TTI: 0-6968

Texas A&M Transportation Institute

Development of Structurally Independent Foundations for 36-inch Tall Single Slope Traffic Rail (SSTR) for *MASH* TL-4

ISO 17025 Laboratory
Testing Certificate # 2821.01

Crash testing performed at:
TTI Proving Ground
3100 SH 47, Building 7091
Bryan, TX 77807

Test Report 0-6968-R7

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

The objective of this project was to develop structurally independent foundations for TxDOT's 36-inch tall single slope traffic rail (SSTR). The barrier and foundation systems were required to meet AASHTO *MASH* Test Level 4 (TL-4) criteria, and require minimal maintenance after a design impact. Foundation designs were needed for two common field installation scenarios; a foundation that has a shallow depth but can have a wider footprint, and a foundation that has a narrow footprint, but can have greater depth.

Researchers developed preliminary design concepts for the barrier and foundation systems. This was followed by developing finite element models of these designs and performing full-scale impact simulations with *MASH* Test 4-12 impact conditions. Results of the simulations were used to modify and improve the foundation designs and select final configurations for developing reinforcement details. Two foundation systems were developed under this project. One was a moment slab foundation, and another was a concrete beam foundation. Of these, the moment slab foundation was evaluated further by performing *MASH* Test 4-12, which involves a 10000S vehicle impacting the barrier at a target impact speed and impact angle of 56 mi/h and 15 degrees. The SSTR on the moment slab foundation performed acceptably for *MASH* Test 4-12 for longitudinal barriers.

This report provides details of the preliminary foundation designs, modeling and simulation of the various designs, and reinforcement details of the selected designs. Also included is a detailed documentation of the crash test and results, and an assessment of the performance of SSTR with moment slab foundation for *MASH* Test 4-12 evaluation criteria for longitudinal barriers.

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DEVELOPMENT OF STRUCTURALLY INDEPENDENT FOUNDATIONS FOR 36-INCH TALL SINGLE SLOPE TRAFFIC RAIL (SSTR) FOR *MASH* TL-4

by

Nauman M. Sheikh, P.E.
Associate Research Engineer
Texas A&M Transportation Institute

Roger P. Bligh, Ph. D., P.E.
Senior Research Engineer
Texas A&M Transportation Institute

James C. Kovar
Associate Transportation Researcher
Texas A&M Transportation Institute

Sofokli Cakalli
Graduate Student Worker
Texas A&M Transportation Institute

Wanda L. Menges
Research Specialist
Texas A&M Transportation Institute

Glenn E. Schroeder
Research Specialist
Texas A&M Transportation Institute

Darrell L. Kuhn, P.E.
Research Specialist
Texas A&M Transportation Institute

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Federal Highway Administration

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TEXAS A&M TRANSPORTATION INSTITUTE
College Station, Texas 77843-3135

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 note intended for construction, bidding, or permit purposes. The researcher in charge of the project was Nauman M. Sheikh, P.E. #105155.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

TTI PROVING GROUND DISCLAIMER

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

REPORT AUTHORIZATION

DocuSigned by: Bill Griffith 44A122CB271845B...	DocuSigned by: Darrell L. Kuhn D4CC23E85D5B4E7...
Bill L. Griffith, Research Specialist Deputy Quality Manager	Darrell L. Kuhn, P.E., Research Specialist Quality Manager
DocuSigned by: Matt Robinson EAA22BFA5BFD417...	DocuSigned by: Nauman M. Sheikh 662F8286A604403...
Matthew N. Robinson, Research Specialist Test Facility Manager & Technical Manager	Nauman M. Sheikh, P.E. Associate Research Engineer

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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

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

TxDOT desired to have structurally independent foundation design options for the 36-inch tall single slope traffic rail (SSTR). These foundations will allow placing the SSTR at locations where a bridge deck is not present. Ideally these foundations would result in minimal deflection of the barrier to eliminate the need to repair or reset the barrier after most crashes. The SSTR and the foundation designs needed to pass the American Association of State Highway and Transportation Officials (AASHTO), *Manual for Assessing Safety Hardware* (*MASH*), Test Level 4 (TL-4) criteria (*1*).

Foundation designs were requested for two common field installation scenarios; a foundation that has a shallow depth but can have a wider footprint, and a foundation that has a narrow footprint but can have greater depth.

1.2 OBJECTIVE/SCOPE OF RESEARCH

Researchers developed preliminary design concepts of the barrier and foundation systems. This was followed by developing finite element models of these designs and performing full-scale impact simulations with *MASH* Test 4-12 impact conditions. Results of the simulations were used to modify and improve the foundation designs, and to select final configurations for developing reinforcement details. A concrete beam foundation and a moment slab foundation were developed under this project. Of these, the moment slab foundation was evaluated further by performing *MASH* Test 4-12, which involves a 10000S vehicle (22,000-lb single-unit truck) impacting the barrier at a target impact speed and impact angle of 56 mi/h and 15°.

Chapter 2 of this report provides details of the preliminary foundation designs, modeling and simulation of the various designs, and reinforcement details of the selected designs. Chapters 3 through 7 of this report provide a detailed documentation of the crash test and results, and an assessment of the performance of SSTR with moment slab foundation for *MASH* Test 4-12 evaluation criteria for longitudinal barriers. Implementation recommendations emanating from this research project are presented in Chapter 8.

CHAPTER 2: SIMULATION AND DESIGN*

Researchers developed preliminary design concepts of the barrier foundations for TxDOT's review and approval. Once approved, researchers developed full-scale finite element (FE) models of these preliminary foundation designs and performed impact simulations using *MASH* TL-4 conditions. Results of the simulations were used to evaluate the performance of the barrier and foundation systems. Researchers then made modifications to the preliminary designs to make them more cost effective. These modified designs were also modeled and simulated.

This chapter presents the preliminary foundation design concepts, details of FE modeling and analysis of the various foundation systems, and reinforcement details of the foundation systems selected after the simulation analyses.

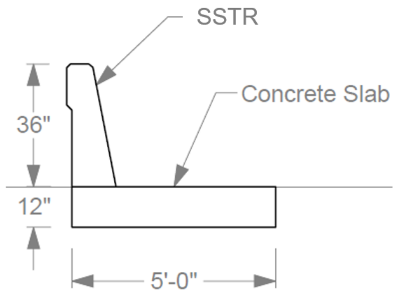
2.1 PRELIMINARY DESIGN CONCEPTS

Researchers developed shallow moment slab foundation and concrete beam foundation (Figure 2.1a and 2.1b) concepts for TxDOT's review. TxDOT also added a third foundation concept – a buried concrete beam and moment slab foundation (Figure 2.1c). TxDOT's SSTR barrier was used for all of the designs. This barrier has an 11-degree slope on the traffic-side face. The back of the barrier is vertical. The overall height of the barrier is 36 inches.

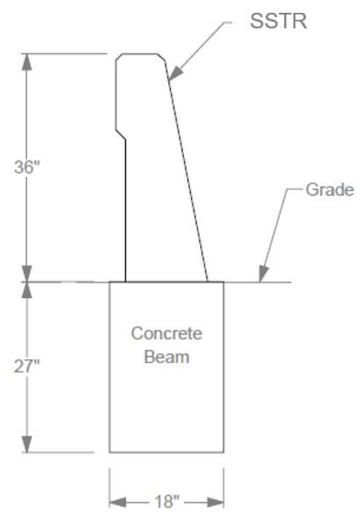
The moment slab foundation (Figure 2.1a) was comprised of a 12-inch deep × 5-ft wide concrete foundation. The concrete beam foundation was comprised of an 18-inch wide × 27-inch deep concrete beam (Figure 2.1b). The hybrid beam and slab foundation was comprised of a 20-inch deep × 27-inch wide concrete beam. This beam was attached to a 51-inch wide slab that extended toward the traffic side for a total foundation width of 78 inches (Figure 2.1c). The extended slab varied in thickness from 12 inches to 10 inches and was buried under soil as shown in Figure 2.1c. All the foundations were continuously attached to the base of the 36-inch tall SSTR.

TTI researchers developed full-scale FE models of these three preliminary foundation designs and performed vehicle impact simulations with *MASH* Test 4-12 impact conditions (22,000-lb single-unit truck impacting the barrier at 56 mi/h and 15°). Researchers then performed additional parametric simulations to optimize each of the three design concepts. In these simulations, TTI researchers reduced some of the design dimensions with the goal of achieving a more cost-effective design. Details of the simulation models and the results of the simulation analyses are presented next.

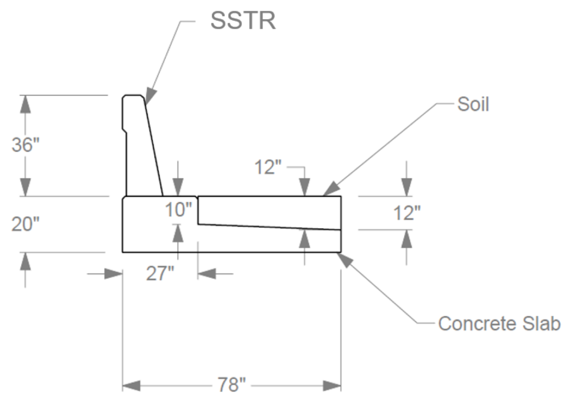
* The opinions/interpretations identified/expressed in this section of the report are outside the scope of TTI Proving Ground's A2LA Accreditation.



(a) Moment Slab



(b) Concrete Beam



(c) Concrete Beam and Slab

Figure 2.1. Preliminary Design Concepts of Foundation Systems.

2.2 FINITE ELEMENT SIMULATIONS

All simulations were performed using the finite element code LS-DYNA, which is a commercially available general-purpose FE analysis software (*2*).

The 36-inch tall SSTR segment and the foundations were modeled as one block using rigid material representation. The foundations were modeled inside a soil continuum that was modeled with deformable soil material properties. The boundaries of the soil continuum were constrained to maintain the shape; however, the soil was free to flow as a result of interaction with the foundation inside the external boundary constraints. The barrier and the foundation could move in the soil due to impact from the single-unit truck.

Deflection of the barrier and foundation systems can be influenced by the strength of the surrounding soil. Typical roadside devices are installed in strong, well compacted soil for testing. However, it was considered more suitable and conservative to model and test the foundation systems in native soil conditions at the TTI Proving Ground testing facility. Native soil at the

TTI Proving Ground is a medium strength clay with typical modulus of elasticity of 900 psi. This was the strength of the soil used in the FE models. The soil was modeled using the jointed rock constitutive material model in LS-DYNA (Material 198) (*2*). Since LS-DYNA being is a dynamic analysis code that makes use of explicit time-integration methodology, loads from the vehicle impact were transferred to the foundation and applied to the soil continuum in a dynamic manner (*3*).

All impact simulations were performed under *MASH* Test 4-12 impact conditions, which involve a 22,000-lb single-unit truck impacting the barrier at an impact speed and angle of 56 mi/h and 15°. The vehicle model used in the simulations was originally developed by the National Crash Analysis Center, and was further improved by TTI over the course of use under various projects.

The impact performance of a rigid single slope barrier is known to be acceptable for *MASH* Test 4-10 and 4-11 impact conditions (*4*, *5*). A barrier system designed for TL-4 impact severity will behave essentially rigidly for the smaller, lighter passenger car (Test 4-10) and pickup truck (Test 4-11). Therefore, simulations were only performed with the single-unit truck.

The length of the barrier and foundation segments ranged from 20 ft to 50 ft. These segments were placed adjacent to each other without any connection between them. In all simulation models, the overall length of the barrier and foundation system was at least 120 ft.

The primary objective in the design of the barrier foundations was to have minimal movement of the barrier during impact to minimize maintenance and repair. Images of the models for the various foundation designs and key results of the impact analyses are presented next.

2.2.1 Concrete Beam Foundation Design

Researchers simulated the preliminary design of the concrete beam foundation presented in Figure 2.1b. Additional simulations were then performed with various design modifications to arrive at the final design. Simulation of this final design is presented next in greater detail. Summary of other key design variations that were simulated but not selected as the final design are presented at the end of this section.

The design selected for the concrete beam foundation was TxDOT’s standard Traffic Rail Foundation (TRF), which is 16 inches wide and 33 inches deep. The SSTR and TRF segments were 30 ft long. The foundation was modeled in front of a 1V:2H slope with a 1-ft offset from the back of the barrier to the break point of the slope (Figure 2.2). TTI researchers developed a model of the TRF and performed the impact simulation with *MASH* Test 4-12 impact conditions. Figure 2.3 shows the results of this simulation. The maximum dynamic deflection at the top of the barrier was 1.2 inches, and the maximum permanent deflection was 0.1 inch. The working width of the barrier and foundation system was 120.3 inches at a height of 99.9 inches.

For the concrete beam foundation concept, the deflection of the 30-ft segments of TxDOT TRF with a 1V:2H slope at a 1-ft offset from the back of the 36-inch tall SSTR was considered acceptable. This design was selected for final detailing of reinforcement.

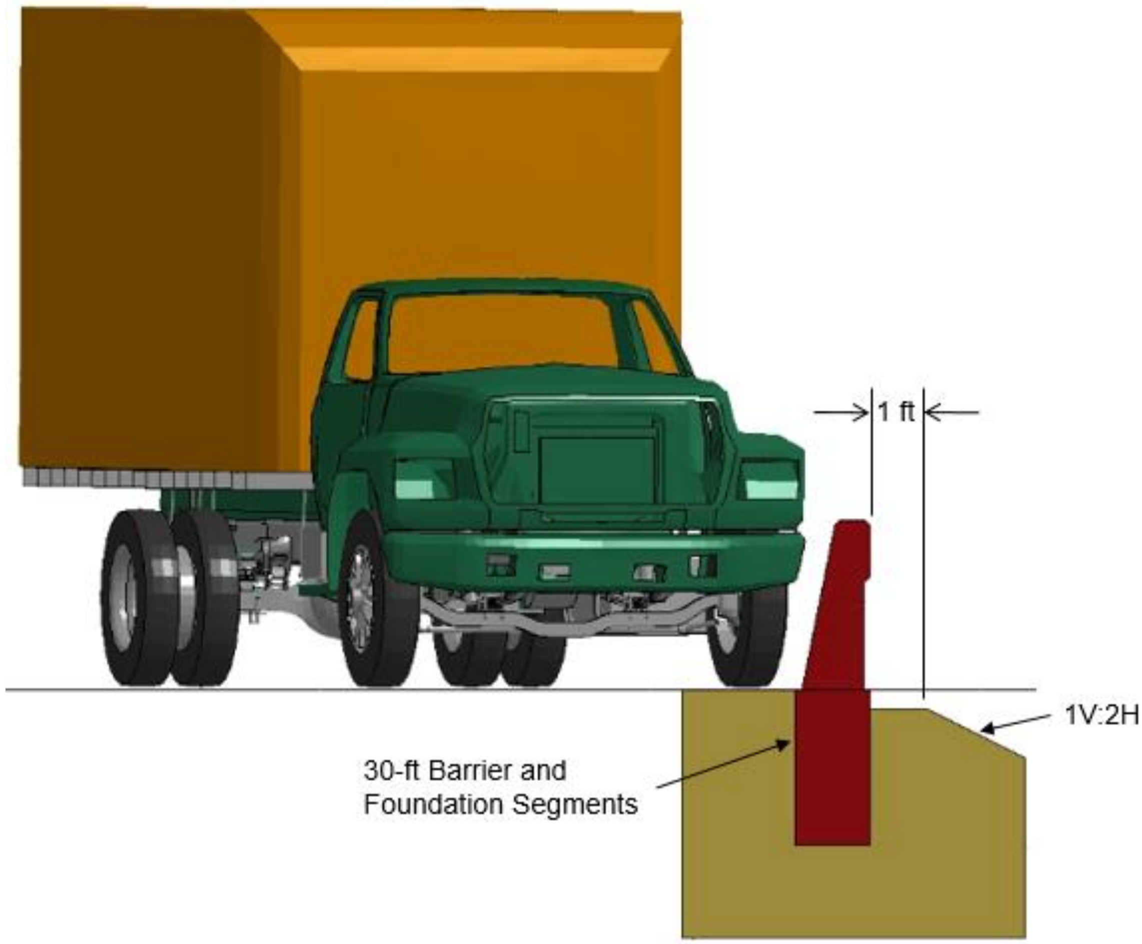


Figure 2.2. Model of TRF Foundation Selected for Reinforcement Design.

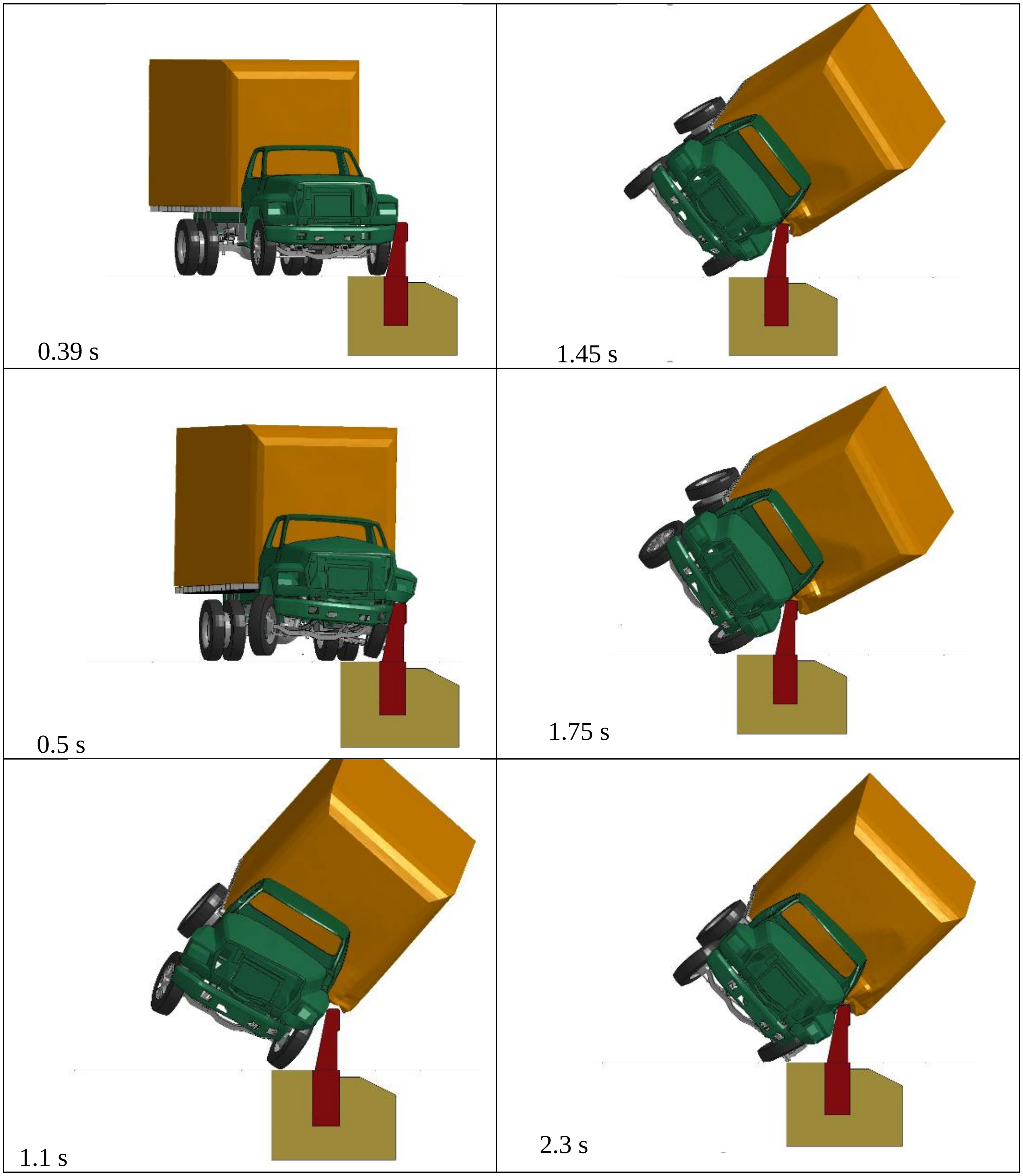
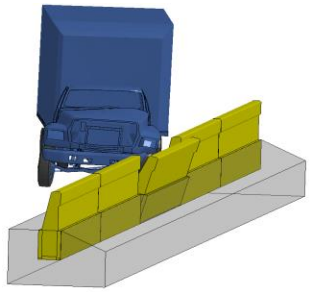
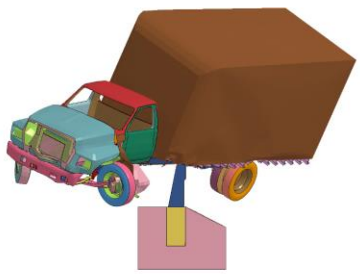
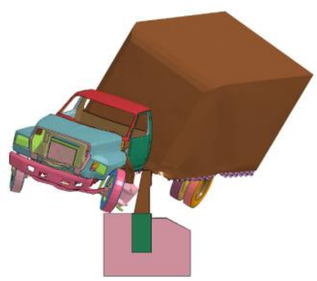
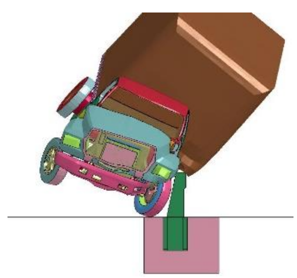
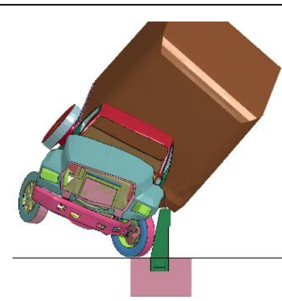


Figure 2.3. Impact Simulation for Preliminary Concrete Beam Foundation Design.

Researchers evaluated several additional designs of the concrete beam foundation that were not selected. Details of these designs, key simulation results, and reasons for not selecting them are summarized in Table 2.1.

Table 2.1. Summarized Results of Concrete Beam Foundation Designs Not Selected

Design Details	Simulation Results and Commentary	
• 19-inch × 33-inch TRF foundation with SSTR • 15-ft segment length • 1V:2H slope behind the barrier with no offset		• Excessive barrier deflection • Barrier was unable to contain or redirect the vehicle
• 19-inch × 33-inch TRF foundation with SSTR • 20-ft segment length • 1V:2H slope behind the barrier with no offset		• Barrier was unable to contain or redirect the vehicle
• 19-inch × 33-inch TRF foundation with SSTR • 20-ft segment length • 1V:2H slope behind the barrier with 1-ft offset		• Barrier was unable to contain or redirect the vehicle
• 27-inch × 18-inch concrete beam foundation with SSTR • 50-ft segment length • No slope behind the barrier		• 0.3 inch dynamic and 0 inch permanent deflection • While the design performed acceptably, a shorter segment length was desired
• 10-inch × 13-inch concrete beam foundation with SSTR • 50-ft segment length • No slope behind the barrier		• 0.7 inch dynamic and 0.3 inch permanent deflection • While the design performed acceptably, a shorter segment length was desired

Once the basic geometric design of the foundation was finalized using the FE analyses, reinforcement details of the foundation and the barrier segment were developed by TxDOT and are shown in Figure 2.4. The reinforcement of the barrier and the foundation were designed such that the foundation and the barrier can be constructed in two separate concrete pours. The barrier and the foundation have a segment length of 30 ft.

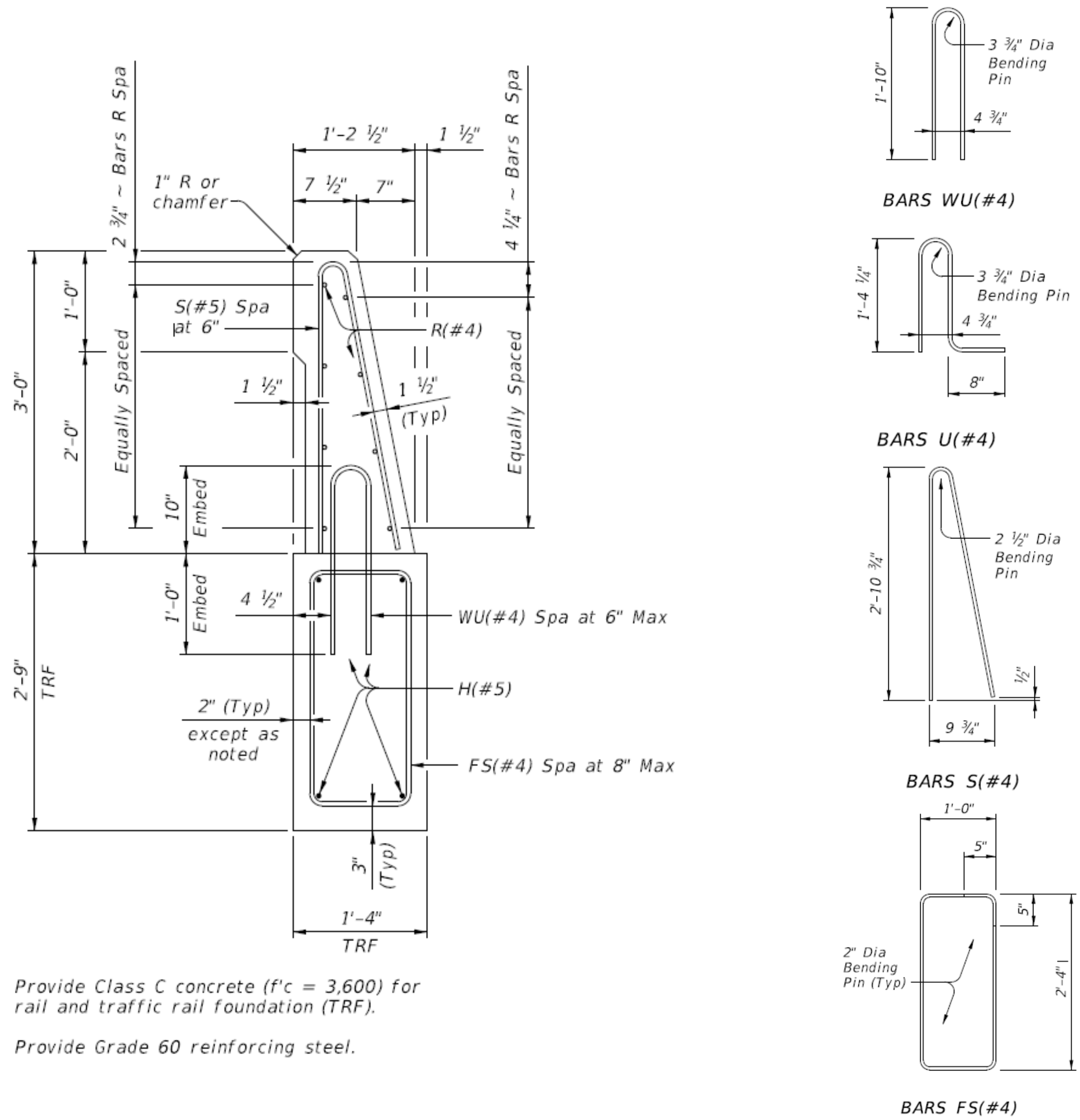


Figure 2.4. Reinforcement Design of SSTR with Concrete Beam Foundation.

2.2.3 Moment Slab Foundation Design

Similar to the concrete beam foundation, TTI researchers evaluated various design iterations of the moment slab foundation. Simulation details of the final design are presented next, followed by summarized results of the other design variations that were not selected.

As shown in Figure 2.1a, this foundation design was comprised of a 12-inch deep and 5-ft wide moment slab that was attached to the base of an SSTR, and ran along the entire length of the barrier segment. The length of the foundation and the barrier segment in the final design was 20 ft. The moment slab was embedded in soil and there was no slope adjacent to the barrier.

Figure 2.5 shows the finite element model of this system and the results of *MASH* Test 4-12 impact simulation with the single-unit truck model. The vehicle was successfully contained and redirected. The maximum dynamic deflection at the top of the barrier was 1.4 inches, and the maximum permanent deflection was 0.1 inch. The working width of the barrier and the foundation system was 109.9 inches at a height of 120.1 inches. These deflections were considered acceptable and the design was selected for final detailing of reinforcement. This moment slab foundation design was also selected for crash testing due to slightly larger deflection compared to the final concrete beam foundation design. Details of the full-scale crash testing are presented in the following chapters.

Researchers evaluated several additional designs of the moment slab foundation concept that were not selected. Details of these designs, key simulation results, and reasons for not selecting them are summarized in Table 2.2.

Once the basic geometric design of the foundation was finalized using the FE analyses, reinforcement details of the foundation and the barrier segments were developed. Since this design was selected for crash testing, the details of the reinforcement are presented in the following chapters along with the details of the crash test installation and the test results.

2.2.3 Concrete Beam and Slab Foundation Design

TTI researchers developed a model of the hybrid concrete beam and slab foundation design shown in Figure 2.1c and performed an impact simulation with *MASH* Test 4-12 impact conditions. TTI researchers also performed a simulation with a reduced foundation design of this concept; in which, the depth of the concrete beam was reduced to 12 inches, and the overall width of the foundation was reduced to 31.3 inches. Both designs successfully contained and redirected the impacting single-unit truck. Figure 2.6 shows the vehicle in both simulations at the point of maximum roll. The maximum dynamic and permanent deflection of the design shown in Figure 2.1c was 0.0 inch. The maximum dynamic and permanent deflection of the reduced hybrid foundation design was 0.4 inch and 0.0 inch, respectively.

While both the original and the reduced designs of this foundation were successful, the buried concrete beam and slab foundation was not preferred over the simpler at grade moment slab foundation. This was due to the relatively simple construction, installation, and maintenance of the latter. Because of this, reinforcement details of the concrete beam and slab foundation were not developed.

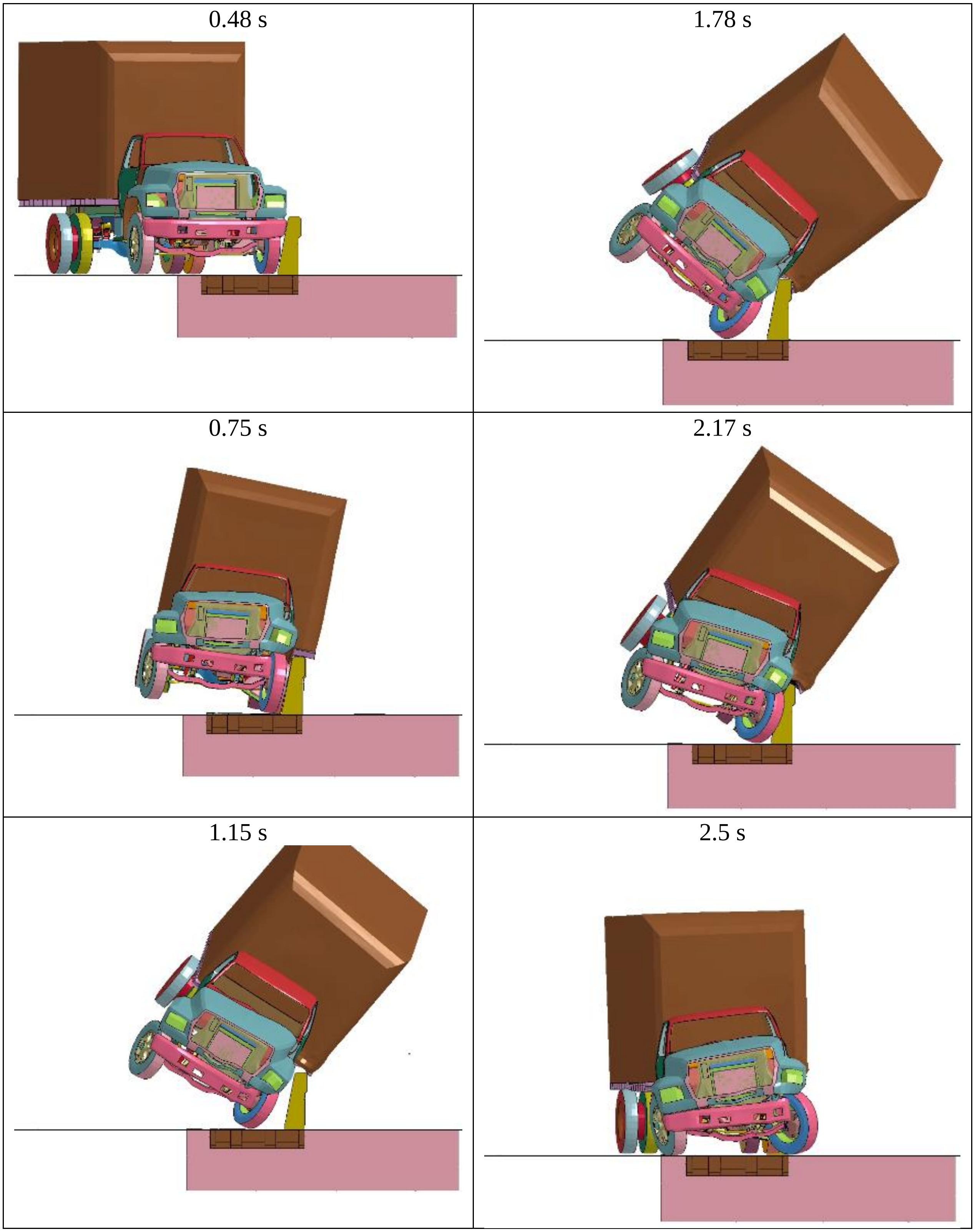
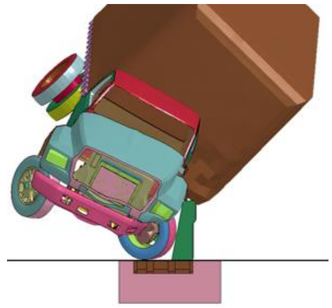
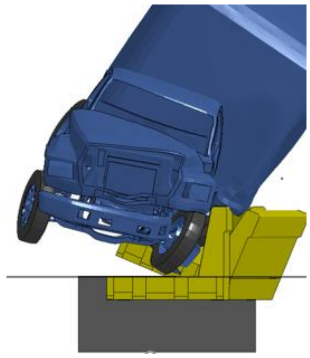
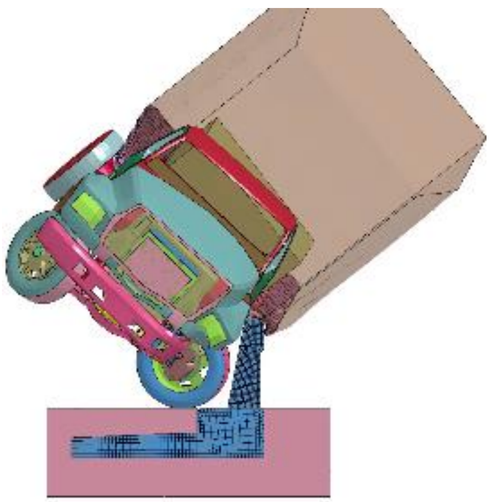


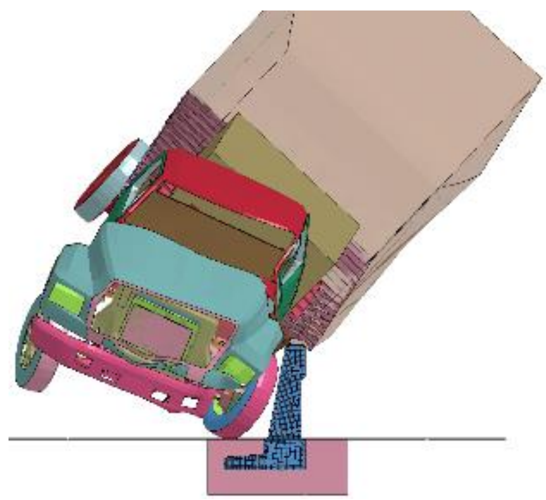
Figure 2.5. 5-ft Wide Moment Slab Foundation Simulation Model.

Table 2.2. Summarized Results of Moment Slab Foundation Designs Not Selected

Design Details	**Simulation Results and Commentary**	
• 8-inch × 36-inch moment slab with SSTR • 50-ft segment length • No slope behind the barrier		• 0.7 inch dynamic and 0.3 inch permanent deflection • While the design performed acceptably, a shorter segment length was desired
• 12-inch × 60-inch moment slab with SSTR • 15-ft segment length • No soil restraint behind barrier		• Barrier segments deflected excessively. Vehicle was not contained or redirected



Original Design



Reduced Design

Figure 2.6. Simulation of Concrete Beam and Slab Foundation System.

CHAPTER 3: SYSTEM DETAILS OF SSTR WITH MOMENT SLAB

3.1 TEST ARTICLE AND INSTALLATION DETAILS

The test installation consisted of five independent segments of reinforced concrete SSTR with a moment slab foundation. The moment slab was 12 inches thick and 60 inches wide. The SSTR was 36 inches tall, 13 inches wide at the bottom, and sloping on the traffic side to 7½ inches wide at the top. A 24-inch tall × 1½-inch deep relief was cast into the field side of the barrier. The SSTR and moment slab segments were attached with anchor bars spaced along the length of the SSTR segments. The segments were each 20 ft long, and were placed with a gap of approximately ¼ inch between them, for a total installation length of approximately 100 ft-1 inch. The moment slabs were embedded in native soil, with the top of the slab at grade level.

Figure 3.1 presents overall information on the SSTR on moment slab foundation, and Figure 3.2 provides photographs of the installation. Appendix A provides further details of the barrier.

3.2 DESIGN MODIFICATIONS DURING TESTS

No modifications were made to the installation during the testing phase.

3.3 MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to install/construct the SSTR on the moment slab foundation.

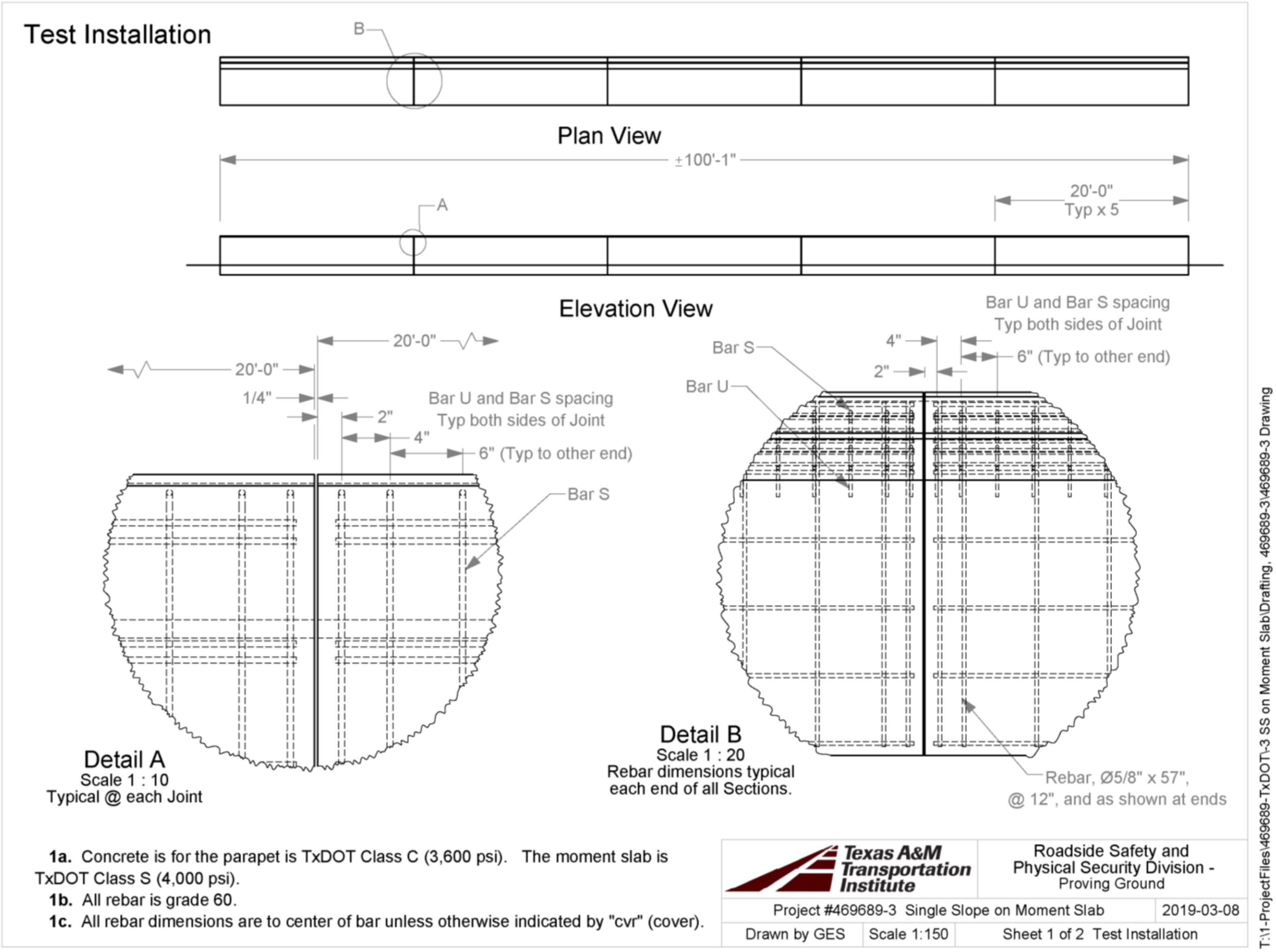


Figure 3.1. Overall Details of SSTR with Moment Slab Foundation.

Figure 3.2. SSTR with Moment Slab Foundation Prior to Testing.

CHAPTER 4:
TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1 CRASH TEST MATRIX

Table 4.1 shows the test conditions and evaluation criteria for *MASH* TL-4 for longitudinal barriers. *MASH* Test 4-12 involves a 10000S vehicle weighing 22,000 lb ±660 lb and impacting the critical impact point (CIP) of the barrier at an impact speed of 56 mi/h ±2.5 mi/h and an angle of 15° ±1.5°. The target CIP for the SSTR with moment slab foundation, shown in Figure 4.1, was determined using the information provided in *MASH* Section 2.2.1, Section 2.3.2, and Figure 2-1.

MASH Tests 4-10 and 4-11 were not performed. The impact performance of a rigid single slope barrier is known to be acceptable for *MASH* Test 4-10 and 4-11 impact conditions (*4*, *5*). A barrier system designed to have minor deflection for Test 4-12 is expected to behave essentially rigidly for the smaller, lighter passenger car (Test 4-10) and pickup truck (Test 4-11). Therefore, test was only performed with the heavier single unit truck (Test 4-12).

Table 4.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-4 Longitudinal Barriers.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Longitudinal Barrier	4-10	1100C	62 mi/h	25	A, D, F, H, I
	4-11	2270P	62 mi/h	25	A, D, F, H, I
	4-12	10000S	56 mi/h	15	A, D, G

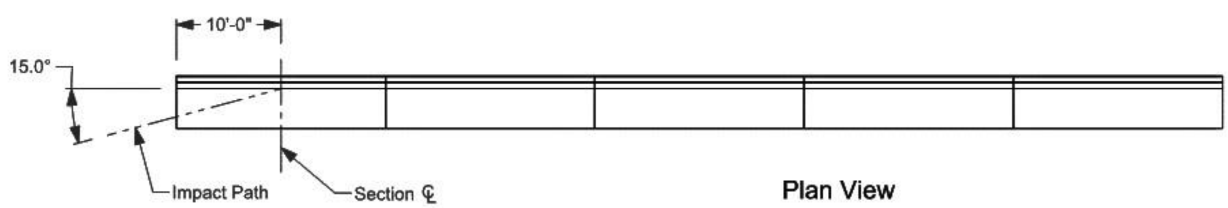


Figure 4.1. Target CIP for *MASH* Test 4-12 on SSTR with Moment Slab Foundation.

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

4.2 EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2 and 5-1 of *MASH* were used to evaluate the crash test reported herein. The test conditions and evaluation criteria required for

MASH Test 4-12 are listed in Table 4.1, and the substance of the evaluation criteria in Table 4.2. An evaluation of the crash test results is presented in detail under the section Assessment of Test Results.

Table 4.2. Evaluation Criteria Required for *MASH* Test 4-12 on Longitudinal Barriers.

Evaluation Factors		Evaluation Criteria
Structural Adequacy	*A.*	*Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*
Occupant Risk	*D.*	*Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone.* *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.*
	G.	*It is preferable, although not essential, that the vehicle remain upright during and after the collision.*

CHAPTER 5:
TEST CONDITIONS

5.1 TEST FACILITY

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

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

5.2 VEHICLE TOW AND GUIDANCE SYSTEM

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

5.3 DATA ACQUISITION SYSTEMS

5.3.1 Vehicle Instrumentation and Data Processing

The test vehicle was instrumented with a self-contained, on-board data acquisition system. The signal conditioning and acquisition system is a 16-channel, Tiny Data Acquisition System (TDAS) Pro produced by Diversified Technical Systems, Inc. The accelerometers, which measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra-small, solid state units designed for crash test service. The TDAS Pro hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 16 channels can provide 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 a SAE Class 180-Hz low-pass digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

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

5.3.2 Anthropomorphic Dummy Instrumentation

MASH does not recommend or require use of a dummy in the 10000S vehicle. A dummy was not used in the test.

5.3.3 Photographic Instrumentation and Data Processing

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

- One overhead with a field of view perpendicular to the ground and directly over the impact point.
- One placed upstream of the impact point on the traffic side of the bridge rail.
- 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 barrier. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.

CHAPTER 6: *MASH* TEST 4-12 (CRASH TEST NO. 469689-3-3) OF SSTR WITH MOMENT SLAB FOUNDATION

6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 4-12 involves a 10000S vehicle weighing 22,000 lb ±660 lb impacting the CIP of the barrier at an impact speed of 56 mi/h ±2.5 mi/h and an angle of 15° ±1.5°. The CIP for *MASH* Test 4-12 of the SSTR with moment slab foundation was 10 ft ±1 ft downstream of the upstream end of the barrier.

The 2009 International 4300 single-unit box-van truck used in the test weighed 22,140 lb, and the actual impact speed and angle were 57.5 mi/h and 14.7°. The actual impact point was 11.1 ft downstream of the end of the barrier. While the actual impact point was 0.1 ft outside the target impact point tolerance, the results of the test are considered valid since the objective was to evaluate the deflection of the 20-ft barrier and moment slab segment due to the load resulting from a 10000S vehicle impact. For this barrier system, a small deviation in impact point does not reduce or alter the impact load applied to the barrier. Minimum target impact severity (IS) for this test was 142 kip-ft, and actual IS was 158 kip-ft.

6.2 WEATHER CONDITIONS

The test was performed on the morning of July 3, 2019. Weather conditions at the time of testing were as follows: wind speed: 6 mi/h; wind direction: 182° (vehicle was traveling at magnetic heading of 345°); temperature: 86°F; relative humidity: 75 percent.

6.3 TEST VEHICLE

Figures 6.1 and 6.2 show the 2009 International 4300 single-unit box-van truck used for the crash test. The vehicle's test inertia weight was 22,140 lb, and its gross static weight was 22,140 lb. The height to the lower edge of the vehicle bumper was 20.5 inches, and height to the upper edge of the bumper was 35.5 inches. The height to the vehicle's ballasted center of mass was 61.25 inches. Table C.1 in Appendix C.1 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.

6.4 TEST DESCRIPTION

The test vehicle was traveling at an impact speed of 57.5 mi/h when it contacted the barrier 11.1 ft downstream of the end of the barrier at an impact angle of 14.7°. Table 6.1 lists events that occurred during Test No. 469689-3-3. Figures C.1 and C.2 in Appendix C.2 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 65.6 ft downstream from loss of contact for heavy vehicles). The test vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle came to rest 240 ft downstream of the impact and 34 ft toward field side. Brakes were applied 4.0 s after impact.


Figure 6.1. Barrier/Test Vehicle Geometrics for Test No. 469689-3-3.

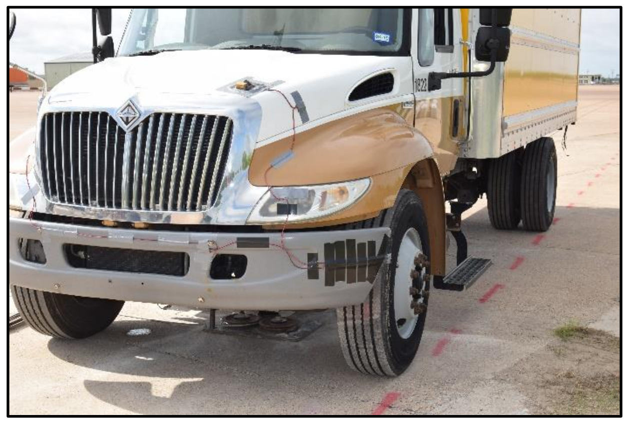



Figure 6.2. Test Vehicle before Test No. 469689-3-3.

Table 6.1. Events during Test No. 469689-3-3.

TIME (s)	EVENTS
0.000	Vehicle contacts barrier (tape strip did not trigger)
0.018	Left front tire lifts off of the pavement and begins to ride up barrier
0.026	Vehicle begins to redirect
0.154	Right front tire begins to lift off of the pavement
0.274	Rear left corner of truck bed impacts top of barrier
0.274	Vehicle is parallel with barrier
0.458	Left front tire makes contact with pavement

6.5 DAMAGE TO TEST INSTALLATION

Figure 6.3 shows the damage to the barrier. There were several gouges in the concrete surface up to 1½ inches deep. There was minimal soil disturbance around the moment slab of the impacted barrier segment. Working width was 66.6 inches (distance measured from the pre-test traffic edge of barrier to maximum extension of the top of the truck into the field side), and height of working width was greater than 88 inches. Exact height of the working width could not be determined as it exceeded the camera's vertical field of view. Slight dynamic deflection of the barrier was perceptible in one of the high-speed camera views, but was too small to be measurable in the video analysis. No permanent deformation was observed.

6.6 DAMAGE TO TEST VEHICLE

Figure 6.4 shows the damage sustained by the vehicle. The front bumper, left front tire and rim, left front springs and U-bolts, left door, left battery box and side steps, air tanks, left front corner of the box, left lower center of the box, and left outer tire and rim were damaged. Maximum exterior crush to the vehicle was 10.0 inches in the side plane at the left front corner at bumper height. Maximum occupant compartment deformation was 6.0 inches in the left front floor pan. Figure 6.5 shows the interior of the vehicle.

6.7 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 6.2. Figure 6.6 summarizes these data and other pertinent information from the test. Figure C.3 in Appendix C.3 shows the vehicle angular displacements, and Figures C.4 through C.9 in Appendix C.4 show acceleration versus time traces.

Figure 6.3. Barrier after Test No. 469689-3-3.

Figure 6.4. Test Vehicle after Test No. 469689-3-3.

Figure 6.5. Interior of Test Vehicle after Test No. 469689-3-3.

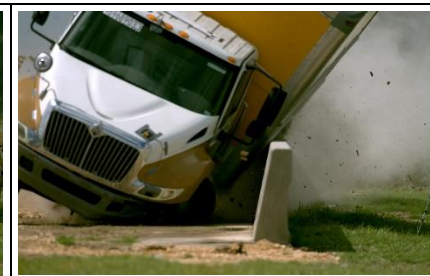
Table 6.2. Occupant Risk Factors for Test No. 469689-3-3.

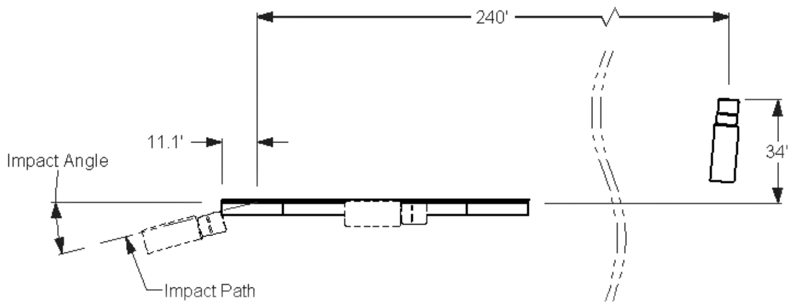
Occupant Risk Factor	Value	Time
Impact Velocity		
Longitudinal	**6.2 ft/s**	at 0.2196 s on left side of interior
Lateral	**11.8 ft/s**	
Ridedown Accelerations		
Longitudinal	**2.1 g**	0.2885–0.2985 s
Lateral	**4.8 g**	0.2552–0.2652 s
THIV	**4.2 m/s**	at 0.2124 s on left side of interior
PHD	**4.8 g**	0.2552–0.2652 s
ASI	**0.40**	0.0894–0.1394 s
Maximum 50-ms Moving Average		
Longitudinal	**–1.5 g**	0.0324–0.0824 s
Lateral	**3.4 g**	0.0619–0.1119 s
Vertical	**–3.9 g**	0.3272–0.3772 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**45°**	0.9092 s
Pitch	**9°**	0.8416 s
Yaw	**44°**	1.6618 s

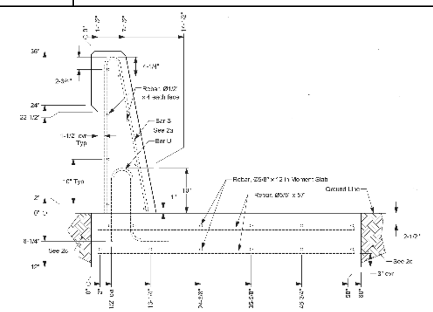

0.000 s


0.200 s


0.400 s


0.700 s





General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 4-12
TTI Test No.	469689-3-3
Test Date	2019-07-03

Test Article

Type	Longitudinal Barrier – Bridge Rail
Name	SSTR with Moment Slab
Installation Length	100 ft 1 inch
Material or Key Elements	Five 20 ft long segments of 36-inch tall SSTR on 12-inch x 60-inch moment slab

Soil Type and Condition ..... Native Soil

Test Vehicle

Type/Designation	10000S
Make and Model	2009 International 4300 truck
Curb	13,660 lb
Test Inertial	22,140 lb
Dummy	No dummy
Gross Static	22,140 lb

Impact Conditions

Speed	57.5 mi/h
Angle	14.7°
Location/Orientation	11.1 ft downstream of barrier end

Impact Severity ..... 158 kip-ft

Exit Conditions

Speed	Not obtainable
Angle	Not obtainable

Occupant Risk Values

Longitudinal OIV	6.2 ft/s
Lateral OIV	11.8 ft/s
Longitudinal Ridedown	2.1 g
Lateral Ridedown	4.8 g
THIV	15.0 km/h
PHD	4.8 g
ASI	0.40
Max. 0.050-s Average	
Longitudinal	-1.5 g
Lateral	3.4 g
Vertical	-3.9 g

Post-Impact Trajectory

Stopping Distance	240 ft downstream 34 ft twd field side

Vehicle Stability

Maximum Yaw Angle	44°
Maximum Pitch Angle	9°
Maximum Roll Angle	45°
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	Unmeasurably small
Permanent	None
Working Width	66.6 inches
Height of Working Width	>88 inches

Vehicle Damage

VDS	NA
CDC	11LFQ4
Max. Exterior Deformation	10.0 inches
OCDI	NA
Max. Occupant Compartment Deformation	6.0 inches

Figure 6.6. Summary of Results for *MASH* Test 4-12 on SSTR with Moment Slab Foundation.

CHAPTER 7:
CRASH TEST SUMMARY AND CONCLUSIONS

7.1 SUMMARY OF RESULTS

An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 4-12 is provided in Table 7.1.

7.2 CONCLUSIONS

The SSTR with moment slab foundation performed acceptably for *MASH* Test 4-12 for longitudinal barriers.

Table 7.1. Performance Evaluation Summary for *MASH* Test 4-12 on SSTR with Moment Slab Foundation.

Test Agency: Texas A&M Transportation Institute | Test No.: 469689-3-3 | Test Date: 2019-07-03

***MASH* Test 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 SSTR with moment slab foundation contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the installation. No dynamic deflection or permanent deformation of the barrier was observed.	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 were present to penetrate or show potential for penetrating the occupant department, or 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 left front floor pan.	
G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	The 10000S vehicle remained upright during and after the collision period.	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 65.6 ft for the 10000S vehicle), and should be documented.	The 10000S vehicle exited within the exit box criteria.	Documentation only

CHAPTER 8: IMPLEMENTATION[†]

Based on the results of the testing and evaluation reported herein, the 36-inch tall SSTR with moment slab foundation and a segment length of 20 ft is considered suitable for implementation as a *MASH* TL-4 barrier system. Only *MASH* Test 4-12 with single unit truck was performed under this project. *MASH* Tests 4-10 and 4-11 were not performed as the impact performance of a rigid single slope barrier is known to be acceptable for these test conditions (*4*, *5*). Furthermore, a barrier system designed to have minor deflection for Test 4-12 is expected to behave essentially rigidly for the smaller, lighter passenger car (Test 4-10) and pickup truck (Test 4-11).

Simulation results of the moment slab foundation, while slightly more conservative than the test results, showed a good correlation between simulation and testing. Since similar barrier and soil models were used in the simulation of the SSTR with TxDOT's TRF foundation, it can be concluded that the 36-inch tall SSTR with 16 inches wide and 33 inches deep TRF foundation (as shown in Figures 2.2 and 2.4) is also suitable for implementation as a *MASH* TL-4 barrier system.

Statewide implementation of the SSTR and its foundation designs can be achieved by TxDOT's Bridge Division through the development and issuance of new standard detail sheets. The barrier details provided in Appendix A and in Figures 2.2 and 2.4 can be used for this purpose.

[†] 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.* Second Edition, 2016, American Association of State Highway and Transportation Officials: Washington, D.C.

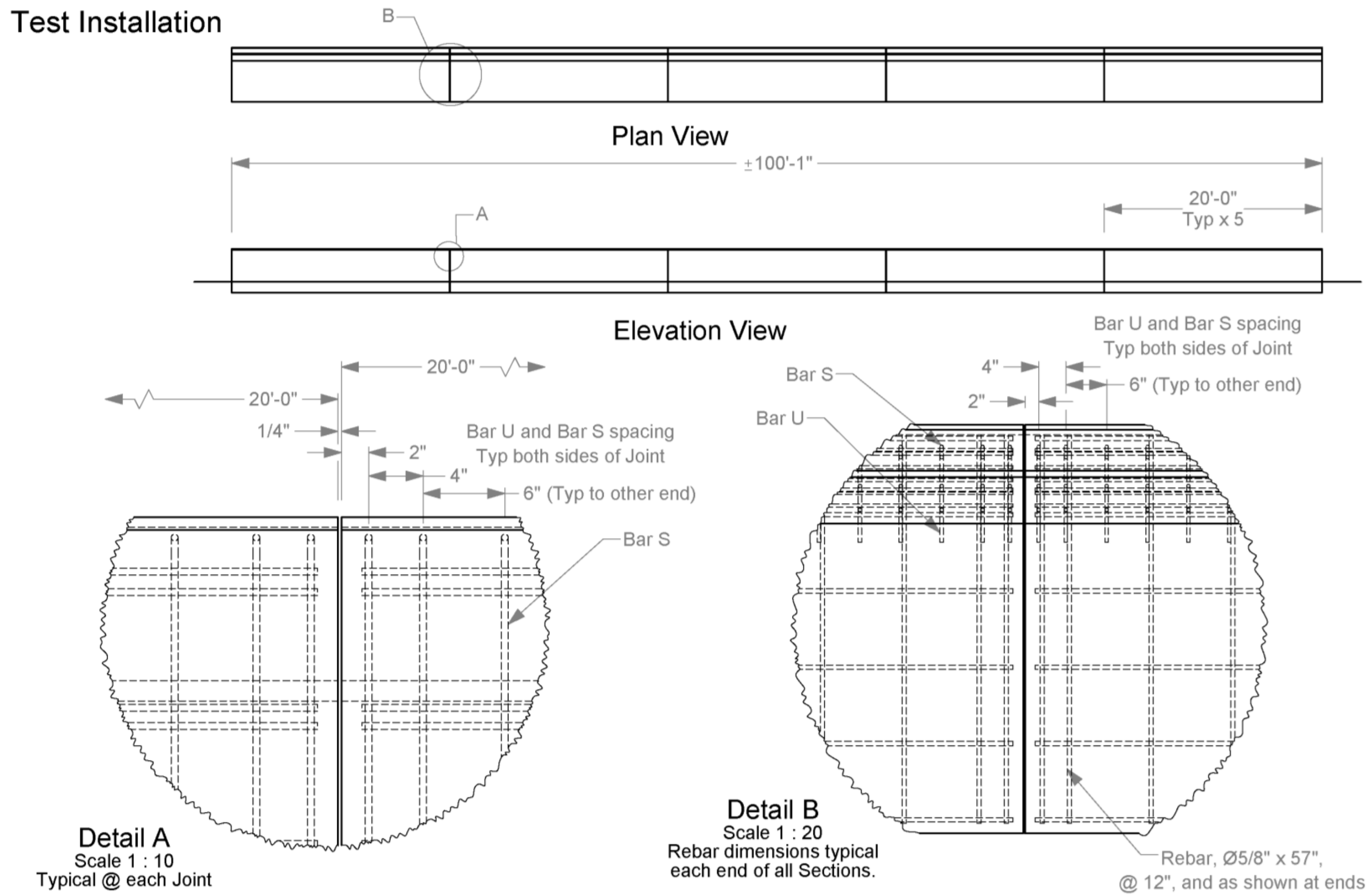
2. Livermore Software Technology Corporation, *LS-DYNA Keyword User's Manual*, 2016, Livermore, California.

3. Livermore Software Technology Corporation, *LS-DYNA Theory Manual*, 2019, Livermore, California.

4. W.F. Williams, R.P. Bligh, and W.L. Menges, *Mash Test 3-11 of the TxDOT Single Slope Bridge Rail (Type SSTR) on Pan-Formed Bridge Deck.* Report 9-1002-3. Texas A&M Transportation Institute, College Station, TX, 2011.

5. D. Whitesel, J. Jewell, and R. Meline, *Compliance Crash Testing of the Type 60 Median Barrier, Test 140MASH3C16-04.* Research Report FHWA/CA17-2654, Roadside Safety Research Group, California Department of Transportation, Sacramento, CA, May 2018.

APPENDIX A. DETAILS OF THE SSTR WITH MOMENT SLAB



1a. Concrete is for the parapet is TxDOT Class C (3,600 psi). The moment slab is TxDOT Class S (4,000 psi).

1b. All rebar is grade 60.

1c. 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 #469689-3 Single Slope on Moment Slab		2019-03-08
Drawn by GES	Scale 1:150	Sheet 1 of 2 Test Installation

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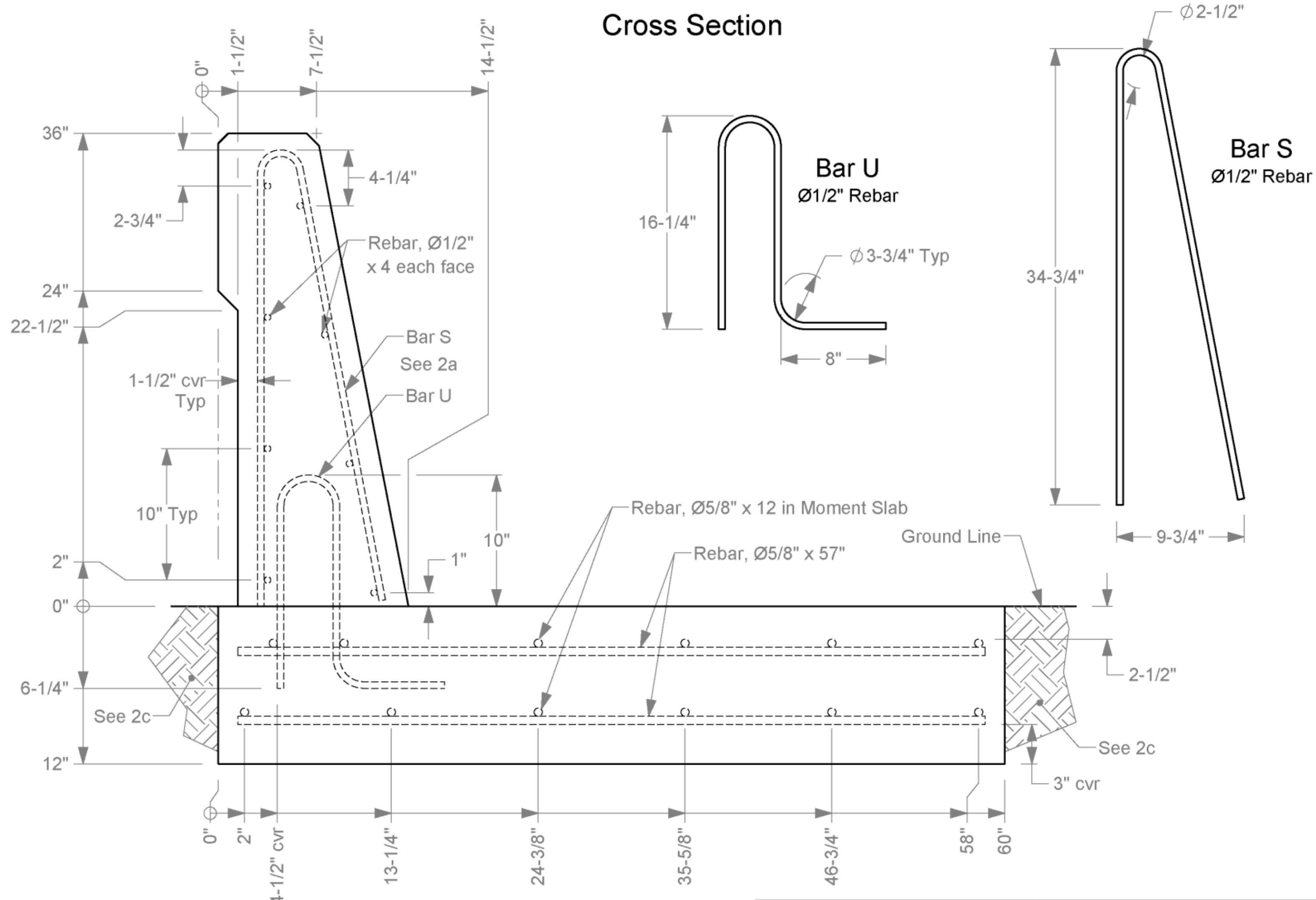

2a. Bar S and Bar U at 2" from each end, then one 4" space, then @ 6" to other end. See Detail Views on previous sheet.

2b. Chamfer top edges of parapet, 3/4" each way.

2c. Backfill with native soil and compact to 95% of standard proctor density.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project #469689-3 Single Slope on Moment Slab			2019-03-08
Drawn by GES	Scale 1:10	Sheet 2 of 2 Cross Section	

T:\1-ProjectFiles\469689-TxDOT\-3 SS on Moment Slab\Drafting, 469689-3\469689-3 Drawing

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.:3085480 SECTION: REBAR 16MM (#5) 20'0" 420/60 GRADE: ASTM A615-18e1 Gr 420/60 ROLL DATE: 01/07/2019 MELT DATE: 01/02/2019 Cert. No.: 82596018 / 085480A371	SOLD TO	Core Lumber & Rebar LLC 11202 Cordoba Dr Houston TX US 77038-3436 2818473656	SHIP TO	CPU Seguin 1 Steel Mill Dr Seguin TX US 78155-7510 9999999999	Delivery#: 82596018 BOL#: 1717858 CUST PO#: 8047 CUST P/N: DLVRY LBS / HEAT: 35040.000 LB DLVRY PCS / HEAT: 1680 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.40%				
Mn	0.96%				
P	0.012%				
S	0.049%				
Si	0.18%				
Cu	0.32%				
Cr	0.10%				
Ni	0.26%				
Mo	0.091%				
V	0.001%				
Cb	0.003%				
Sn	0.012%				
Al	0.002%				
Yield Strength test 1	69.0ksi				
Tensile Strength test 1	108.5ksi				
Elongation test 1	12%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	2.188IN				
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 :

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Page 1 OF 1

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CERTIFIED MILL TEST REPORT

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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.:3085996 SECTION: REBAR 10MM (#3) 20'0" 300/40 GRADE: ASTM A615-18e1 Grade 300/40 ROLL DATE: 01/28/2019 MELT DATE: 01/23/2019 Cert. No.: 82627512 / 085996A357	SOLD TO	Core Lumber & Rebar LLC 11202 Cordoba Dr Houston TX US 77038-3436 2818473656	SHIP TO	CPU Seguin 1 Steel Mill Dr Seguin TX US 78155-7510 9999999999	Delivery#: 82627512 BOL#: 1731213 CUST PO#: 8175 CUST P/N: DLVRY LBS / HEAT: 48438.000 LB DLVRY PCS / HEAT: 6440 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.25%	Bend Test Diameter	1.313IN		
Mn	0.95%				
P	0.011%				
S	0.027%				
Si	0.21%				
Cu	0.28%				
Cr	0.15%				
Ni	0.13%				
Mo	0.066%				
V	0.000%				
Cb	0.018%				
Sn	0.012%				
Al	0.002%				
Carbon Eq A706	0.44%				
Yield Strength test 1	63.9ksi				
Tensile Strength test 1	97.1ksi				
Elongation test 1	16%				
Elongation Gage Lgth test 1	8IN				
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 :

02/25/2019 17:36:54

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: 469689-3 **Casting Date:** 2019-05-20 **Mix Design (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	Tucker	10989	
T2	Tucker	10992	

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
T1	2019-05-28	8 days	101000	3570	
T1	2019-7-2	43 DAYS	127,000	4490	
↓			115,000	4070	4210
↓			115,000	4070	
T2			139,000	4915	
↓			137,000	4845	4965
↓	↓	↓	145,000	5130	

[initials] 2019-05-28

TUCKER Concrete
8930 LACY WELL RD, 77845
979 777 6749

Job # TUCKER CONSTRUCTION
TTI

TICKET # 10989
START DATE: 05/20/2019 TIME: 15:32:22
STOP DATE: 05/20/2019 TIME: 15:47:59

MIX DESIGN 40T1RNMO

TOTAL YARDS 4.20

MATERIAL	RATE SETTING	TOTAL
CAPTYPE1	__ 444.1LBPM__	2368.8LBS
LRMSAND	__ 5.6 GATE_	5993.4LBS
LRMRG	__ 6.2 GATE_	7156.8LBS
WATER	__ 24.0GPM __	128.1GAL
SIKA686	__ 22.0OZPM__	117.6OZ

WATER / CEMENT RATIO__ 0.45
ASTM C-618

NAME________________________________
NOTES:

TUCKER Concrete
8930 LACY WELL RD, 77845
979 777 6749

Job # TUCKER CONSTRUCTION
TTI

TICKET # 10992
START DATE: 05/20/2019 TIME: 17:20:35
STOP DATE: 05/20/2019 TIME: 17:25:47

MIX DESIGN 40T1RNMO

TOTAL YARDS 2.10

MATERIAL	RATE SETTING	TOTAL
CAPTYPE1	__ 444.1LBPM__	1184.4LBS
LRMSAND	__ 5.6 GATE_	2996.7LBS
LRMRG	__ 6.2 GATE_	3578.4LBS
WATER	__ 24.0GPM __	64.1GAL
SIKA686	__ 22.0OZPM__	58.8OZ

WATER / CEMENT RATIO__ 0.45
ASTM C-618

NAME________________________________
NOTES:

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

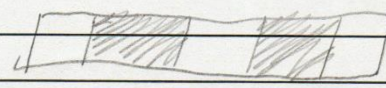
Project No: 469689-3 **Casting Date:** 2019-6-3 **Mix Design (psi):** ______

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	TUCKER	MIX	SECTIONS 2 4
	ON	SITE	

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
T1	2019-7-2	28 DAYS	122,000	4315	
↓	↓	↓	111,000	3925	4160
			120,000	4245	

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.

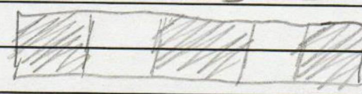
Project No: 469689-3 **Casting Date:** 2019-5-30 **Mix Design (psi):**

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	TUCKER MIX		SECTIONS 1 3 5
	ON SITE		

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
T1	2019-7-2	33 DAYS	155,000	5480	
↓	↓	↓	125,000	4420	5010
			145,000	5130	

TUCKER Concrete
8930 LACY WELL RD
77845 979 777 6749

Job # TUCKER CONSTRUCTION
TTI;;
TICKET # 757
START DATE: 06/03/2019 TIME: 13:12:11
STOP DATE: 06/03/2019 TIME: 13:39:12

MIX DESIGN 40T1RNMO
RAW CEMENT COUNTS__________ 2716
RAW CONVEYOR COUNTS__________ 2016

TOTAL YARDS 3.87

MATERIAL	RATE SETTING	TOTAL
CAPTYPE1	__ 490.7LBPM__	2183.4LBS
LRMSAND	__ 5.4 GATE_	5011.5LBS
LRMRG	__ 6.7 GATE_	7047.0LBS
WATER	__ 26.5gpm __	608.7gal
SIKA686	__ 24.4opm __	108.4oz

WATER / CEMENT RATIO__ 2.33
REQUEST ASTM INFORMATION

NAME______________________________
NOTES:

TUCKER concrete
8930 LACY WELL RD, 77845
979 777 6749

Job # TUCKER ;CONSTRUCTION
TTI SINGLE SLOPE
TICKET # 669
START DATE: 05/30/2019 TIME: 11:09:28
STOP DATE: 05/30/2019 TIME: 11:56:22

MIX DESIGN 40T1RNMO

TOTAL YARDS 5.70

MATERIAL	RATE SETTING	TOTAL
CAPTYPE1	__ 447.8LBPM__	3214.8LBS
LRMSAND	__ 5.2 GATE_	8133.9LBS
LRMRG	__ 6.1 GATE_	9712.8LBS
WATER	__ 24.6gpm __	176.7gal
SIKA686	__ 22.2OZPM__	159.6OZ

WATER / CEMENT RATIO _ 0.46

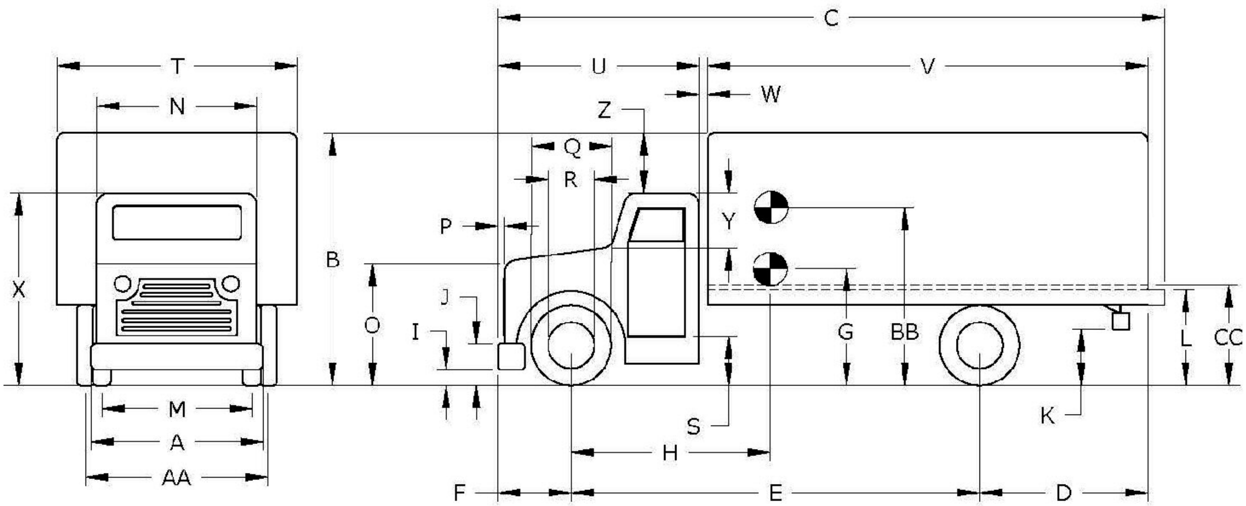
NAME______________________________
NOTES:

APPENDIX C. *MASH* TEST 4-12 (CRASH TEST NO. 469689-3-3)

C.1 VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 469689-3-3.

Date:	2019-7-3	Test No.:	469689-03-3	VIN No.:	1HTMMAAN59H164190
Year:	2009	Make:	INTERNATIONAL	Model:	4300
Odometer:	137305	Tire Size Front:	275/80R22.5	Tire Size Rear:	275/80R22.5



Vehicle Geometry: ☑ inches or ☐ mm

A	Front Bumper Width:	95.00	K	Rear Bumper Bottom:		U	Cab Length:	106.00
B	Overall Height:	143.50	L	Rear Frame Top:	36.50	V	Trailer/Box Length:	225.00
C	Overall Length:	329.75	M	Front Track Width:	80.00	W	Gap Width:	2.00
D	Rear Overhang:	89.00	N	Roof Width:	71.00	X	Overall Front Height:	98.50
E	Wheel Base:	204.75	O	Hood Height:	60.00	Y	Roof-Hood Distance:	30.00
F	Front Overhang:	36.00	P	Bumper Extension:	1.00	Z	Roof-Box Height Difference:	45.00
G	C.G. Height:	-	Q	Front Tire Width:	39.00	AA	Rear Track Width:	73.00
H	C.G. Horizontal Dist. w/Ballast:	129.75	R	Front Wheel Width:	23.50	BB	Ballast Center of Mass:	61.25
I	Front Bumper Bottom:	20.50	S	Bottom Door Height:	37.50	CC	Cargo Bed Height:	49.00
J	Front Bumper Top:	35.50	T	Overall Width:	96.00			

Allowable Range: C = 394 inches max.; E = 240 inches max.; CC = 49 ±2 inches; BB = 63 ±2 inches above ground;

Wheel Center Height Front	19.00	Wheel Well Clearance (Front)	9.00	Bottom Frame Height (Front)	25.50
Wheel Center Height Rear	19.00	Wheel Well Clearance (Rear)	3.25	Bottom Frame Height (Rear)	27.00

Table C.1. Vehicle Properties for Test No. 469689-3-3 (Continued).

Date:	2019-7-3	Test No.:	469689-03-3	VIN No.:	1HTMMAAN59H164190
Year:	2009	Make:	INTERNATIONAL	Model:	4300

WEIGHTS
(☑ lb or ☐ kg)

	CURB	TEST INERTIAL
$W_{front\ axle}$	6800	8110
$W_{rear\ axle}$	6860	14030
W_{TOTAL}	13660	22140

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

Ballast: 8480 (☑ lb or ☐ kg) **(as-needed)**
(See *MASH* Section 4.2.1.2 for recommended ballasting)

Mass Distribution
(☑ lb or ☐ kg): **LF:** 4140 **RF:** 3970 **LR:** 7060 **RR:** 6970

Engine Type: DT

Engine Size: 466

Transmission Type:

☑ Auto or ☐ Manual

☐ FWD ☑ RWD ☐ 4WD

Accelerometer Locations (☐ inches or ☐ mm)

	x[1]	y	z[2]
Front:			
Center:	129.75	0.00	49.00
Rear:	217.75	0.00	49.00

Describe any damage to the vehicle prior to test:

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

TWO 4,000 LB BLOCKS H 30" W 60" D 30" EACH

CENTERED IN MIDDLE OF BED

61.25" FROM GROUND TO CENTER OF LOAD

FOUR 4/16" CABLES PER BLOCK

C.2 SEQUENTIAL PHOTOGRAPHS

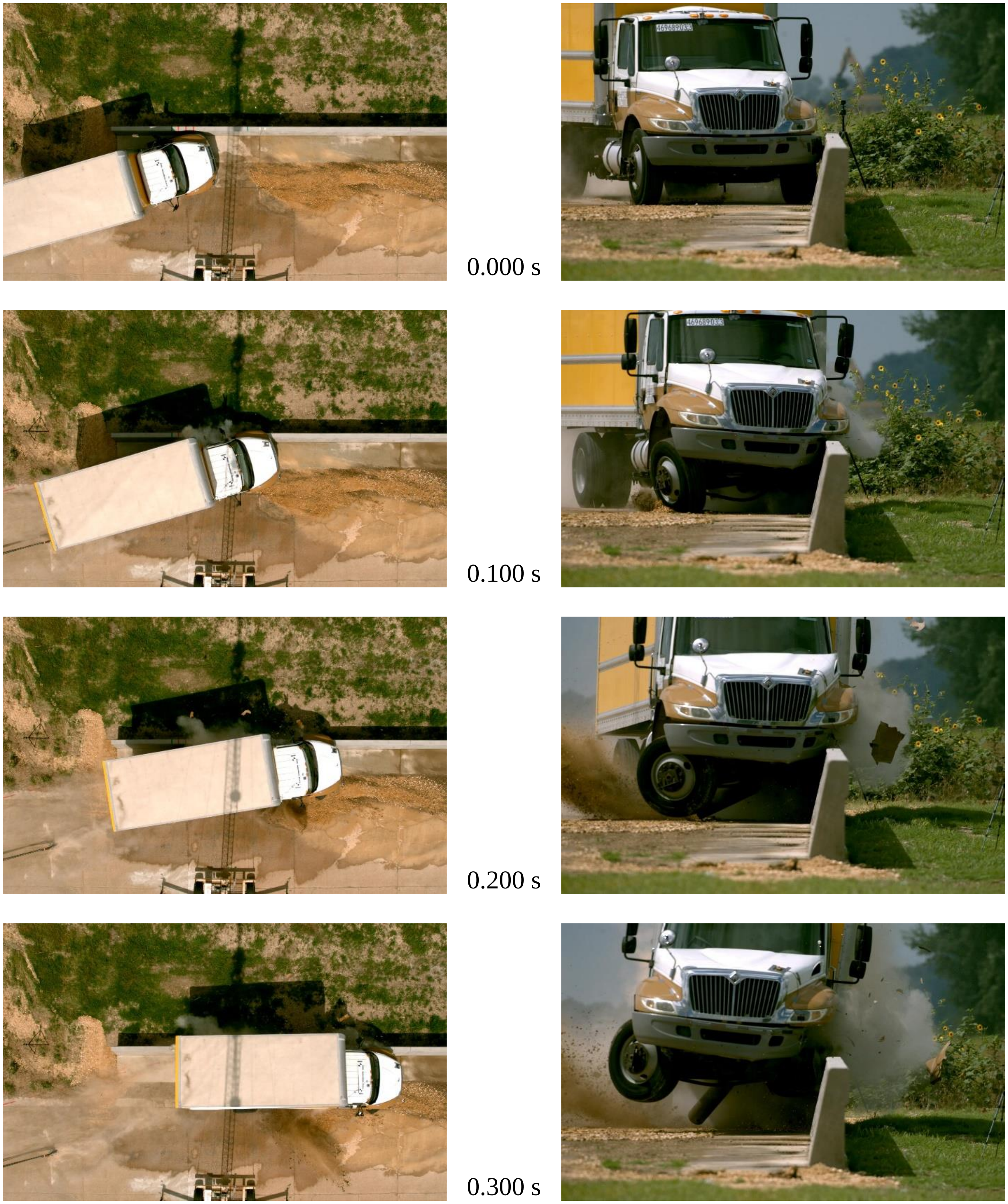


Figure C.1. Sequential Photographs for Test No. 469689-3-3 (Overhead and Frontal Views).

Figure C.1. Sequential Photographs for Test No. 469689-3-3 (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 C.2. Sequential Photographs for Test No. 469689-3-3 (Rear View).

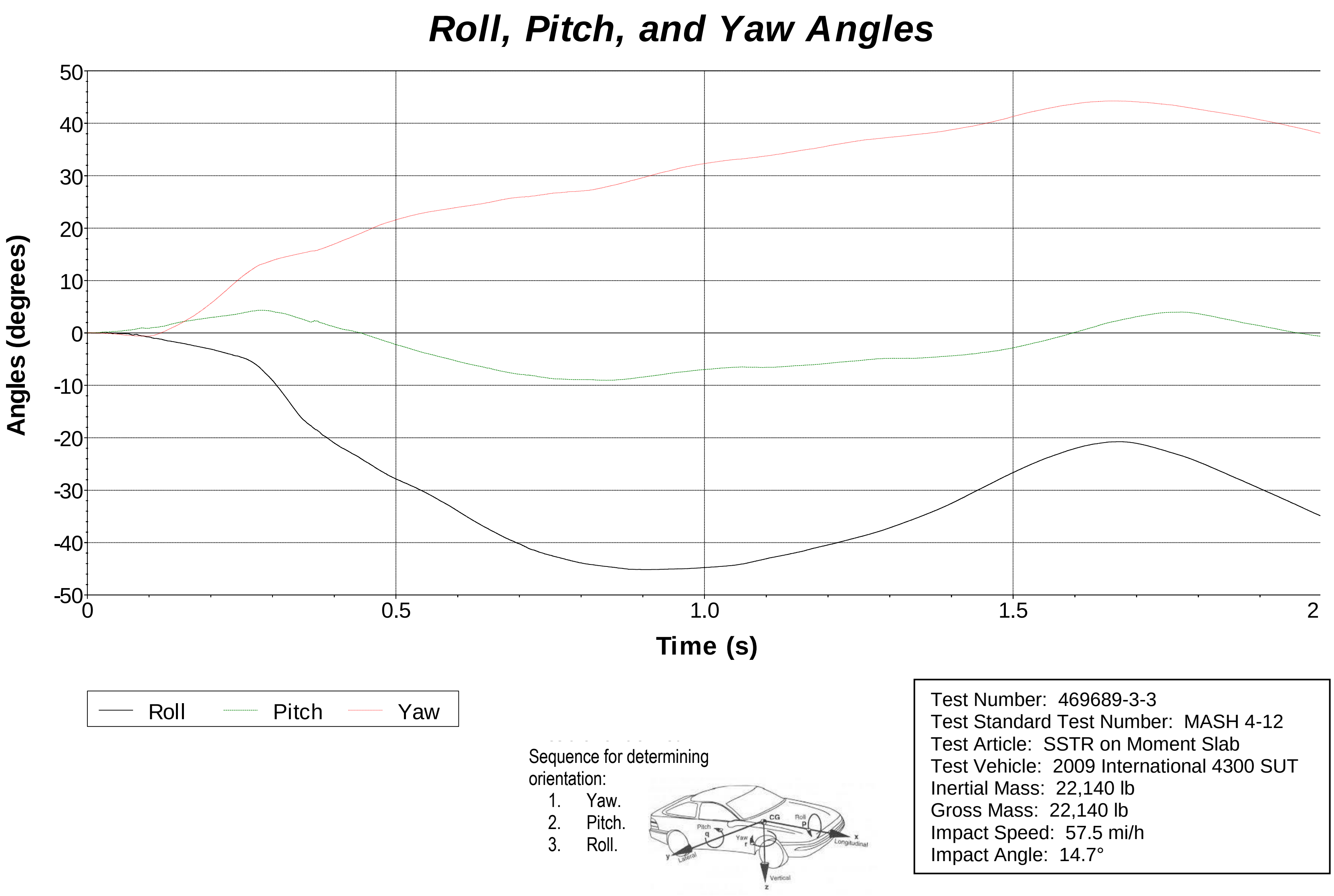


Figure C.3. Vehicle Angular Displacements for Test No. 469689-3-3.

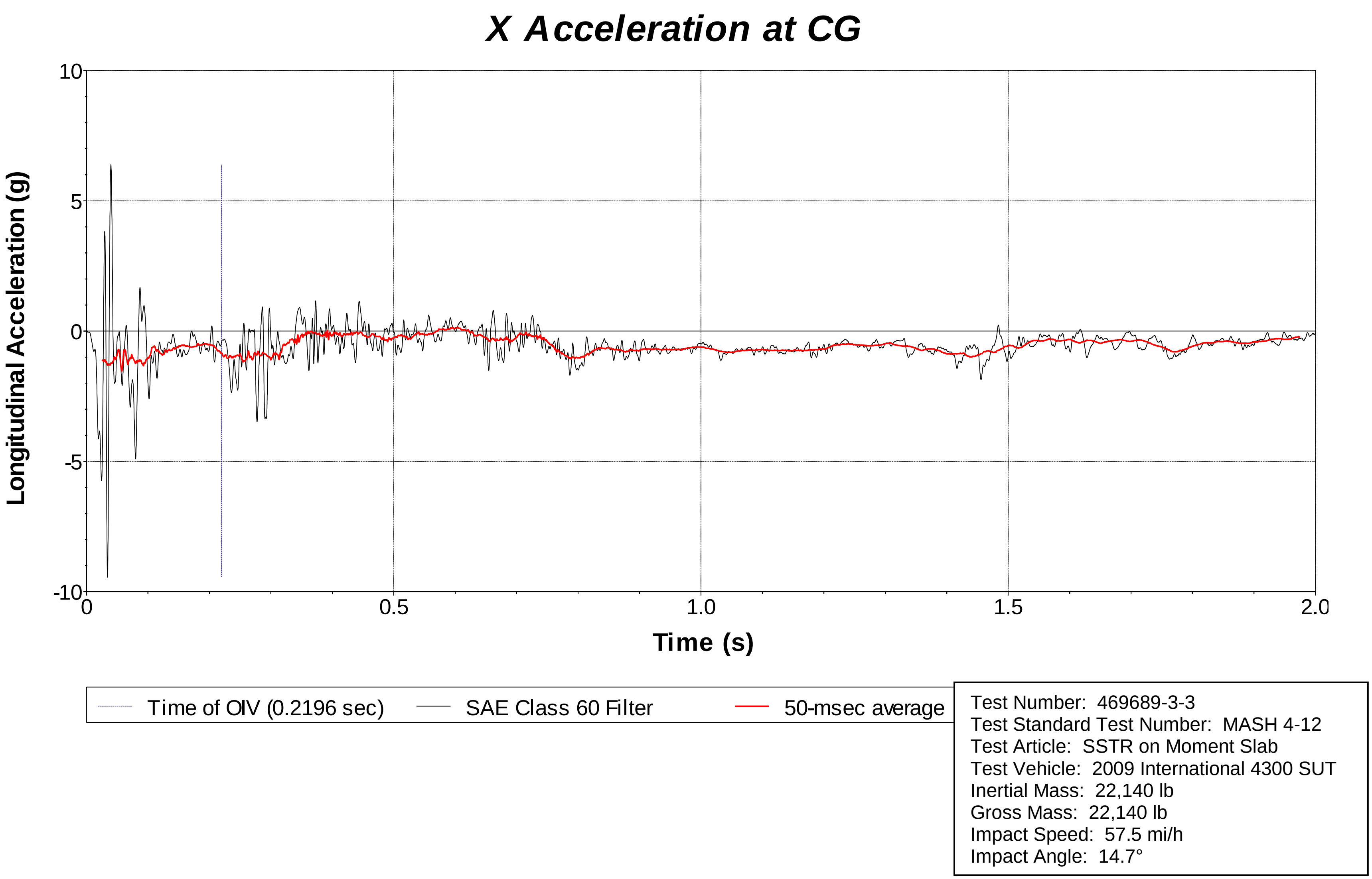


Figure C.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469689-3-3 (Accelerometer Located at Center of Gravity).

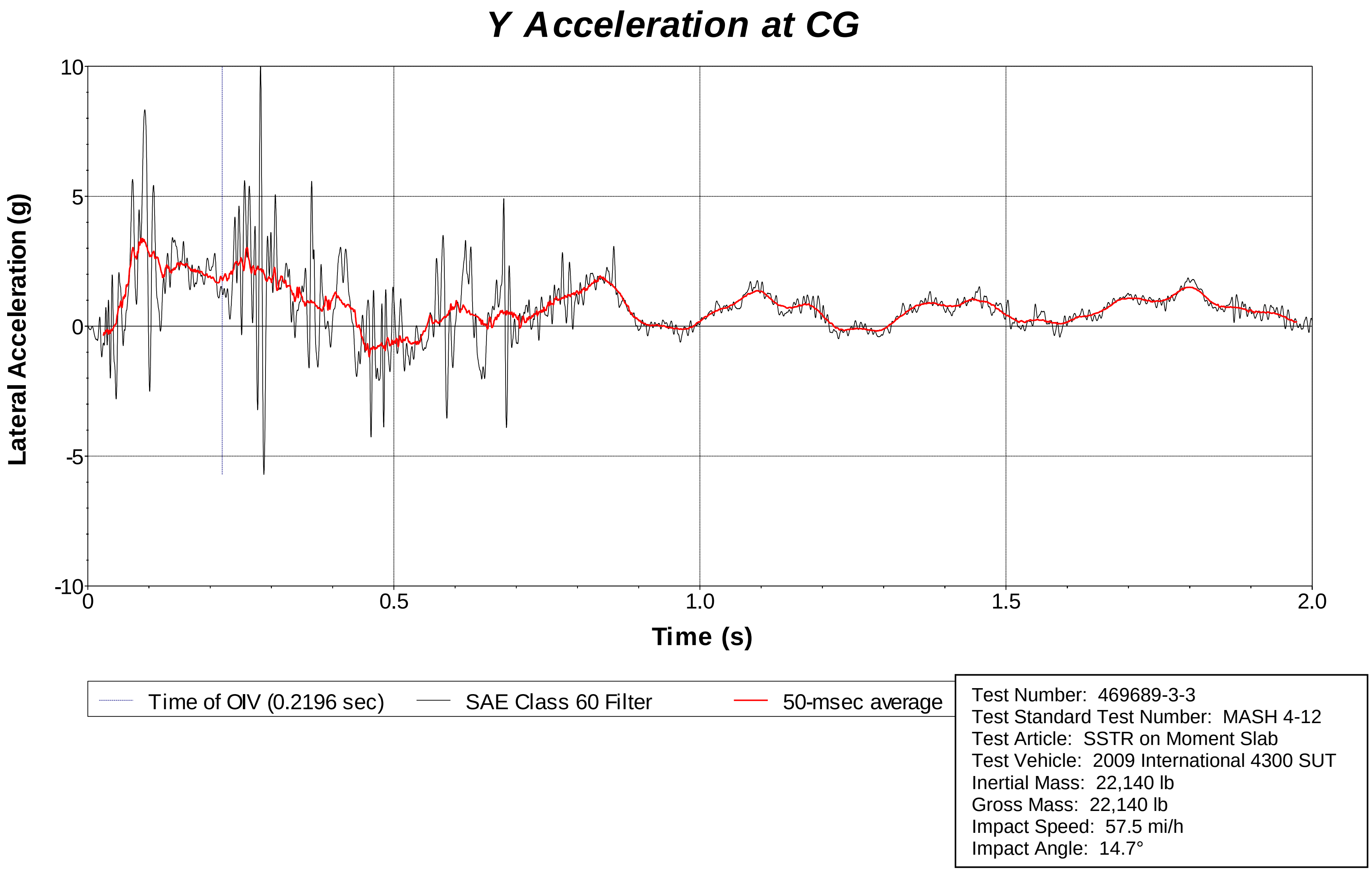


Figure C.5. Vehicle Lateral Accelerometer Trace for Test No. 469689-3-3 (Accelerometer Located at Center of Gravity).

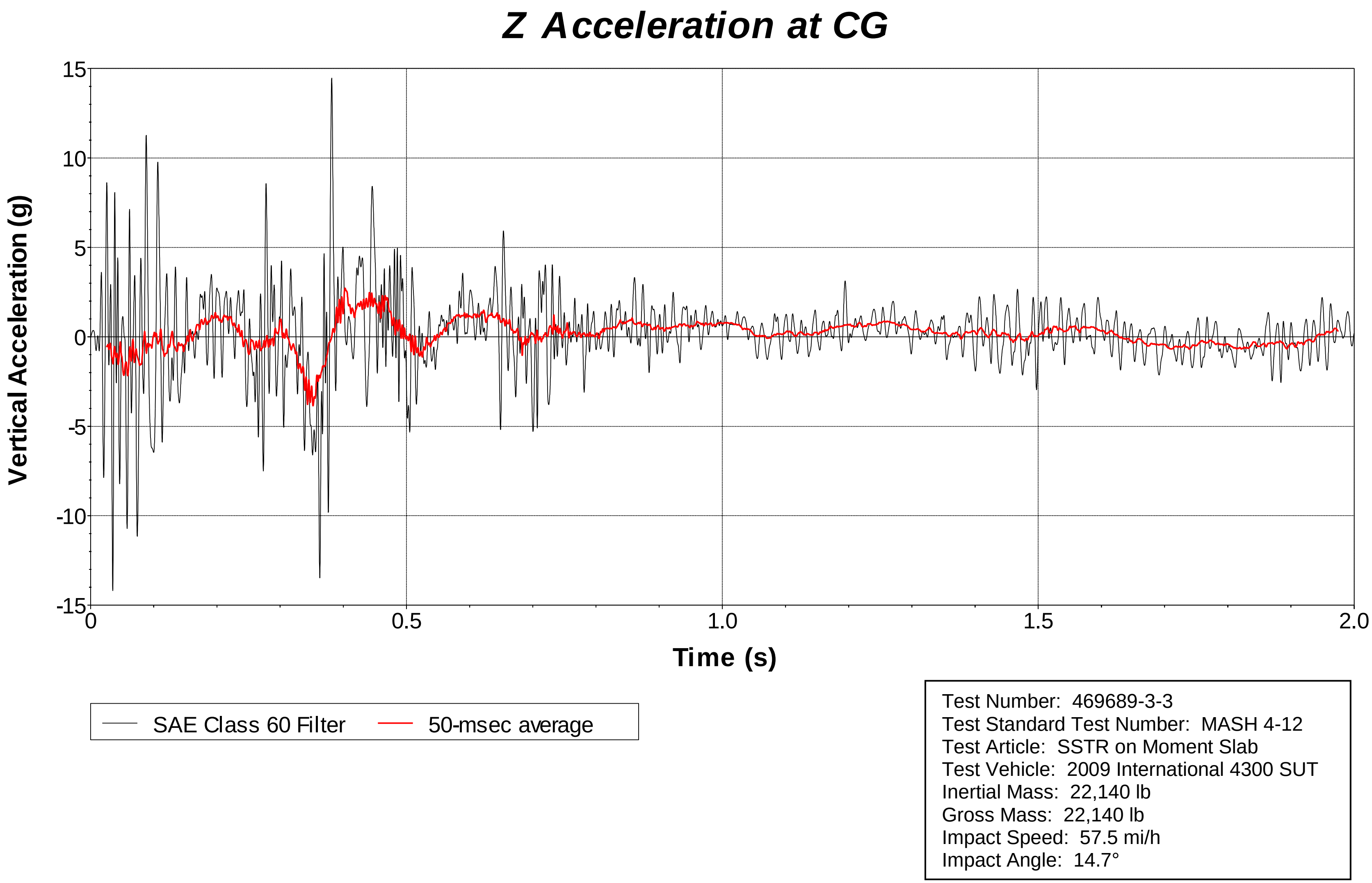


Figure C.6. Vehicle Vertical Accelerometer Trace for Test No. 469689-3-3 (Accelerometer Located at Center of Gravity).

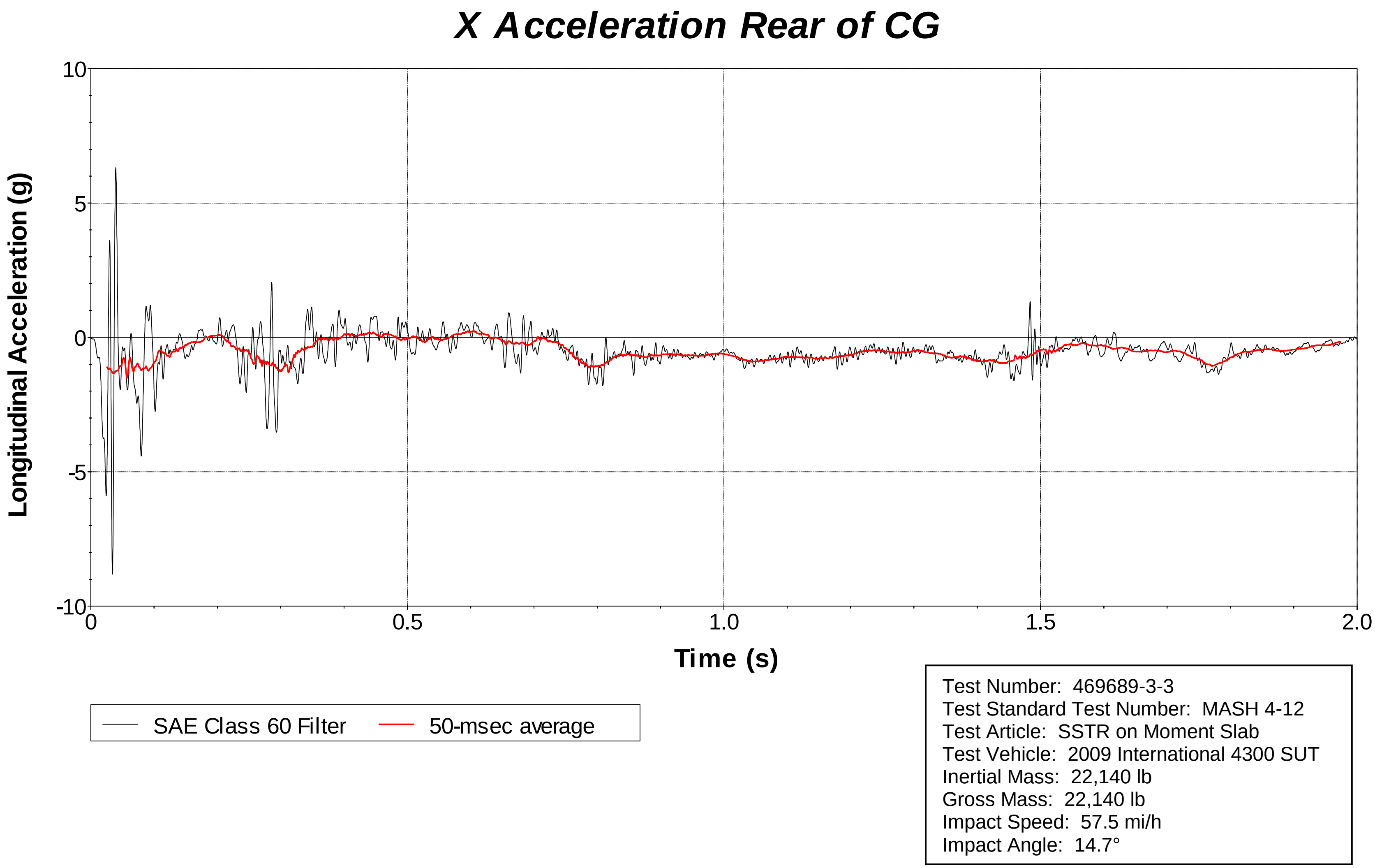


Figure C.7. Vehicle Longitudinal Accelerometer Trace for Test No. 469689-3-3 (Accelerometer Located Rear of Center of Gravity).

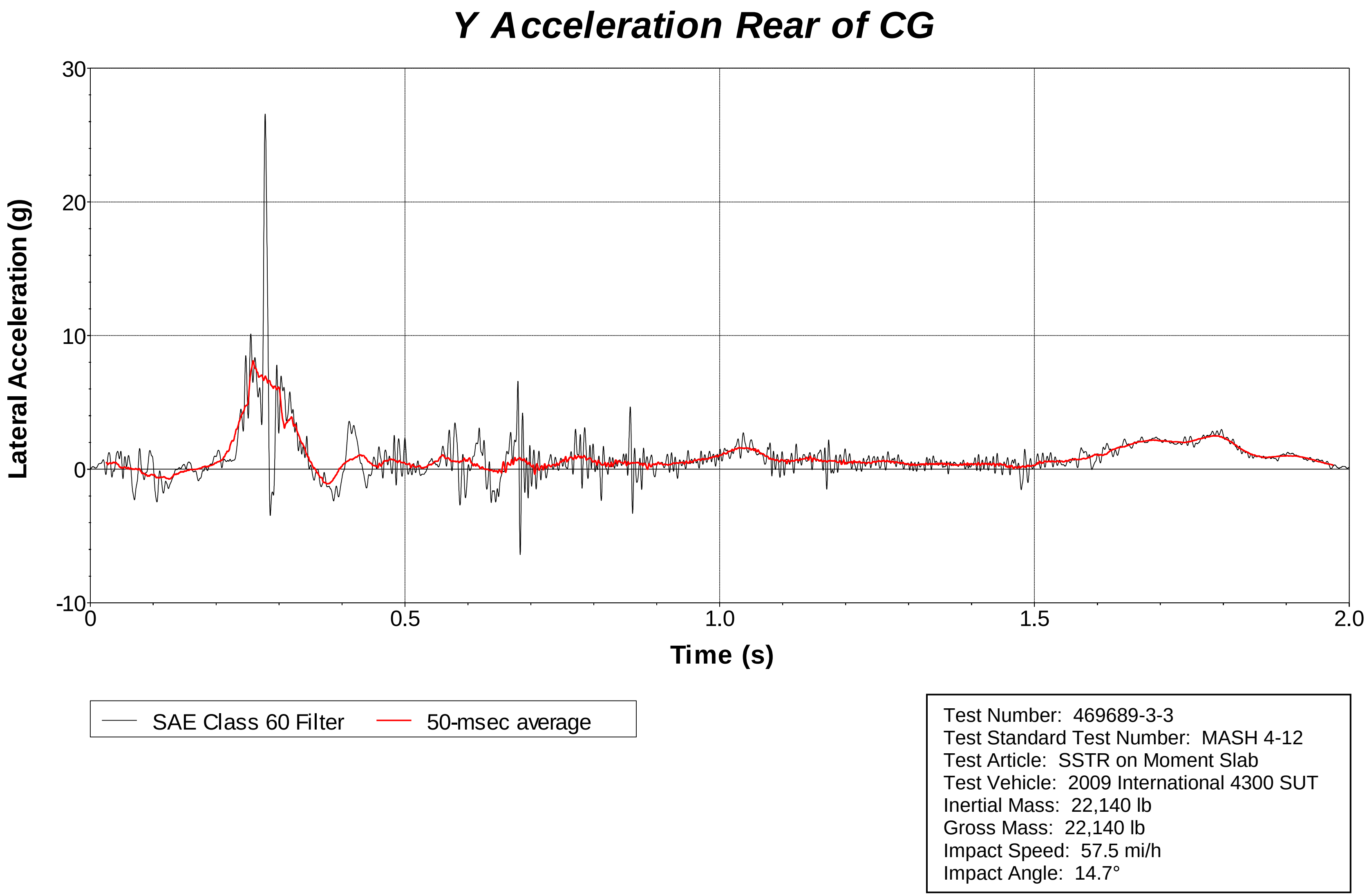


Figure C.8. Vehicle Lateral Accelerometer Trace for Test No. 469689-3-3 (Accelerometer Located Rear of Center of Gravity).

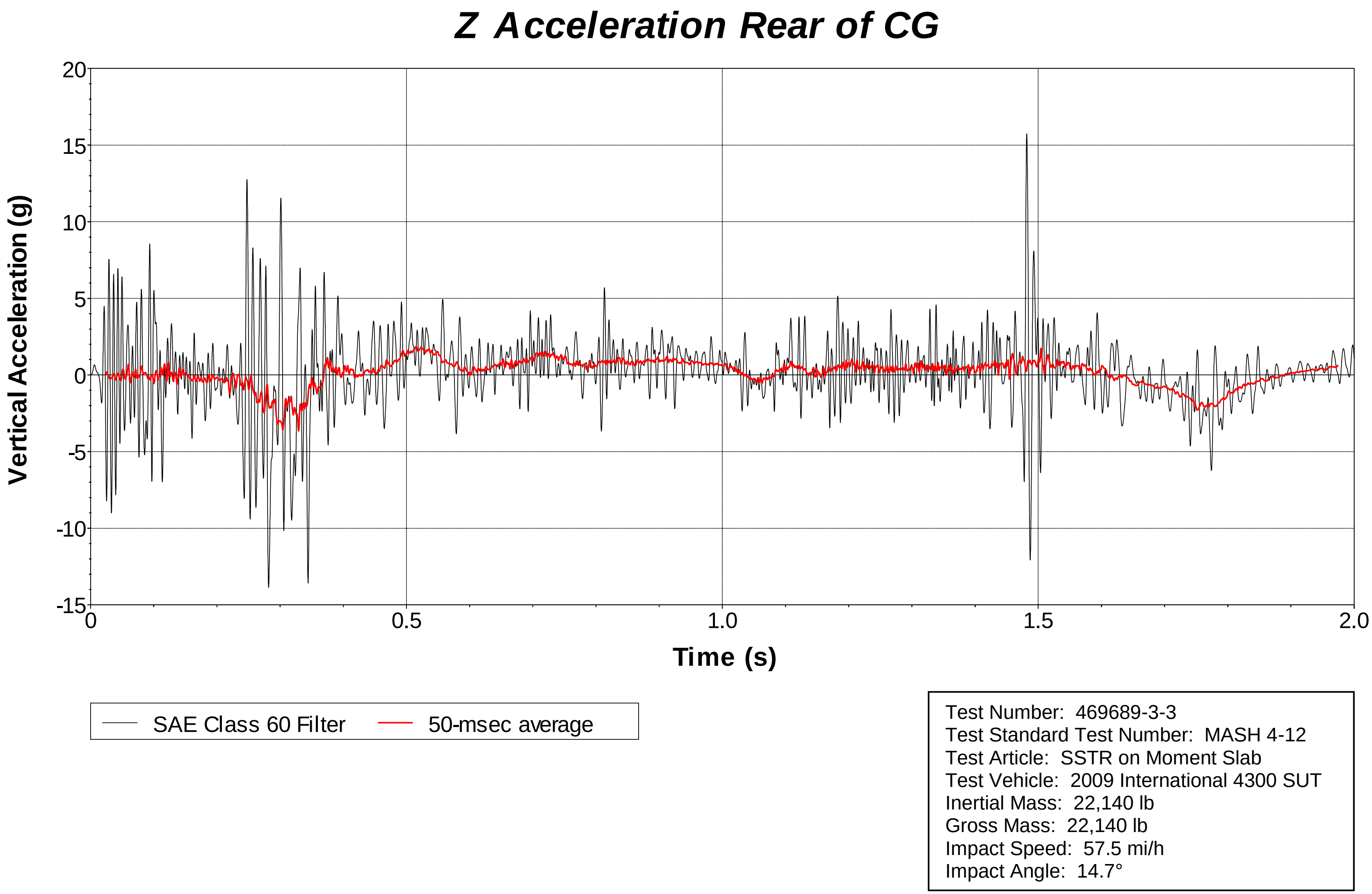


Figure C.9. Vehicle Vertical Accelerometer Trace for Test No. 469689-3-3 (Accelerometer Located Rear of Center of Gravity).