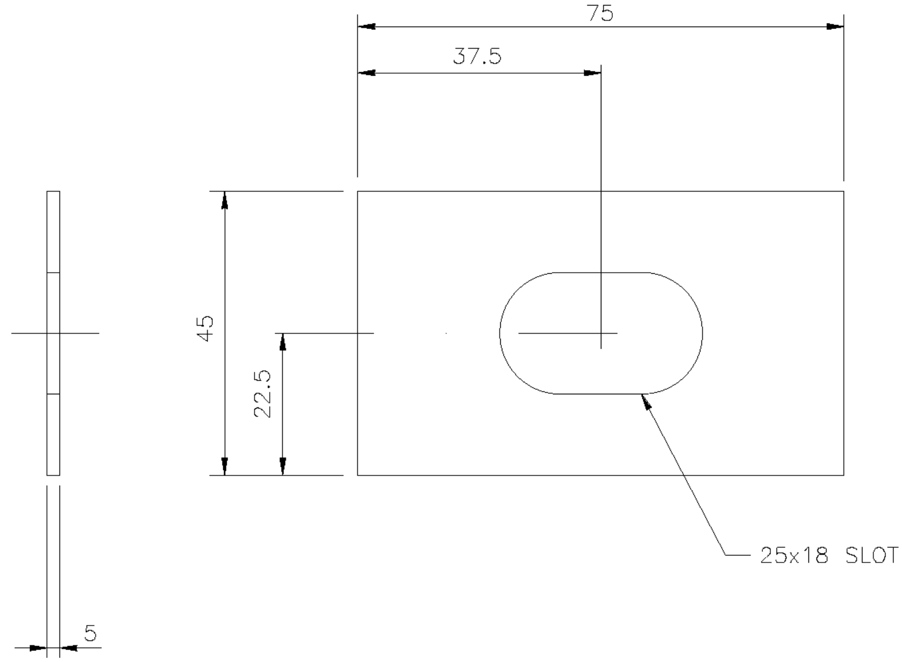
Post PWE03 is used with the SGR09a guardrail and the SGM09a median barrier. Wood or plastic blockouts like the PWB02 are attached to each post with FBB03 bolts and FWC16a washers under the nuts.

Post PWE04 is used with the SGR09b guardrail and the SGM09b median barrier. A modified steel blockout PWB03 is attached to each post with at least two 1.5-inch [40 mm] long FBX16a bolts and nuts.

WIDE-FLANGE GUARDRAIL POST

PWE01-04

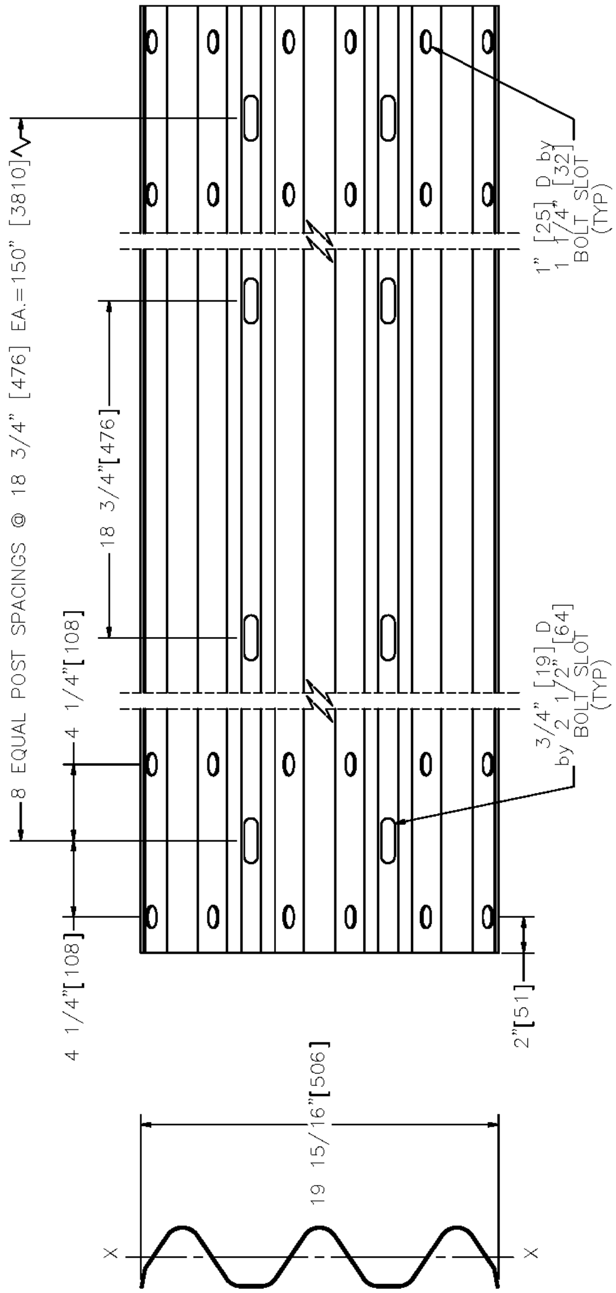
SHEET NO.	DATE
2 of 2	7/06/2005



1994

RECTANGULAR GUARDRAIL PLATE WASHER

	FWR03	
	SHEET NO.	REF. NO.
	1 of 2	F-12-73



DESIGNATOR	BASE METAL THICKNESS	TOTAL LENGTH	POST SPACINGS
RTM08a	12 GAUGE [2.67]	162 1/2" [4128]	8
RTM08b	10 GAUGE [3.43]	162 1/2" [4128]	8

THE CROSS-SECTIONAL DIMENSIONS OF THIS PART ARE THE SAME AS PART RTM01a (SHT 3 of 4)

8-SPACE THRIE-BEAM GUARDRAIL

	RTM08a-b	
	SHEET NO.	DATE:
	1 of 2	12/6/2016

SPECIFICATIONS

Corrugated sheet thrie beam guardrail shall conform to the current requirements of AASHTO M180. The section shall be manufactured from sheets with a nominal width of 29½" [750]. RTM08a shall conform to AASHTO M180 Class A and RTM08b shall conform to Class B. Thrie beams may be either Type I or II (zinc-coated) or Type IV (corrosion resistant steel). Corrosion resistant steel should conform to ASTM A606 for Type IV material and shall not be zinc-coated, painted or otherwise treated. Inertial properties are calculated for the whole cross-section without a reduction for the splice bolt holes or slots.

Designator	**Area** in.^{2} [10^3 mm^2]	**I_x** in.^{4} [10^6 mm^4]	**I_y** in.^{4} [10^6 mm^4]	**S_x** in.^{3} [10^3 mm^3]	**S_y** in.^{4} [10^3 mm^3]
RTM08a	3.16 [2.0]	3.8 [1.6]	--	2.22 [36.4]	--
RTM08b	4.03 [2.6]	4.8 [2.0]	--	2.87 [47.0]	--

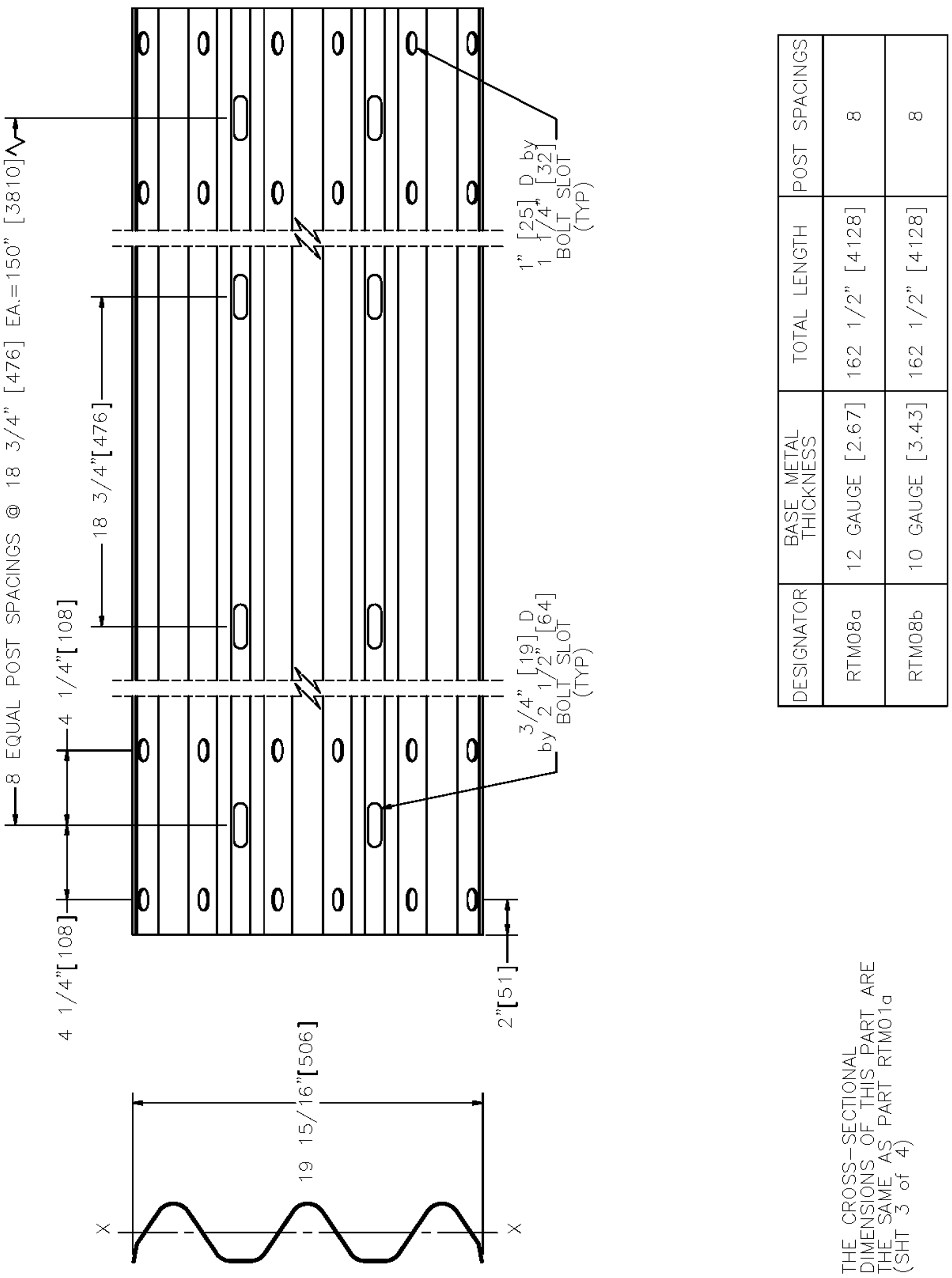
Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

INTENDED USE

The 8-space thrie beam guardrail is used in the W-beam to thrie beam transition with standard posts (STG03a-b).

8-SPACE THRIE-BEAM GUARDRAIL

RTM08a-b	
SHEET NO.	DATE:
2 of 2	12/6/2016



DESIGNATOR	BASE METAL THICKNESS	TOTAL LENGTH	POST SPACINGS
RTM08a	12 GAUGE [2.67]	162 1/2" [4128]	8
RTM08b	10 GAUGE [3.43]	162 1/2" [4128]	8

8-SPACE THRIE-BEAM GUARDRAIL

RTM08a-b	
SHEET NO.	DATE:
1 of 2	12/6/2016

SPECIFICATIONS

Corrugated sheet thrie beam guardrail shall conform to the current requirements of AASHTO M180. The section shall be manufactured from sheets with a nominal width of 29½" [750]. RTM08a shall conform to AASHTO M180 Class A and RTM08b shall conform to Class B. Thrie beams may be either Type I or II (zinc-coated) or Type IV (corrosion resistant steel). Corrosion resistant steel should conform to ASTM A606 for Type IV material and shall not be zinc-coated, painted or otherwise treated. Inertial properties are calculated for the whole cross-section without a reduction for the splice bolt holes or slots.

Designator	**Area** in.^{2} [10^3 mm^2]	I_x in.^{4} [10^6 mm^4]	I_y in.^{4} [10^6 mm^4]	S_x in.^{3} [10^3 mm^3]	S_y in.^{4} [10^3 mm^3]
RTM08a	3.16 [2.0]	3.8 [1.6]	--	2.22 [36.4]	--
RTM08b	4.03 [2.6]	4.8 [2.0]	--	2.87 [47.0]	--

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

INTENDED USE

The 8-space thrie beam guardrail is used in the W-beam to thrie beam transition with standard posts (STG03a-b).

8-SPACE THRIE-BEAM GUARDRAIL

RTM08a-b	
SHEET NO.	DATE:
2 of 2	12/6/2016

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

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

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

Rolando A Davila
Quality Assurance Manager

HEAT NO.:3085125 SECTION: REBAR 13MM (#4) 20'0" 420/60 GRADE: ASTM A615-16 Gr 420/60 ROLL DATE: 12/16/2018 MELT DATE: 12/15/2018 Cert. No.: 82574497 / 085125A130	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 82574497 BOL#: 72761068 CUST PO#: 802106 CUST P/N: DLVRY LBS / HEAT: 35056.000 LB DLVRY PCS / HEAT: 2624 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.41%				
Mn	1.03%				
P	0.018%				
S	0.042%				
Si	0.16%				
Cu	0.40%				
Cr	0.11%				
Ni	0.13%				
Mo	0.030%				
V	0.002%				
Cb	0.003%				
Sn	0.013%				
Al	0.002%				
Yield Strength test 1	68.5ksi				
Tensile Strength test 1	109.4ksi				
Elongation test 1	16%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	1.750IN				
Bend Test 1	Passed				

The Following is true of the material represented by this MTR:

**Material is fully killed*
**100% melted and rolled in the USA*
**EN10204:2004 3.1 compliant*
**Contains no weld repair*
**Contains no Mercury contamination*
**Manufactured in accordance with the latest version of the plant quality manual*
**Meets the "Buy America" requirements of 23 CFR635.410*
**Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov*

REMARKS :

469458

12/26/2018 18:31:43
Page 1 OF 1

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

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

Rolando A Davila
Quality Assurance Manager

HEAT NO.:3083663 SECTION: REBAR 16MM (#5) 20'0" 420/60 GRADE: ASTM A615-16 Gr 420/60 ROLL DATE: 10/08/2018 MELT DATE: 10/04/2018 Cert. No.: 82559398 / 083663A371	SOLD TO: CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO: CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900

Delivery#: 82559398
BOL#: 72737129
CUST PO#: 800421
CUST P/N:
DLVRY LBS / HEAT: 6570.000 LB
DLVRY PCS / HEAT: 315 EA

Characteristic	Value
C	0.42%
Mn	1.00%
P	0.012%
S	0.050%
Si	0.21%
Cu	0.28%
Cr	0.10%
Ni	0.14%
Mo	0.050%
V	0.000%
Cb	0.001%
Sn	0.009%
Al	0.001%
Yield Strength test 1	65.5ksi
Tensile Strength test 1	104.6ksi
Elongation test 1	13%
Elongation Gage Lgth test 1	8IN
Bend Test Diameter	2.188IN
Bend Test 1	Passed

Characteristic	Value

Characteristic	Value

The Following is true of the material represented by this MTR:

Material is fully killed
100% melted and rolled in the USA
EN10204:2004 3.1 compliant
Contains no weld repair
Contains no Mercury contamination
Manufactured in accordance with the latest version of the plant quality manual
Meets the "Buy America" requirements of 23 CFR635.410
Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov

REMARKS :

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

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

Rolando A Davila
Quality Assurance Manager

	SOLD TO	SHIP TO	
HEAT NO.:3083448 SECTION: REBAR 19MM (#6) 20'0" 420/60 GRADE: ASTM A615-16 Gr 420/60 ROLL DATE: 09/30/2018 MELT DATE: 09/25/2018 Cert. No.: 82563673 / 083448A619	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 82563673 BOL#: 72743918 CUST PO#: 800936 CUST P/N: DLVRY LBS / HEAT: 6489.000 LB DLVRY PCS / HEAT: 216 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.42%				
Mn	0.82%				
P	0.010%				
S	0.056%				
Si	0.18%				
Cu	0.30%				
Cr	0.17%				
Ni	0.30%				
Mo	0.087%				
V	0.001%				
Cb	0.002%				
Sn	0.009%				
Al	0.001%				
Yield Strength test 1	68.2ksi				
Tensile Strength test 1	104.2ksi				
Elongation test 1	16%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	3.750IN				
Bend Test 1	Passed				

The Following is true of the material represented by this MTR:

**Material is fully killed*
**100% melted and rolled in the USA*
**EN10204:2004 3.1 compliant*
**Contains no weld repair*
**Contains no Mercury contamination*
**Manufactured in accordance with the latest version of the plant quality manual*
**Meets the "Buy America" requirements of 23 CFR635.410*
**Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov*

REMARKS :

NUCOR

NUCOR CORPORATION
NUCOR STEEL TEXAS

Mill Certification
11/15/2018

MTR #: J1-432871
8812 Hwy 79 W
Jewett, TX 75846
(903) 626-4461
Fax: (903) 626-6290

Sold To: TRIPLE S STEEL SUPPLY CO
PO BOX 21119
HOUSTON, TX 77226-1119
(713) 697-7105
Fax: (713) 697-5945

Ship To: TRIPLE S STEEL SUPPLY (JENSEN)
6000 JENSEN DR
HOUSTON, TX 77026-1113
(713) 354-4113

Customer P.O.	HOU-182960	Sales Order	284218.9
Product Group	Merchant Bar Quality	Part Number	53750A0024010W0
Grade	NUCOR MULTIGRADE	Lot #	JW1810912351
Size	3/4x10" Flat	Heat #	JW18109123
Product	3/4x10" Flat 20' NUCOR MULTIGRADE	B.L. Number	J1-845498
Description	NUCOR MULTIGRADE	Load Number	J1-432871
Customer Spec		Customer Part #	

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.

Roll Date: 10/4/2018 Melt Date: 9/28/2018 Qty Shipped LBS: 9,188 Qty Shipped Pcs: 18

ASTM A36/A36M-12, A709/709M-13 GR36, ASME SA36-10 Ed '11 Ad.
ASME SA36-2010 EDITION-2011 ADDENDA
ASTM A709/A709M-13 GR 36 [250]

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Sn
0.14%	0.85%	0.015%	0.032%	0.19%	0.29%	0.13%	0.20%	0.047%	0.0549%	0.002%	0.010%

Ti	CE4020	CEA529
0.001%	0.37%	0.40%

CE4020: C. E. CSA G4020, AASHTO M270
CEA529: A529 CARBON EQUIVALENT

Yield 1: 56,000psi	Tensile 1: 71,700psi	Elongation: 24% in 8"(% in 203.3mm)
Yield 2: 55,900psi	Tensile 2: 71,600psi	Elongation 24% in 8"(% in 203.3mm)

Specification Comments: NUCOR MULTIGRADE MEETS THE REQUIREMENTS OF: ASTM A36/A36M-14; A529/529M-05(2009) GR50(345), A572/572M-07 GR50(345); A709/709M-10 GR36(250) & GR50(345); CSA G40.21-04 GR44W(300W)& GR50W(350W); ASME SA36/SA36M-07; MEETS REPORTING REQUIREMENTS OF EN10204 SEC 3.1

Comments: E-mail: websales@nstexas.com

1. All manufacturing processes of the steel, including melting, casting & hot rolling, have been performed in U.S.A
2. Mercury in any form has not been used in the production or testing of this product.
3. Welding or weld repair was not perfomed on this material.
4. This material conforms to the specifications described on this document and may not be reproduced, except in full, without written approval of Nucor Corporation.
5. Results reported for ASTM E45 (Inclusion content) and ASTM E381 (Macro-etch) are provided as interpretation of ASTM procedures.

465549

Bhargava R Vantari
Division Metallurgist

NBMG-10 October 1, 2017

STELFAST® INC.

22979 Stelfast Parkway
Strongsville, Ohio 44149

CERTIFICATE OF CONFORMANCE

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

- Sales Order #: 212848
- Part No: CB2G06253000C
- Quantity (PCS): 150
- Description: 5/8-11x3 Rd Hd Sq Nk Carr Bolt A307 GrA FT HDG
- Specification: ANSI B18.5
- Stelfast I.D. NO: NBPX-2017-0251-1
- Customer PO: 34593
- Warehouse: HOU

The data in this report is a true representation of the information provided by the material supplier certifying that the product meets the mechanical and material requirements of the listed specification. This certificate applies to the product shown on this document, as supplied by STELFAST INC. Alterations to the product by our customer or a third party shall render this certificate void.

This document may only be reproduced unaltered and only for certifying the same or lesser quantity of the product specified herein. Reproduction or alteration of this document for any other purpose is prohibited.

Stelfast certifies parts to the above description. The customer part number is only for reference purposes.

David Biss
Quality Manager

469549

January 28, 2019

Page 1 of 1

ZHEJIANG LAIBAO PRECISION TECHNOLOGY CO.,LTD

NO.668 DONGHAI ROAD,XITANGQIAO TOWN,HAIYAN,ZHEJIANG,CHINA

TEL: +86-573-86813788 FAX:+86-573-86811201

QUALITY CERTIFICATE

Customer Name :	BRIGHTON - BEST INTERNATIONAL (TAIWAN), INC.	**Country of origin:**	China
INV.NO.:	BBT1941	**QUANTITY:**	4.500 MPcs
P.O.NO.:	U48606	**TEST DATE:**	04.07.2018
S/C NO.:	BBI17375	**ON BOARD:**	04.08.2018
PART NO.:	490079	**SIZE:**	5/8-11×2
LOT NO.:	1709341801	**DESCRIPTION:**	A307 GRADE A CARRAGE BOLT H.D.G
PRODUCTION DATE:	09.07.2017		

Size: ASME B18.5 2012

Material and Mechanical properties: ASTM A307-2014 GR.A

Zinc Coatings: ASTM F2329-13

1.Chemical Composition Of Material （%）

STEEL GRADE /HEAT NO:	DIA. (mm)	C	Si	Mn	P	S	Cr	B	Ni	Al	Mo
Q195/180450	16	0.06	0.1	0.34	0.018	0.029					

2.Dimension

INSPECTION ITEM	SPECIFICATION	RESULT	SAMPLE SIZE
Head Marking	LB 307A	LB 307A	1
Head Dia (inch)	1.219-1.344	1.259-1.310	9
Head Height (inch)	0.313-0.344	0.323-0.338	9
Square Width (inch)	0.616-0.642	0.621-0.635	9
Square Depth (inch)	0.313-0.344	0.324-0.335	9
Total Length (inch)	1.920-2.060	1.985-2.008	9
Thread Length (inch)	FULL THREAD	FULL THREAD	9
Major Dia (inch)	0.6112-0.6250	0.617-0.621	3
GO Ring Gauge	THE NUT OF UNC 5/8-11$^{+0.40}$ 2B	OK	3
NO GO Ring Gauge	UNC 5/8-11 2A	OK	3
Tensile Strength (Psi)	MIN 60000	83394-87475	2
Hardness (HRB)	MAX 100	84-86	4
Visual	OK	OK	25
Salt Spray Test	/	/	/
Zinc Thickness (μm)	MIN 53	59-60	9

We hereby certify that the material described herein has been manufactured and tested with satisfactory results in accordance with the requirement of the above material/dimensional specifications.

QIN YUE ZHU
Q.C Supervisor

STELFAST® INC.

22979 Stelfast Parkway
Strongsville, Ohio 44149

CERTIFICATE OF CONFORMANCE

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

- Sales Order #: 212848
- Part No: MB2G06255000C
- Quantity (PCS): 90
- Description: 5/8-11x5 Hx Hd Mach Bolt A307 GrA HDG
- Specification: ANSI B18.2.1
- Stelfast I.D. NO: 16082332801
- Customer PO: 34593
- Warehouse: HOU

The data in this report is a true representation of the information provided by the material supplier certifying that the product meets the mechanical and material requirements of the listed specification. This certificate applies to the product shown on this document, as supplied by STELFAST INC. Alterations to the product by our customer or a third party shall render this certificate void.

This document may only be reproduced unaltered and only for certifying the same or lesser quantity of the product specified herein. Reproduction or alteration of this document for any other purpose is prohibited.

Stelfast certifies parts to the above description. The customer part number is only for reference purposes.

David Biss
Quality Manager

January 28, 2019

Page 1 of 1

STELFAST® INC.

22979 Stelfast Parkway
Strongsville, Ohio 44149

CERTIFICATE OF CONFORMANCE

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

- Sales Order #: 212849
- Part No: DUSGA06250
- Quantity (PCS): 50
- Description: 5/8 U.S.S Flat Washer HDG
- Specification: ASME B18.21.1
- Stelfast I.D. NO: 731195-O204269
- Customer PO: 34641
- Warehouse: HOU

The data in this report is a true representation of the information provided by the material supplier certifying that the product meets the mechanical and material requirements of the listed specification. This certificate applies to the product shown on this document, as supplied by STELFAST INC. Alterations to the product by our customer or a third party shall render this certificate void.

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Stelfast certifies parts to the above description. The customer part number is only for reference purposes.

David Biss
Quality Manager

January 28, 2019

Page 1 of 1

Stelfast Inc.

22979 Stelfast Parkway
Strongsville, Ohio

44149

Report of Chemical and Physical Properties

Issued To: Mack Bolt, Steel & Machine
5875 Hwy 21 East
BRYAN, TX
77808

Purchase Order: 34641
Stelfast Order: SO 212849
Certificate #: 724,768

Quantity: 150
Part #: AHHAG0875C
Description: 7/8-9 Hvy Hx Nut GrA HDG/TOS 0.022

Lot Number: N2017120942GH
Heat Number: G631006485
Country of Origin: CN

Chemical Analysis

C	Mn	P	S	Si	Cr	Mo	V	B	Ni	Cu
0.07	0.32	0.009	0.005							

Mechanical Properties

Hardness (Core)	93 - 95 HRB
Proof Load	100 KSI MIN
Specification	ASTM A563-GR.A

We hereby certify that the above data is a true copy of the data furnished to us by the producing mill or the data resulting from tests performed in approved laboratories. Stelfast does not certify to customer's part numbers.
This certificate applies to the product shown on this document, as supplied by Stelfast Inc. Alterations to the product by our customer or a third party will render this certificate void.

David Biss
Quality Manager

January 28, 2019

Page 1 of 1

Stelfast Inc.

22979 Stelfast Parkway
Strongsville, Ohio

44149

Report of Chemical and Physical Properties

Mack Bolt, Steel & Machine
5875 Hwy 21 East
BRYAN, TX
77808

Purchase Order: 34593
Stelfast Order: SO 212848
Certificate #: 746,208

Quantity: 1,000
Part #: DHWGA07500
Description: 3/4 Hardened Washer F436 HDG

Lot Number: GTR18538142A-020
Heat Number: 16606158
Country of Origin: CN

Chemical Analysis

C	Mn	P	S	Si	Cr
0.45	0.67	0.018	0.004	0.2	

Mechanical Properties

Core Hardness	29 - 34 HRC
Grade Marking	ASTM F436(11) Type 1

We hereby certify that the above data is a true copy of the data furnished to us by the producing mill or the data resulting from tests performed in approved laboratories. Stelfast does not certify to customer's part numbers.
This certificate applies to the product shown on this document, as supplied by Stelfast Inc. Alterations to the product by our customer or a third party will render this certificate void.

David Biss
Quality Manager

January 28, 2019

Page 1 of 1

Stelfast Inc.

22979 Stelfast Parkway
Strongsville, Ohio

44149

Report of Chemical and Physical Properties

Issued To: Mack Bolt, Steel & Machine
5875 Hwy 21 East
BRYAN, TX
77808

Purchase Order: 34641
Stelfast Order: SO 212849
Certificate #: 717,272

Quantity: 250
Part #: AHHAG0750C
Description: 3/4-10 Hvy Hx Nut GrA HDG/TOS 0.020

Lot Number: 18HYFX0064
Heat Number: G731008294
Country of Origin: CN

Chemical Analysis

C	Mn	P	S	Si	Cr	Mo	V	B	Ni	Cu
0.08	0.35	0.012	0.004	0.03						

Mechanical Properties

Hardness (Core)	8 HRC
Proof Load	100 KSI MIN
Specification	ASTM A563-GR.A

We hereby certify that the above data is a true copy of the data furnished to us by the producing mill or the data resulting from tests performed in approved laboratories. Stelfast does not certify to customer's part numbers.
This certificate applies to the product shown on this document, as supplied by Stelfast Inc. Alterations to the product by our customer or a third party will render this certificate void.

David Biss
Quality Manager

January 28, 2019

Page 1 of 1

This Memorandum is an acknowledgement that a Bill of Lading has been issued and is not the original Bill of Lading, nor a copy or duplicate, covering the property named herein, and is intended solely for filing or record.

RECEIVED, subject to the classifications and tariffs in effect on the date of receipt by the carrier of the property described in the Original Bill of Lading, at Ft Worth (THP), TX 2-8 20, 19 from Trinity Highway Products LLC — Carrier: 3

the property described below, in apparent good order, except as noted (contents and condition of contents of packages unknown) marked, consigned and destined as shown below, which said company (the word company being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its own railroad, water line, highway route or routes, or within the territory of its highway operations, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the conditions not prohibited by law, whether printed or written, herein contained, including the conditions on back hereof, which are hereby agreed to by the shipper and accepted for himself and his assigns.

Shipper's No. 16-75025

S/O No. 1306037

Subject to Section 7 of Conditions of applicable Bill of Lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.

TRINITY HIGHWAY PRODUCTS, LLC

Per Trinity Highway Products LLC (Signature of Consignor)

If charges are to be prepaid, write or stamp here, "To be Prepaid."

TO BE PREPAID

Received $ to apply in prepayment of the charges on the property described hereon.

Agent or Cashier

Per

(The signature here acknowledges only the amount prepaid.)

Charges advanced:

Consigned to: SAMPLES, TESTING MATERIALS — Cust. P.O. TXDOT TEST — Load No.: 48-1

Destination: 3100 STATE HWY 47, BLDG. 7090 — Total Weight: 9,878.40

City: BRYAN State: TX Zip: 77807

Ship: 2/8/2019

Arrive: 2/8/19 5:00:00PM

Contact: GARY GERKE — Phone: 936-825-4661

555087

Delivering Carrier: XPO — Vehicle or Car Initial: — No.

Collect On Delivery:

$ **and remit to:**

Street **City** **State**

C.O.D. charge to be paid by Shipper ☐ Consignee ☐

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
		Upon delivery, all materials subject to Trinity Highway Products,LLC Storage Stain Policy No. OMS-LG-002.			
		Project Info: TEXAS DOT TEST WINGWALL TTI 469548			
		LD Comments:			
	20	11G 12/12'6/3'1.5/S			
	50	533G 6'0 POST/8.5/DDR			
	8	724G 6'0 TUBE SL/.125X8X6			
	4	850G 12/BUFFER/ROLLED			
	4	975G T10/END SHOE			
	4	3000G CBL 3/4X6'6/DBL SWG/NOHWD			
	25	3320G 3/16"X1.75"X3" WASHER			
	400	3340G 5/8" GR HEX NUT			
	300	3360G 5/8"X1.25" GR BOLT			
	50	3500G 5/8"X10" GR BOLT A307			
	50	4076B WD BLK RTD 6X8X14			
	8	4140B WD 4'0.25 POST 5.5X7.5			
	8	10967G 12/9'4.5/3'1.5/S			
	8	12227G T12/12'6/3'1.5:6@1'6.75/S			
	8	19481G C3X5#X6'-8" RUBRAIL			
	4	20207G 12/9'4.5/8-HOLE ANCH/S			
	4	32218G T10/TRAN/TB:WB/ASYM/RT			
	4	36120A DAT-31-TX-HDW-CAN			
		2-Bundle			
		4-Pallets			

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
		465549			
		GUARDRAIL HWY STEEL NMFC ITEM 105460 CLASS 50			

SPECIAL INSTRUCTIONS:

SHIPPER LOAD - CONSIGNEE UNLOAD 16-75025

Total Weight # 9,878 — 3

*If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is "carrier's or shipper's weight."
NOTE - Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property.
The agreed or declared value of the property is hereby specifically stated by the shipper to be not exceeding per

ORIGIN — SHIPPER OR AGENT — SIGN HERE: I hereby authorize this shipment and make the declaration of values (if any) and agree to the contract terms and conditions hereof. [signature] DATE 2-8-19

AGENT OR DRIVER — (SIGN HERE): This shipment received subject to exceptions as noted and according to the terms and conditions hereof. DATE

DESTINATION — CONSIGNEE OR AGENT — SIGN HERE: Received the above described property in good condition except as noted on the back hereof and agree to the foregoing contract terms and conditions. DATE / / TIME A.M. P.M.

DRIVER — NO

Permanent post-office address of shipper,

RI 609-RF (R 10/93) — (This Bill of Lading is to be signed by the shipper

CONSIGNEE/CUSTOMER COPY

Certified Analysis

Trinity Highway Products, LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: SAMPLES, TESTING MATERIALS
2525 STEMMONS FRWY

DALLAS, TX 75207

Order Number: 1306037 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: TXDOT TEST
BOL Number: 75025 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 2/7/19

469549

Project: TEXAS DOT TEST WINGWALL TTI 469548

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
20	11G	12/12'6/3'1.5/S	RHC		2	L23818													4
			M-180	A	2	230046	62,830	81,430	27.2	0.200	0.750	0.009	0.002	0.020	0.140	0.000	0.050	0.002	4
			M-180	A	2	230048	61,910	79,610	25.7	0.190	0.730	0.012	0.002	0.020	0.140	0.000	0.070	0.002	4
			M-180	A	2	230049	59,510	78,150	28.8	0.190	0.740	0.010	4.000	0.010	0.120	0.000	0.050	0.002	4
			M-180	A	2	231186	57,040	77,590	26.9	0.180	0.720	0.010	0.004	0.020	0.110	0.000	0.060	0.002	4
			M-180	A	2	231187	55,080	78,060	25.3	0.180	0.720	0.014	0.004	0.010	0.110	0.000	0.070	0.008	4
			M-180	A	2	231188	59,830	82,260	22.6	0.190	0.740	0.010	0.002	0.020	0.120	0.000	0.050	0.002	4
			M-180	A	2	231189	59,500	81,190	23.6	0.190	0.700	0.014	0.004	0.010	0.110	0.000	0.060	0.002	4
			M-180	A	2	A89864	64,500	86,000	19.7	0.200	0.720	0.015	0.002	0.030	0.050	0.001	0.060	0.001	4
			M-180	A	2	C87743	60,600	83,000	22.1	0.200	0.680	0.008	0.003	0.030	0.060	0.001	0.050	0.001	4
	11G				2	F10519													
			M-180	A	2	1187949	65,100	87,200	17.0	0.210	0.750	0.009	0.001	0.030	0.090	0.003	0.040	0.003	4
			M-180	A	2	1187950	64,800	87,400	22.0	0.210	0.750	0.009	0.002	0.020	0.090	0.004	0.040	0.003	4
			M-180	A	2	1287622	54,900	76,100	17.0	0.190	0.760	0.008	0.002	0.030	0.080	0.005	0.040	0.002	4
			M-180	A	2	1287623	58,900	79,800	28.0	0.180	0.770	0.009	0.001	0.030	0.090	0.002	0.040	0.002	4
50	533G	6'0 POST/8.5/DDR	A-36			59083349	61,493	77,009	9,999.0	0.080	0.860	0.024	0.031	0.100	0.310	0.011	0.220	0.002	4
8	724G	6'0 TUBE SL/.125X8X6	A-500			C86781	54,400	65,800	32.0	0.050	0.390	0.007	0.002	0.020	0.110	0.000	0.050	0.001	4
4	850G	12/BUFFER/ROLLED	M-180	A	2	229319	62,700	81,420	24.3	0.190	0.720	0.007	0.004	0.010	0.060	0.002	0.050	0.000	4
	850G		M-180	A	2	11719850	51,600	62,400	33.0	0.050	0.520	0.009	0.003	0.040	0.100	0.001	0.050	0.002	4
4	975G	T10/END SHOE	M-180	B		231842	47,330	60,030	36.4	0.050	0.470	0.013	0.004	0.010	0.130	0.000	0.080	0.000	4
4	3000G	CBL 3/4X6'6/DBL	HW			315648													

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: SAMPLES, TESTING MATERIALS
2525 STEMMONS FRWY

DALLAS, TX 75207

Order Number: 1306037 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: TXDOT TEST
BOL Number: 75025 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 2/7/19

Project: TEXAS DOT TEST WINGWALL TTI 469548

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	3320G	3/16"X1.75"X3" WASHER	HW			11747860													
400	3340G	5/8" GR HEX NUT	HW			18-42-060													
300	3360G	5/8"X1.25" GR BOLT	HW			1568224													
50	3500G	5/8"X10" GR BOLT A307	HW			31647													
50	4076B	WD BLK RTD 6X8X14	HW			36087													
8	4140B	WD 4'0.25 POST 5.5X7.5	HW			26543													
8	10967G	12/9'4.5/3'1.5/S	RHC		2	L13318													4
			M-180	A	2	228149	59,790	78,060	27.8	0.190	0.740	0.011	0.005	0.010	0.130	0.000	0.040	0.002	4
			M-180	A	2	228150	60,150	78,580	26.1	0.190	0.710	0.012	0.003	0.020	0.120	0.000	0.050	0.001	4
			M-180	A	2	229087	61,480	79,640	25.5	0.200	0.730	0.013	0.004	0.020	0.100	0.000	0.080	0.000	4
			M-180	A	2	229089	58,490	78,020	26.3	0.190	0.720	0.013	0.006	0.010	0.110	0.000	0.070	0.002	4
			M-180	A	2	229090	61,420	79,550	29.0	0.200	0.730	0.014	0.005	0.010	0.110	0.000	0.070	0.001	4
			M-180	A	2	229091	61,440	78,930	26.1	0.190	0.710	0.015	0.004	0.010	0.120	0.000	0.080	0.002	4
			M-180	A	2	229321	61,460	81,180	27.4	0.190	0.730	0.008	0.003	0.010	0.090	0.002	0.050	0.000	4
			M-180	A	2	229322	61,140	79,320	27.5	0.190	0.730	0.008	0.003	0.020	0.100	0.000	0.060	0.001	4
			M-180	A	2	229323	60,720	79,850	24.8	0.200	0.730	0.008	0.002	0.020	0.100	0.000	0.050	0.001	4
			M-180	A	2	229324	61,360	79,890	27.3	0.190	0.730	0.008	0.002	0.020	0.100	0.000	0.060	0.001	4
			M-180	A	2	A88986	63,200	83,700	17.7	0.200	0.700	0.009	0.002	0.030	0.070	0.001	0.040	0.000	4
			M-180	A	2	A89601	62,600	82,400	17.7	0.200	0.680	0.008	0.002	0.030	0.080	0.001	0.040	0.001	4
			M-180	A	2	C86850	63,800	83,000	20.2	0.210	0.680	0.011	0.002	0.040	0.060	0.001	0.050	0.000	4
			M-180	A	2	C87490	61,500	83,800	24.3	0.190	0.710	0.009	0.004	0.030	0.080	0.001	0.060	0.001	4

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: SAMPLES, TESTING MATERIALS
2525 STEMMONS FRWY

DALLAS, TX 75207

Project: TEXAS DOT TEST WINGWALL TTI 469548

Order Number: 1306037 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: TXDOT TEST
BOL Number: 75025 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 2/7/19

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
8	12227G	T12/12'6/3'1.5:6@1'6.75/S	RHC		2	L30518													4
			M-180	A	2	222039	61,590	79,770	24.0	0.190	0.720	0.011	0.003	0.020	0.110	0.000	0.060	0.002	4
	12227G		RHC		2	L32418													4
			M-180	A	2	229322	61,140	79,320	27.5	0.190	0.730	0.008	0.003	0.020	0.100	0.000	0.060	0.001	4
			M-180	A	2	226511	61,110	79,440	27.4	0.180	0.720	0.009	0.004	0.010	0.110	0.000	0.070	0.002	4
			M-180	A	2	227752	60,970	79,700	24.9	0.190	0.730	0.014	0.004	0.010	0.120	0.000	0.060	0.002	4
			M-180	A	2	227753	61,750	80,930	24.3	0.190	0.730	0.013	0.004	0.020	0.090	0.000	0.050	0.001	4
8	19481G	C3X5#X6'-8" RUBRAIL	A-36			3077310	55,400	77,200	32.0	0.170	0.560	0.013	0.039	0.210	0.330	0.002	0.090	0.017	4
4	20207G	12/9'4.5/8-HOLE ANCH/S	RHC		2	L14818													4
			M-180	A	2	232196	61,710	79,460	28.7	0.180	0.720	0.012	0.005	0.020	0.120	0.000	0.070	0.002	4
			M-180	A	2	233123	63,570	82,430	22.7	0.190	0.720	0.013	0.004	0.020	0.110	0.000	0.070	0.000	4
			M-180	A	2	233124	62,720	82,150	24.5	0.190	0.720	0.011	0.003	0.010	0.130	0.001	0.060	0.000	4
			M-180	A	2	233125	63,900	83,490	21.4	0.200	0.730	0.018	0.004	0.020	0.110	0.000	0.090	0.001	4
			M-180	A	2	A90778	65,800	86,800	20.7	0.210	0.680	0.012	0.003	0.030	0.120	0.000	0.060	0.001	4
			M-180	A	2	A90779	55,100	78,200	20.6	0.190	0.660	0.010	0.002	0.020	0.120	0.000	0.070	0.001	4
			M-180	A	2	C88581	59,000	79,100	16.3	0.210	0.690	0.009	0.002	0.030	0.110	0.000	0.060	0.001	4
			M-180	A	2	C88582	63,500	82,200	23.6	0.200	0.710	0.011	0.001	0.040	0.090	0.000	0.060	0.001	4
	20207G		RHC		2	L11118													4
			M-180	A	2	224112	63,490	81,930	25.0	0.190	0.730	0.014	0.005	0.020	0.130	0.000	0.060	0.010	4
			M-180	A	2	224113	62,130	80,880	24.2	0.190	0.730	0.014	0.003	0.020	0.120	0.000	0.080	0.002	4
			M-180	A	2	224115	63,530	82,190	23.9	0.190	0.730	0.011	0.003	0.020	0.120	0.000	0.070	0.002	4
			M-180	A	2	224275	63,280	81,880	24.5	0.200	0.720	0.011	0.005	0.020	0.110	0.000	0.050	0.002	4
			M-180	A	2	224276	62,740	83,080	26.9	0.190	0.720	0.013	0.005	0.020	0.120	0.001	0.060	0.001	4
4	32218G	T10/TRAN/TB:WB/ASYM/R	M-180	B	2	A90940	54,700	77,700	25.8	0.200	0.500	0.010	0.003	0.030	0.130	0.002	0.060	0.001	4

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: SAMPLES, TESTING MATERIALS
2525 STEMMONS FRWY

DALLAS, TX 75207

Order Number: 1306037   Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: TXDOT TEST
BOL Number: 75025   Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 2/7/19

Project: TEXAS DOT TEST WINGWALL TTI 469548

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
4	36120A	DAT-31-TX-HDW-CAN	A-36			2804979	43,400	64,800	30.0	0.190	0.480	0.006	0.001	0.030	0.080	0.000	0.030	0.003	4

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy QMS-LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED

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.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 7th day of February, 2019 .

Notary Public:
Commission Expires:

JOMARY LUGINSLAND
Notary Public, State of Texas
My Commission Expires
May 28, 2019

Jomary Luginsland

Trinity Highway Products , LLC
Certified By: Luis Ortiz
Quality Assurance

PO# 469549

NUCOR

NUCOR CORPORATION
NUCOR STEEL TEXAS

Mill Certification
10/8/2018

Metals 2 Go
254-235-7700

Sold To: MJ LATHERN CO INC
DBA METALS 2 GO
PO BOX 20425
WACO, TX 76702
(254) 235-7700
Fax: (254) 235-7703

Ship To: METALS 2 GO
224 N. HEWITT DR
HEWITT, TX 76643
(254) 235-7700

Customer P.O.	70801	Sales Order	282180.18
Product Group	Merchant Bar Quality	Part Number	2150303724010W0
Grade	NUCOR MULTIGRADE	Lot #	JW1810879151
Size	5x3x3/8 Angle	Heat #	JW18108791
Product	5x3x3/8 Angle 20' NUCOR MULTIGRADE	B.L. Number	J1-840626
Description	NUCOR MULTIGRADE	Load Number	J1-428421
Customer Spec		Customer Part #	

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.

Roll Date: 9/26/2018 **Melt Date: 9/17/2018** **Qty Shipped LBS: 4,900** **Qty Shipped Pcs: 25**

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Sn
0.14%	0.84%	0.022%	0.023%	0.18%	0.31%	0.13%	0.23%	0.045%	0.0452%	0.002%	0.010%
CE4020	CEA529										
0.37%	0.40%										

CE4020: C. E. CSA G4020, AASHTO M270
CEA529: A529 CARBON EQUIVALENT

Yield 1: 60,100psi
Yield 2: 60,100psi

Tensile 1: 76,300psi
Tensile 2: 77,400psi

Elongation: 20% in 8"(% in 203.3mm)
Elongation 21% in 8"(% in 203.3mm)

Specification Comments: NUCOR MULTIGRADE MEETS THE REQUIREMENTS OF: ASTM A36/A36M-14; A529/529M-05(2009) GR50(345); A572/572M-07 GR50(345); A709/709M-10 GR36(250) & GR50(345); CSA G40.21-04 GR44W(300W)& GR50W(350W); AASHTO M270/M270M-10 GR36(270) & GR50(345); ASME SA36/SA36M-07; MEETS REPORTING REQUIREMENTS OF EN10204 SEC 3.1

Comments: E-mail: websales@nstexas.com

1. All manufacturing processes of the steel, including melting, casting & hot rolling, have been performed in U.S.A
2. Mercury in any form has not been used in the production or testing of this product.
3. Welding or weld repair was not perfomed on this material.
4. This material conforms to the specifications described on this document and may not be reproduced, except in full, without written approval of Nucor Corporation.
5. Results reported for ASTM E45 (Inclusion content) and ASTM E381 (Macro-etch) are provided as interpretation of ASTM procedures.

BAYOU STEEL GROUP

MATERIAL CERTIFICATION REPORT

BAYOU STEEL GROUP
(LAPLACE)
138 HWY 3217
LaPlace LOUISIANA 70068
Telephone (985) 652-4900

TRIPLE-S STEEL
HOUSTON TX 77226
USA

TRIPLE-S STEEL COMPANY
HOUSTON, TX
6000 JENSEN DRIVE
HOUSTON TX 77026
USA

Tested in Accordance
With: ASTM A6

Sales Order	184770-4	Date	04/30/2018	PO:	HOU-180305
Product	Channels	Cust	40006725	Ref.	81007704
Heat NO.	L112123	Grade	A3652950	Pieces	30
Cust.Mat.	C6B2360240	Length	20' 00"	Weight	4920
Size	C6X8.2 * LP				

CHEMICAL ANALYSIS	
C	0.12
Mn	1.07
P	0.016
S	0.033
Si	0.28
Cu	0.30
Ni	0.23
Cr	0.20
Mo	0.090
Cb	0.015
V	0
B	.
Al	
Sn	0.014
N	
Ti	
Ci	6.1
CE	0.39

MECHANICAL PROPERTIES	TEST 1		TEST 2		TEST 3	
	IMPERIAL	METRIC	IMPERIAL	METRIC	IMPERIAL	METRIC
YIELD STRENGTH	59200 PSI	408 MPa	59100 PSI	407 MPa		
TENSILE STRENGTH	79900 PSI	551 MPa	79900 PSI	551 MPa		
ELONGATION	21 %	21 %	23 %	23 %		
GAUGE LENGTH	8 IN	203 mm	8 IN	203 mm		
BEND TEST DIAMETER						
BEND TEST RESULTS						
SPECIMEN AREA						
REDUCTION OF AREA						
IMPACT STRENGTH						

IMPACT STRENGTH	IMPERIAL	METRIC	INTERNAL CLEANLINESS		GRAIN SIZE	
AVERAGE			SEVERITY		HARDNESS	
TEST TEMP			FREQUENCY		GRAIN PRACTICE	
ORIENTATION			RATING		REDUCTION RATIO	

This heat makes the following grades: A36-14, A52950-14, G40.21-CSA50W, CSA44W, A70936-13a, ASME SA36-2010, A57250-12a, A70950-13a, and the following AASHTO M270 Grades: 36, 50, and 345. Heat is free of Mercury contamination in the process. This material is Hot Rolled Carbon Steel.EN10204-3.1B.

I hereby certify that the material test results presented here are from the reported heat and are correct. All tests were performed in accordance to the specification reported above. All steel is electric arc furnace melted (billets), manufactured, processed, tested in the U.S.A with satisfactory results. No weld repair was performed on this heat.

Notarized upon request:
Sworn to and subscribed before me on this 30th day of April, 2018

Signed Mark Edwards
MARK EDWARDS, QUALITY ASSURANCE SUPERVISOR

Notary Public ______ Parish/County ______

Direct any questions or necessary clarifications concerning this report to the Sales Department 1-800-535-7692 (USA)

DEACERO
EXCELENCIA EN CALIDAD

Acería Ramos Arizpe
CARRETERA MONCLOVA KM 4 NUMERO 2125
TRAMO SANTA CRUZ OJO CALIENTE
C.P./ZIP RAMOS ARIZPE, COAHUILA
Tel/Phone (+52) 01 818 386 1111
MX 01 800 021 3322, USA 1800 332 2376

/ CERTIFICATE OF TEST AN ANALYSIS

No. Certificado / Certificate No:	125036 - 21639397
Fecha / Date:	29/07/2018

Hecho en México / Made in Mexico

DATOS DEL CLIENTE / SOLD TO

Cliente / Customer: DEACERO USA INC (HOUSTON DISTRIBUTION CENTER)
Dirección / Address: 8411 IRVINGTON BLVD
Ciudad / City: HOUSTON — Estado / State: , TX
Teléfono / Phone: 332 2376 — País / Country: U.S.A. C.P./ZIP 77022-3
Correo Electrónico / eMail:

CLIENTE CONSIGNADO / SHIP TO

Cliente / Customer: DEACERO USA INC (HOUSTON DISTRIBUTION CENTER)
Dirección / Address: 1755 FEDERAL RD
Ciudad / City: HOUSTON — Estado / State: , TX

DATOS DEL EMBARQUE / SHIPPING INFORMATION

Núm. Viaje / Travel No: 125036
Núm. Factura / Invoice No: FO59628
Pedido / Customer Order No: 21639397
Núm. Plan / Shipping Plan: 133765
Fecha Embarque / Date: 28/07/2018
Orden de Compra / Purchase Order:

COMPOSICIÓN QUÍMICA / CHEMICAL COMPOSITION (% PESO / WEIGHT)

Colada / Heat	Secuencia / Sequence	Clave / Code	Producto / Description of Goods	% C AVG	% Mn AVG	% Si AVG	% P AVG	% S AVG	% Cu AVG	% Cr AVG	% Ni AVG	% Mo AVG	% Sn AVG	% Ti AVG	% V AVG	% Nb AVG	% N AVG	CE AVG
30842	37791	10702	FLAT BAR 8" x 3/8" A36/529-50 20' 2.0T	0.21	0.90	0.18	0.006	0.007	0.17	0.045 0	0.056 0	0.015 5	0.009 0	0.008 8	0.012 0	0.009 8	0.007 8	0.000 0

PROPIEDADES MECÁNICAS / MECHANICAL PROPERTIES

Colada / Heat	Secuencia / Sequence	Clave / Code	Producto / Description of Goods	Calibre / Diameter	Cantidad / Bundle	RT kg/mm² AVG	TS PSI AVG	% Elong / Elong AVG	LF kg/mm² AVG	YS PSI AVG	P. Doblez / Bend Test
30842	37791	10702	FLAT BAR 8" x 3/8" A36/529-50 20' 2.0T	8" x 3/8"	8	52.88	74935.18	31.48	42.86	60975.55	Cumple / Successfully

CE=[C]+([Cu]/40)+([Mn]/6)+([Ni]/20)+([Cr]/10)-([Mo]/50)-([V]/10)

DEACERO +VERDE

Certificamos que este material ha sido producido, inspeccionado y probado de acuerdo a las normas de fabricación del acero aplicables a la ASTM A36-2008, A529-2005 (re aprobada el 2009), A572-2012 y A992-2011 y a las normas dimensionales NMX B252, ASTM A6/A6M-2012. / We certify that this material has been produced hot-rolled carbon, inspected and tested according to standards applicable steelmaking to ASTM A36-2008, A529-2005 (Reapproved 2009), A572-2012 y A992-2011, and the dimensional standards NMX B252, ASTM A6/A6M-2012

GUSTAVO GABRIEL MANCILLA GARZA
Gerente de Aseguramiento de Calidad / Quality Assurance Manager

NUCOR

NUCOR CORPORATION
NUCOR STEEL TEXAS

Mill Certification
11/15/2018

MTR #: J1-432871
8812 Hwy 79 W
Jewett, TX 75846
(903) 626-4461
Fax: (903) 626-6290

Sold To: TRIPLE S STEEL SUPPLY CO
PO BOX 21119
HOUSTON, TX 77226-1119
(713) 697-7105
Fax: (713) 697-5945

Ship To: TRIPLE S STEEL SUPPLY (JENSEN)
6000 JENSEN DR
HOUSTON, TX 77026-1113
(713) 354-4113

Customer P.O.	HOU-182960		
Product Group	Merchant Bar Quality	Sales Order	284218.9
Grade	NUCOR MULTIGRADE	Part Number	53750A0024010W0
Size	3/4x10" Flat	Lot #	JW1810912351
Product	3/4x10" Flat 20' NUCOR MULTIGRADE	Heat #	JW18109123
Description	NUCOR MULTIGRADE	B.L. Number	J1-845498
Customer Spec		Load Number	J1-432871
		Customer Part #	

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.

Roll Date: 10/4/2018 **Melt Date: 9/28/2018** **Qty Shipped LBS: 9,188** **Qty Shipped Pcs: 18**

ASTM A36/A36M-12, A709/709M-13 GR36, ASME SA36-10 Ed '11 Ad.
ASME SA36-2010 EDITION-2011 ADDENDA
ASTM A709/A709M-13 GR 36 [250]

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Sn
0.14%	0.85%	0.015%	0.032%	0.19%	0.29%	0.13%	0.20%	0.047%	0.0549%	0.002%	0.010%
Ti	CE4020	CEA529									
0.001%	0.37%	0.40%									

CE4020: C. E. CSA G4020, AASHTO M270
CEA529: A529 CARBON EQUIVALENT

Yield 1: 56,000psi
Yield 2: 55,900psi
Tensile 1: 71,700psi
Tensile 2: 71,600psi
Elongation: 24% in 8"(% in 203.3mm)
Elongation 24% in 8"(% in 203.3mm)

Specification Comments: NUCOR MULTIGRADE MEETS THE REQUIREMENTS OF: ASTM A36/A36M-14; A529/529M-05(2009) GR50(345), A572/572M-07 GR50(345); A709/709M-10 GR36(250) & GR50(345); CSA G40.21-04 GR44W(300W)& GR50W(350W); ASME SA36/SA36M-07; MEETS REPORTING REQUIREMENTS OF EN10204 SEC 3.1

Comments: E-mail: websales@nstexas.com

1. All manufacturing processes of the steel, including melting, casting & hot rolling, have been performed in U.S.A
2. Mercury in any form has not been used in the production or testing of this product.
3. Welding or weld repair was not perfomed on this material.
4. This material conforms to the specifications described on this document and may not be reproduced, except in full, without written approval of Nucor Corporation.
5. Results reported for ASTM E45 (Inclusion content) and ASTM E381 (Macro-etch) are provided as interpretation of ASTM procedures.

Texas A&M Transportation Institute Proving Ground 3100 SH 47, Bldg 7091 Bryan, TX 77807 Texas A&M University College Station, TX 77843 Phone 979-845-6375	QF 7.3-01 Concrete Sampling	Doc. No. QF 7.3-01	Issue Date: 2018-06-18
Quality Form	Prepared by: Wanda L. Menges Approved by: Darrell L. Kuhn	Revision: 6	Page: 1 of 1

The information contained in this document is confidential to TTI Proving Ground.

Project No: 469545 Casting Date: 2019-02-04 Mix Design (psi): class C (3600)

Name of Technician Taking Sample: Bill Griffith

Name of Technician Breaking Sample: GREG FRITZ

Signature of Technician Taking Sample: [signature]

Signature of Technician Breaking Sample: [signature]

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	7110	5208584	100% of Footing

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
T1	2019-3-4	28 DAYS	151,000	5340	
↓	↓	↓	144,000	5095	5245
			150,000	5305	

TICKET NO.

CUSTOMER'S COPY

Martin Marietta

1503 LBJ Freeway
Suite 400
Dallas, Tx 75234

5208584

LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
10:38	10:50	11:05	11:15	:	:	:

WATER ADDED ON JOB AT CUSTOMER'S REQUEST ________ GAL.
ALLOWABLE WATER (withheld from batch) 7.1 GAL.
TEST CYLINDER TAKEN ☐ YES ☐ NO BY ________
CYLINDER TAKEN ☐ BEFORE ☐ AFTER WATER

ADDITIONAL WATER ADDED TO THIS CONCRETE WILL REDUCE ITS STRENGTH. ANY WATER ADDED IN EXCESS OF SPECIFIED SLUMP IS AT CUSTOMER'S RISK.

CUSTOMER SIGNATURE
X

DELIVERY OF THESE MATERIALS IS SUBJECT TO THE TERMS A CONDITIONS ON THE REVERSE SIDE HEREOF AS ACCEPTED SIGNATURE ABOVE.

CUSTOMER NAME AND DELIVERY ADDRESS
TEXAS A & M UNIVERSI
TTI-Riverside Campus

PLANT	TRUCK	ORDER NO.	SLUMP	P.O. #/JOB/LOT	GRID
617	7110	2028	5.0	469459	

DRIVER NAME	DATE
RONALD CONLEY	2/4/19

CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY
783659	79546	3.50	3.50

LOAD QUANTITY		PRODUCT CODE	DESCRIPTION	UNIT PRICE	AMOUNT
3.50	yd	BDOTCC00	DOT CLASS 6		
1.00	ea	12987	FREIGHT CHARGE		

SPECIAL DELIVERY INSTRUCTIONS
SOUTH 2818, RIGHT ON LEONARD, RIGHT ON HWY-47, LEFT INTO RELLIS CAMPUS AND THEY WILL MEET YOU ATTHE ROUND ABOUT

SALES TAX

TOTAL

DANGER! MAY CAUSE ALKALI BURNS.
SEE WARNINGS ON REVERSE SIDE.

FOR OFFICE USE ONLY **FORM:** 2677993

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
7110	919766	user	5208584	73614	10:38	2/4/19

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
3.50 CYDS	BDOTCC00				D	74622

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
1"CS	1945 lb	6855 lb	6840 lb	-0.23%	0.70% M	6 gl
SAND-1	1269 lb	4675 lb	4680 lb	0.10%	5.00% M	28 gl
CMT-I/II	358 lb	1253 lb	1270 lb	* 1.36%		
FLYASH-C	193 lb	676 lb	680 lb	0.67%		
P80	14 oz	50 oz	50 oz	-0.24%		
H20	250 lb	493 lb	492 lb	-0.22%		59 gl
Actual	Num Batches: 1					

Load Total: 13965 lb Design 0.454 Water/Cement 0.449 T Design 104.9 gl Actual 92.7 gl To Add: 7.1 gl
Slump: 5.00 in Water in Truck: 5.0 gl Adjust Water: 0.0 gl / Load Trim Water: -2.0 gl/ CYD

469549

Texas A&M Transportation Institute Proving Ground, 3100 SH 47, Bldg 7091, Bryan, TX 77807 Texas A&M University, College Station, TX 77843, Phone 979-845-6375	QF 7.3-01 Concrete Sampling	Doc. No. QF 7.3-01	Issue Date: 2018-06-18
Quality Form	Prepared by: Wanda L. Menges Approved by: Darrell L. Kuhn	Revision: 6	Page: 1 of 1

The information contained in this document is confidential to TTI Proving Ground.

Project No: 469545 **Casting Date:** 2019-02-15 **Mix Design (psi):** 3600 psi

Name of Technician Taking Sample: Bill Griffith

Name of Technician Breaking Sample: GREG FRITZ

Signature of Technician Taking Sample: [signature]

Signature of Technician Breaking Sample: [signature]

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	9035	5232558	100 % of Deck

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
T1	2019-3-4	17 DAYS	129,000	4565	
↓	↓	↓	128,000	4530	4590
			132,000	4670	

CUSTOMER'S COPY

TICKET NO. 5232598

Martin Marietta

Martin Marietta

1503 LBJ Freeway
Suite 400
Dallas, Tx 75234

LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
14:23	2:35	3:15	:	:	:	:

WATER ADDED ON JOB AT CUSTOMER'S REQUEST ______ GAL.
ALLOWABLE WATER (withheld from batch) 0.0 GAL.
TEST CYLINDER TAKEN ☐ YES ☐ NO BY ______
CYLINDER TAKEN ☐ BEFORE ☐ AFTER WATER

ADDITIONAL WATER ADDED TO THIS CONCRETE WILL REDUCE ITS STRENGTH. ANY WATER ADDED IN EXCESS OF SPECIFIED SLUMP IS AT CUSTOMER'S RISK.

CUSTOMER SIGNATURE
X

DELIVERY OF THESE MATERIALS IS SUBJECT TO THE TERMS AND CONDITIONS ON THE REVERSE SIDE HEREOF AS ACCEPTED BY SIGNATURE ABOVE.

CUSTOMER NAME AND DELIVERY ADDRESS
TEXAS A & M UNIVERSI
TTI-Riverside Campus

PLANT	TRUCK	ORDER NO.	SLUMP	P.O. #/JOB/LOT	GRID
618	9035	2017	5.0	469459	

DRIVER NAME	DATE
HOUSE, JOHN	2/15/19

CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY
783659	79546	3.50	3.50

LOAD QUANTITY	PRODUCT CODE	DESCRIPTION	UNIT PRICE	AMOUNT
3.50	BDOTCC00	DOT CLASS C		
1.00	12987	FREIGHT CHARGE		

+6 gallon water

SPECIAL DELIVERY INSTRUCTIONS
S 2818-RT ON LEONARD RT ON HWY-47-LFT INTO RIVERSIDE
CAMPUS WILLMEET AT ROUND-A-BOUT

SALES TAX

TOTAL

DANGER! MAY CAUSE ALKALI BURNS.
SEE WARNINGS ON REVERSE SIDE.

FOR OFFICE USE ONLY **FORM:** 2586291

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
9035	725360	user	5232598	1390	14:23	2/15/19

Load/Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
3.50 CYDS	BDOTCC00				D	1484

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
8	193 lb	676 lb	675 lb	-0.07%		
P80	14 oz	50 oz	50 oz	-0.24%		
1	358 lb	1253 lb	1240 lb	-1.04%		
10	1269 lb	4686 lb	4680 lb	-0.12%	5.50% M	29 gl
157	1945 lb	6842 lb	6860 lb	0.27%	0.50% M	4 gl
H20	250 lb	544 lb	679 lb	24.77%		82 gl

Actual Num Batches: 1
Load Total: 14137 lb Design 0.454 Water/Cement 0.499 A
Slump: 5.00 in Water in Truck: 0.0 lb Adjust Water: 0.0 lb / Load Design 105.4 gl Trim Water: -15.0 lb/ CYD Actual 115.3 gl To Add: 0.0 gl

465545

Texas A&M Transportation Institute Proving Ground 3100 SH 47, Bldg 7091 Bryan, TX 77807 Texas A&M University College Station, TX 77843 Phone 979-845-6375	QF 7.3-01 Concrete Sampling	Doc. No. QF 7.3-01	Issue Date: 2018-06-18
Quality Form	Prepared by: Wanda L. Menges Approved by: Darrell L. Kuhn	Revision: 6	Page: 1 of 1

The information contained in this document is confidential to TTI Proving Ground

Project No: 469549 **Casting Date:** 2019-2-18 **Mix Design (psi):** CLASS C

Name of Technician Taking Sample: GREG FRITZ
Name of Technician Breaking Sample: GREG FRITZ

Signature of Technician Taking Sample: [signature]
Signature of Technician Breaking Sample: [signature]

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	7211	5237307	100% OF DECK

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
T1	2019-3-4	14 DAYS	112,000	3960	
↓	↓	↓	112,000	3960	4010
			116,000	4105	

CUSTOMER'S COPY

Martin Marietta

1503 LBJ Freeway
Suite 400
Dallas, Tx 75234

TICKET NO.
5237307

LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
13:30	13:47	14:10	14:14	:	:	:

WATER ADDED ON JOB AT CUSTOMER'S REQUEST ________ GAL.
ALLOWABLE WATER (withheld from batch) 6.0 GAL.
TEST CYLINDER TAKEN ❑ YES ❑ NO BY ________
CYLINDER TAKEN ❑ BEFORE ❑ AFTER WATER

ADDITIONAL WATER ADDED TO THIS CONCRETE WILL REDUCE ITS STRENGTH. ANY WATER ADDED IN EXCESS OF SPECIFIED SLUMP IS AT CUSTOMER'S RISK.

CUSTOMER SIGNATURE
X

DELIVERY OF THESE MATERIALS IS SUBJECT TO THE TERMS AN CONDITIONS ON THE REVERSE SIDE HEREOF AS ACCEPTED B SIGNATURE ABOVE.

CUSTOMER NAME AND DELIVERY ADDRESS
TEXAS A & M UNIVERSI
TTI-Riverside Campus

PLANT	TRUCK	ORDER NO.	SLUMP	P.O. #/JOB/LOT	GRID
617	7211	2012	5.0	469549	

DRIVER NAME LARRY JANTZEN DATE 2/18/19

CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY
783659	79546	3.00	3.00

LOAD QUANTITY	PRODUCT CODE	DESCRIPTION	UNIT PRICE	AMOUNT
3.00 yd	BDOTCC00	DOT CLASS T		
1.00 ea	12987	FREIGHT CHARGE		

SPECIAL DELIVERY INSTRUCTIONS
SOUTH 2818, RIGHT LEONARD RD, RIGHT HWY 47, LEFT INTO RELLIS CAMPUS, WILL MEET YOU AT ROUND-A-BOUT

SALES TAX

TOTAL

DANGER! MAY CAUSE ALKALI BURNS.
SEE WARNINGS ON REVERSE SIDE.

FOR OFFICE USE ONLY **FORM:** 2678319

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time Date
7211	777135	user	5237307	73939	13:30 2/18/19

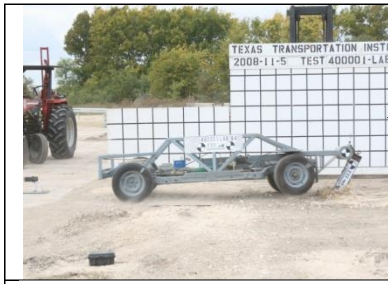
Load Size	Mix Code	Returned Qty	Mix Age	Seq	Load ID
3.00 CYDS	BDOTCC00			D	74949

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
1"CS	1945 lb	5876 lb	5880 lb	0.07%	0.70% M	5 gl
SAND-1	1269 lb	4007 lb	4040 lb	0.81%	5.00% M	24 gl
CMT-I/II	358 lb	1074 lb	1090 lb	1.49%		
FLYASH-C	193 lb	579 lb	570 lb	-1.55%		
P80	14 oz	43 oz	42 oz	-2.23%		
H20	250 lb	433 lb	432 lb	-0.32%		
Actual	Num Batches: 1					52 gl

Load Total: 12015 lb Design 0.454 Water/Cement 0.452 T Design 89.9 gl / Load Actual 80.9 gl To Add: 6.0 gl
Slump: 5.00 in Water in Truck: 3.0 gl Adjust Water: 0.0 gl Trim Water: -2.0 gl/ CYD

469549

Table C.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.

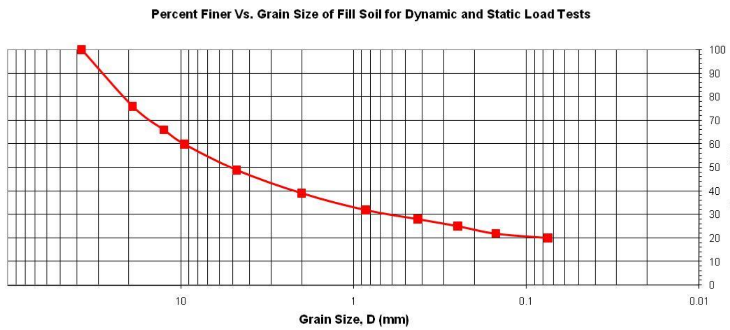


Dynamic Setup

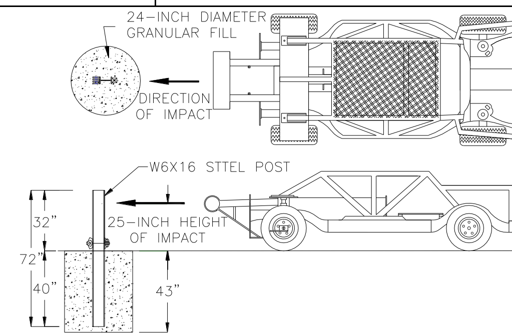
Post-Test Photo of post

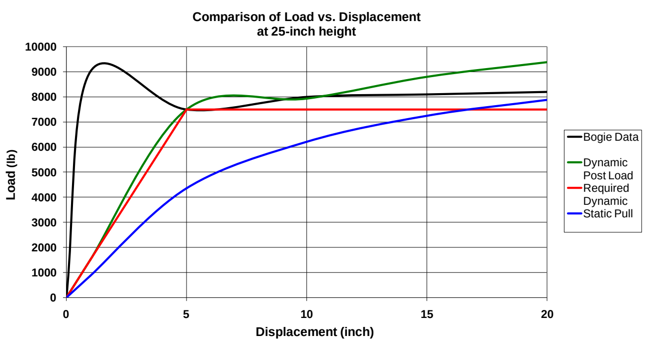
Post-Test Photo

Static Load Test

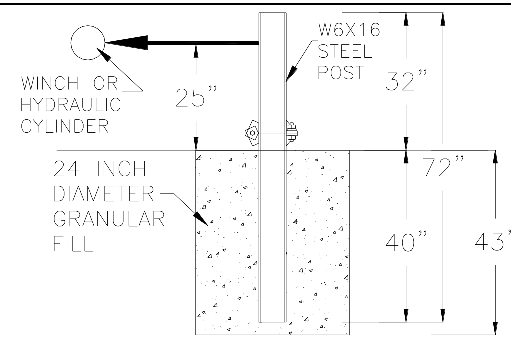


Dynamic Test Installation Details



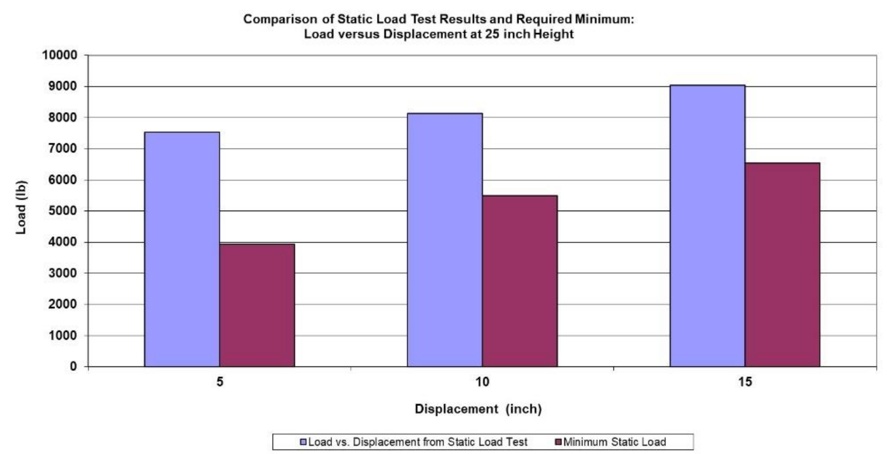


Static Load Test Installation Details

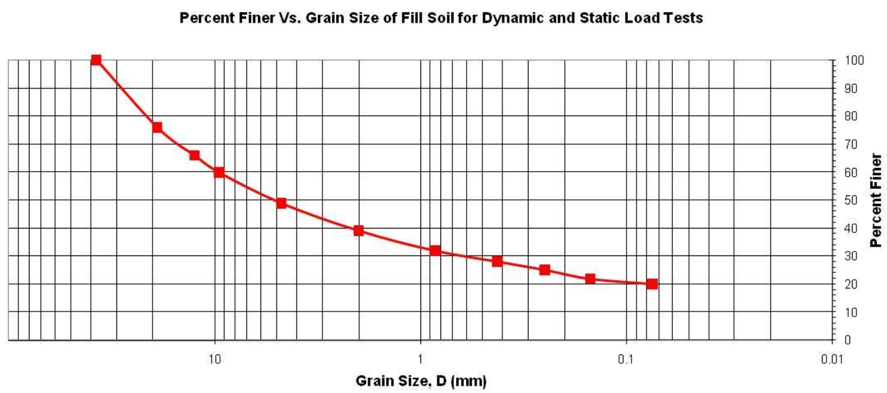


Date	2008-11-05
Test Facility and Site Location........	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis........	AASHTO Grade B Soil-Aggregate (see sieve analysis above)
Description of Fill Placement Procedure........	6-inch lifts tamped with a pneumatic compactor
Bogie Weight........	5009 lb
Impact Velocity........	20.5 mph

Table C.2. Test Day Static Soil Strength Documentation for Test No. 469549-01-1.



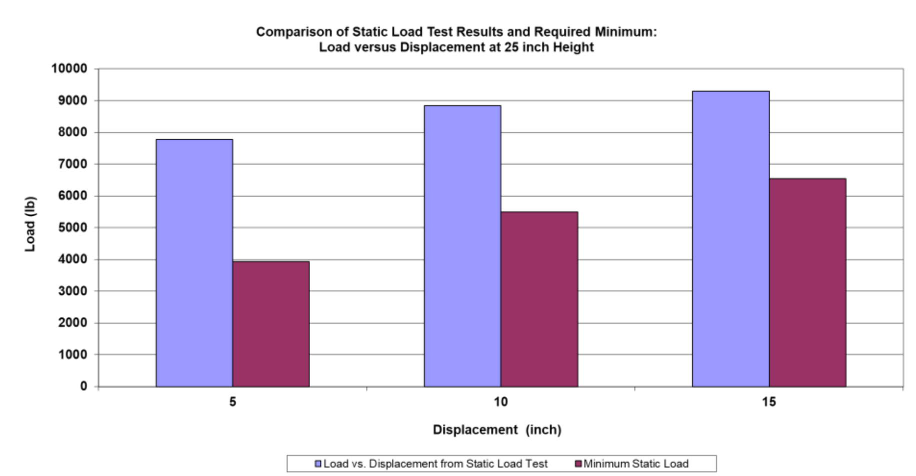
Static Load Setup



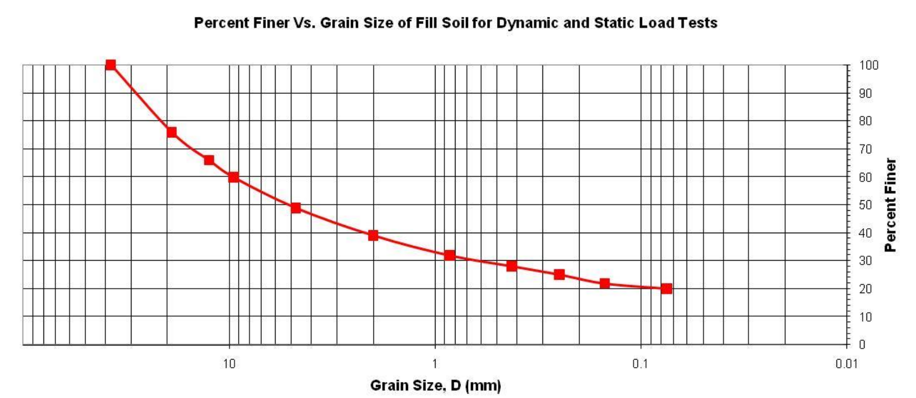
Post-Test Photo of Post

Date..	2019-03-04
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis ..	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.3. Test Day Static Soil Strength Documentation for Test No. 469549-01-2.



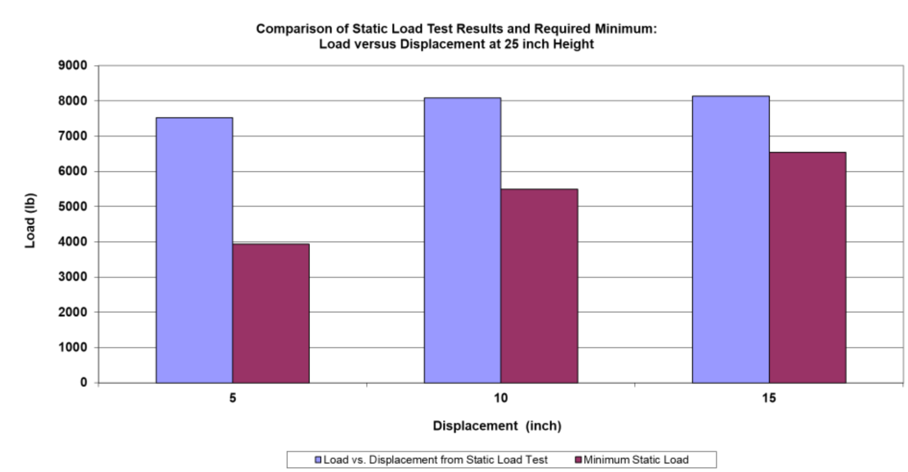
Static Load Setup



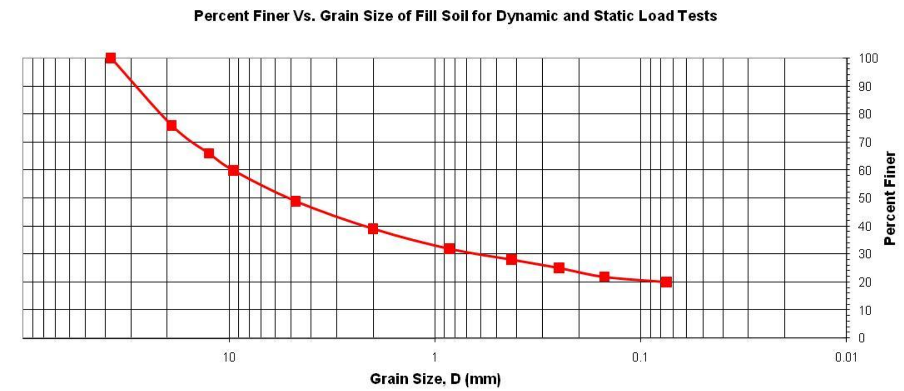
Post-Test Photo of Post

Date	2019-03-06
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.4. Test Day Static Soil Strength Documentation for Test No. 469549-01-4.



Typical Static Load Setup



Post-Test Photo of Post

Date	2019-03-19
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

APPENDIX D. *MASH* TEST 3-20 (CRASH TEST NO. 469549-01-1)

D.1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 469549-01-1.

Date: 2019-03-04 Test No.: 469549-1 VIN No.: KNADE123976243438

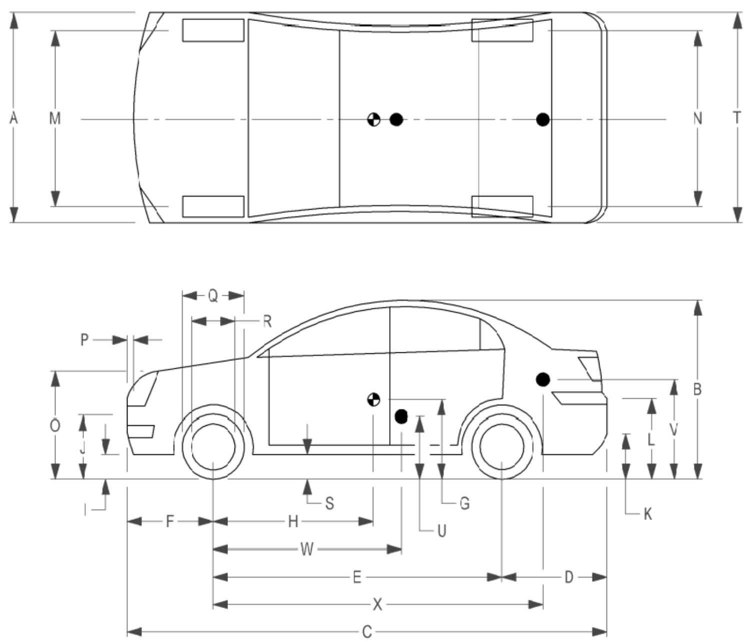
Year: 2007 Make: Kia Model: Rio

Tire Inflation Pressure: 32 PSI Odometer: 188865 Tire Size: 185/65R14

Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES:



Engine Type: 4 CYL
Engine CID: 1.6 L
Transmission Type:
☑ Auto or ☐ Manual
☑ FWD ☐ RWD ☐ 4WD
Optional Equipment:
None

Dummy Data:
Type: 50th Percentile Male
Mass: 165 lb
Seat Position: Impact side

Geometry: inches

A	66.38	F	33.00	K	12.25	P	4.12	U	14.75
B	51.50	G		L	25.25	Q	22.50	V	20.50
C	165.75	H	35.80	M	57.75	R	15.50	W	35.80
D	34.00	I	7.75	N	57.70	S	8.25	X	101.75
E	98.75	J	21.50	O	27.00	T	66.20		

Wheel Center Ht Front 11.00 Wheel Center Ht Rear 11.00 W-H 0.00

RANGE LIMIT: A = 65 ±3 inches; C = 169 ±8 inches; E = 98 ±5 inches; F = 35 ±4 inches; H = 39 ±4 inches; O (Bottom of Hood Lip) = 24 ±4 inches
TOP OF RADIATOR SUPPORT = 28.26 inches; (M+N)/2 = 56 ±2 inches; W-H < 2 inches or use MASH Paragraph A4.3.2

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1718	M_{front}	1592	1557	1642
Back	1874	M_{rear}	891	887	967
Total	3638	M_{Total}	2483	2444	2609

Allowable TIM = 2420 lb ±55 lb | Allowable GSM = 2585 lb ± 55 lb

Mass Distribution:
lb LF: 777 RF: 780 LR: 402 RR: 485

Table D.2. Exterior Crush Measurements of Vehicle for Test No. 469549-01-1.

Date:	2019-03-04	Test No.:	469549-1	VIN No.:	KNADE123976243438
Year:	2007	Make:	Kia	Model:	Rio

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________	Bowing: B1 _____ X1 _____
Corner shift: A1 ________	B2 _____ X2 _____
A2 ________	
End shift at frame (CDC)	Bowing constant
(check one)	$\frac{X1+X2}{2}$ = _______
< 4 inches ________	
≥ 4 inches ________	

Note: Measure C_1 to C_6 from Driver to Passenger Side in Front or Rear Impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front Plane at bumper ht	12	7	18	7	3	1				16
2	Side Plane at bumper ht	12	10	40	2	4	6	8	9	10	62
	Measurements recorded										
	☑ **inches** or ☐ **mm**										

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

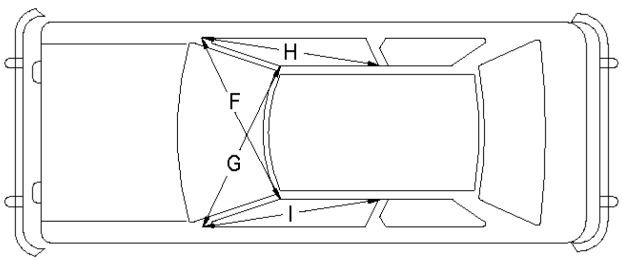
***Measure and document on the vehicle diagram the location of the maximum crush.

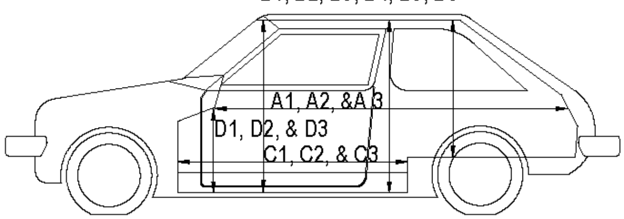
Note: Use as many lines/columns as necessary to describe each damage profile.

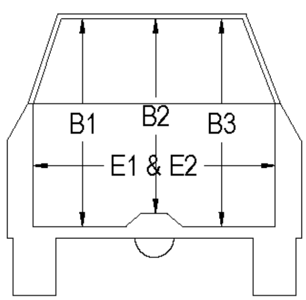
Table D.3. Occupant Compartment Measurements of Vehicle for Test No. 469549-1.

Date: 2019-03-04 Test No.: 469549-1 VIN No.: KNADE123976243438

Year: 2007 Make: Kia Model: Rio







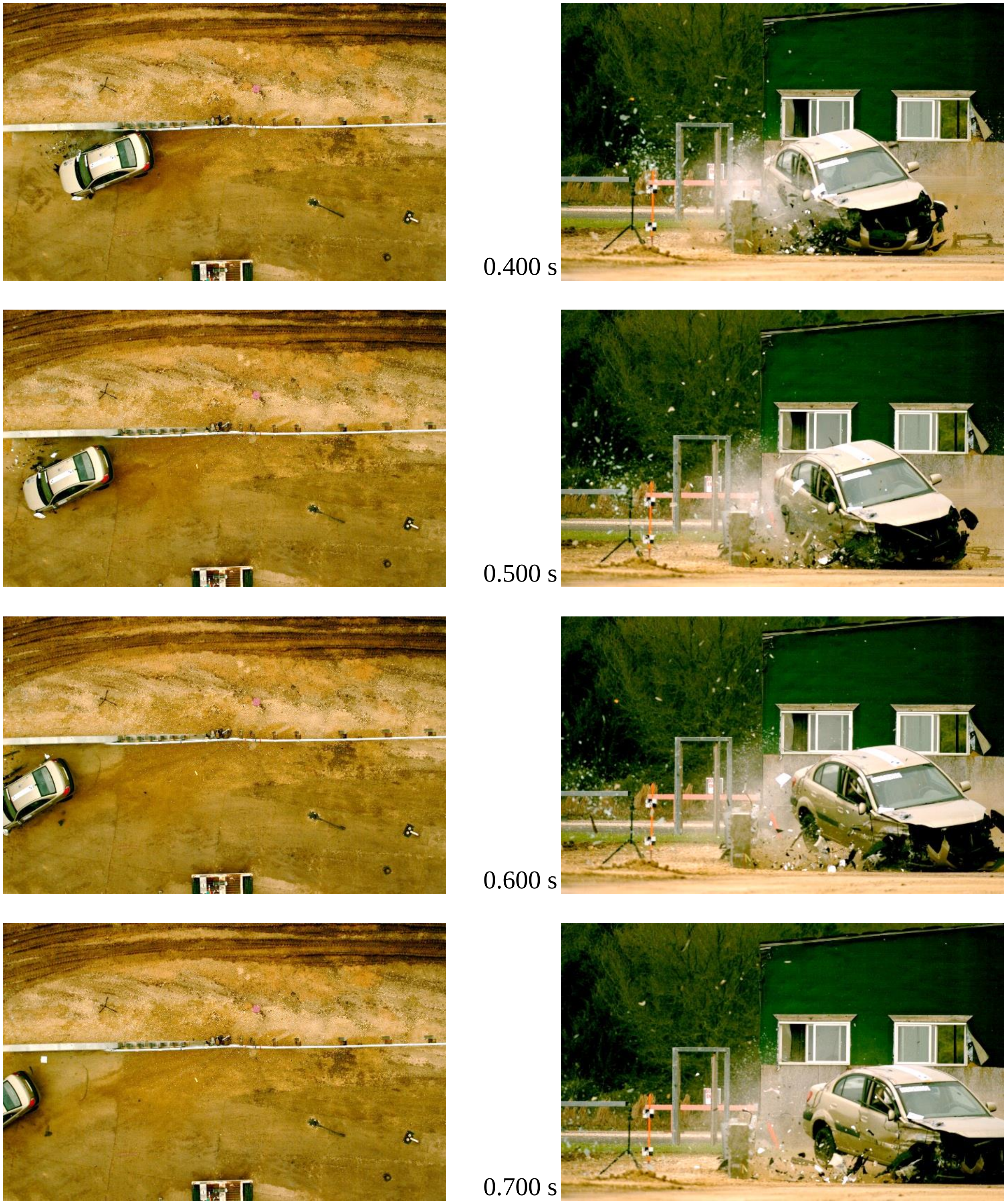
*Lateral area across the cab from driver's side kick panel to passenger's side kick panel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	67.50	67.50	0.00
A2	67.25	67.25	0.00
A3	67.75	67.50	-0.25
B1	40.50	40.50	0.00
B2	39.00	39.00	0.00
B3	40.50	39.50	-1.00
B4	36.25	36.25	0.00
B5	36.00	36.00	0.00
B6	36.25	36.25	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	25.00	-1.00
D1	9.50	9.50	0.00
D2	0.00	0.00	0.00
D3	9.50	9.00	-0.50
E1	51.50	53.50	2.00
E2	51.00	54.00	3.00
F	51.00	51.00	0.00
G	51.00	51.00	0.00
H	37.50	37.00	-0.50
I	37.50	37.50	-0.50
J*	51.00	49.75	-1.25

D.2 SEQUENTIAL PHOTOGRAPHS

Figure D.1. Sequential Photographs for Test No. 469549-01-1 (Overhead and Frontal Views).



0.400 s

0.500 s

0.600 s

0.700 s

Figure D.1. Sequential Photographs for Test No. 469549-01-1 (Overhead and Frontal Views) (Continued).


0.000 s


0.100 s


0.200 s


0.300 s

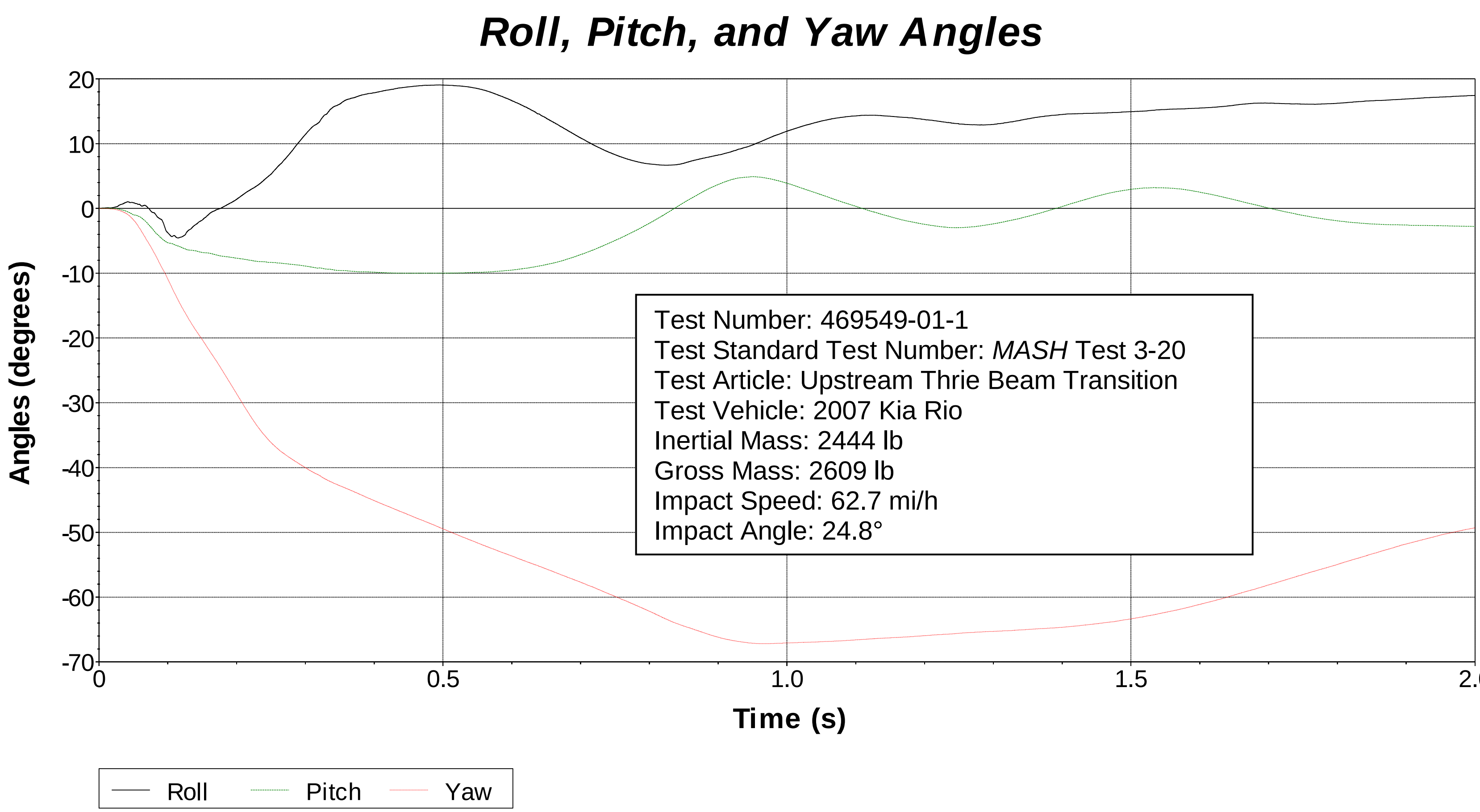

0.400 s


0.500 s


0.600 s


0.700 s

Figure D.2. Sequential Photographs for Test No. 469549-01-1 (Rear View).



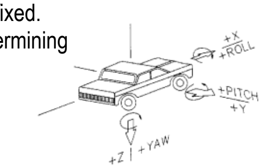


Figure D.3. Vehicle Angular Displacements for Test No. 469549-01-1.

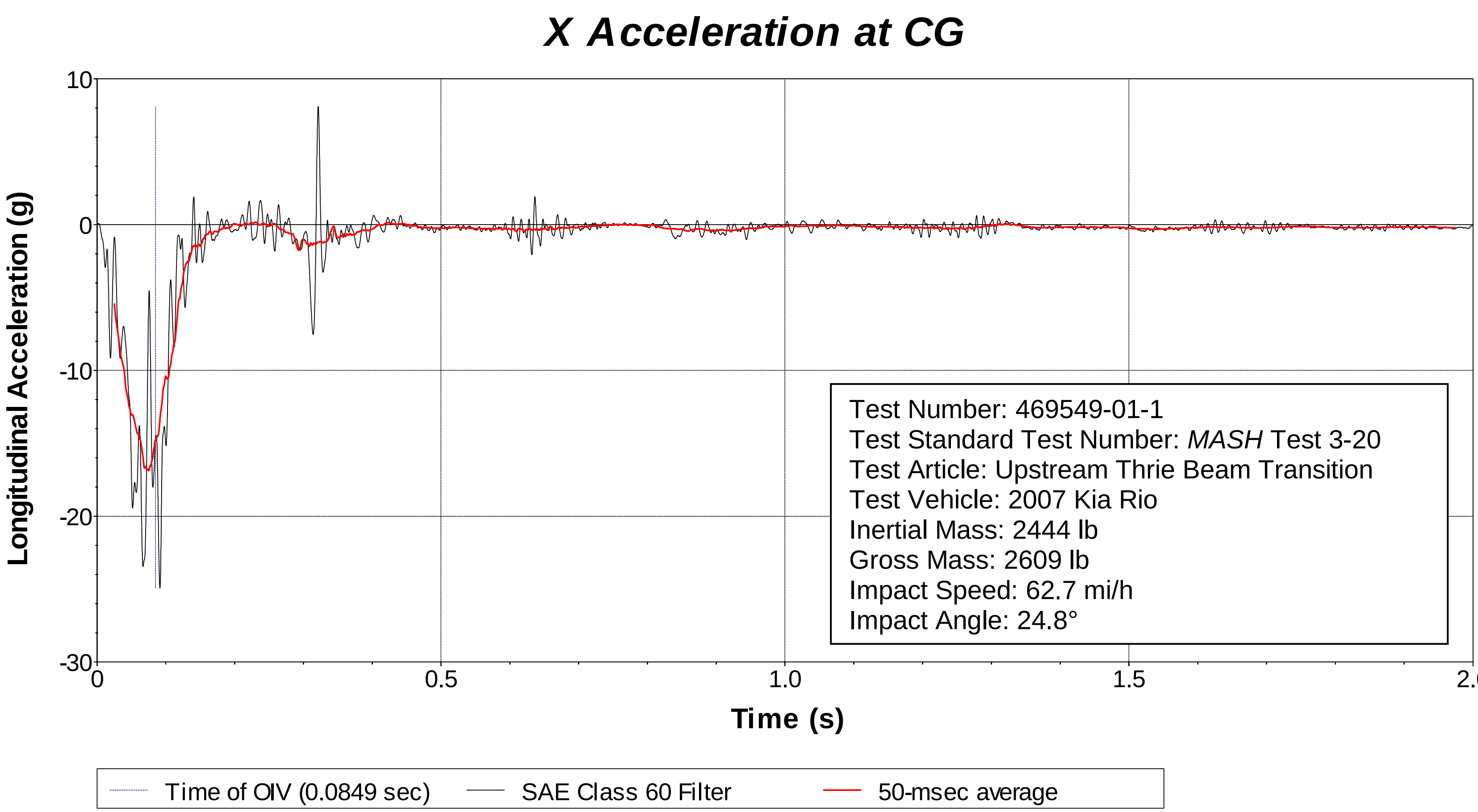


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469549-01-1 (Accelerometer Located at Center of Gravity).

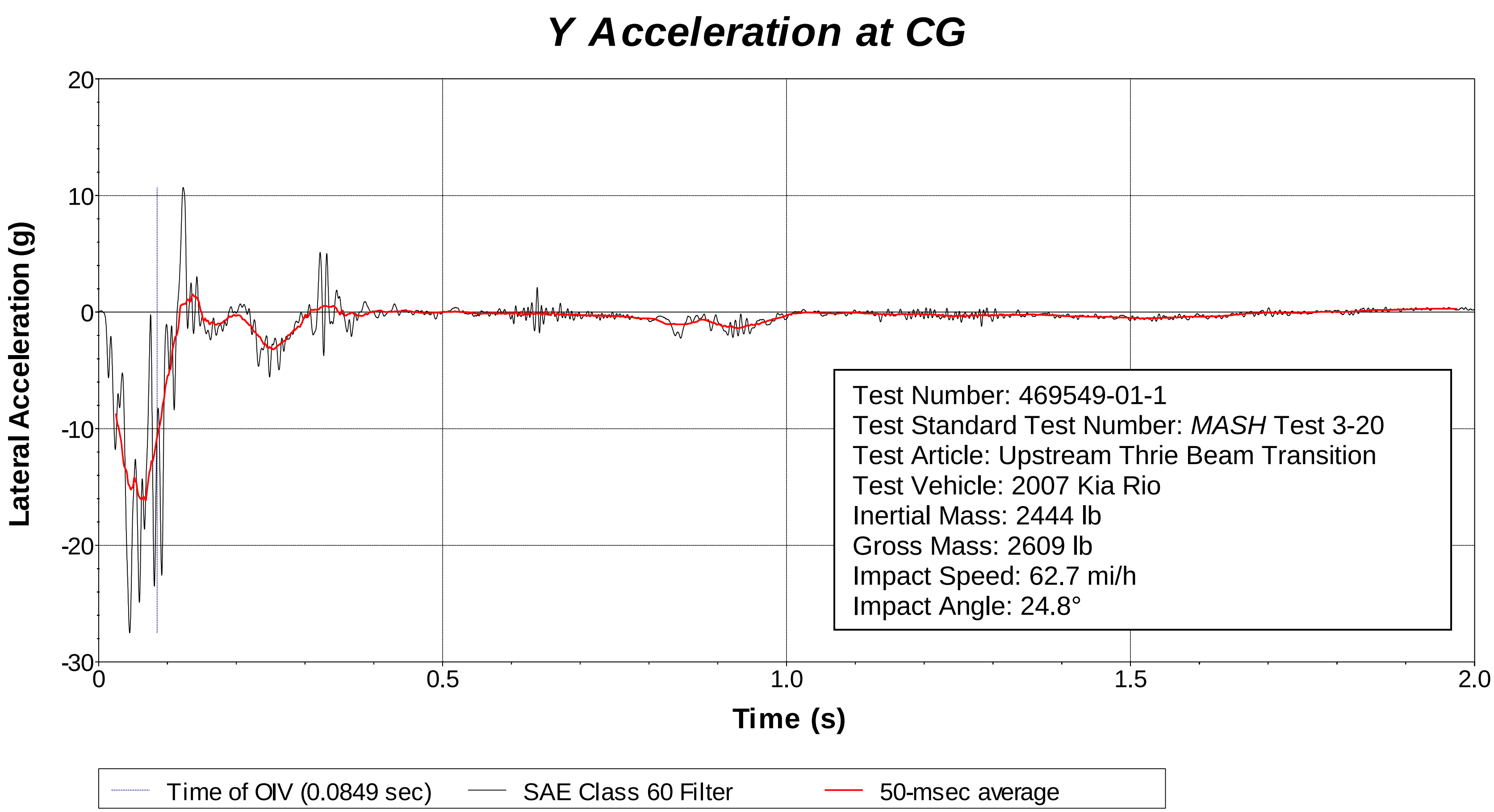


Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 469549-01-1 (Accelerometer Located at Center of Gravity).

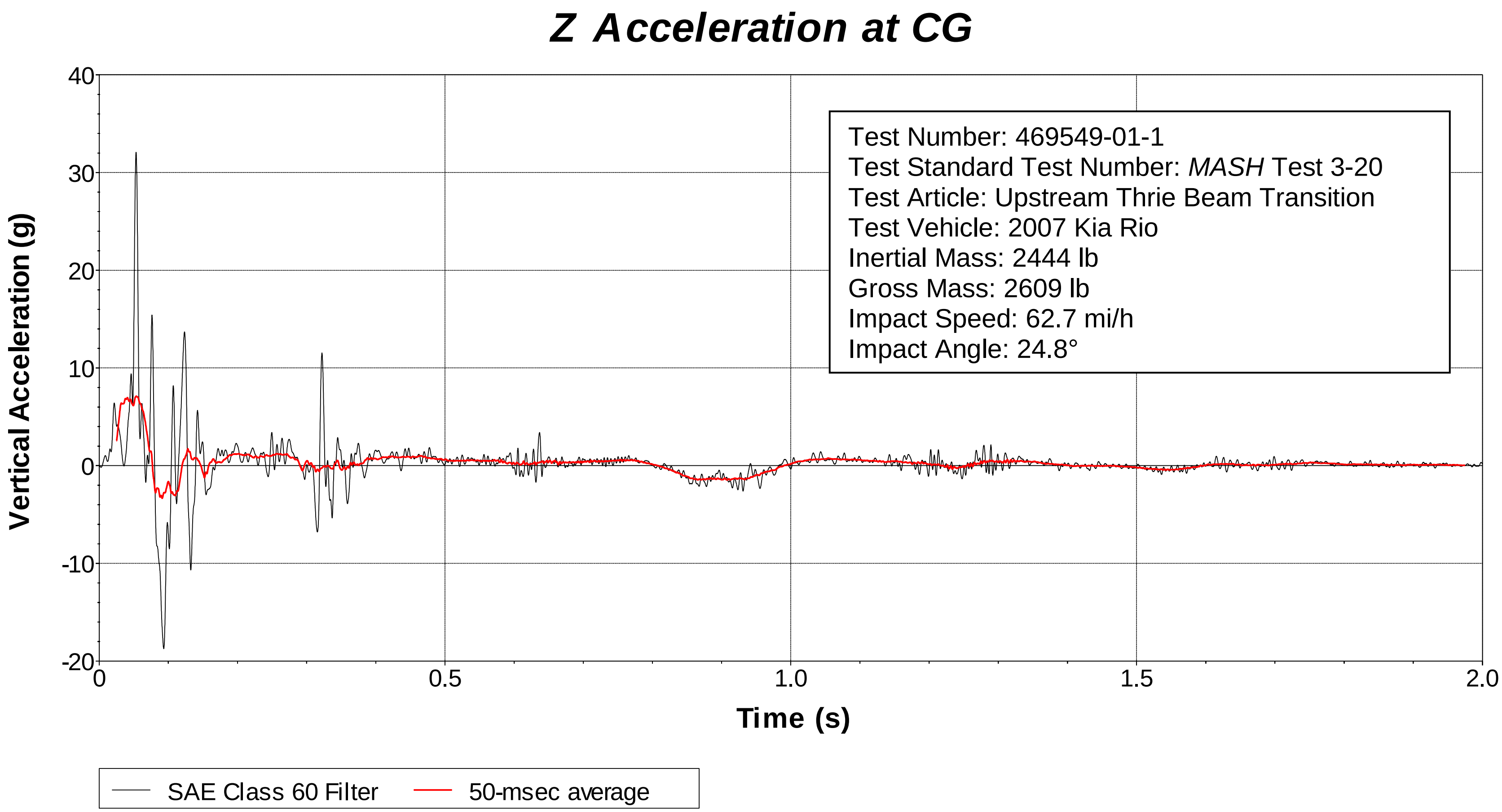


Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 469549-01-1 (Accelerometer Located at Center of Gravity).

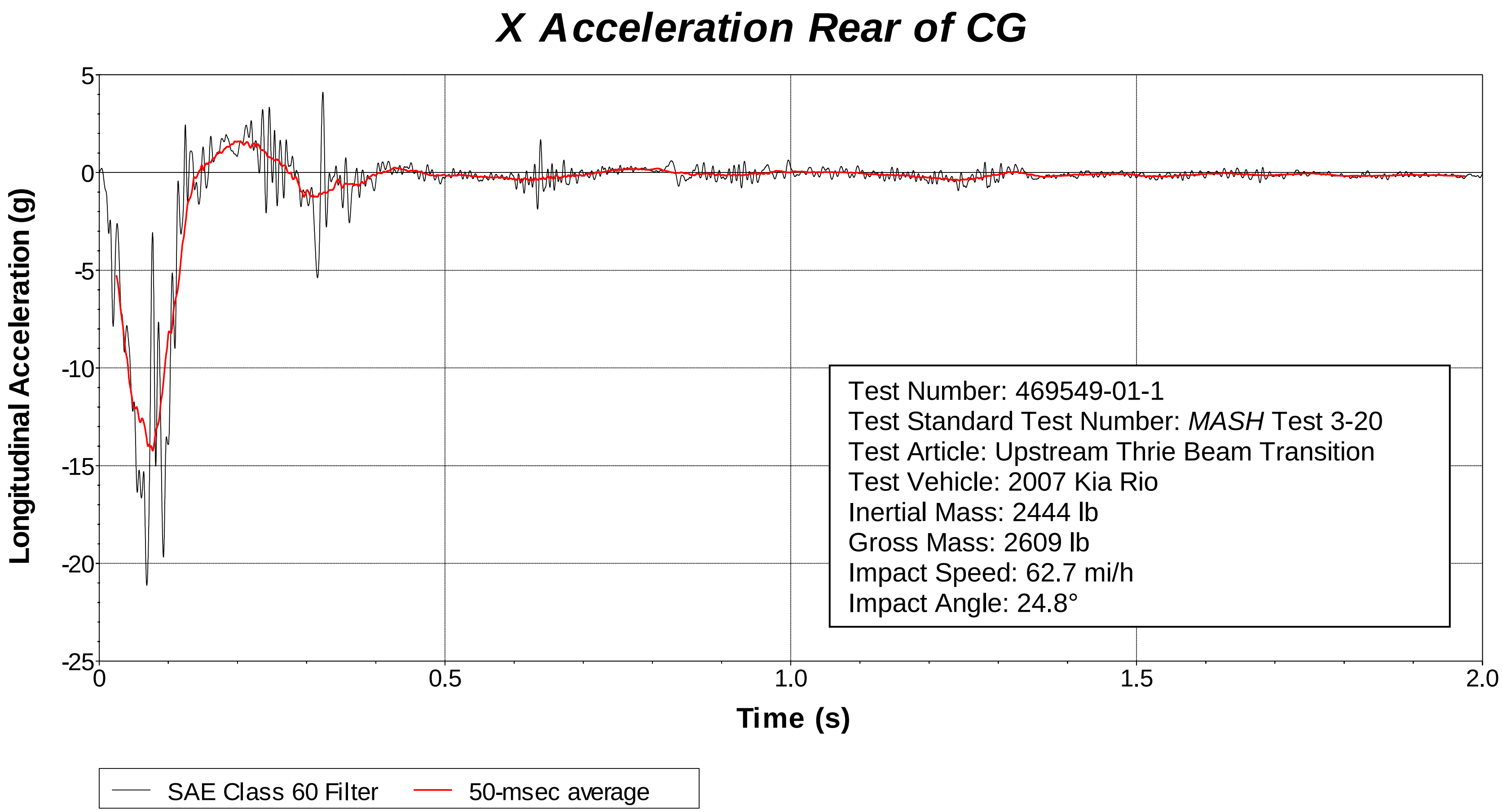


Figure D.7. Vehicle Longitudinal Accelerometer Trace for Test No. 469549-01-1 (Accelerometer Located Rear of Center of Gravity).

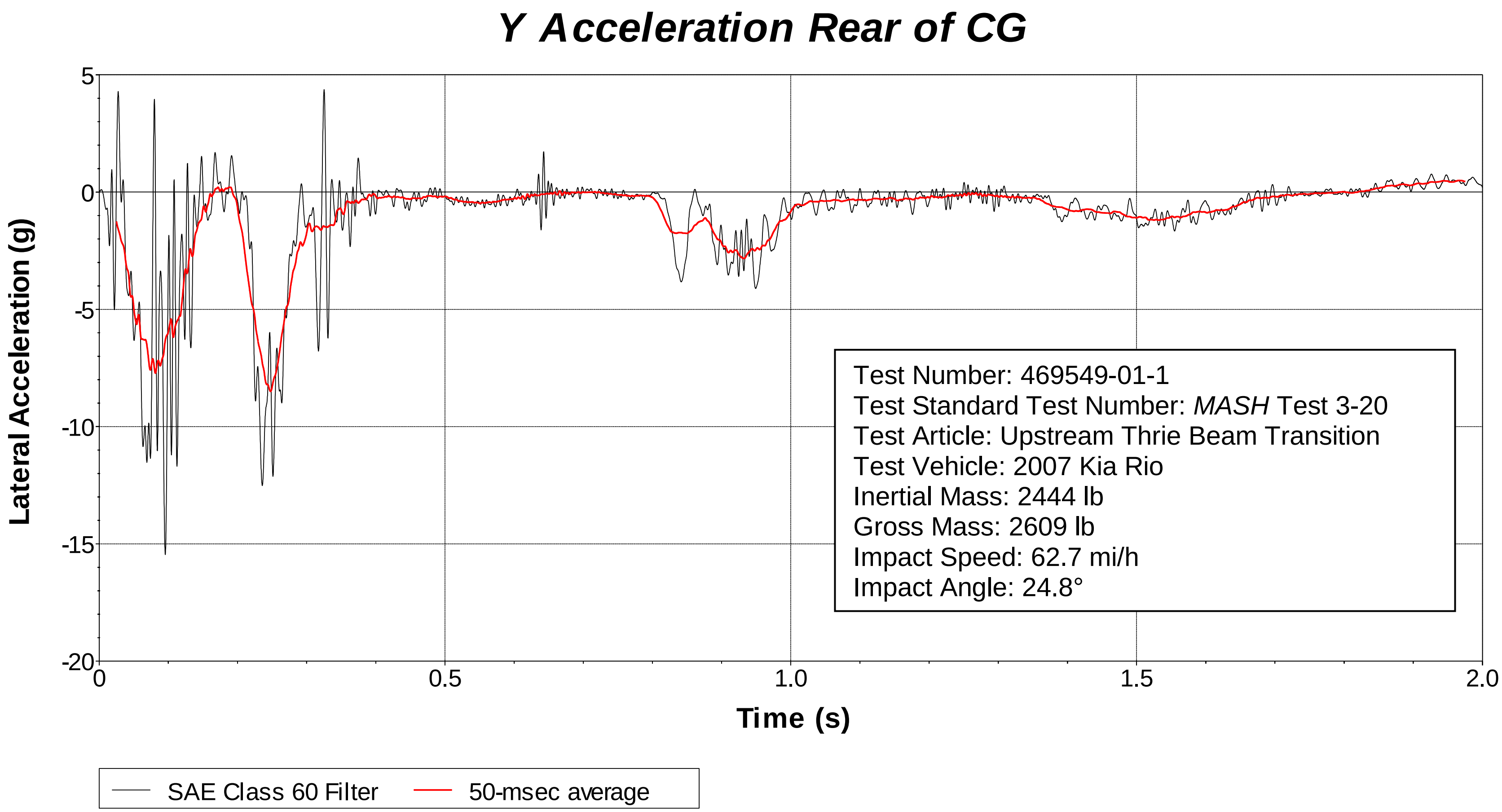


Figure D.8. Vehicle Lateral Accelerometer Trace for Test No. 469549-01-1 (Accelerometer Located Rear of Center of Gravity).

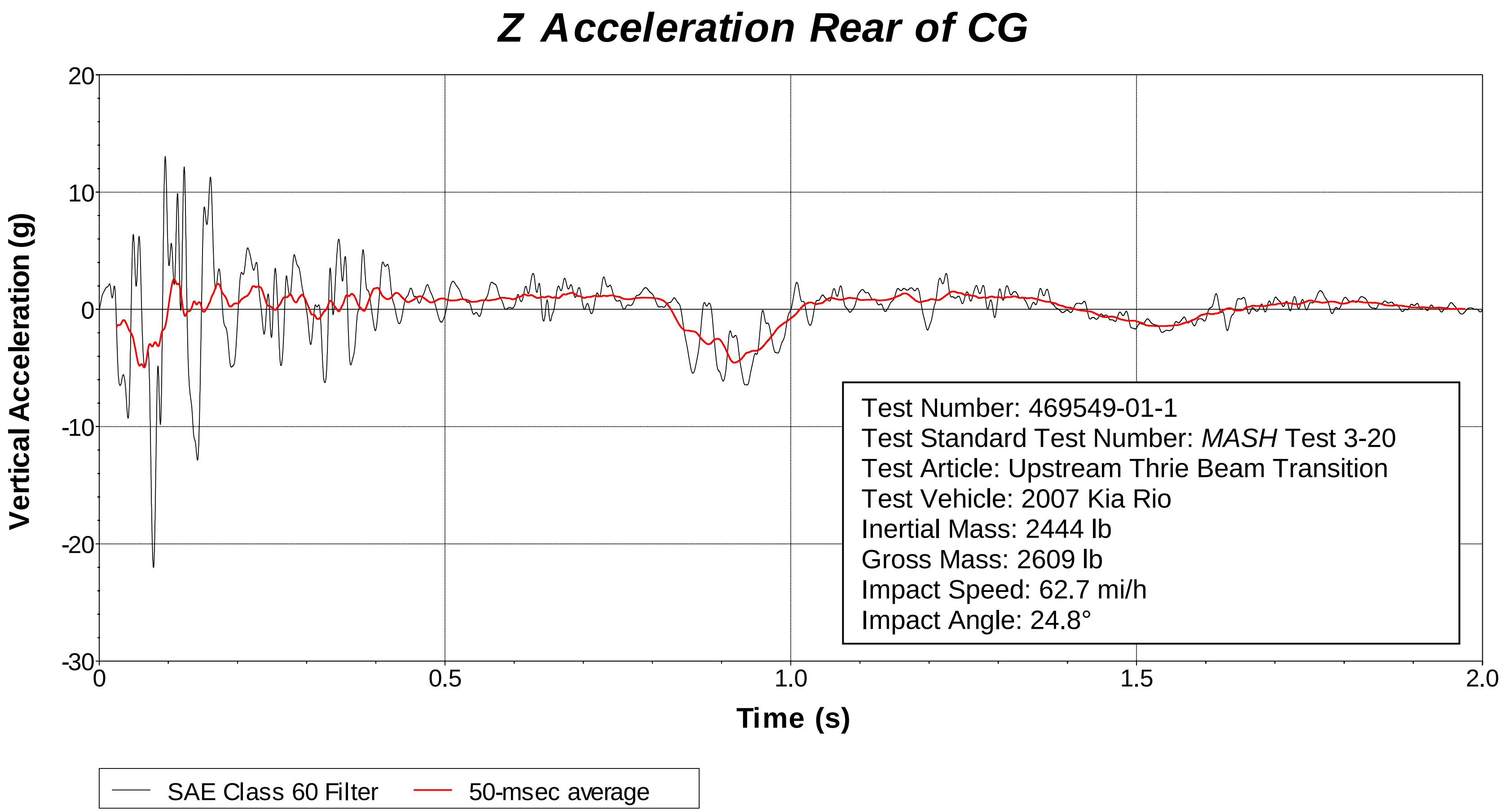


Figure D.9. Vehicle Vertical Accelerometer Trace for Test No. 469549-01-1 (Accelerometer Located Rear of Center of Gravity).

APPENDIX E. *MASH* TEST 3-21 (CRASH TEST NO. 469549-01-2)

E.1 VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 469549-01-2.

Date: 2019-03-06 Test No.: 469549-2 VIN No.: 1C6RR6T6DS628453

Year: 2013 Make: RAM Model: 1500

Tire Size: 265/70 R 17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 185392

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

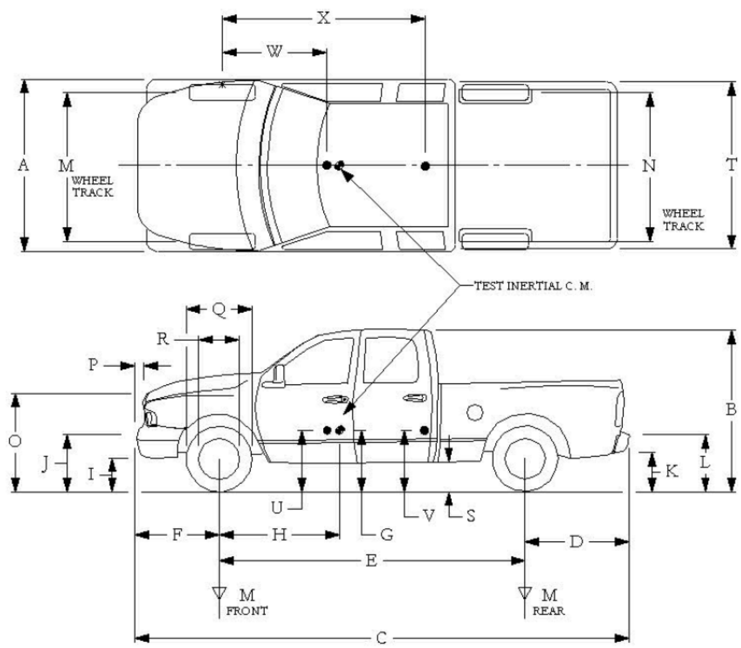
NOTES: None

Engine Type: V-8
Engine CID: 4.7 liter

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

Optional Equipment:
None

Dummy Data:
Type: No dummy
Mass: 0 lb
Seat Position: NA



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	
B	74.00	G	29.00	L	30.00	Q	30.50	V	
C	227.50	H	60.78	M	68.50	R	18.00	W	
D	44.00	I	11.75	N	68.00	S	13.00	X	
E	140.50	J	27.00	O	46.00	T	77.00		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	12.50
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	22.50

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; (M+N)/2=67 ±1.5 inches

GVWR Ratings:		Mass: lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2969	2856	2856
Back	3900	M_{rear}	2202	2178	2178
Total	6700	M_{Total}	5171	5034	5034

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:
lb LF: 1423 RF: 1433 LR: 1120 RR: 1058

Table E.2. Measurements of Vehicle Vertical CG for Test No. 469549-01-2.

Date: 2019-03-06 Test No.: 469549-2 VIN: 1C6RR6T6DS628453

Year: 2013 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 185392

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 60 (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70 R 17

Measured Vehicle Weights: (lb)								
LF:	1423		RF:	1433		Front Axle:	2856	
LR:	1120		RR:	1058		Rear Axle:	2178	
Left:	2543		Right:	2491		Total:	5034	
							5000 ±110 lb allowed	
Wheel Base:		140.50	inches	Track: F:	68.50	inches R:	68.00	inches
	148 ±12 inches allowed				Track = (F+R)/2 = 67 ±1.5 inches allowed			
Center of Gravity, SAE J874 Suspension Method								
X:	60.79	inches	Rear of Front Axle		(63 ±4 inches allowed)			
Y:	-0.35	inches	Left -	Right +	of Vehicle Centerline			
Z:	29.00	inches	Above Ground		(minumum 28.0 inches allowed)			

Hood Height: 46.00 inches Front Bumper Height: 27.00 inches

43 ±4 inches allowed

Front Overhang: 40.00 inches Rear Bumper Height: 30.00 inches

39 ±3 inches allowed

Overall Length: 227.50 inches

237 ±13 inches allowed

Table E.3. Exterior Crush Measurements of Vehicle for Test No. 469549-01-2.

Date:	2019-03-06	Test No.:	469549-2	VIN No.:	1C6RR6T6DS628453
Year:	2013	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________	Bowing: B1 _____ X1 _____
Corner shift: A1 ________	B2 _____ X2 _____
A2 ________	
End shift at frame (CDC)	Bowing constant
(check one)	$\frac{X1+X2}{2}$ = _______
< 4 inches ________	
≥ 4 inches ________	

Note: Measure C_1 to C_6 from Driver to Passenger Side in Front or Rear Impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bumper ht	23	15	36	1	4	7	11	13	15	-18
2	Side plane at bumper ht	23	14	48	6	8	--	--	12	14	+76
	Measurements recorded										
	☑ **inches** **or** ☐ **mm**										

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

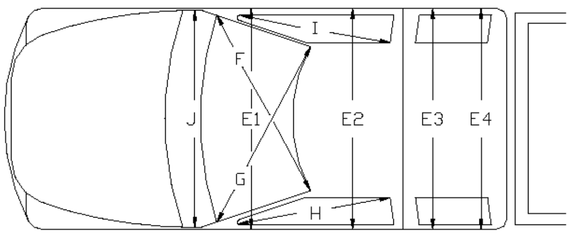
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

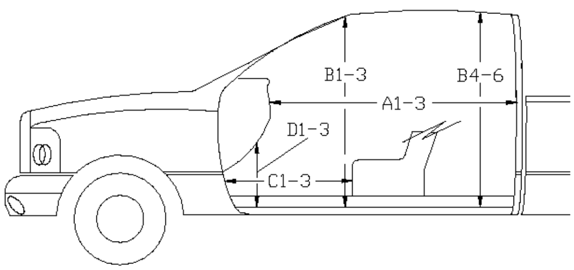
***Measure and document on the vehicle diagram the location of the maximum crush.

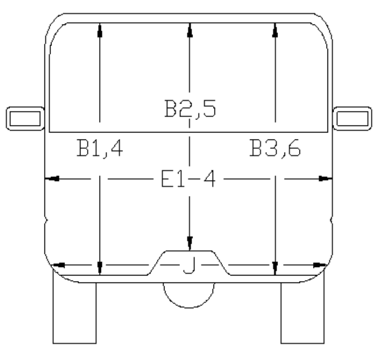
Note: Use as many lines/columns as necessary to describe each damage profile.

Table E.4. Occupant Compartment Measurements of Vehicle for Test No. 469549-01-2.

Date:	2019-03-06	Test No.:	469549-2	VIN No.:	1C6RR6T6DS628453
Year:	2013	Make:	RAM	Model:	1500







*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.50	0.50
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	24.00	-2.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	12.00	0.50
E1	58.50	58.00	-0.50
E2	63.50	64.00	0.50
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	21.00	-4.00

E.2 SEQUENTIAL PHOTOGRAPHS

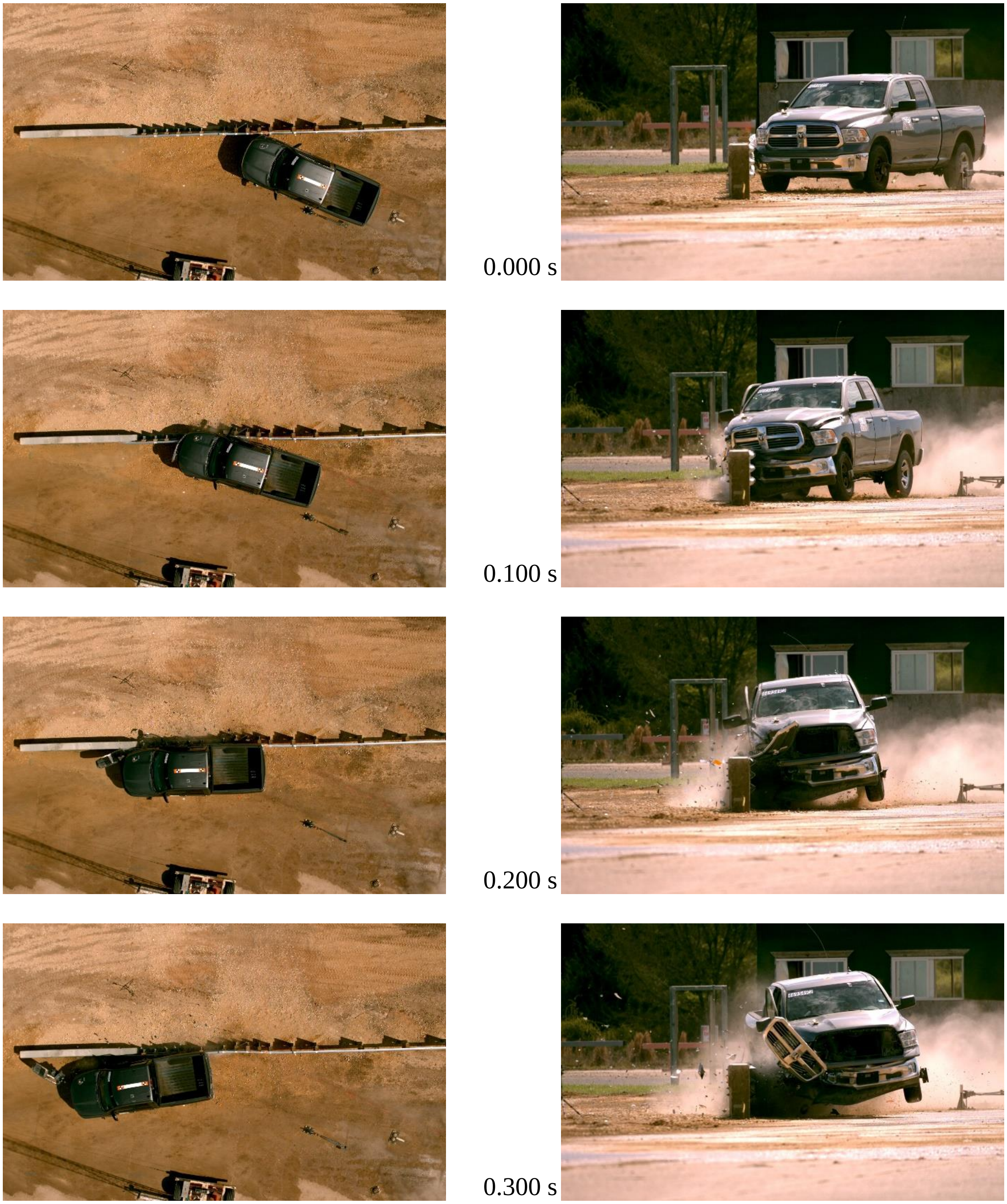


Figure E.1. Sequential Photographs for Test No. 469549-01-2 (Overhead and Frontal Views).

0.400 s

0.500 s

0.600 s

0.700 s

Figure E.1. Sequential Photographs for Test No. 469549-01-2 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

0.200 s

0.300 s

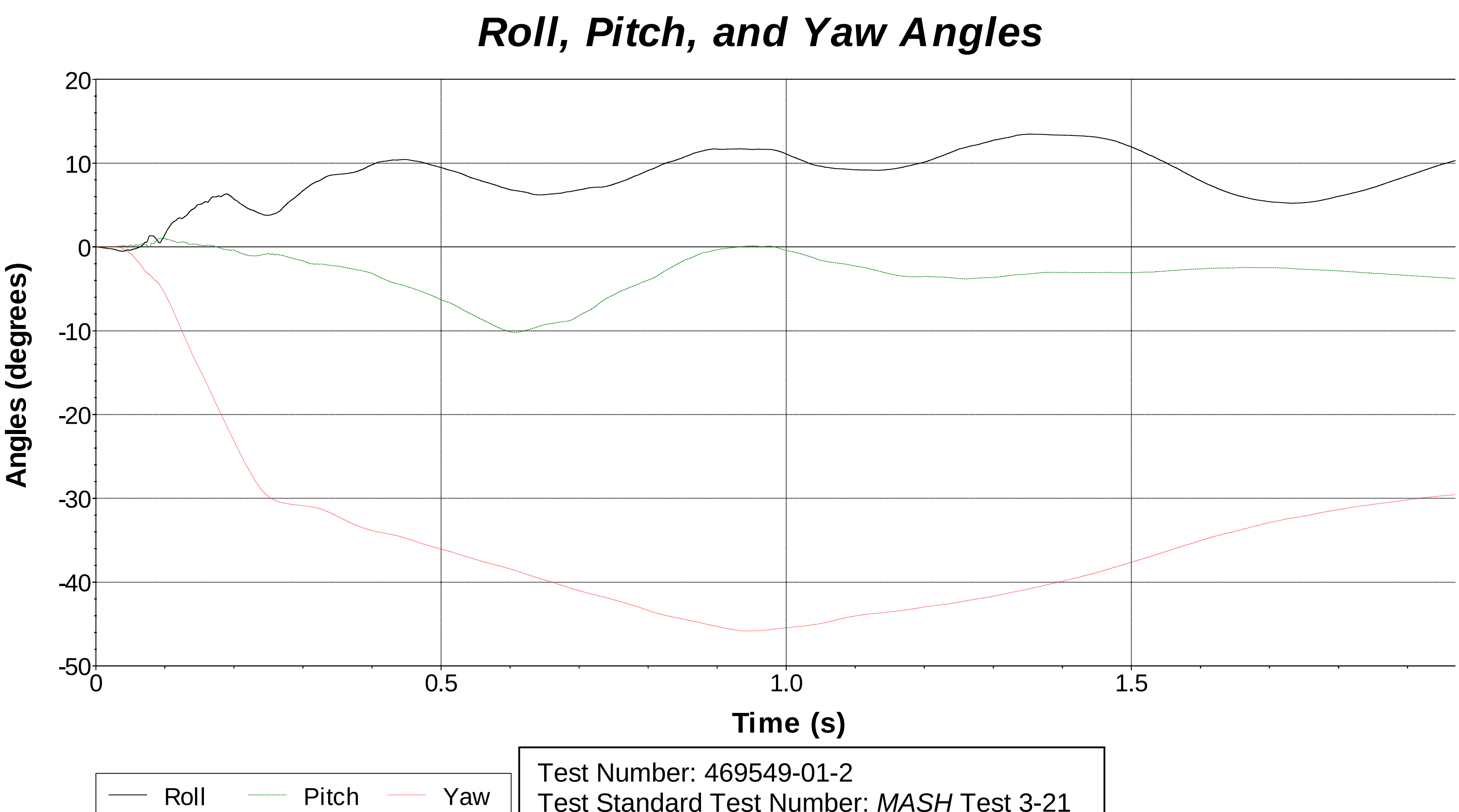
0.400 s

0.500 s

0.600 s

0.700 s

Figure E.2. Sequential Photographs for Test No. 469549-01-2 (Rear View).



Test Number: 469549-01-2
Test Standard Test Number: *MASH* Test 3-21
Test Article: Upstream Thrie Beam Transition
Test Vehicle: 2013 RAM 1500 Pickup
Inertial Mass: 5034 lb
Gross Mass: 5034 lb
Impact Speed: 62.2 mi/h
Impact Angle: 23.8°

Axes are vehicle-fixed.
Sequence for determining orientation:
1. Yaw.
2. Pitch.
3. Roll.

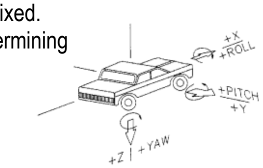


Figure E.3. Vehicle Angular Displacements for Test No. 469549-01-2.

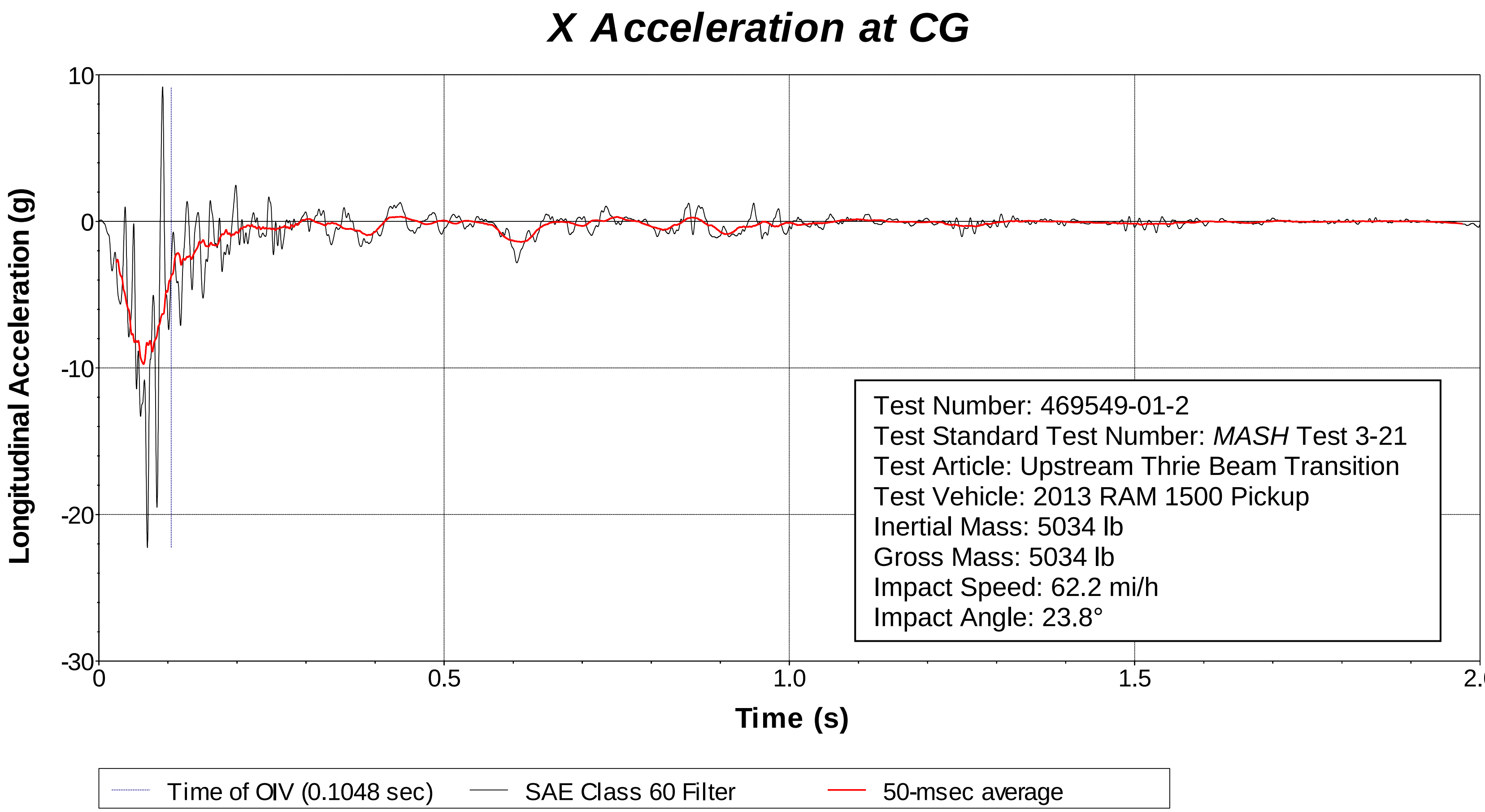


Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469549-01-2 (Accelerometer Located at Center of Gravity).

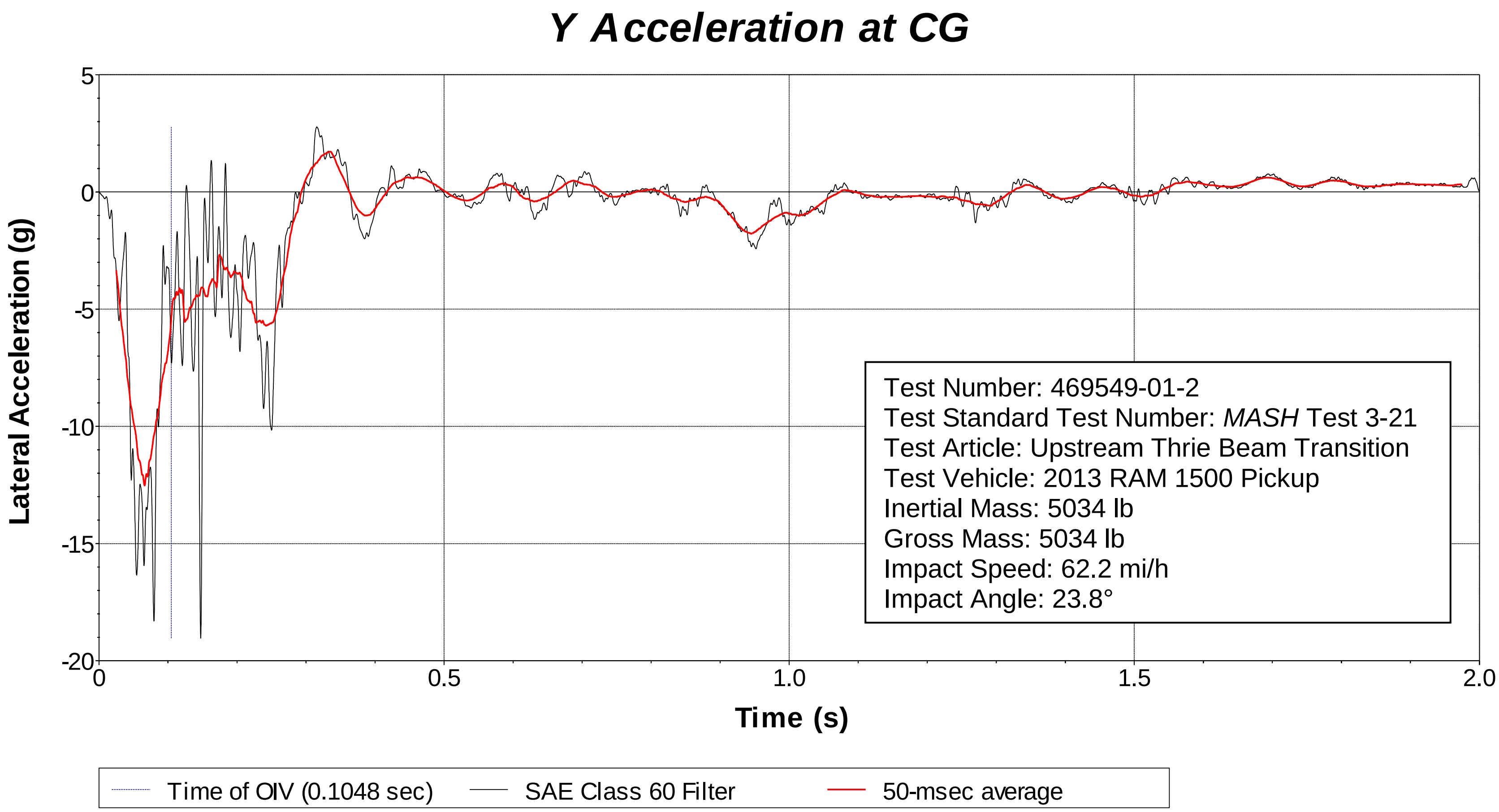


Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 469549-01-2 (Accelerometer Located at Center of Gravity).

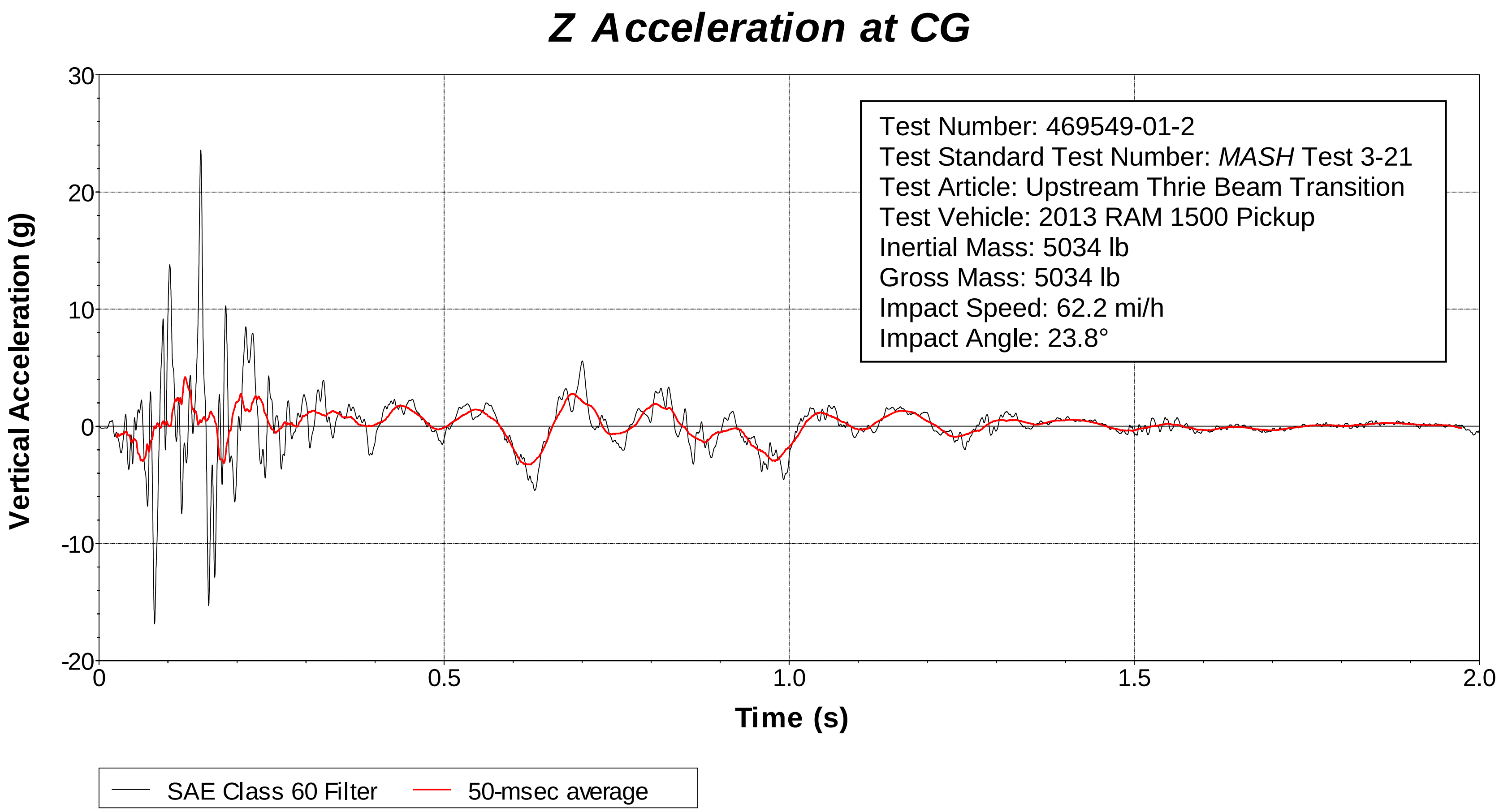


Figure E.6. Vehicle Vertical Accelerometer Trace for Test No. 469549-01-2 (Accelerometer Located at Center of Gravity).

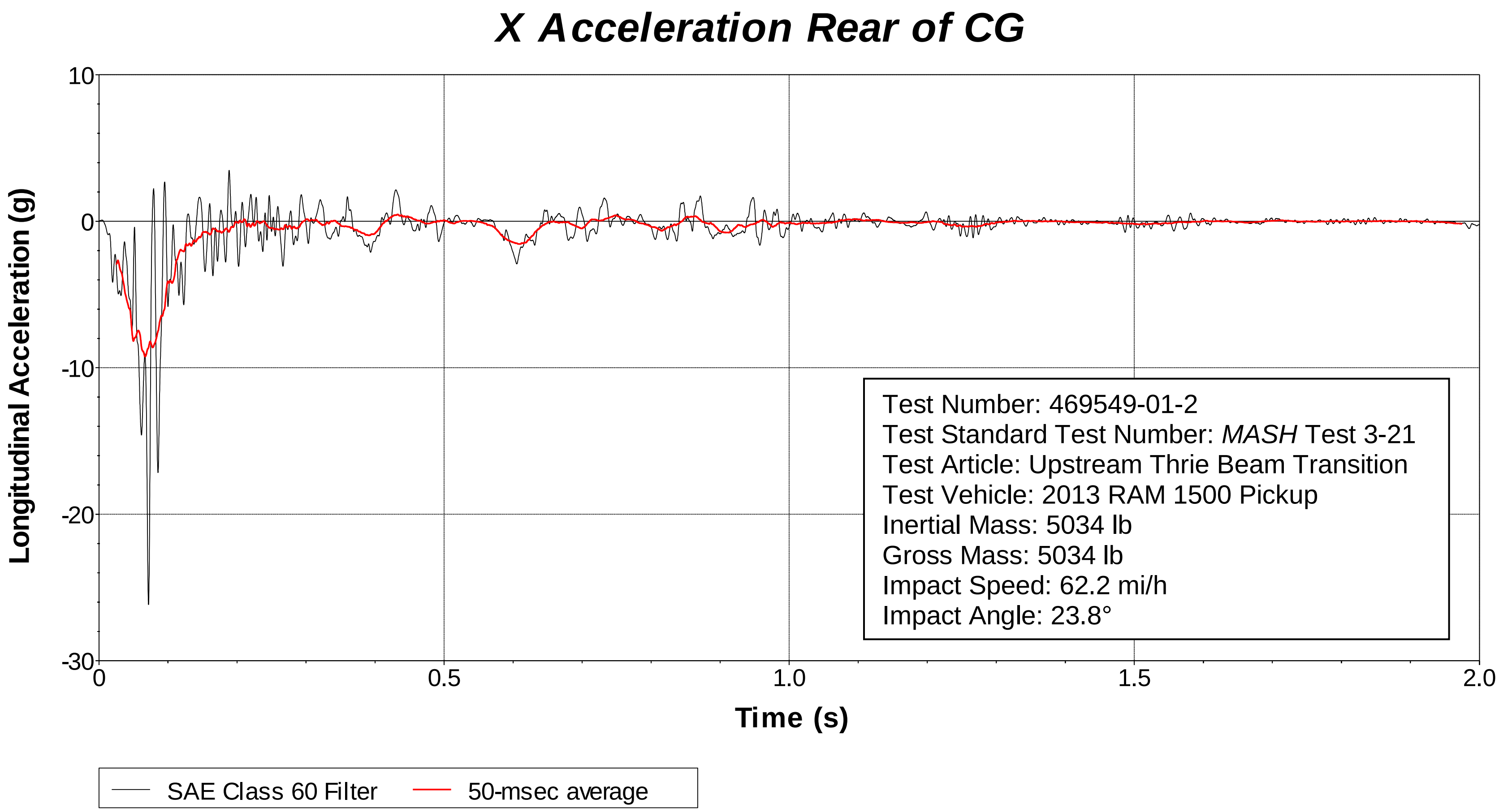


Figure E.7. Vehicle Longitudinal Accelerometer Trace for Test No. 469549-01-2 (Accelerometer Located Rear of Center of Gravity).

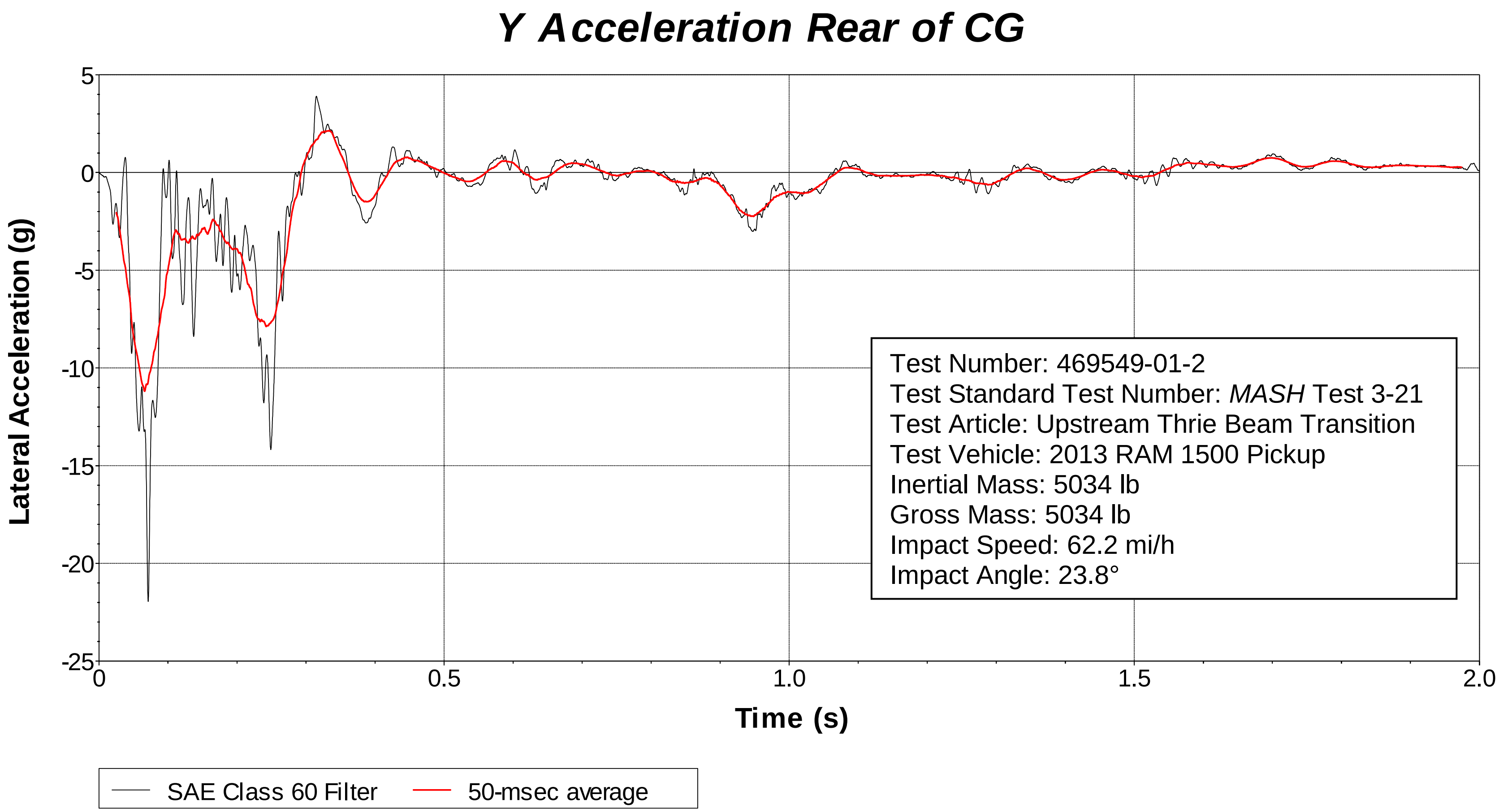


Figure E.8. Vehicle Lateral Accelerometer Trace for Test No. 469549-01-2 (Accelerometer Located Rear of Center of Gravity).

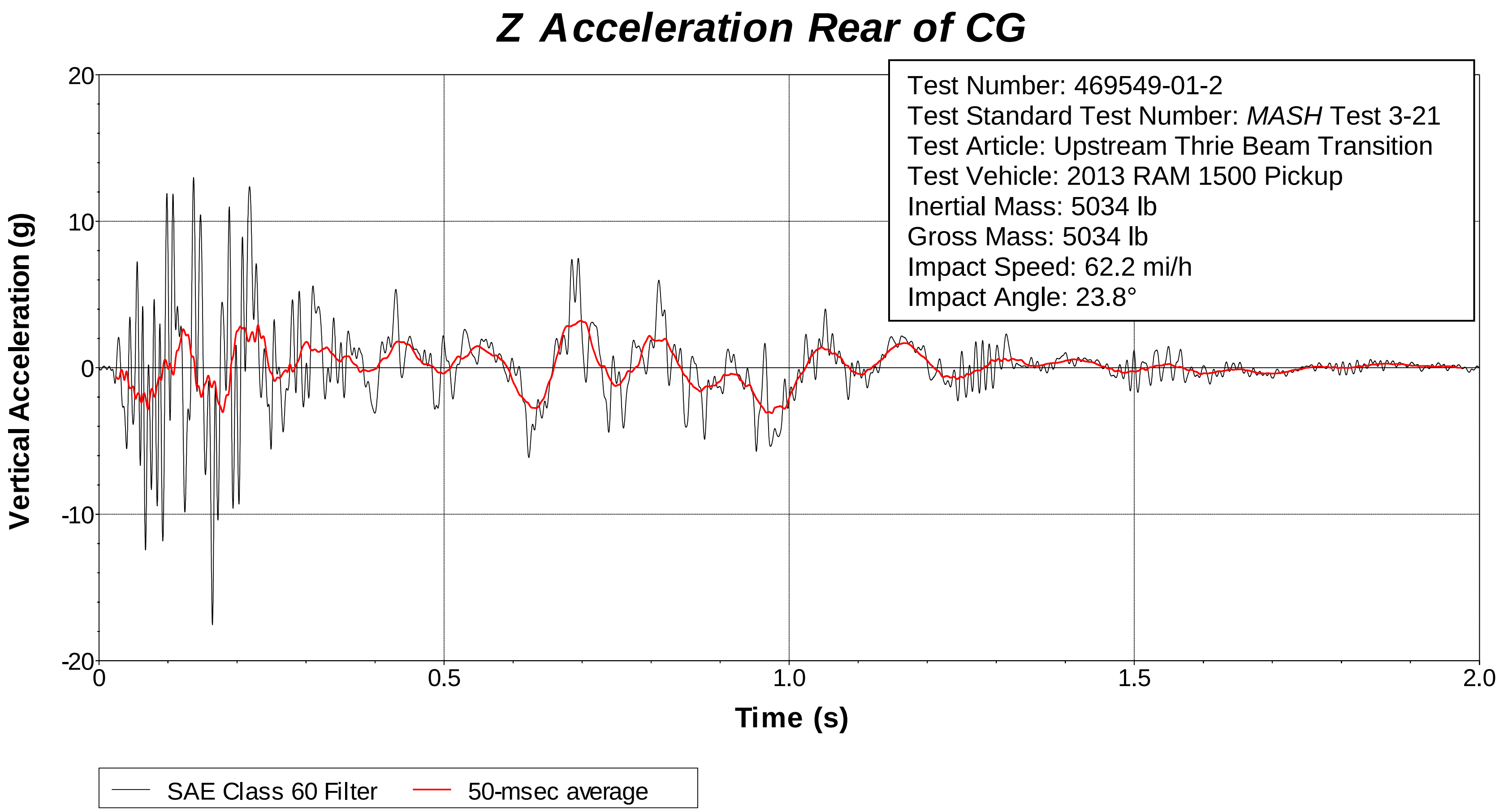


Figure E.9. Vehicle Vertical Accelerometer Trace for Test No. 469549-01-2 (Accelerometer Located Rear of Center of Gravity).

APPENDIX F. *MASH* TEST 3-21 (CRASH TEST NO. 469549-01-4)

F.1 VEHICLE PROPERTIES AND INFORMATION

Table F.1. Vehicle Properties for Test No. 469549-01-4.

Date:	2019-03-19	Test No.:	469549-4	VIN No.:	1C6RR6FT9DS519308
Year:	2013	Make:	RAM	Model:	1500

Tire Size: 265/70 R 17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 130203

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

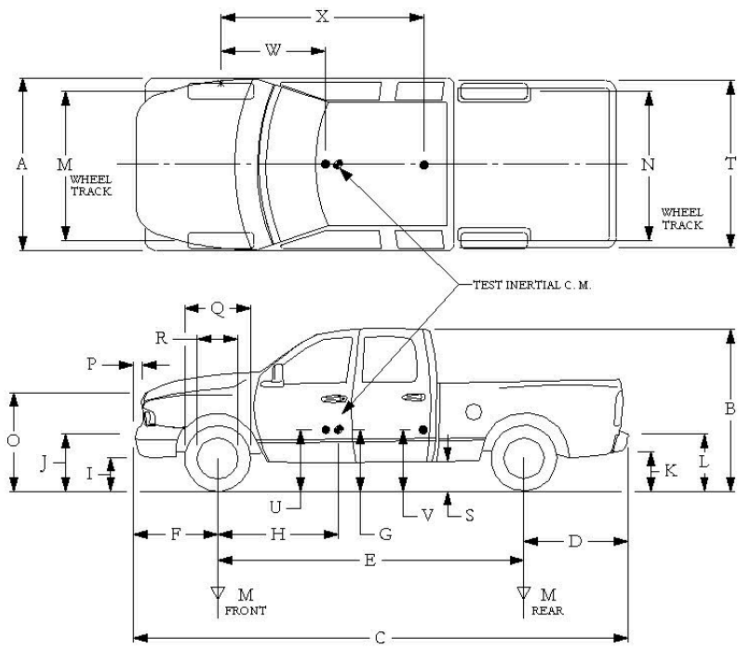
NOTES: None

Engine Type: V-8
Engine CID: 4.7 liter

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

Optional Equipment:
None

Dummy Data:
Type: None
Mass: 0 lb
Seat Position: NA



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	27.50
B	74.00	G	28.25	L	30.00	Q	30.50	V	31.25
C	227.50	H	61.54	M	68.50	R	18.00	W	61.54
D	44.00	I	11.75	N	68.00	S	13.00	X	77.75
E	140.50	J	27.00	O	46.00	T	77.00		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	12.50
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	22.50

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; (M+N)/2=67 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2915	2839	2839
Back	3900	M_{rear}	2038	2213	2213
Total	6700	M_{Total}	4953	5052	5052

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:
lb LF: 1421 RF: 1418 LR: 1110 RR: 1103

Table F.2. Measurements of Vehicle Vertical CG for Test No. 469549-01-4.

Date: 2019-03-19 Test No.: 469549-4 VIN: 1C6RR6FT9DS519308

Year: 2013 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 130203

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 158 (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70 R 17

Measured Vehicle Weights: (lb)					
LF:	1421	RF:	1418	Front Axle:	2839
LR:	1110	RR:	1103	Rear Axle:	2213
Left:	2531	Right:	2521	Total:	5052
					5000 ±110 lb allowed
Wheel Base:	140.50 inches	Track: F:	68.50 inches	R:	68.00 inches
	148 ±12 inches allowed		Track = (F+R)/2 = 67 ±1.5 inches allowed		
Center of Gravity, SAE J874 Suspension Method					
X:	61.55 inches	Rear of Front Axle	(63 ±4 inches allowed)		
Y:	-0.07 inches	Left - Right +	of Vehicle Centerline		
Z:	28.25 inches	Above Ground	(minumum 28.0 inches allowed)		

Hood Height: 46.00 inches (43 ±4 inches allowed)

Front Bumper Height: 27.00 inches

Front Overhang: 40.00 inches (39 ±3 inches allowed)

Rear Bumper Height: 30.00 inches

Overall Length: 227.50 inches (237 ±13 inches allowed)

Table F.3. Exterior Crush Measurements of Vehicle for Test No. 469549-01-4.

Date:	2019-03-19	Test No.:	469549-4	VIN No.:	1C6RR6FT9DS519308
Year:	2013	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	**Side Damage**
Undeformed end width ________	Bowing: B1 _____ X1 _____
Corner shift: A1 ________	B2 _____ X2 _____
A2 ________	
End shift at frame (CDC)	Bowing constant
(check one)	$\frac{X1+X2}{2}$ = ________
< 4 inches ________	
≥ 4 inches ________	

Note: Measure C_1 to C_6 from Driver to Passenger Side in Front or Rear Impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane@bumper ht	18	17	28	1	2	5	8	15	17	+16
2	Side plane@bumper ht	18	14	56	4	6			12	14	+72
	Measurements recorded										
	☑ **inches** **or** ☐ **mm**										

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

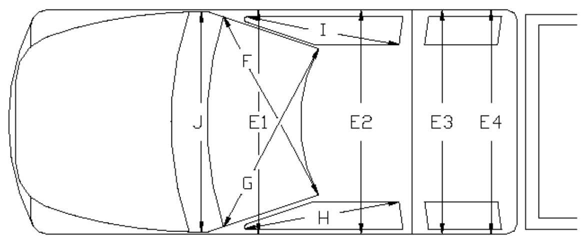
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

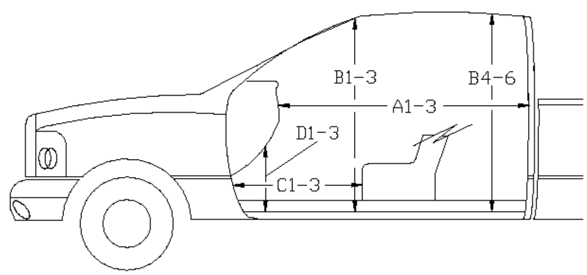
***Measure and document on the vehicle diagram the location of the maximum crush.

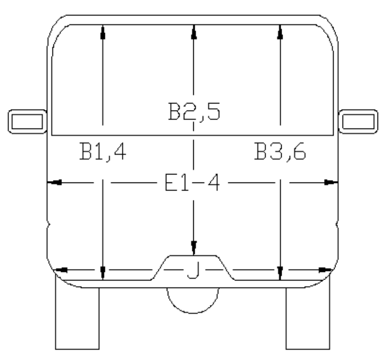
Note: Use as many lines/columns as necessary to describe each damage profile.

Table F.4. Occupant Compartment Measurements of Vehicle for Test No. 469549-01-4.

Date:	2019-03-19	Test No.:	469549-4	VIN No.:	1C6RR6FT9DS519308
Year:	2013	Make:	RAM	Model:	1500







*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	64.50	-1.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	46.00	1.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	20.00	-6.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	8.50	-3.00
E1	58.50	60.50	2.00
E2	63.50	65.00	1.50
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	19.00	-6.00

F.2 SEQUENTIAL PHOTOGRAPHS

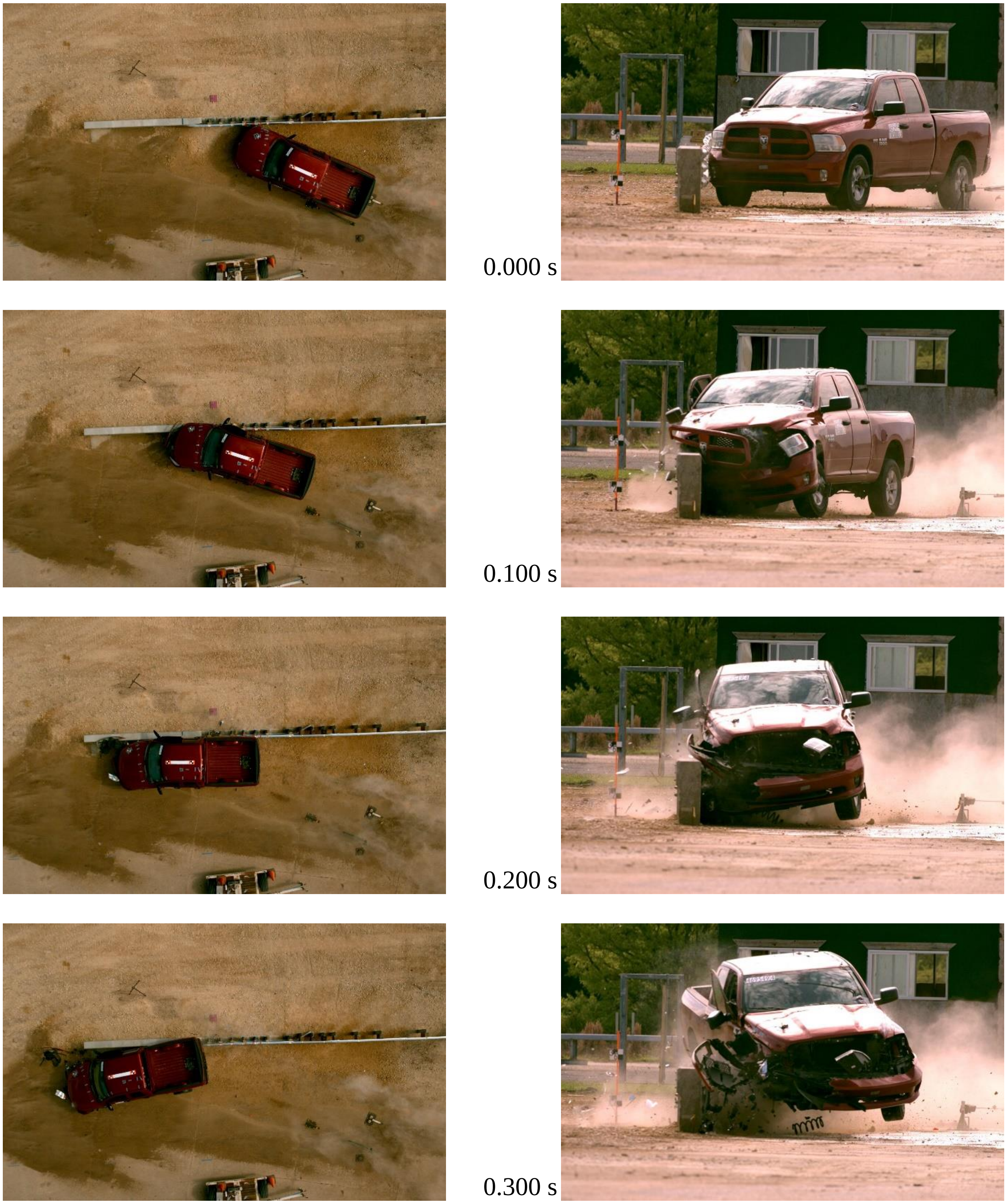


Figure F.1. Sequential Photographs for Test No. 469549-01-4 (Overhead and Frontal Views).

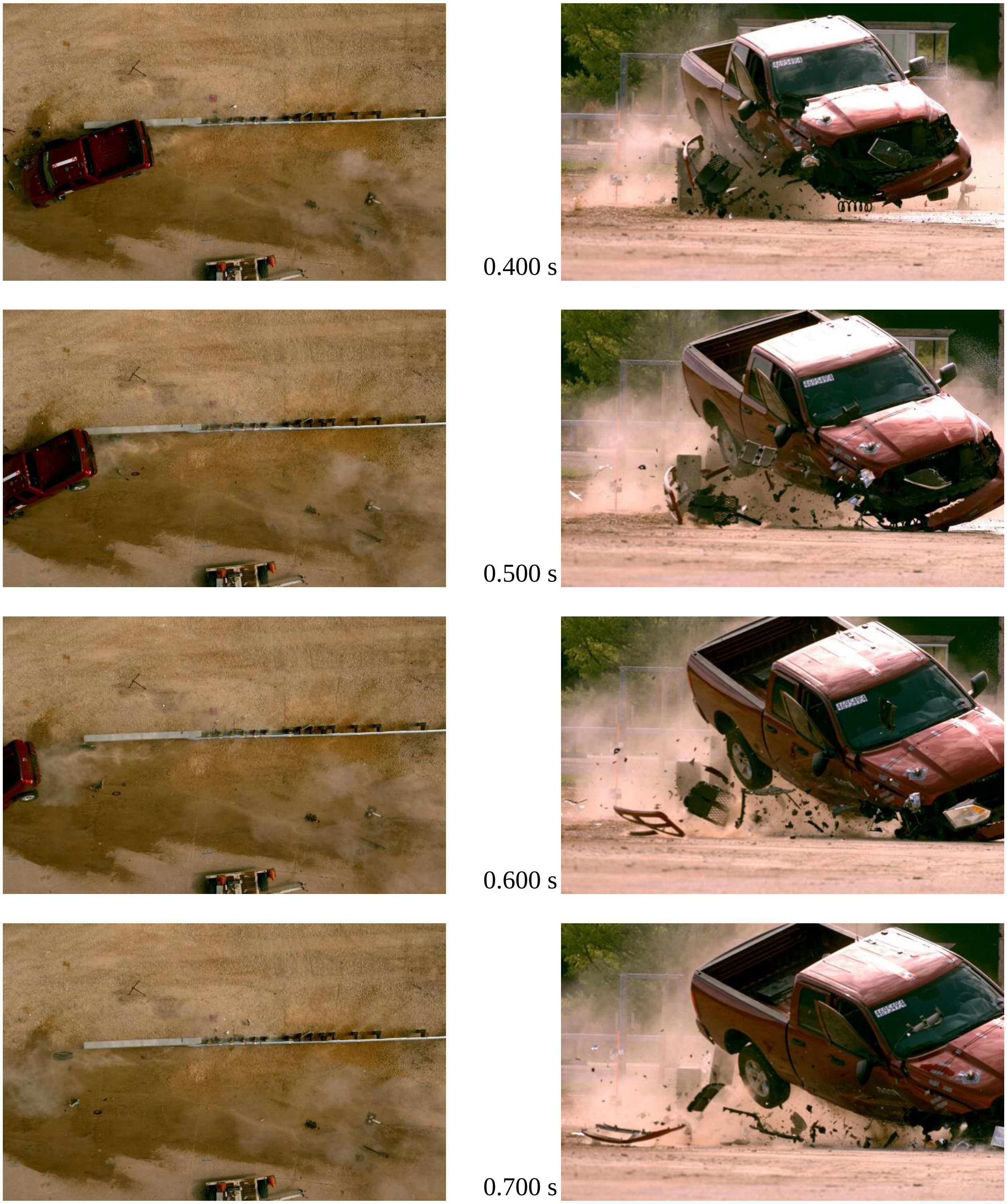
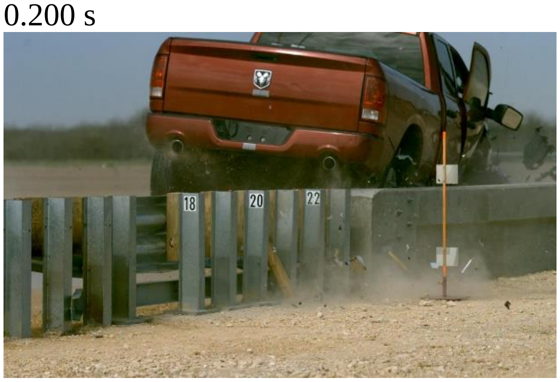


Figure F.1. Sequential Photographs for Test No. 469549-01-4 (Overhead and Frontal Views) (Continued).


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 F.2. Sequential Photographs for Test No. 469549-01-4 (Rear View).

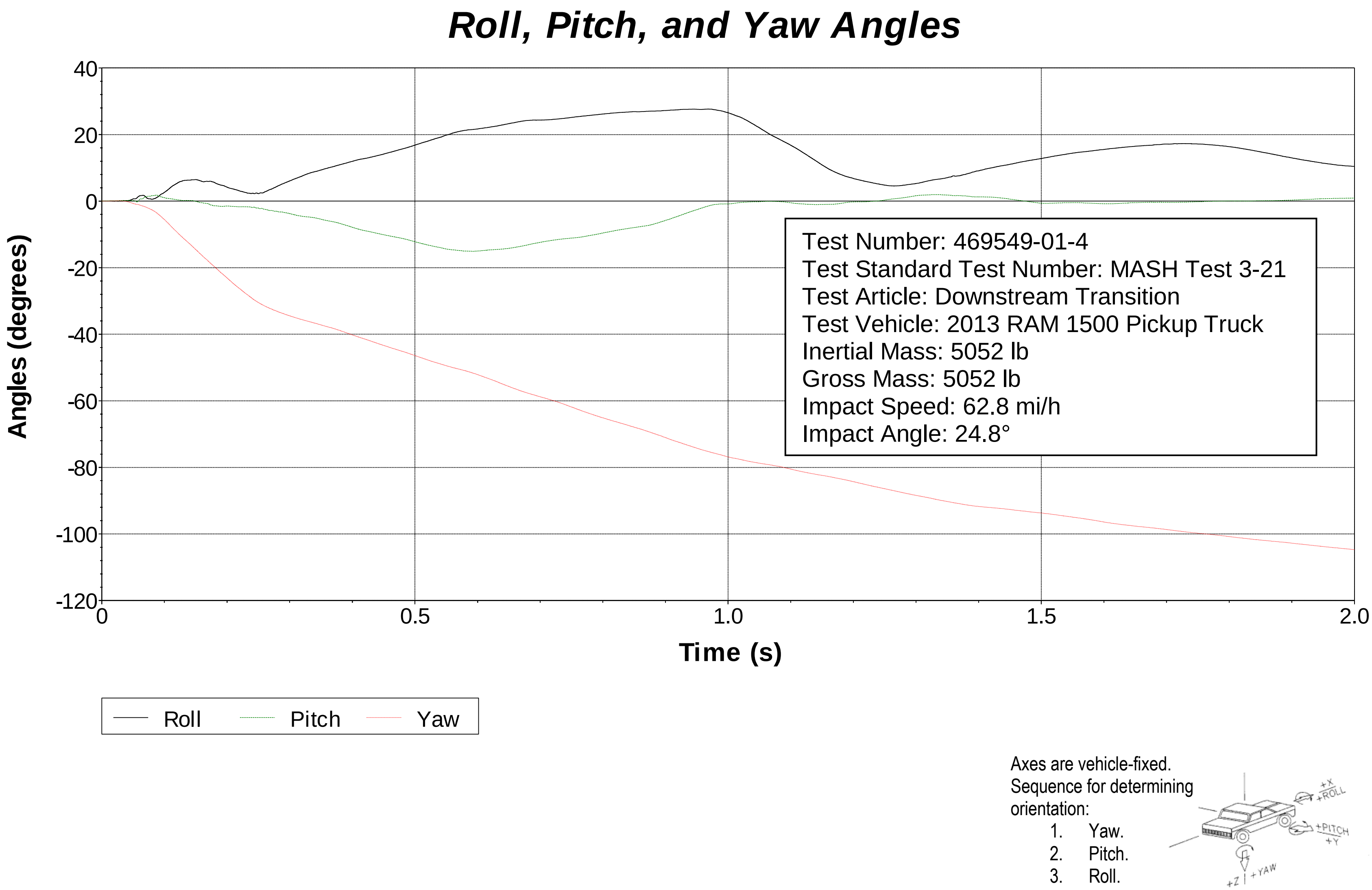


Figure F.3. Vehicle Angular Displacements for Test No. 469549-01-4.

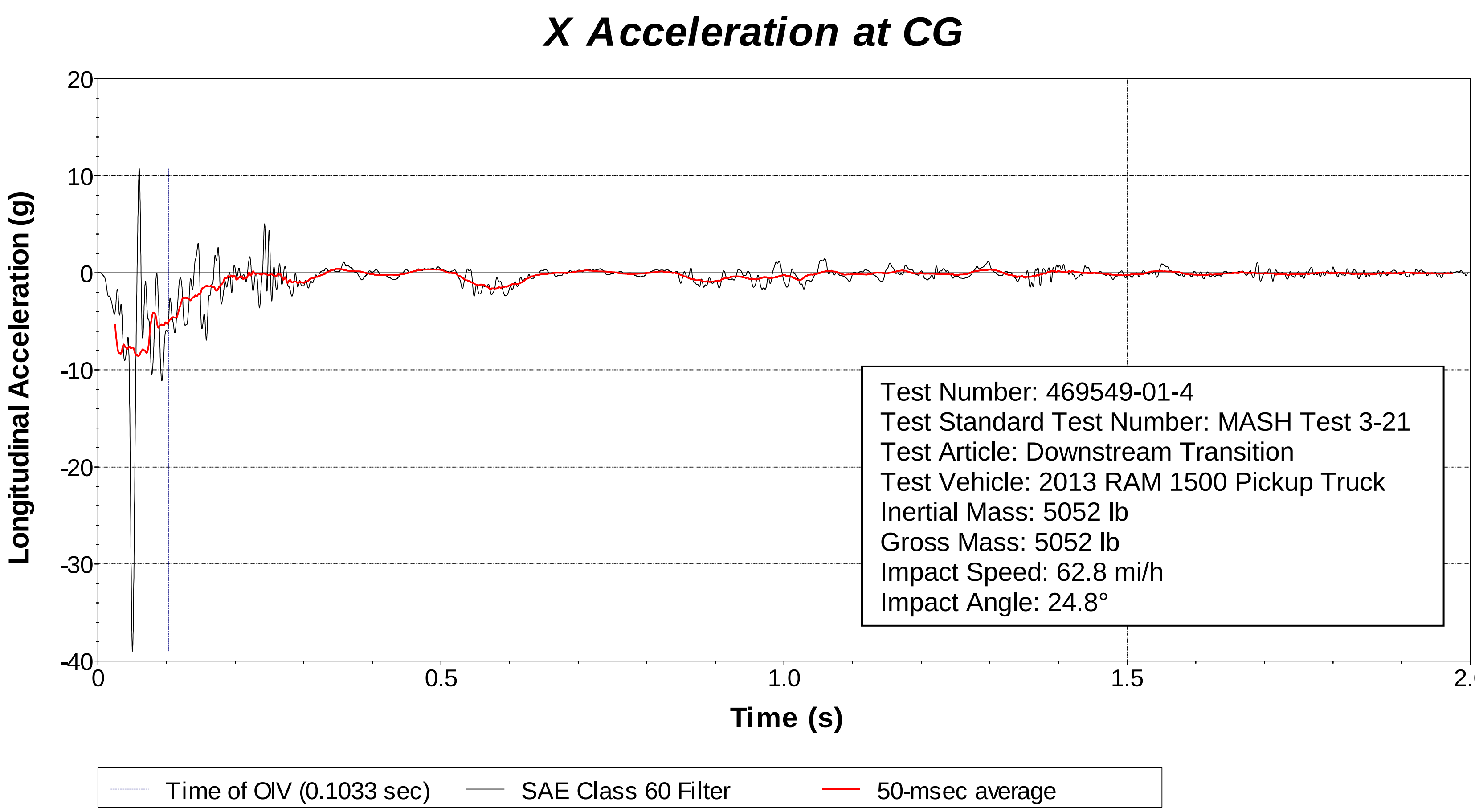


Figure F.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469549-01-4 (Accelerometer Located at Center of Gravity).

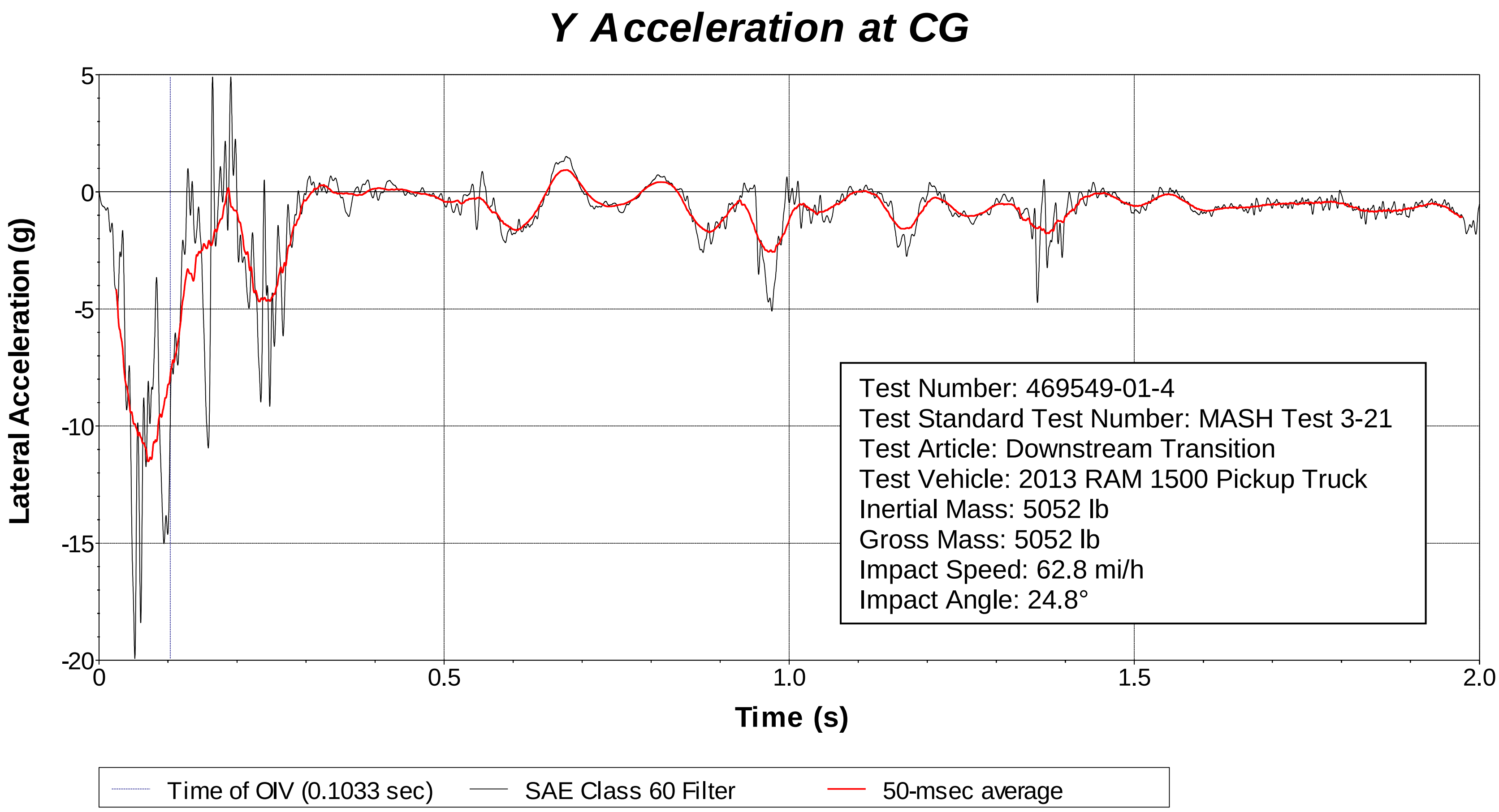


Figure F.5. Vehicle Lateral Accelerometer Trace for Test No. 469549-01-4 (Accelerometer Located at Center of Gravity).

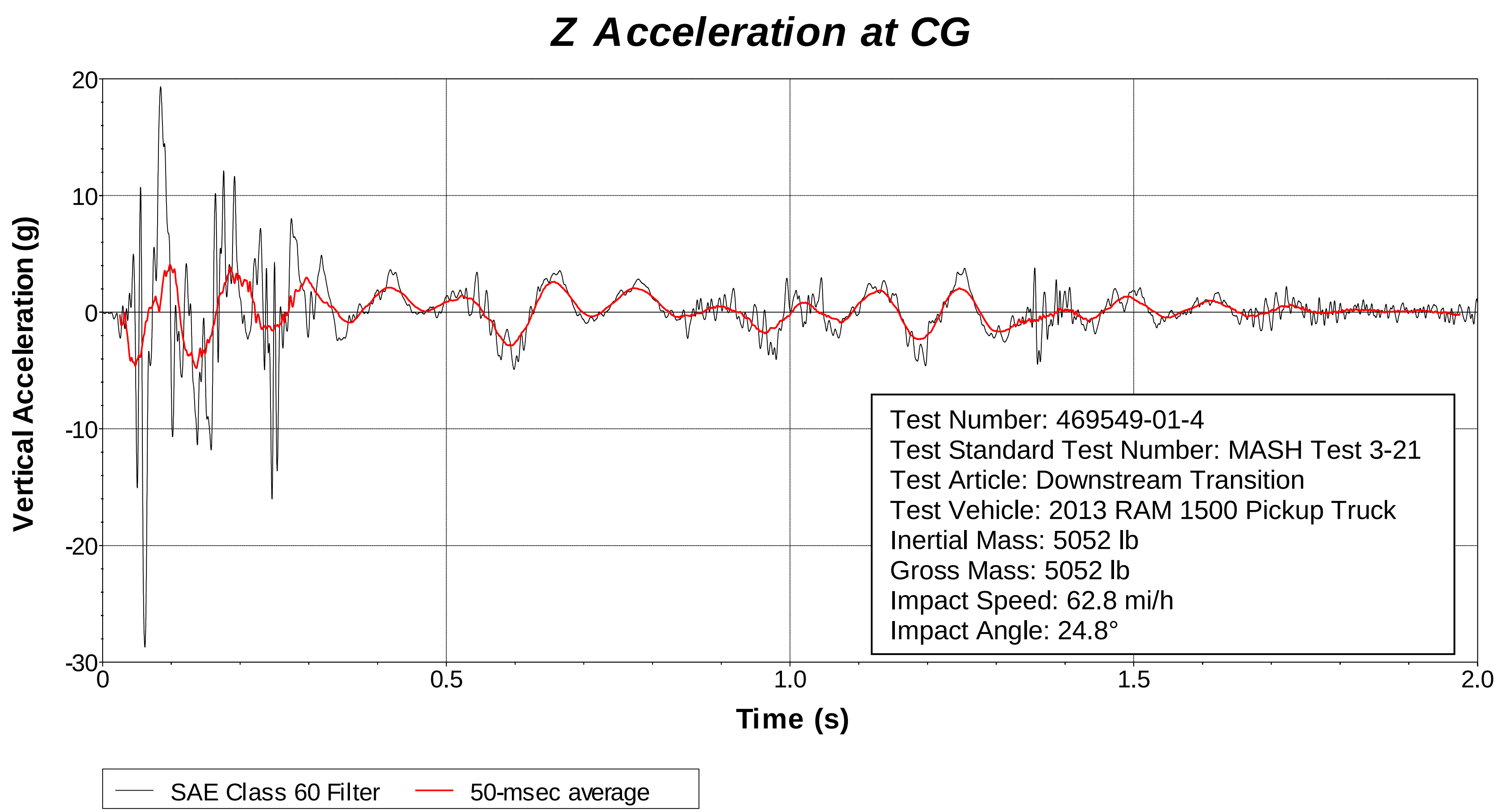


Figure F.6. Vehicle Vertical Accelerometer Trace for Test No. 469549-01-4 (Accelerometer Located at Center of Gravity).

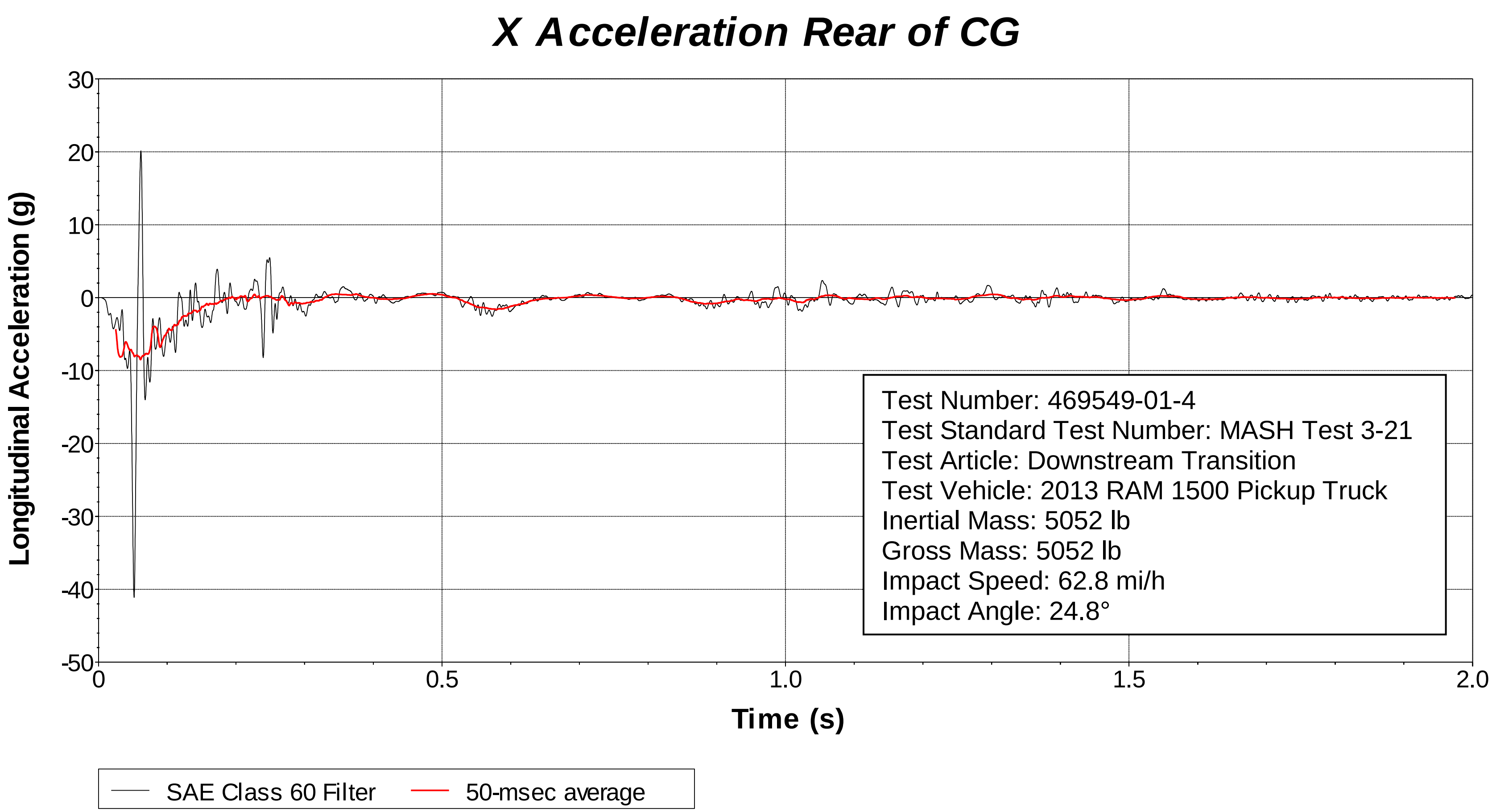


Figure F.7. Vehicle Longitudinal Accelerometer Trace for Test No. 469549-01-4 (Accelerometer Located Rear of Center of Gravity).

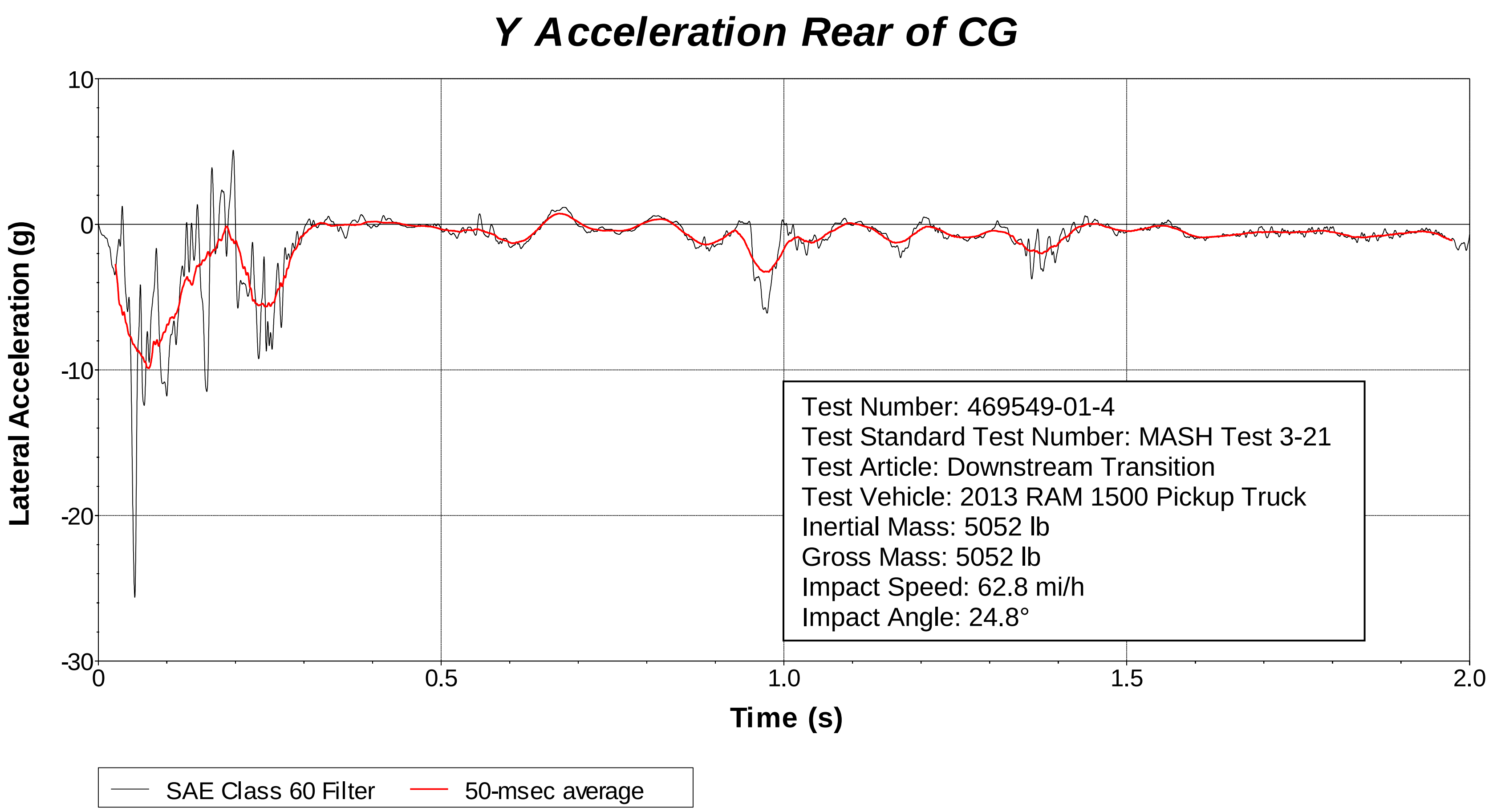


Figure F.8. Vehicle Lateral Accelerometer Trace for Test No. 469549-01-4 (Accelerometer Located Rear of Center of Gravity).

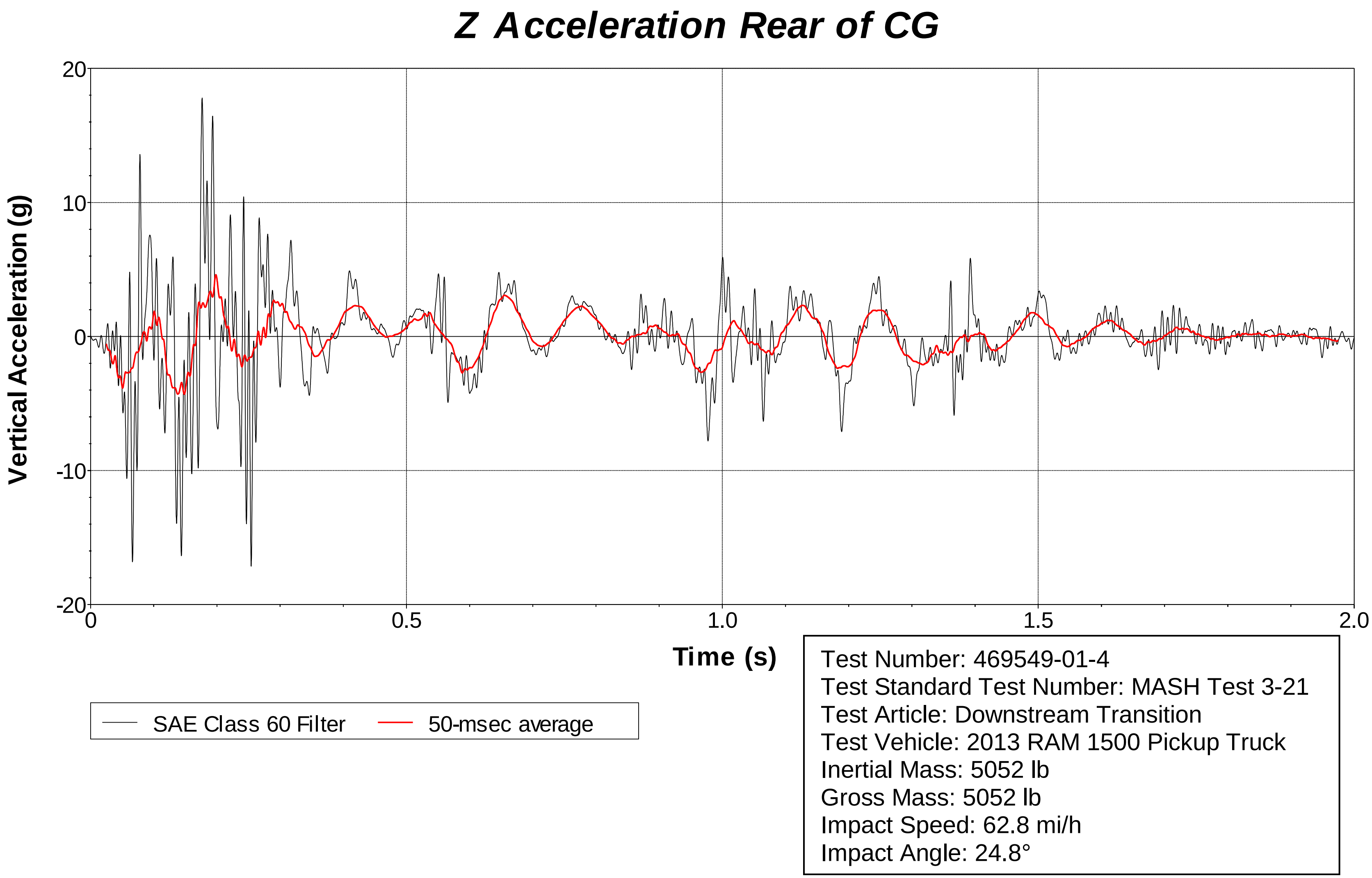


Figure F.9. Vehicle Vertical Accelerometer Trace for Test No. 469549-01-4 (Accelerometer Located Rear of Center of Gravity).