TTI: 0-6948

Analysis of 54-Inch Tall Single-Slope Concrete Barrier on a Structurally Independent Foundation

ISO 17025 Laboratory
Testing Certificate # 2821.01

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

Test Report 0-6948-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
http://tti.tamu.edu/documents/0-6948-R1.pdf

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-19/0-6948-R1		

4. Title and Subtitle ANALYSIS OF 54-INCH TALL SINGLE SLOPE CONCRETE BARRIER ON A STRUCTURALLY INDEPENDENT FOUNDATION	5. Report Date September 2019 6. Performing Organization Code 469489-01-3
7. Author(s) Nauman M. Sheikh, James C. Kovar, Sofokli Cakalli, Wanda L. Menges, Glenn E. Schroeder, and Darrell L. Kuhn	8. Performing Organization Report No. Report 0-6948-R1
9. Performing Organization Name and Address Texas A&M Transportation Institute College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-6948
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office 125 E. 11th Street Austin, Texas 78701-2483	13. Type of Report and Period Covered Technical Report: August 2017–August 2019 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

Project Title: Analysis of 54-inch Tall Single Slope Concrete Barrier on a Structurally Independent Foundation

URL: http://tti.tamu.edu/documents/0-6948-R1.pdf

16. Abstract

This project developed structurally independent foundation designs for 54-inch tall single slope concrete barrier (SSCB) for shielding bridge columns near roadsides that do not meet Texas Department of Transportation's (TxDOT's) design impact load criteria. Such columns are required to be shielded with a 54-inch tall barrier with an independent foundation that meets performance criteria of AASHTO *MASH* Test Level 5.

Researchers developed seven preliminary foundation design concepts for the SSCB. Of these, TxDOT selected three concepts for further development. The foundation concepts selected were a shallow moment slab, a vertical wall, and a drilled shaft foundation. TTI researchers developed simulation models of the selected preliminary designs and performed vehicle impact simulations to determine the performance of these systems under *MASH* Test 5-12 impact conditions, which involve impacting the barrier with a 36000V tractor-van trailer vehicle at an impact speed and angle of 50 mi/h and 15 degrees, respectively.

Simulation was used to optimize the foundation sizes and select one of the three designs for full-scale crash testing. The drilled shaft foundation design was selected for crash testing as it had the largest deflection among the designs simulated. Furthermore, the discrete attachment of the shafts to the barrier was considered more critical for further evaluation compared to continuous barrier to foundation connection in the other concepts. While the full scale testing was performed with the drilled shaft foundation only, researchers developed reinforcement details for all three barrier and foundation systems.

TTI researchers constructed the 54-inch tall SSCB barrier with the drilled shaft foundation and performed *MASH* Test 5-12. The barrier performed acceptably for *MASH* Test 5-12. Results of the testing were similar to the simulation results, with the simulation results being slightly more conservative for barrier deflection. Therefore, the designs of the moment slab and the vertical wall foundations, while not crash tested, are also expected to meet the *MASH* Test 5-12 impact performance criteria.

17. Key Words	18. Distribution Statement
Longitudinal Barrier, Concrete Barrier, Single Slope Concrete Barrier, MASH, Crash Testing, Roadside Safety	No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia http://www.ntis.gov

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	92	

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Report 0-6948-R1
Project 0-6948
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Performed in cooperation with the
Texas Department of Transportation
and the
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September 2019

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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 research engineer 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 tested.

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ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. The authors thank Taya Retterer and Jon Ries of TxDOT Bridge Division for their valuable contributions to this project. The authors also thank Derrin Jensen and Kevin Pete of TxDOT RTI for their support.

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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

The Texas Department of Transportation (TxDOT) requires that on roadways exceeding certain annual traffic frequency, bridge columns adjacent to roadways should be designed for impacts from heavy trucks, or should be shielded with a 54-inch tall barrier that has a structurally independent foundation. This barrier must pass American Association of State Highway and Transportation Officials (AASHTO), *Manual for Assessing Safety Hardware* (*MASH*), Test Level 5 (TL-5) testing requirements (*1*). Currently, there is no available design for a 54-inch tall barrier with a structurally independent foundation that meets *MASH* TL-5 criteria.

1.2 RESEARCH OBJECTIVE AND SCOPE

The main objective of this project was to develop structurally independent foundation designs for 54-inch tall single slope concrete barrier (SSCB) that meet the impact performance requirements of *MASH* TL-5.

Researchers developed seven preliminary foundation design concepts for the SSCB. Of these, TxDOT selected three concepts for further development. The concepts selected were a shallow moment slab, a vertical beam, and a drilled shaft foundation. TTI researchers developed simulation models of the selected preliminary designs and performed vehicle impact simulations to determine the performance of these systems under *MASH* Test 5-12 impact conditions, which involves impacting the barrier with a 36000V tractor-van trailer vehicle at an impact speed and angle of 50 mi/h and 15°, respectively.

Simulations were used to optimize the foundation sizes and select one of the three designs for full-scale crash testing. The drilled shaft foundation design was selected for crash testing. While the full-scale testing was performed with the drilled shaft foundation, researchers developed reinforcement details for all three barrier and foundation systems.

TTI constructed the 54-inch tall SSCB barrier with the drilled shaft foundation and performed *MASH* Test 5-12.

CHAPTER 2: SIMULATION AND DESIGN*

Researchers developed seven preliminary barrier foundation design concepts for TxDOT's review. Of these seven preliminary concepts, three were selected for further development. These included a shallow moment slab foundation, a drilled shaft foundation, and a vertical beam foundation.

Researchers developed full-scale finite element (FE) models of the three selected preliminary foundation concepts. Using these FE models, TTI researchers performed impact simulations using *MASH* test conditions to evaluate the performance of the barrier and foundation systems. Based on the results of these simulations, researchers optimized and finalized the foundation designs. Researchers then developed reinforcement details for each of the three foundation types.

This chapter presents the seven preliminary foundation design concepts, details of FE modeling and analysis of the three selected foundation systems and their optimized designs, and the reinforcement details for each foundation system.

2.1 PRELIMINARY DESIGN CONCEPTS

Researchers developed seven preliminary foundation design concepts for the 54-inch tall single slope barrier. Figure 2.1 shows the single-face barrier profile used. The segment length of the single slope barrier was selected to be 50 ft on direction of TxDOT. This length is expected to be the minimum barrier length needed to shield bridge columns.

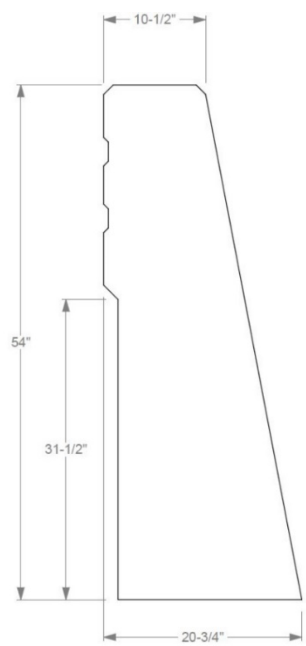


Figure 2.1. 54-Inch Tall Single Slope Barrier Profile.

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

An initial engineering analysis accounted for the static load resistance provided by the soil and the weight of the foundation and barrier system. This approach provides conservative foundation designs because it does not take dynamic inertial effects into account. These designs were later optimized using FE analyses that explicitly accounted for the dynamic loading and response of the barrier and soil. The barrier and the preliminary foundation design concepts are shown in Figures 2.2 through 2.8.

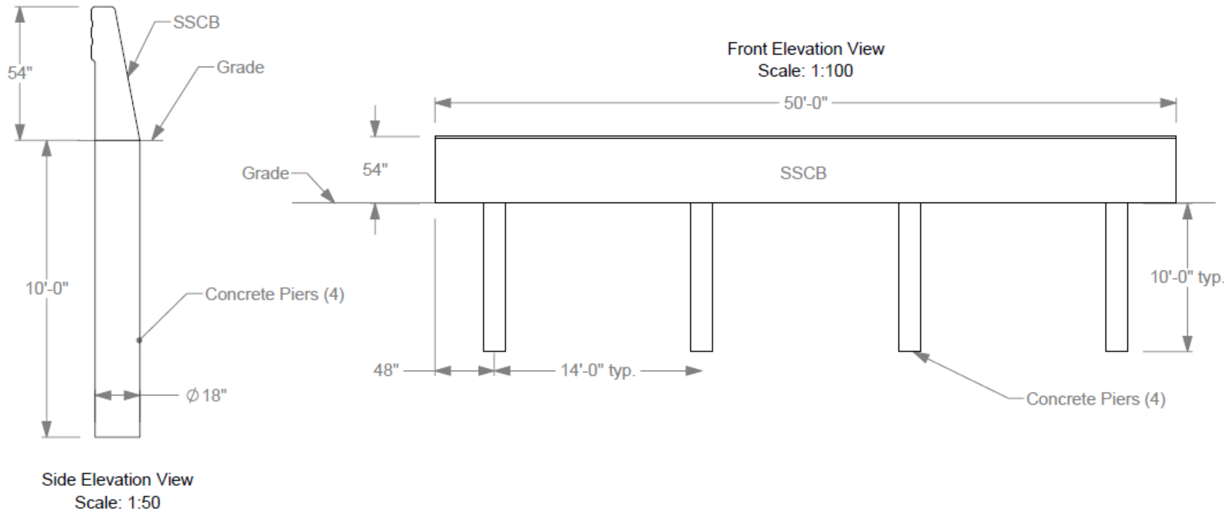


Figure 2.2. Concept 1 – Drilled Shaft Design.

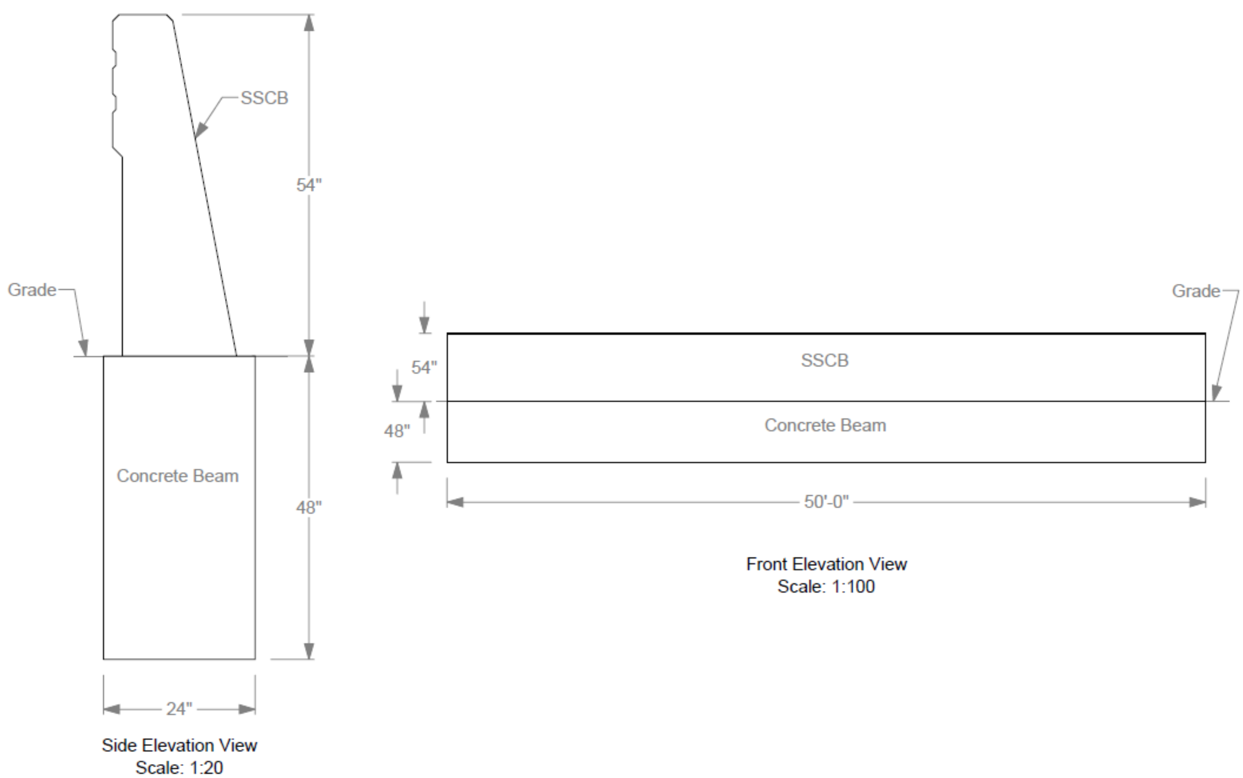


Figure 2.3. Concept 2 – Concrete Beam Design.

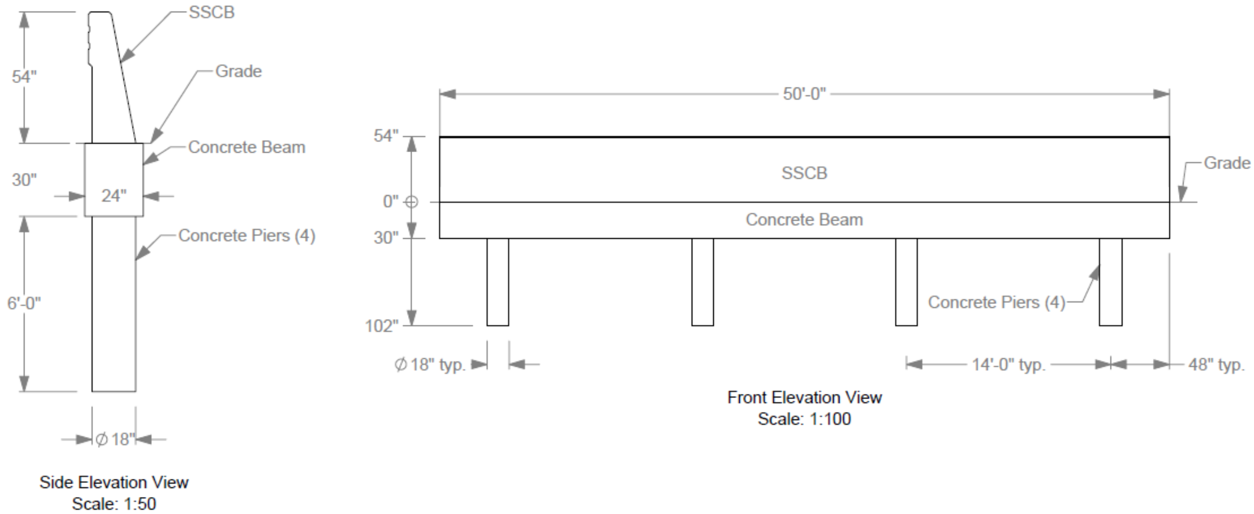


Figure 2.4. Concept 3 – Drilled Shaft with Concrete Beam Design.

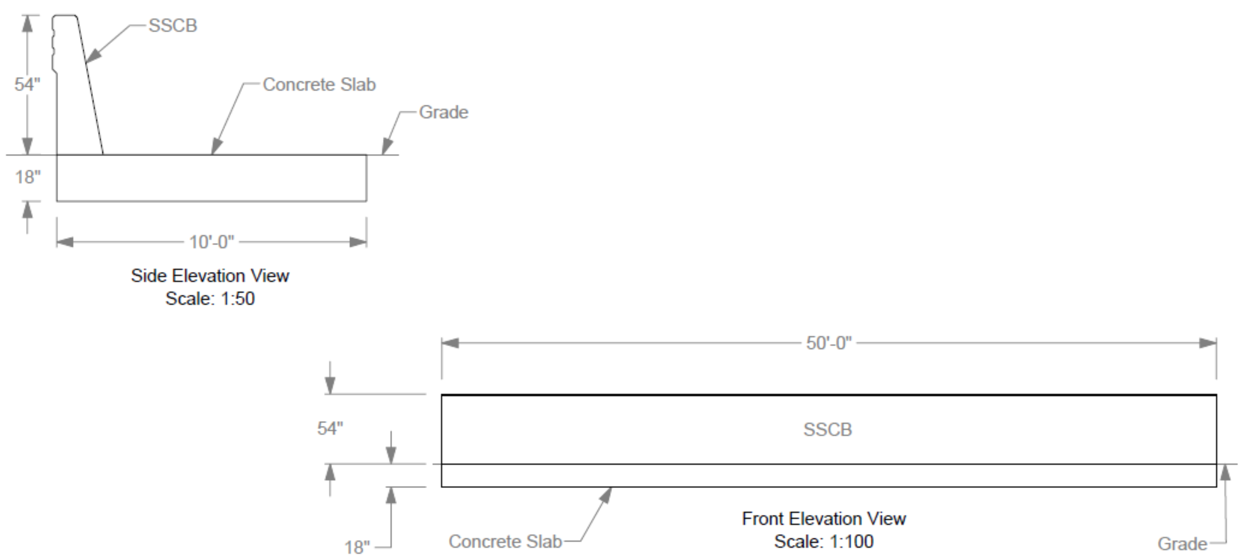


Figure 2.5. Concept 4 – Moment Slab Design.

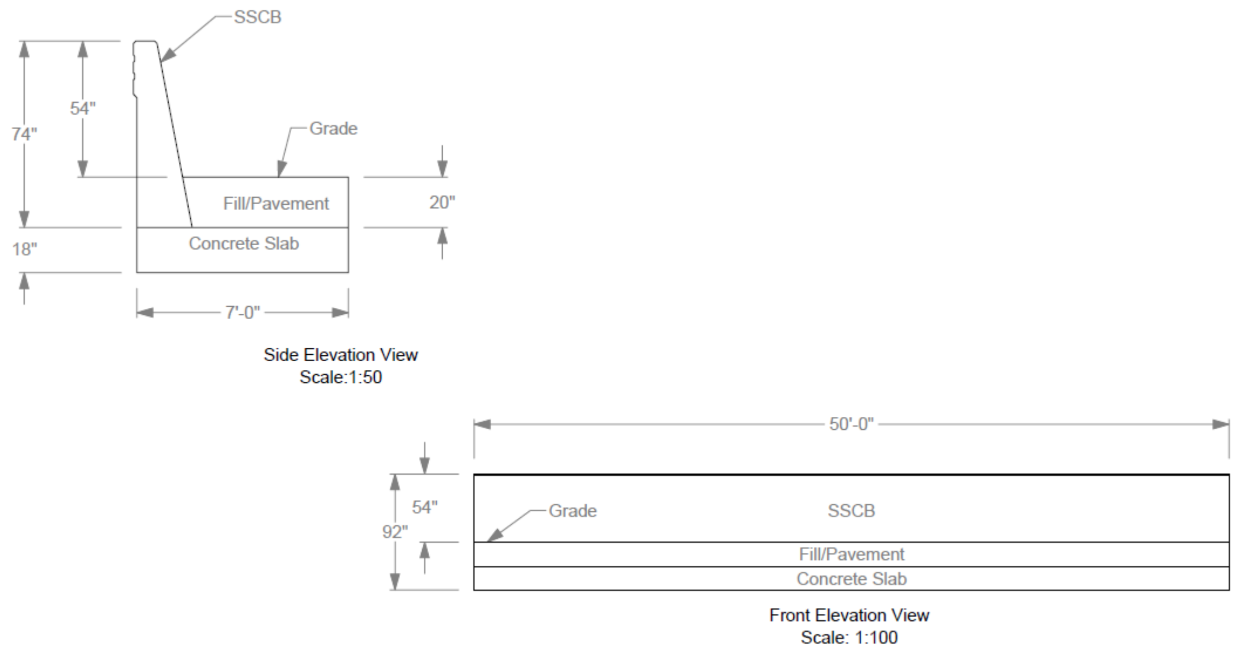


Figure 2.6. Concept 5 – Moment Slab with Fill/Pavement Overlay Design.

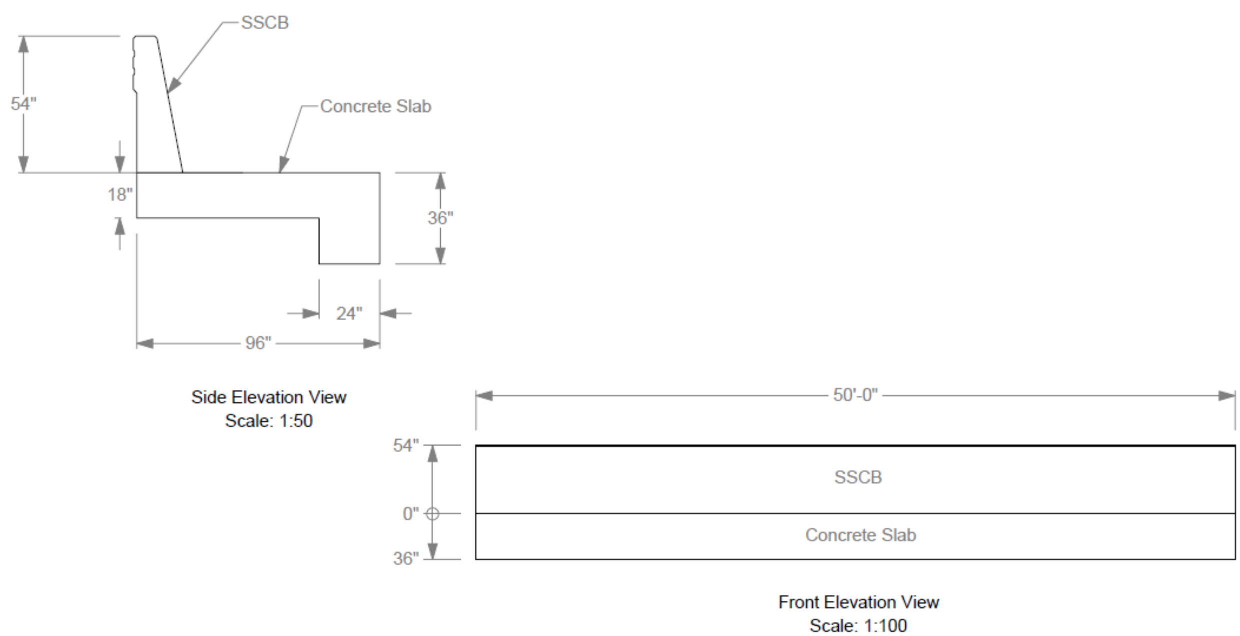


Figure 2.7. Concept 6 – Moment Slab with Concrete Beam Design.

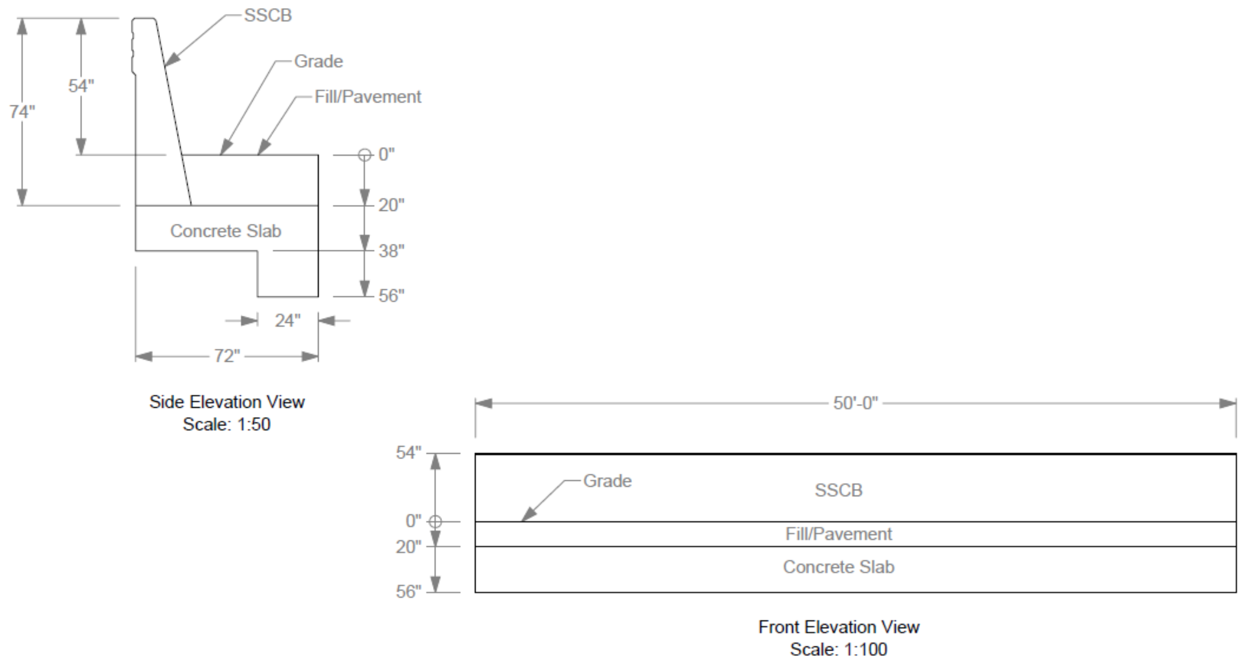


Figure 2.8. Concept 7 – Moment Slab with Concrete Beam and Overlay Design.

2.1.1 Concept 1 – Drilled Shaft

Figure 2.2 shows the drilled shaft foundation design concept. The shaft diameter was 18 inches to match TxDOT's standard shaft design. Using the preliminary design analysis, TTI researchers arrived at the shaft spacing of 14 ft and a depth of 10 ft. This foundation allows installation at locations where a larger foundation footprint is not possible, but deeper drilled shafts can be installed.

2.1.2 Concept 2 – Concrete Beam

Figure 2.3 shows the concrete beam foundation design. The beam is 24 inches wide and 48 inches deep. This foundation has a greater footprint compared to the drilled shaft foundation, but it is not as deep as the drilled shaft foundation and not as wide as a moment slab foundation.

2.1.3 Concept 3 – Drilled Shaft and Beam

Figure 2.4 shows this concept, which is a hybrid of the drilled shaft and concrete beam foundations. The overall depth of this foundation's shafts was 8.5 ft. TTI researchers initially thought that this hybrid concept may reduce the depth of the drilled shafts significantly compared to Concept 1. However, preliminary design analysis resulted in a depth reduction of only 1.5 ft. Furthermore, this concept requires a continuous beam at the base of the barrier. While this preliminary design could be further optimized in the simulation phase, it was not expected to have much advantage due to the additional cost of a continuous beam, and a smaller reduction in shaft depth than initially anticipated.

2.1.4 Concept 4 – Moment Slab

Figure 2.5 shows the moment slab foundation preliminary design. A continuous moment slab that is 18 inches deep and 10 ft wide is cast underneath the barrier. The moment slab has a shallow depth and is ideal for sites where deep excavation is not possible or is restricted.

2.1.5 Concept 5 – Moment Slab with Overlay

Figure 2.6 shows this concept, which is essentially the moment slab foundation with an addition of 20 inches of soil and pavement overlay. This design reduces the overall width of the moment slab.

2.1.6 Concept 6 – Moment Slab with Concrete Beam

Figure 2.7 presents a moment slab foundation with an offset concrete beam on the traffic side of the barrier. Due to the concrete beam, this design provides additional counter moment to resist the overturning of the barrier due to the impact load. This design reduces the width of the moment slab in Concept 4 but increases the depth at the location of the concrete beam.

2.1.7 Concept 7 – Moment Slab with Concrete Beam and Overlay

Figure 2.8 shows this concept, which is the same as a moment slab with offset concrete beam (Concept 6) with a soil and/or asphalt overlay. The overlay provides a counter moment to the rotation of the barrier due to impact, thus allowing the reduction in the width of the moment slab.

Of the seven preliminary foundation design concepts presented above, three were selected for further design development through FE analysis. These were the drilled shaft foundation, moment slab foundation, and concrete beam foundation. TTI researchers developed full-scale FE models of these three preliminary foundation designs and performed vehicle impact simulations with *MASH* Test 5-12 impact conditions (79,300-lb tractor-van trailer impacting the barrier at 50 mi/h and 15 degrees). Subsequent to the simulation of the preliminary foundation design, researchers 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.

2.2 FINITE ELEMENT SIMULATIONS

All simulations were performed using the finite element method. LS-DYNA, which is a commercially available general-purpose FE analysis software, was used for the analyses.

The 54-inch tall single slope barrier 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 the impact from the tractor-van trailer. For all foundation designs, the barrier and the foundation had a segment length of 50 ft, as selected at the start of the project. Each barrier and foundation model was comprised of three independent 50-ft segments for a total barrier length of 150 ft.

The deflection of barrier and foundation system can be influenced by the strength of the surrounding soil. Typical roadside devices are installed in 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 TTI Proving Ground is 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*). LS-DYNA being 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 5-12 impact conditions, which involves a 79,300-lb tractor-van trailer vehicle impacting the barrier at an impact speed and angle of 50 mi/h and 15 degrees, respectively. The vehicle model used in the simulations was originally developed by the National Crash Analysis Center and Battelle. This model 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 3-10 and 3-11 impact conditions. A barrier system designed for a TL-5 impact will behave essentially rigidly for the smaller, lighter passenger car (Test 3-10) and pickup truck (Test 3-11). Therefore, simulations were only performed with the tractor trailer vehicle.

Primary objectives in the design of the barrier foundations was to have minimal offset between the barrier and a bridge column shielded by the barrier, and to have minimal movement of the barrier during impact to minimize maintenance and repair.

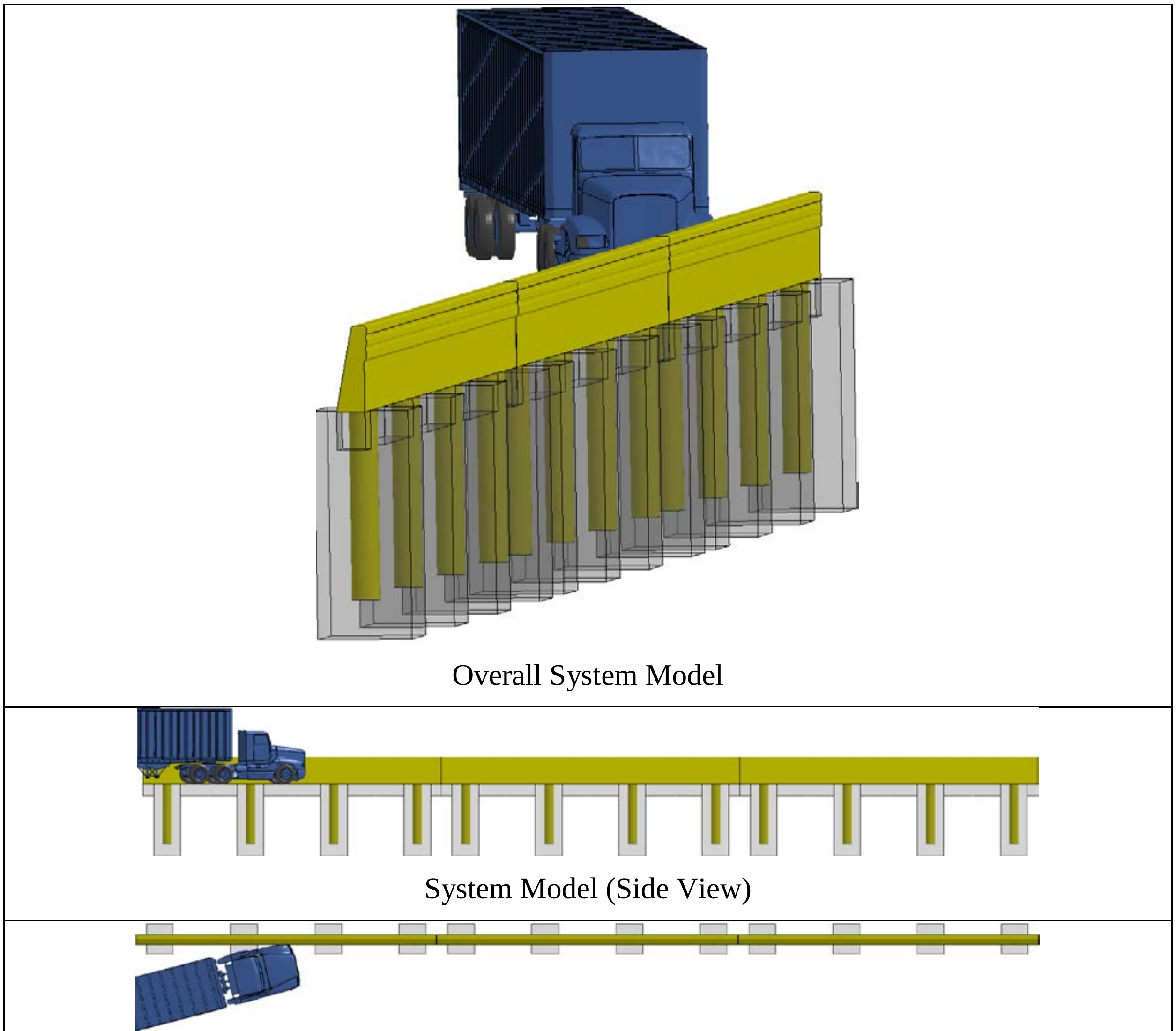
Images of the models for the various foundation designs and results of the impact analyses are presented next.

2.2.1 Drilled Shaft Foundation Design

This foundation design was comprised of 18-inch diameter standard TxDOT drill-shafts that were 10-ft deep (Figure 2.2). Each 50-ft segment of the barrier had four drilled shafts. The centers of the shafts were spaced at 14 ft from each other. The centers of the two end shafts were offset 4-ft from the ends of the segments.

Figure 2.9 shows the FE model of this barrier and foundation. Figure 2.10 shows the results of *MASH* Test 5-12 impact simulation with the tractor trailer vehicle model. The vehicle was successfully contained and redirected by the barrier and the foundation system. There was very little movement of the barrier and the foundation. The maximum dynamic deflection of the barrier was 1.5 inches, and the maximum permanent deflection was 0.75 inch. The working width of the barrier and the foundation system was 29.5 inches at the height of 149.6 inches.

After observing the low deflection of the foundation design, TTI researchers reduced the depth of drilled shafts to 6 ft and performed another impact simulation. Figure 2.11 shows the results of the simulation. The maximum dynamic deflection of the barrier was 6.3 inches, and the permanent deflection was 4.3 inches.



Overall System Model

System Model (Side View)

System Model (Top View)

Soil shown with transparency to show the drilled shafts

Figure 2.9. Drilled Shaft Foundation Simulation Model Details (10-Ft Deep Shafts).

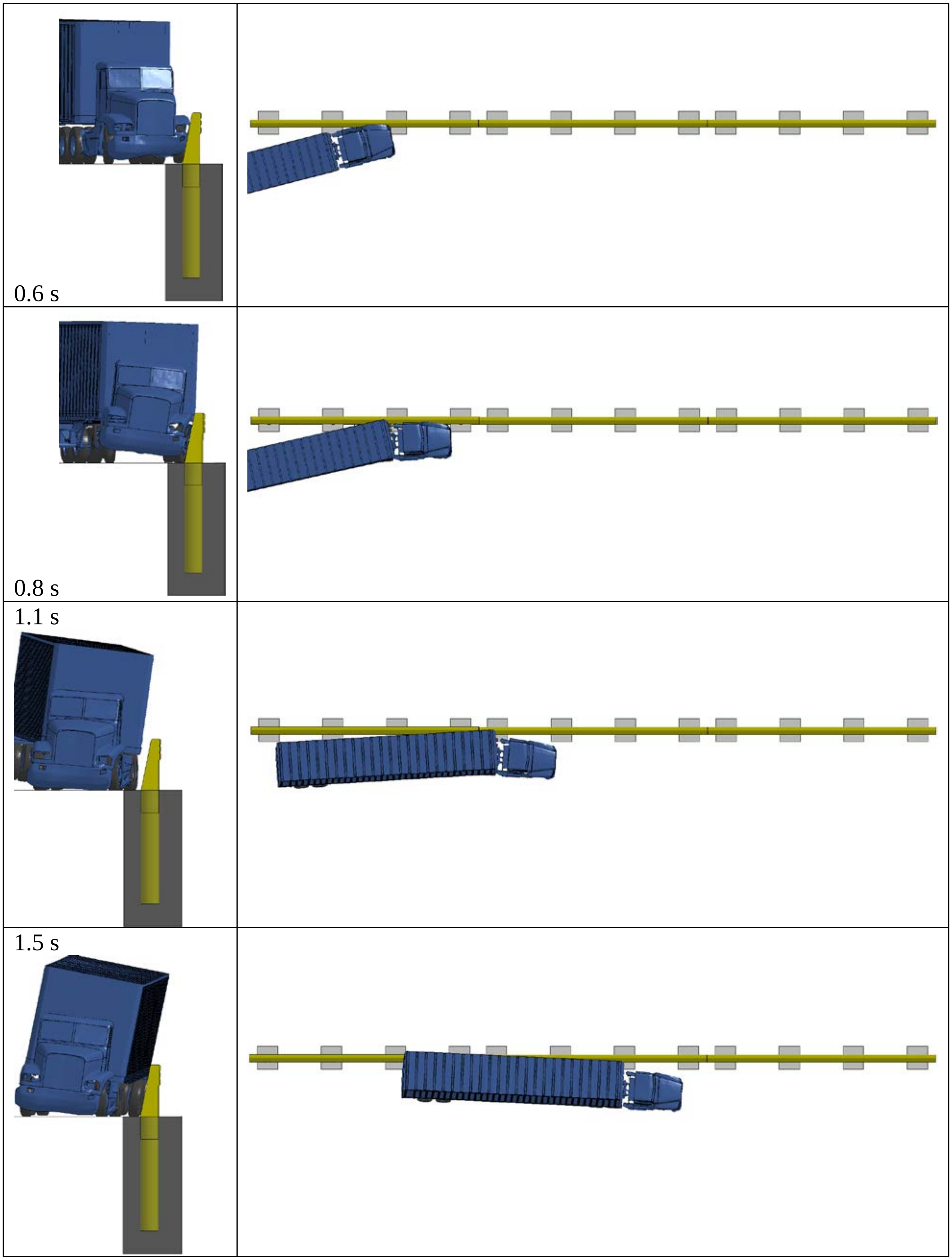


Figure 2.10. Impact Simulation for Drilled Shaft Foundation with 10-Ft Deep Shafts.

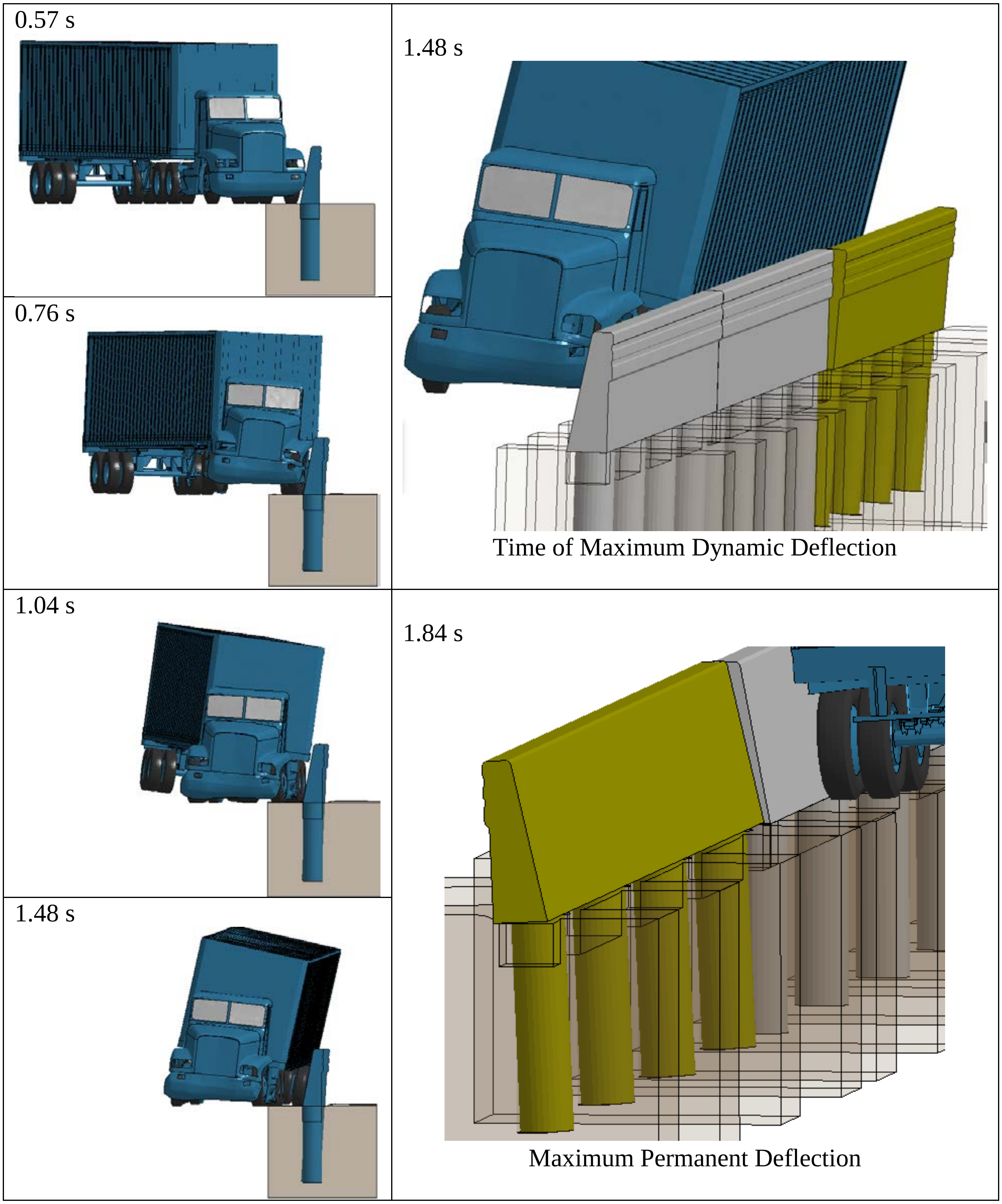


Figure 2.11. Impact Simulation for Drilled Shaft Foundation Design with Four 6-Ft Deep Drilled Shafts.

The permanent deflection observed with the 6-ft long drilled shaft was higher than desired, because it would likely require resetting the barrier and the foundation after a design vehicle impact in the field. To reduce the dynamic and permanent deflection of the barrier without increasing the depth of the foundation, another foundation design was modeled with five 6-ft long drilled shafts instead of four (Figure 2.12). In this design, the adjacent drilled shaft centers were spaced 11 ft apart. The end shafts were spaced 3 ft from the respective ends of the barrier segments. Figure 2.13 shows the results of the simulation with this foundation. The maximum dynamic deflection of the barrier was 3.75 inches, and the maximum permanent deflection was 1.22 inches. The working width of the barrier and foundation system was 31.8 inches at the height of 148.6 inches.

For the drilled shaft foundation design concept, the five 6-ft drilled shaft design was selected for final detailing of reinforcement.

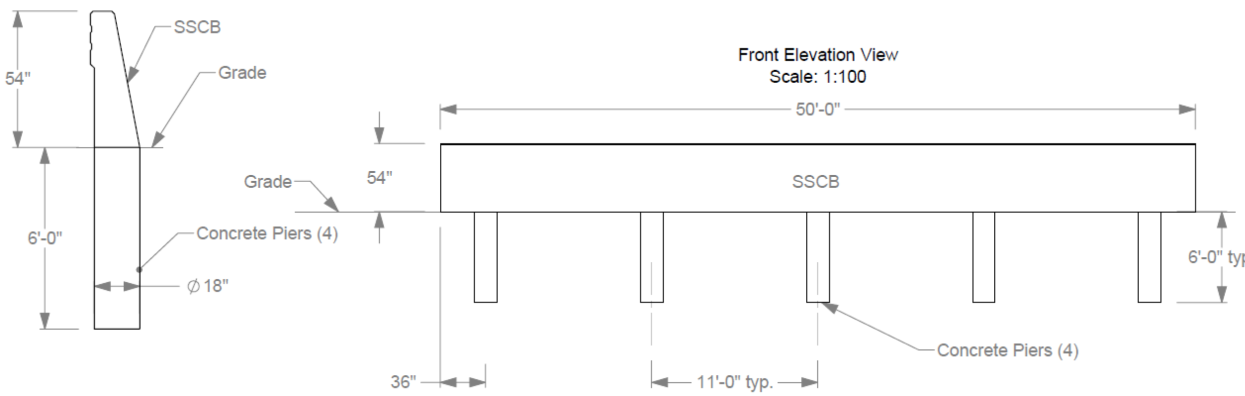


Figure 2.12. Drilled Shaft Foundation with Five 6-Ft Long Drilled Shafts.

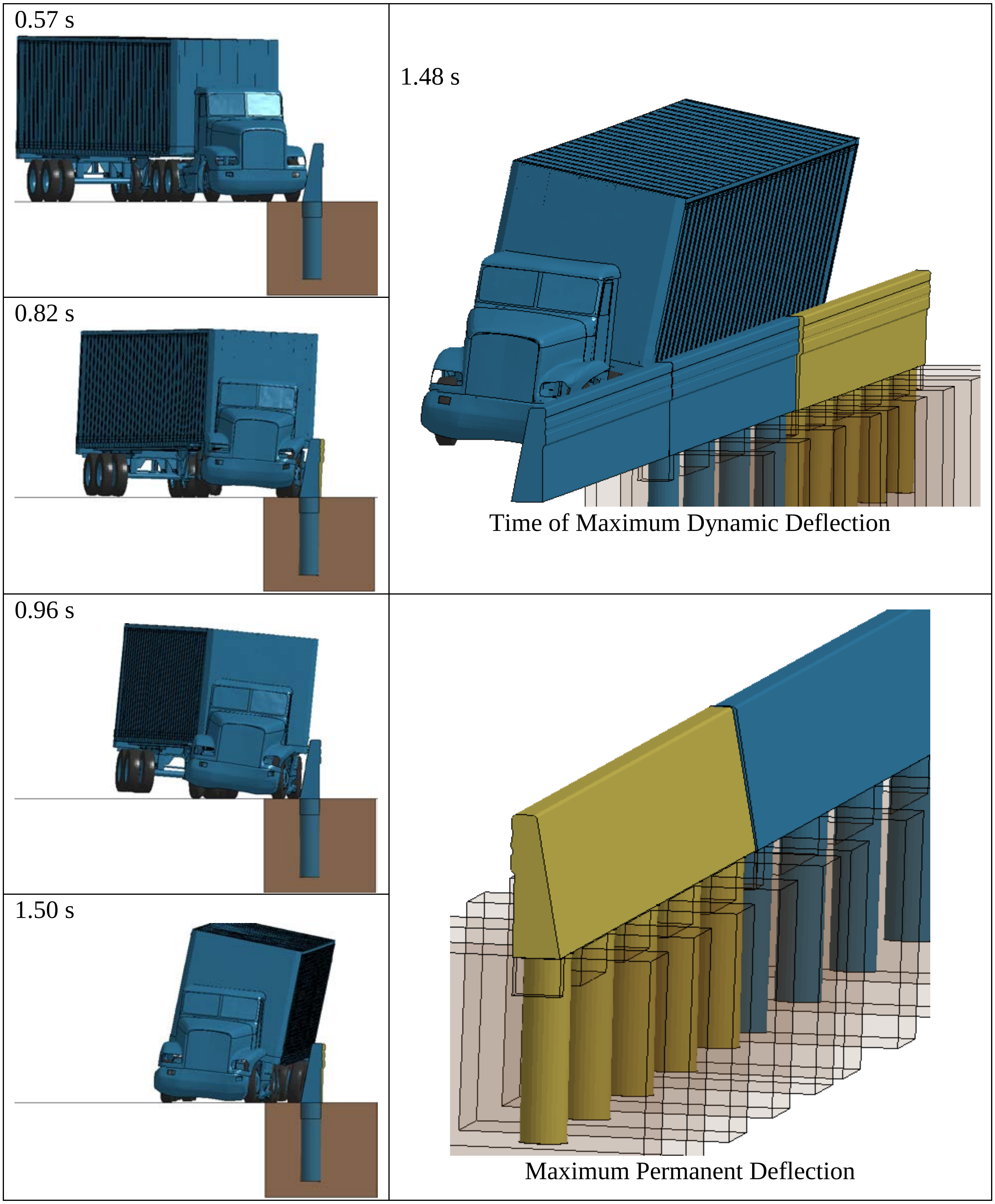
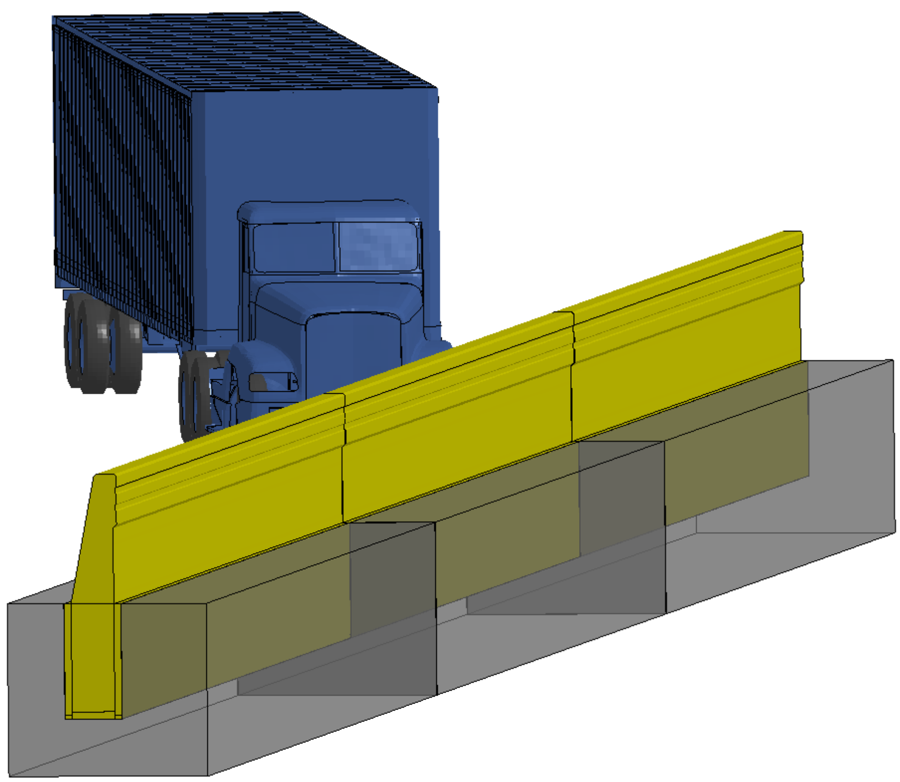


Figure 2.13. Impact Simulation of Drilled Shaft Foundation with Five 6-Ft Deep Drilled Shafts.

2.2.2 Concrete Beam Foundation Design

As shown in Figure 2.3, this foundation design was comprised of a 48-inch deep, 24-inch wide concrete beam that was attached to the base of the single slope barrier along the entire length of the 50-ft segment.

Figure 2.14 shows the finite element model of this barrier and foundation. Figure 2.15 shows the results of the *MASH* Test 5-12 impact simulation with the tractor trailer vehicle model. There was very little movement of the barrier and the foundation, as shown in the sequential images of the impact in Figure 2.15. The vehicle was successfully contained and redirected by the barrier and the foundation system. The maximum dynamic deflection of the barrier was 1.8 inches, and the maximum permanent deflection was 0.4 inch. The working width of the barrier was 33.0 inches at the height of 148.4 inches.



(soil shown with transparency to show the foundation)

Figure 2.14. Concrete Beam Foundation Simulation Model (48-Inch × 24-Inch Foundation).

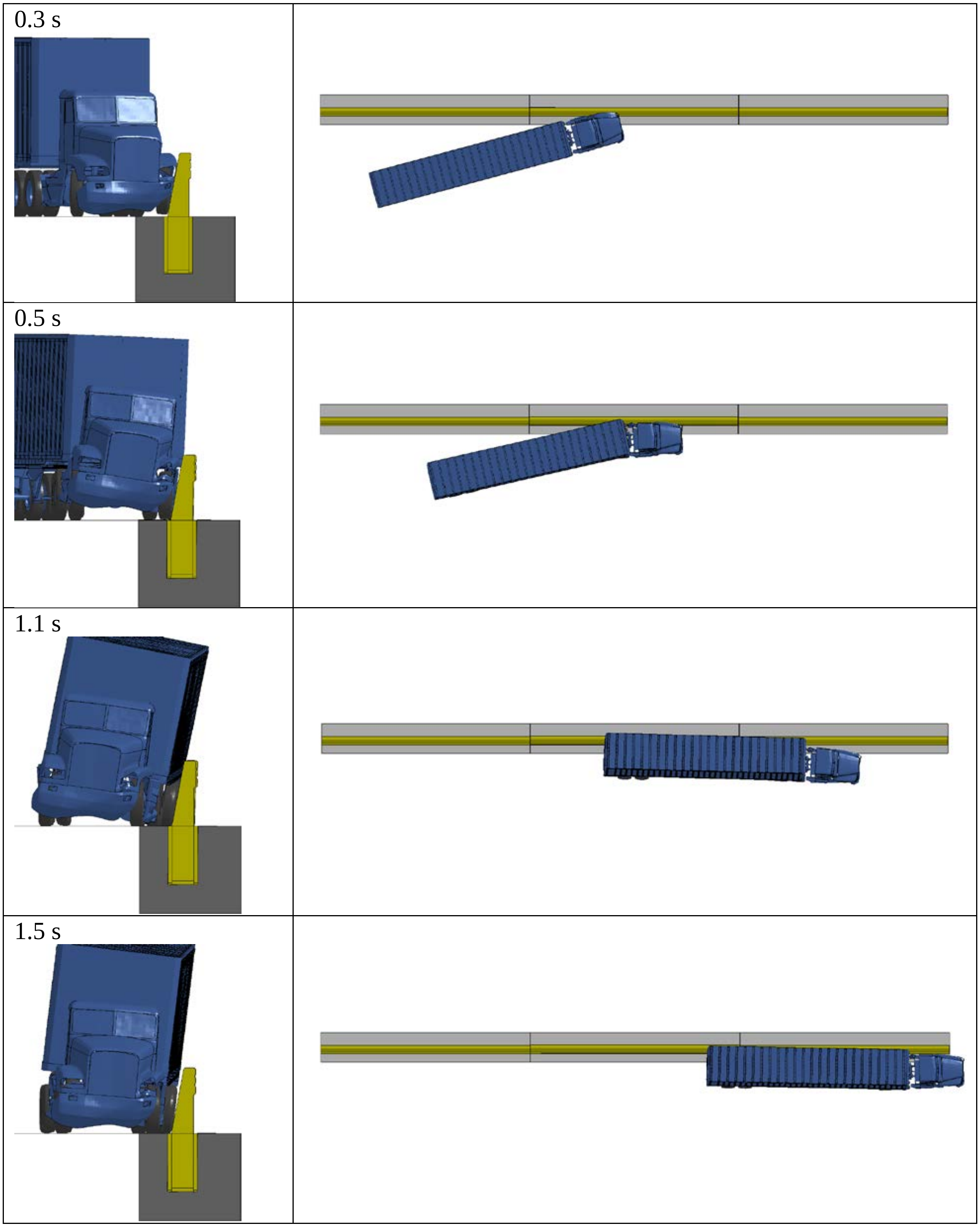


Figure 2.15. Impact Simulation for Preliminary Concrete Beam Foundation Design.

Due to the low deflection of the foundation design, researchers reduced the depth and width of the concrete beam to 36 inches and 18 inches, respectively, and performed another impact simulation under *MASH* Test 5-12 conditions. For this case, the maximum dynamic deflection of the barrier was 2.5 inches, and the maximum permanent deflection was 1.2 inches. The working width of the barrier and foundation system was 33.6 inches at the height of 148.0 inches.

While the results of the 18-inch by 36-inch beam foundation were considered acceptable, TxDOT wished to evaluate its standard Traffic Rail Foundation (TRF) that is very similar in dimensions with a width and depth of 19 inches and 33 inches, respectively. TTI researchers developed a model of the Traffic Rail Foundation and performed another impact simulation with *MASH* Test 5-12 impact conditions. Figure 2.16 shows the results of this simulation. The maximum dynamic deflection of the barrier was 3.6 inches, and the maximum permanent deflection was 0.35 inches. The working width of the barrier and foundation system was 34.2 inches at the height of 149.2 inches.

For the concrete beam foundation concept, the TxDOT TRF results were considered acceptable and it was selected for final detailing of reinforcement.

2.2.3 Moment Slab Foundation Design

As shown in Figure 2.5, this foundation design was comprised of an 18-inch deep and 10-ft wide moment slab that was attached to the base of the single slope barrier and ran along the entire length of the 50-ft segment.

Figure 2.17 shows the finite element model of this barrier and foundation. Figure 2.18 shows the results of *MASH* Test 5-12 impact simulation with the tractor trailer vehicle model. As can be seen from the sequential images of the impact, there was very little movement of the barrier and the foundation. The vehicle was successfully contained and redirected by the barrier and the foundation system. The maximum dynamic deflection of the barrier was 0.6 inch, and the maximum permanent deflection was 0.0 inch. The working width of the barrier and the foundation system was 36.3 inches at the height of 148.0 inches.

Due to the low deflection of the foundation design observed in the simulation, TTI researchers reduced the width of the moment slab to 6 ft, while keeping the same 18-inch depth. A finite element model of this modified foundation was developed, and the results of the impact simulation are shown in Figure 2.19. The maximum dynamic deflection of the barrier was 3.1 inches, and the maximum permanent deflection was 0.1 inch. The working width of the barrier and foundation system was 38.0 inches at the height of 149.2 inches.

While the deflection of the 6-ft wide moment slab was considered acceptable, there was lifting of the slab observed during the vehicle impact, which was considered undesirable (see Figure 2.20). For this reason, the 10-ft wide moment slab foundation was selected for final detailing of reinforcement.

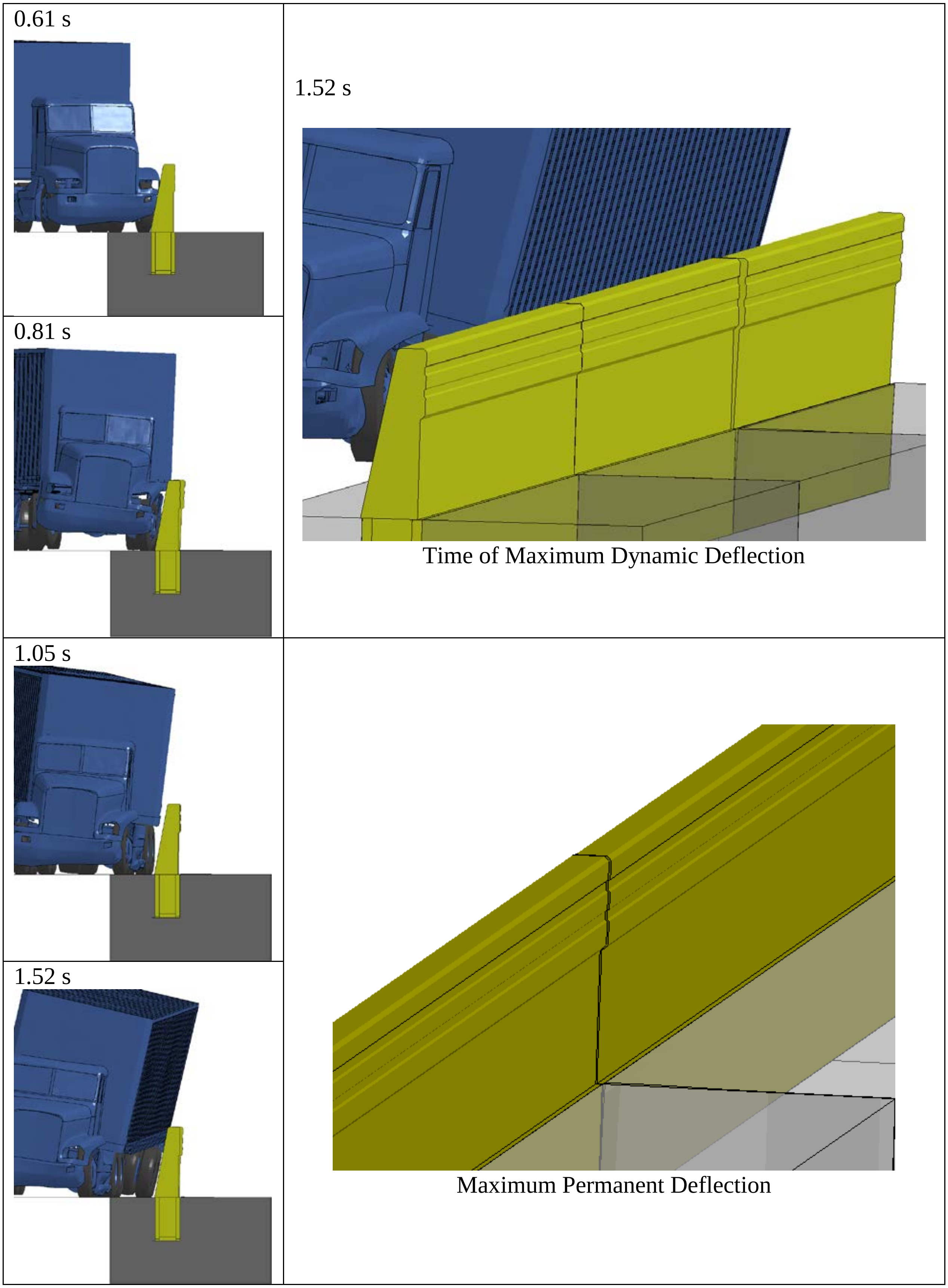
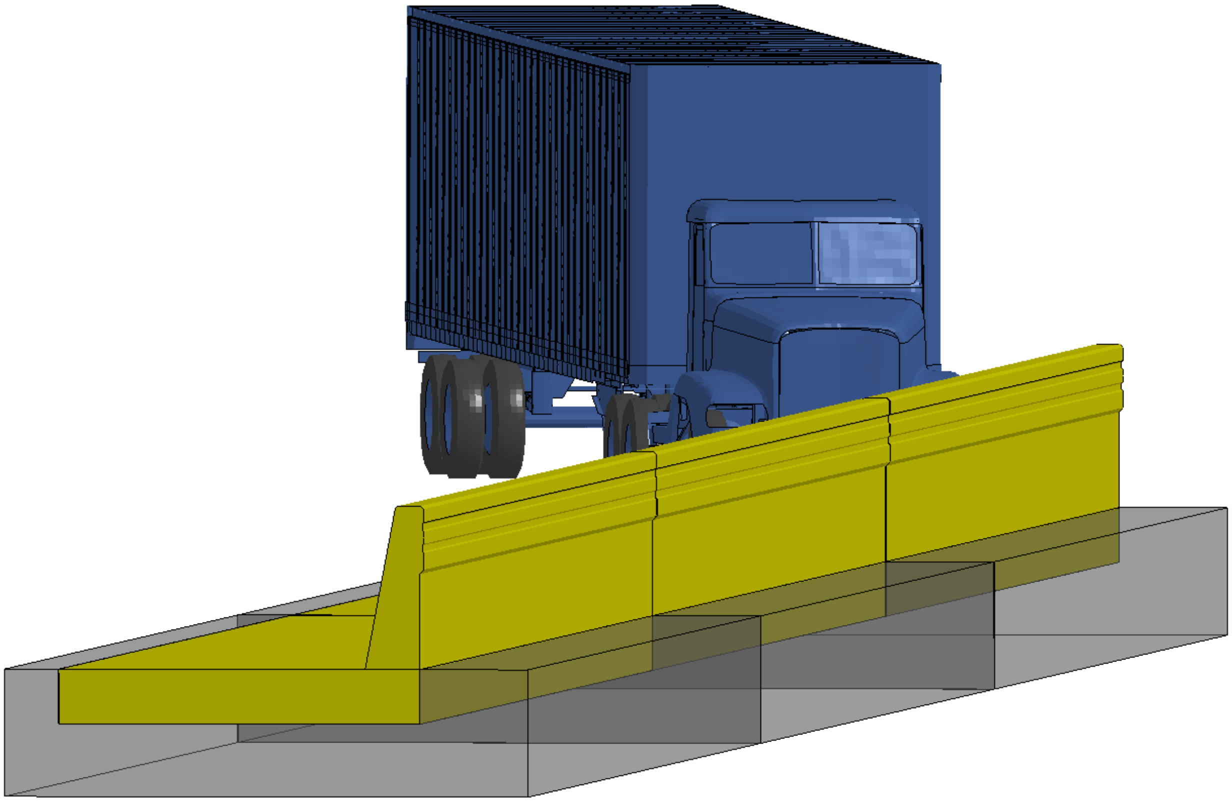


Figure 2.16. Impact Simulation with Standard TxDOT Traffic Rail Foundation.



Soil shown with transparency to show foundation.

Figure 2.17. 10-Ft Wide Moment Slab Foundation Simulation Model.

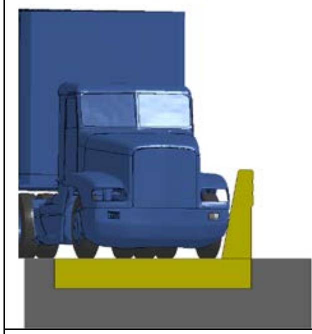
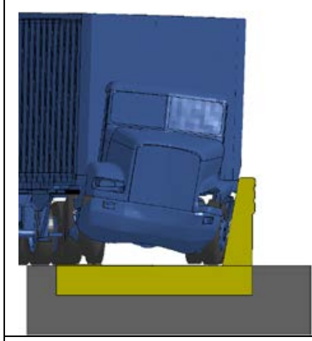
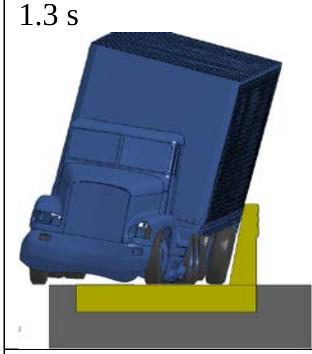
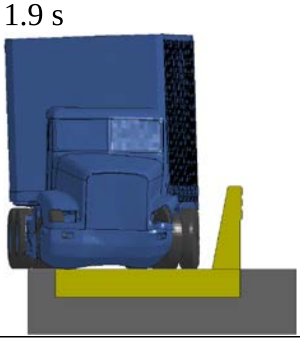
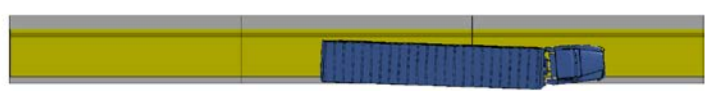
0.4 s 	
0.6 s 	
1.3 s 	
1.9 s 	

Figure 2.18. Impact Simulation for 10-Ft Wide Moment Slab Foundation.

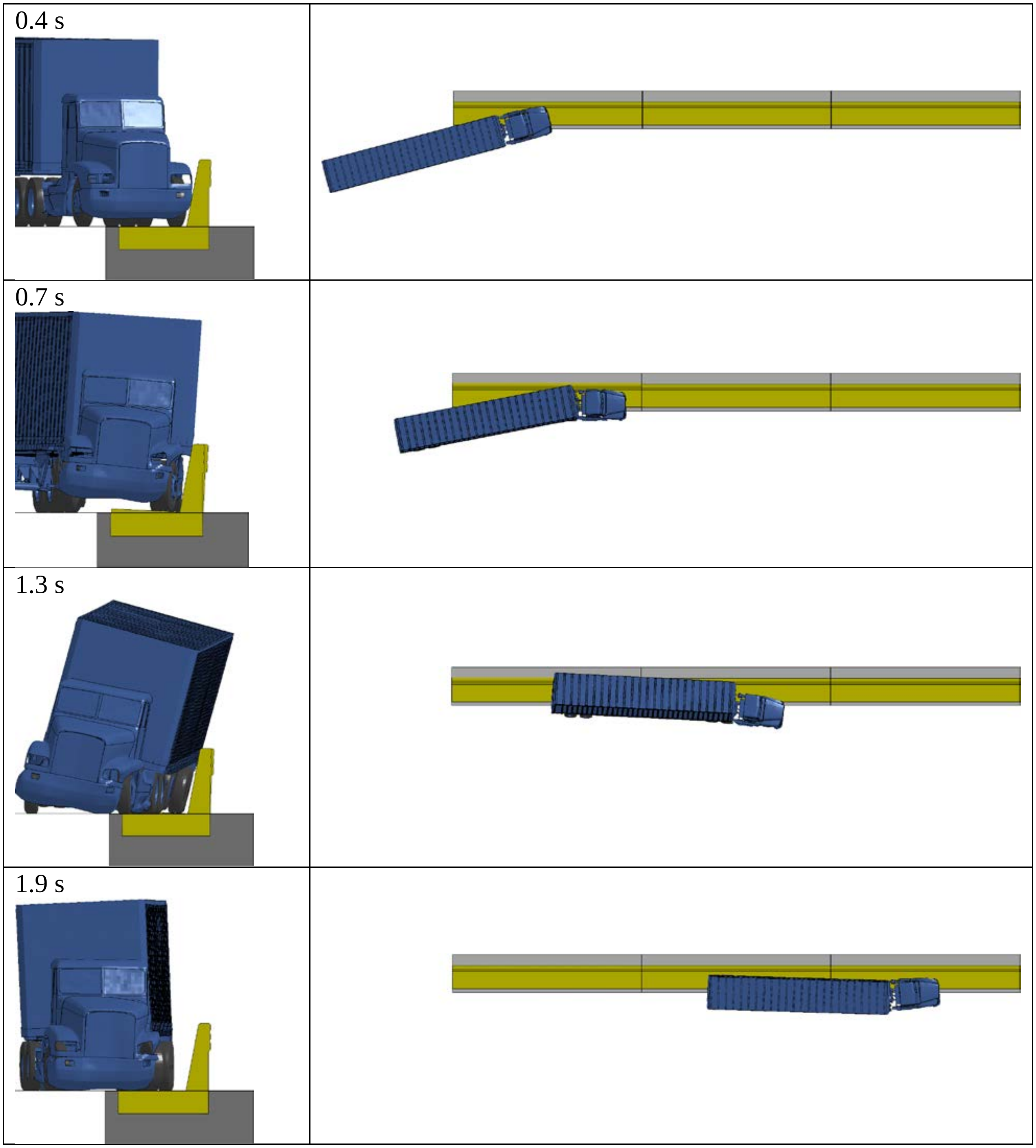


Figure 2.19. Impact Simulation for 6-Ft Wide Moment Slab Foundation.

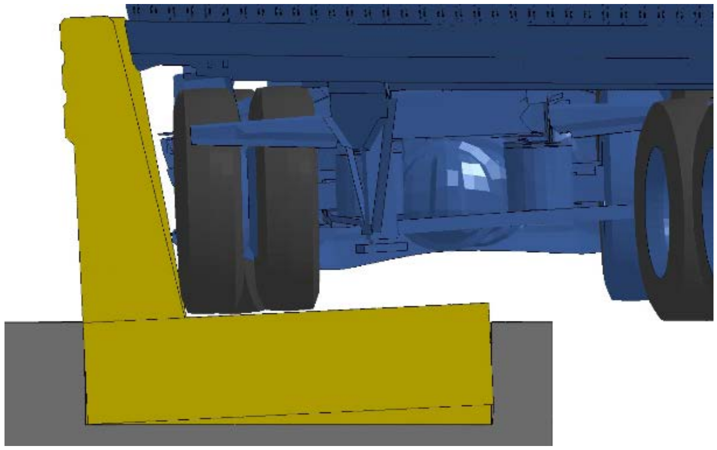


Figure 2.20. Lifting of 6 Ft Wide Moment Slab.

2.2.4 Simulation Analyses Summary

The final foundation designs selected for further development of reinforcement details are summarized in Table 2.1. Of these designs, the drilled shaft foundation was selected for full-scale crash testing due to having the largest deflection, and because its discrete connection to the barrier segment was considered more critical than the continuous barrier-to-foundation connection of the moment slab and the beam foundations.

Table 2.1. Summary of Simulation Analyses.

Foundation Type	Permanent Deflection (inches)	Maximum Dynamic Deflection (inches)	Working Width (inches)	Working Width Height (inches)
Drilled Shaft Five 6-ft long shafts	1.22	3.75	31.8	148.6
Concrete Beam TRF 19 inch × 33 inch	0.35	3.6	34.2	149.2
Moment Slab 18 inch × 10 ft	0.0	0.6	36.3	148.0

2.3 REINFORCEMENT DESIGN

Once the basic geometric designs of the foundations were finalized using the FE analyses, TTI researchers developed reinforcement details of the 54-inch tall single slope barrier and the three selected foundations. The designs were reviewed and revised by TxDOT, and the final details are presented in this report.

Details of the drilled shaft foundation, which was selected for full-scale crash testing, are presented in Chapter 3. Details of the concrete beam foundation and moment slab foundation designs are presented in Figure 2.21 and Figure 2.22, respectively. Figure 2.23 presents details of the various stirrups used in these foundations. The reinforcement of the barrier and the foundations were designed such that the foundation and the barrier can be constructed in two separate concrete pours. The barrier and the foundations have a segment length of 50 ft, which was the desired minimum length for a single segment that is expected to shield bridge columns.

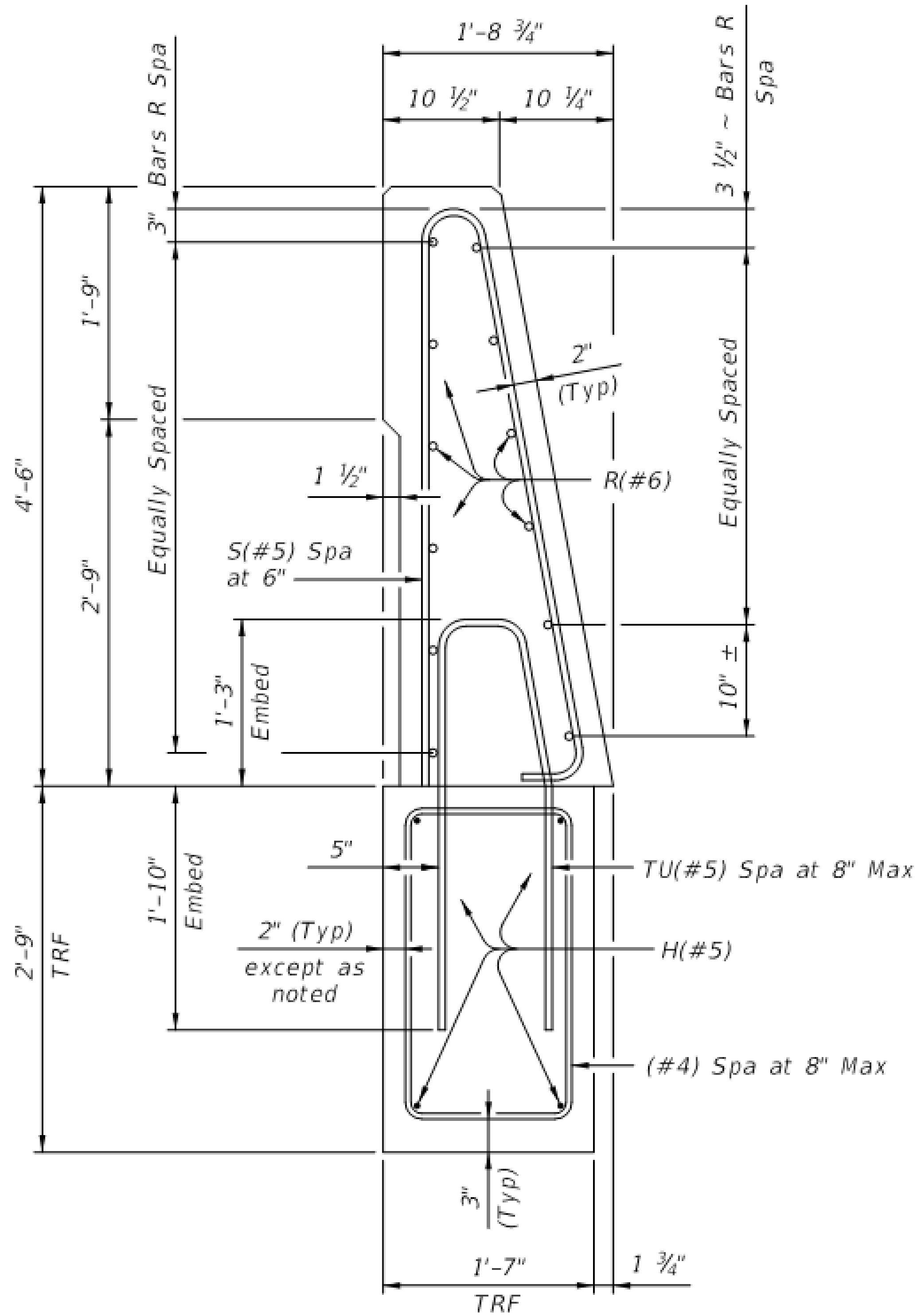


Figure 2.21. Reinforcement Details of Single Slope Barrier with TRF Concrete Beam Foundation.

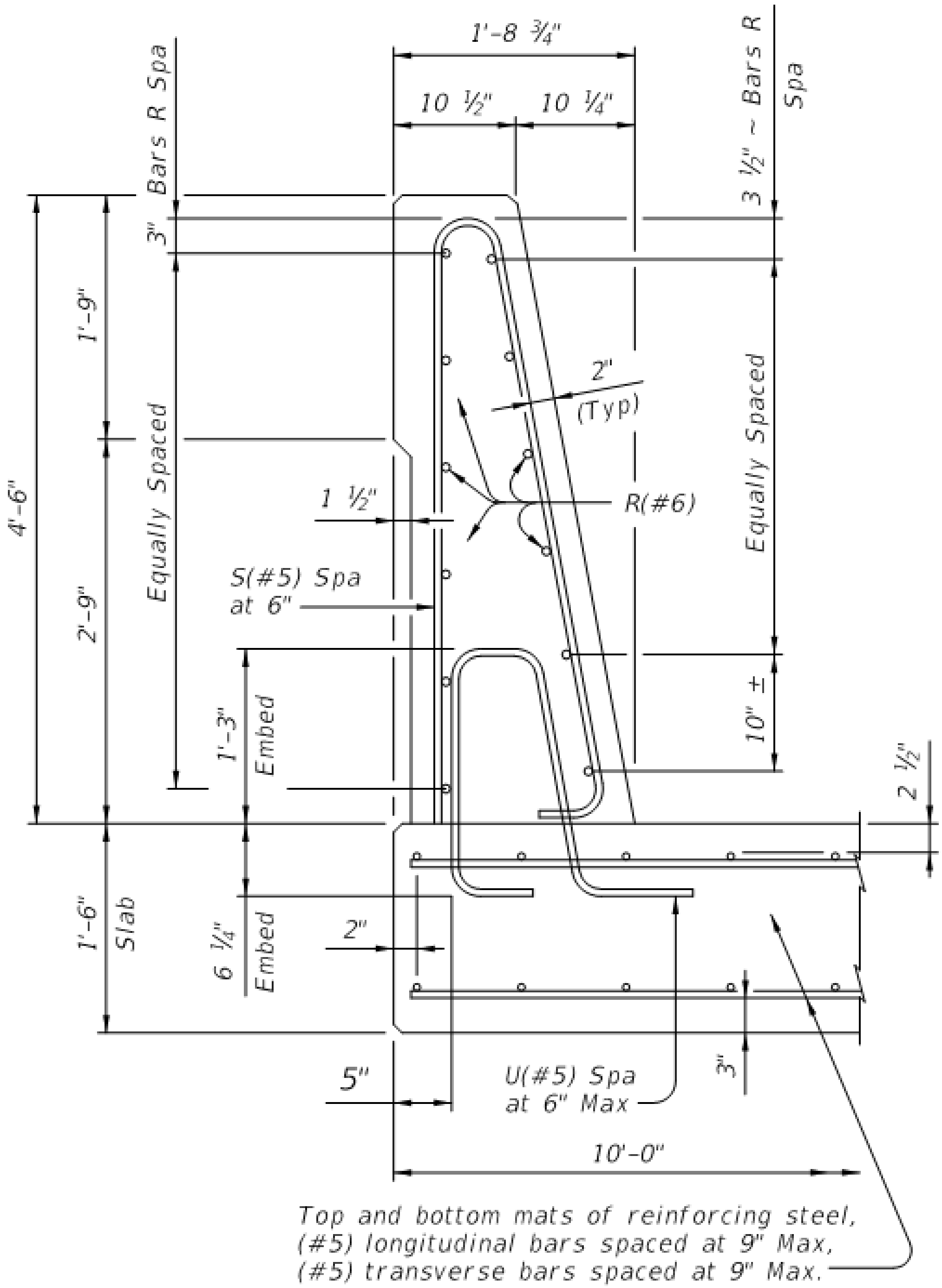


Figure 2.22. Reinforcement Details of Single Slope Barrier with Moment Slab Foundation.

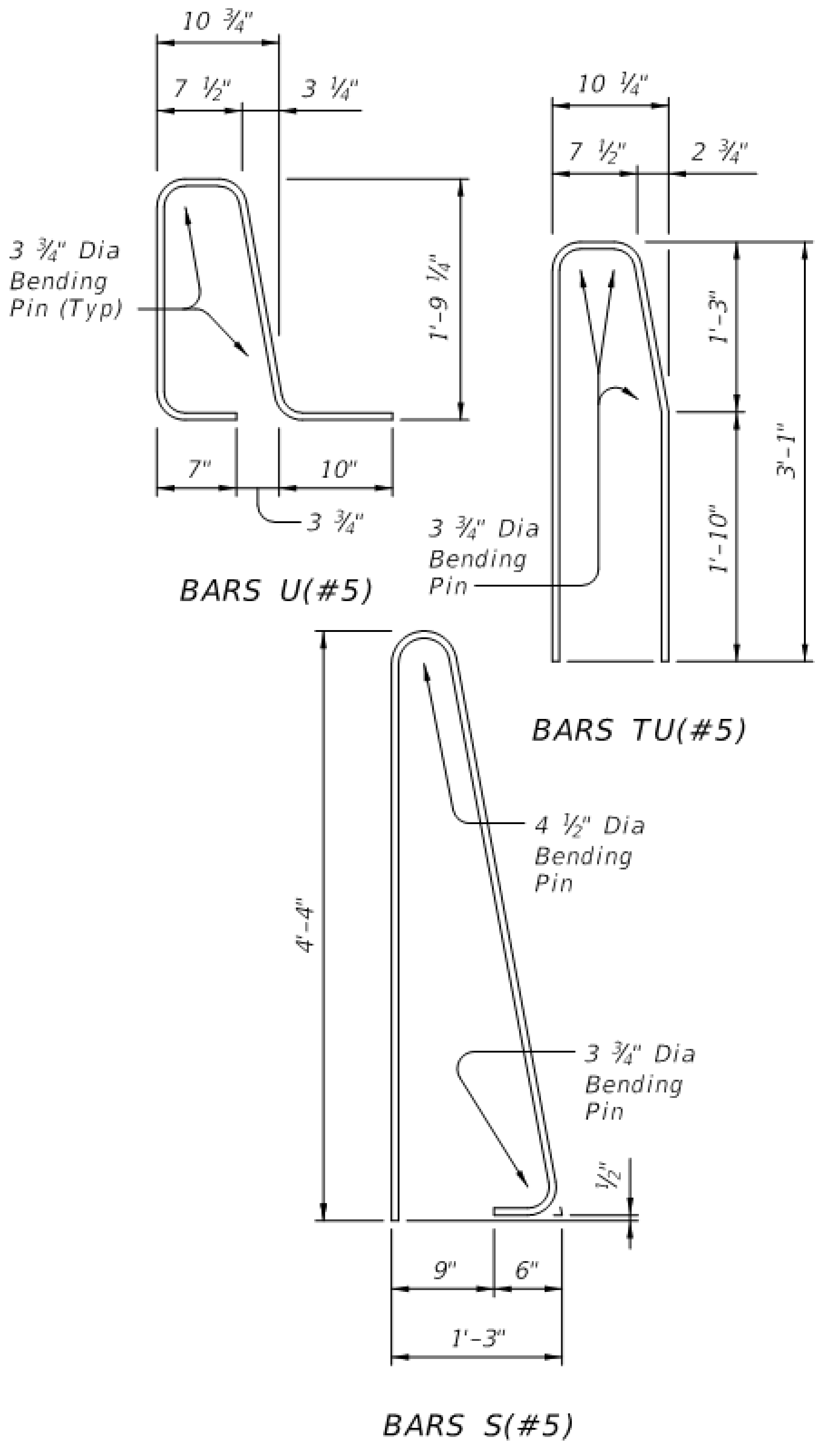


Figure 2.23. Details of Stirrups Used in Barrier and Foundation Designs.

CHAPTER 3:
SYSTEM DETAILS

3.1 TEST ARTICLE AND INSTALLATION DETAILS

The test installation consisted of three 54-inch tall segments of steel reinforced single slope concrete barrier with drilled shaft foundation. Each segment was 50 ft long and had five drilled shafts spaced 11 ft from each other. The two end shafts of each segment were spaced 3 ft from the ends. The shafts were 18 inches in diameter and 6 ft deep. The single slope barrier segments were 19¼ inches wide at bottom, sloping on the traffic side to 10½ inches wide at top, with a 1½-inch wide by 21-inch tall offset at the top of the otherwise vertical field side face. The three segments were unconnected and independent with a gap of approximately ½-inch between them. The total installation length was approximately 150 ft-1 inch. The test installation was installed in native soil at the test site.

Figure 3.1 presents overall information on the SSCB with the drilled shaft foundation, and Figures 3.2 and 3.3 provide photographs of the installation. Appendix A provides further details of the installation.

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 SSCB with the drilled shaft foundation.

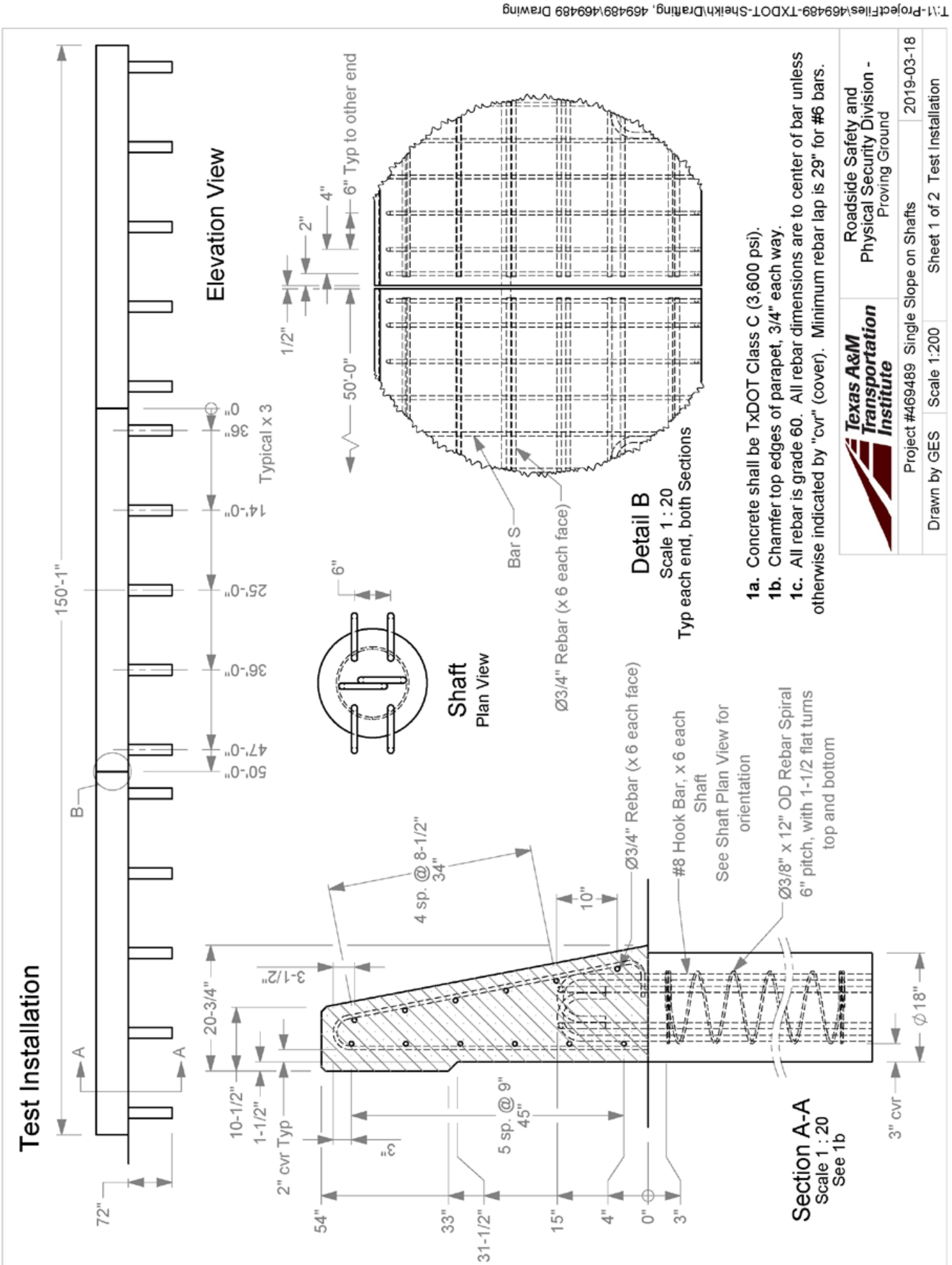


Figure 3.1. Overall Details of SSCB with the Drilled Shaft Foundation.

Figure 3.2. SSCB with the Drilled Shaft Foundation Construction.

Figure 3.3. SSCB with the Drilled Shaft 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-5 longitudinal barriers. *MASH* Test 5-12 involves a 36000V vehicle weighing 79,300 lb ±1100 lb impacting the critical impact point (CIP) of the barrier at an impact speed of 50 mi/h ±2.5 mi/h and an impact angle of 15° ±1.5°. The target CIP was determined through simulation and was chosen to maximize the barrier's lateral deflection. Figure 4.1 shows the target CIP for the 54-inch SSCB on the drilled shaft foundation.

MASH Tests 5-10 and 5-11 were not performed. The single slope concrete barrier with drilled shaft foundations is expected to behave nearly rigidly when impacted by the lighter small car and pickup truck vehicles. Since the impact performance of a rigid single slope concrete barrier is considered acceptable for Test 5-10 and 5-11 based on past testing, these tests were not considered critical for evaluation of the SSCB with the drilled shaft foundation under this project (*4, 5*).

Table 4.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-5 Longitudinal Barriers.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Longitudinal Barrier	5-10	1100C	62 mi/h	25	A, D, F, H, I
	5-11	2270P	62 mi/h	25	A, D, F, H, I
	5-12	36000V	50 mi/h	15	A, D, G

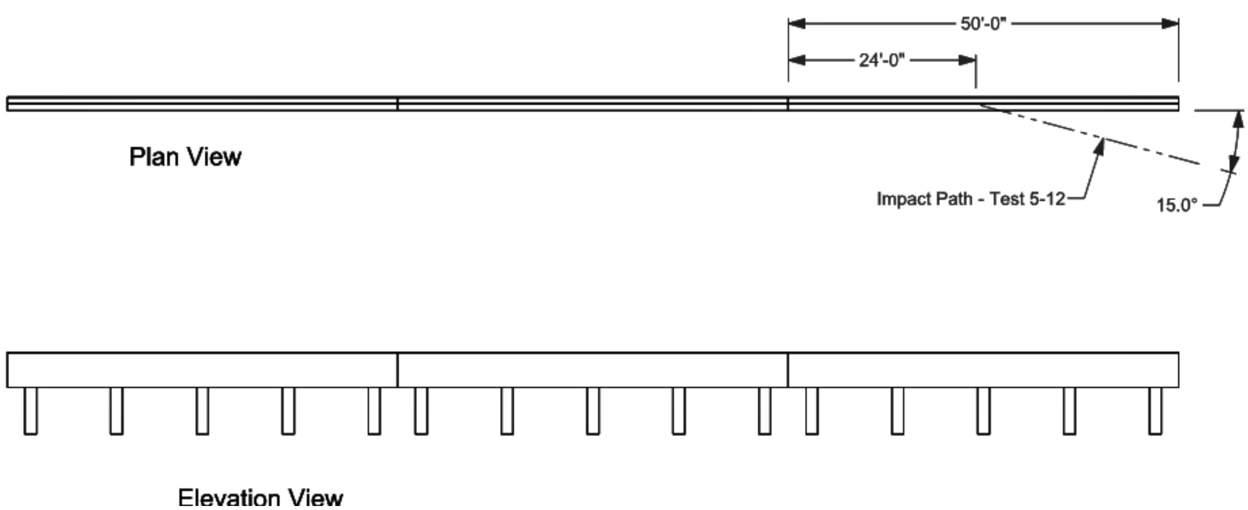


Figure 4.1. Target CIP for *MASH* Test 5-12 on SSCB with the Drilled Shaft Foundation.

The crash test and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 5 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 5-12 are listed in Table 4.1, and the substance of the evaluation criteria in Table 4.2. Chapter 7 presents an evaluation of the crash test results.

Table 4.2. Evaluation Criteria Required for *MASH* Test 5-12.

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 barrier was at the end 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 36000V tractor-trailer was self-powered and was guided into the test installation via a cable guidance 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) throughout the impact event.

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 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 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).

Placement of the electronic instrumentation is shown in Figure 5.1:

(A) The front accelerometers were placed on the truck frame rail 17 inches forward of the front axle, in the longitudinal centerline, at height of 32 inches above ground surface.

(B) The accelerometers and rate transducers at the rear of the tractor were placed 125 inches rearward of the front axle, at the longitudinal centerline, at a height of 36 inches above ground surface.

(C) The rear accelerometers were placed on the trailer frame 720 inches rearward of the front axle, at longitudinal centerline, at a height of 50 inches above ground surface.

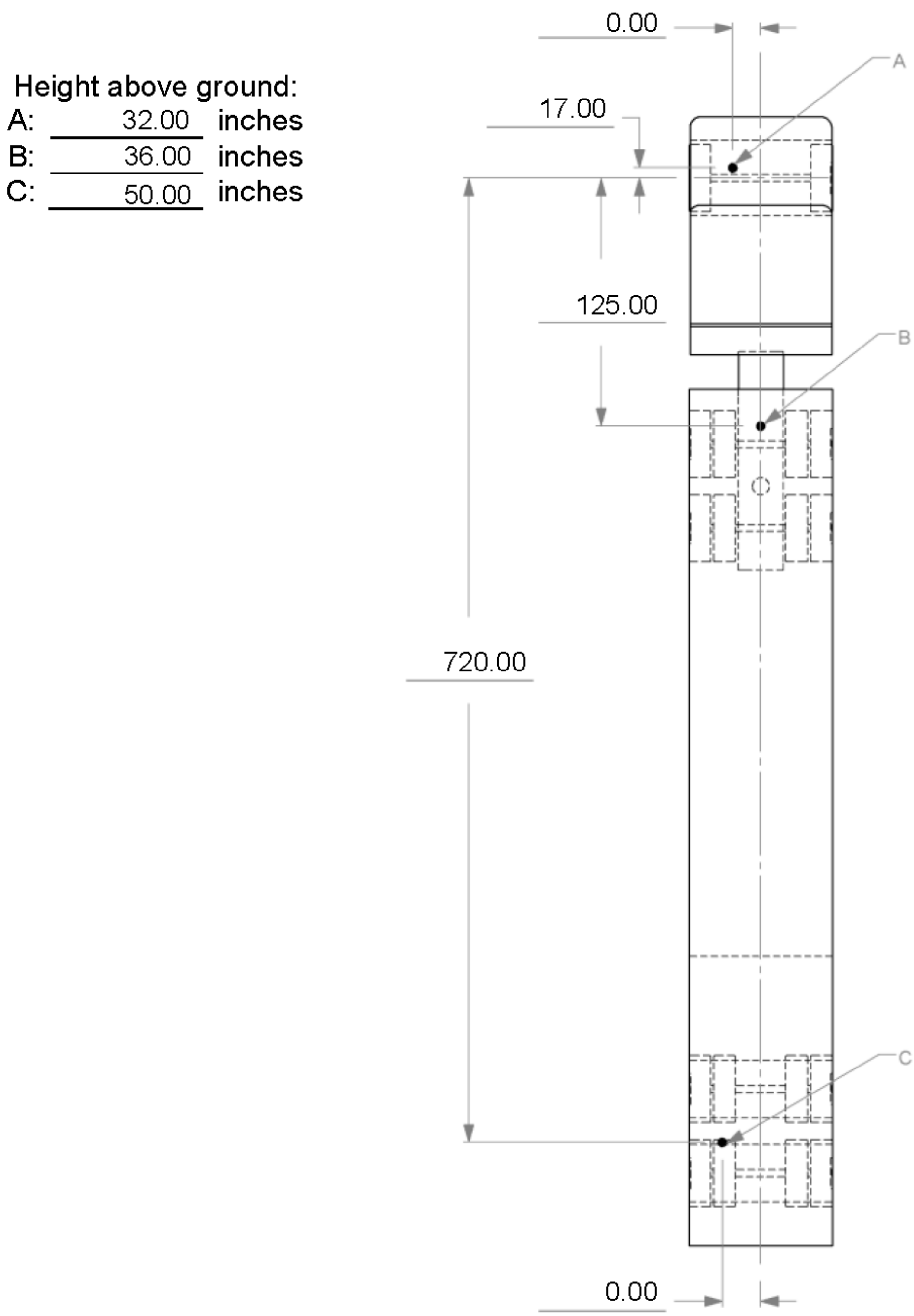


Figure 5.1. Location of Instrumentation.

5.3.2 Anthropomorphic Dummy Instrumentation

MASH does not recommend or require use of a dummy in the 36000V vehicle and none was 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 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 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 5-12 (CRASH TEST NO. 469489-01-3)

6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 5-12 involves a 36000V vehicle weighing 79,300 lb ±1100 lb impacting the CIP of the test article at an impact speed of 50 mi/h ±2.5 mi/h and an impact angle of 15° ±1.5°. The CIP for *MASH* Test 5-12 on the SSCB with the drilled shaft foundation was 24 ft ±1 ft upstream of the centerline of the joint between barrier segments 1 and 2. This impact point was selected to maximize the deflection of the 50-ft barrier segment.

The 2006 Freightliner TR tractor with 1999 TRL VN 53 trailer used in the test weighed 80,170 lb, and the actual impact speed and angle were 48.9 mi/h and 15.0°, respectively. The actual impact point was 24.9 ft upstream of the centerline of the joint between barrier segments 1 and 2. Minimum target impact severity (IS) was 404 kip-ft, and actual IS was 429 kip-ft.

6.2 WEATHER CONDITIONS

The test was performed on the afternoon of July 12, 2019. Weather conditions at the time of testing were as follows: wind speed: 7 mi/h; wind direction: 26° (vehicle was traveling at magnetic heading of 180°); temperature: 93°F; relative humidity: 60 percent.

6.3 TEST VEHICLE

Figures 6.1 and 6.2 show the 2006 Freightliner TR tractor with 1999 TRL VN 53 trailer used for the crash test. The vehicle's test inertia weight was 80,170 lb, and its gross static weight was 80,170 lb. The height to the lower edge of the vehicle bumper was 17.5 inches, and the height to the upper edge of the bumper was 34.0 inches. The height to the ballast's center of gravity was 71.75 inches. Table C.1 in Appendix C.1 gives additional dimensions and information on the vehicle. The 36000V vehicle was directed into the test installation via a cable guidance system while traveling under its own power, and was released to be freewheeling and unrestrained just prior to impact.

Figure 6.1. SSCB/Test Vehicle Geometrics for Test No. 469489-01-3.

Figure 6.2. Test Vehicle before Test No. 469489-01-3.

6.4 TEST DESCRIPTION

The test vehicle was traveling at an impact speed of 48.9 mi/h when it contacted the SSCB with the drilled shaft foundation 24.9 ft upstream of the centerline of the joint between barrier segments 1 and 2 at an impact angle of 15.0°. Table 6.1 lists events that occurred during

Test No. 469489-01-3. Figures C.1 and C.2 in Appendix C.2 present sequential photographs during the test.

Table 6.1. Events during Test No. 469489-01-3.

TIME (s)	EVENTS
0.0000	Vehicle tractor contacts the barrier.
0.0460	Vehicle tractor begins to redirect.
0.2210	Front right lower corner of trailer impacts the barrier.
0.2640	Tractor traveling parallel with the barrier.
0.7530	Trailer traveling parallel with the barrier.
0.7820	Right rear lower corner of trailer impacts the barrier

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*. Brakes on the vehicle were applied 4.1 s after impact, and the vehicle came to rest 351 ft downstream of the impact and 82 ft toward the field side.

6.5 DAMAGE TO TEST INSTALLATION

Figure 6.3 shows the damage to the SSCB. There were several gouges in the face of the concrete up to 0.75-inch deep, and the soil was disturbed on the field side indicating up to 0.75 inch of dynamic deflection at ground level. There were several hairline cracks roughly perpendicular to the barrier approximately 30 inches up and downstream of impact. Working width[†] was 40.2 inches, and height of working width was 147.1 inches. Both were attributed to the trailer. Maximum dynamic deflection during the test was 2.9 inches, and maximum permanent deformation was 0.6 inch.

6.6 DAMAGE TO TEST VEHICLE

Figure 6.4 shows the damage sustained by the vehicle. The front bumper, right frame rail, hood, right front springs and U-bolts, right front tire and rim, right fuel tank and side steps, right rear tractor tandem outer tire and rims, right side of the trailer, and the right trailer tandem outer tires and rims were damaged. Maximum exterior crush to the vehicle was 16.0 inches in the side plane at the right front corner at bumper height. No occupant compartment deformation or intrusion was observed. Figure 6.5 shows the interior of the vehicle.

[†] Working width is defined as the distance between the traffic face of the barrier before impact and the maximum lateral position of any major part of the barrier or the vehicle after impact.

Figure 6.3. SSCB after Test No. 469489-01-3.

Figure 6.4. Test Vehicle after Test No. 469489-01-3.

Figure 6.5. Interior of Test Vehicle after Test No. 469489-01-3.

6.7 OCCUPANT RISK FACTORS

Placement of the electronic instrumentation is described below and shown in Figure 5.1:

(A) The front accelerometers were placed on the truck frame rail 17 inches forward of the front axle, in the longitudinal centerline, at height of 32 inches above ground surface.

(B) The accelerometers and rate transducers at the rear of the tractor were placed 125 inches rearward of the front axle, at the longitudinal centerline, at a height of 36 inches above ground surface.

(C) The rear accelerometers were placed on the trailer frame 720 inches rearward of the front axle, at longitudinal centerline, at a height of 50 inches above ground surface.

Data from the accelerometer at location B in Figure 5.1 were digitized for evaluation of occupant risk for informational purposes only, and the 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.

Table 6.2. Occupant Risk Factors for Test No. 469489-01-3.

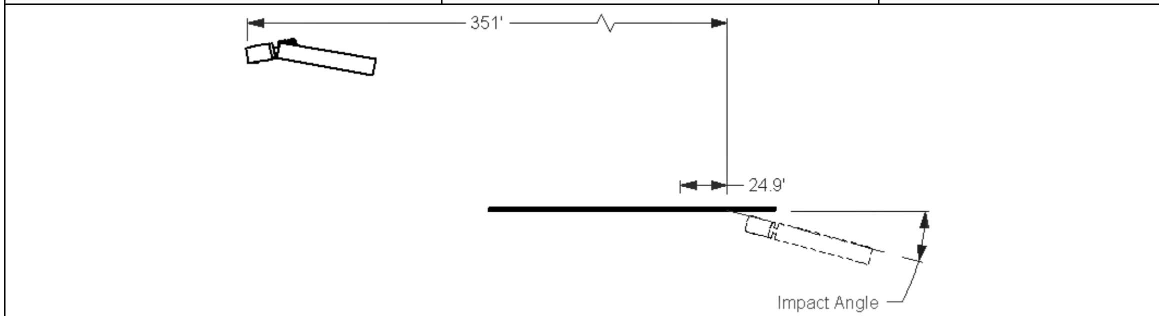
Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)		
Longitudinal	**1.3 ft/s**	at 0.2253 s on right side of interior
Lateral	**12.1 ft/s**	
Occupant Ridedown Accelerations		
Longitudinal	**6.0 g**	0.2347–0.2447 s
Lateral	**10.4 g**	0.2341–0.2441 s
Theoretical Head Impact Velocity (THIV)	**16.8 km/h** **4.7 m/s**	at 0.2234 s on right side of interior
Post Head Deceleration (PHD)	**11.9 g**	0.2347–0.2447 s
Accident Severity Index (ASI)	**0.75**	0.1944–0.2444 s
Maximum 50-ms Moving Average		
Longitudinal	**−1.1 g**	0.2253–0.2753 s
Lateral	**−7.0 g**	0.1624–0.2124 s
Vertical	**−1.7 g**	0.6821–0.7321 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**11°**	0.9858 s
Pitch	**3°**	0.2358 s
Yaw	**32°**	4.0000 s

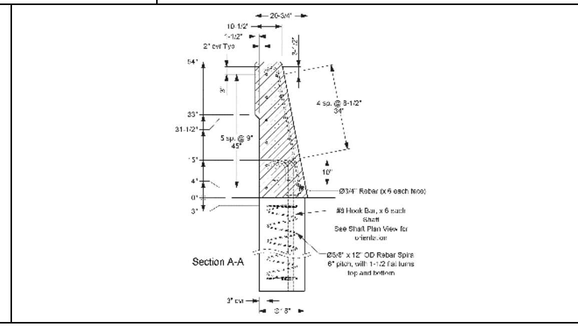
0.000 s

0.350 s

0.700 s

1.050 s





General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 5-12
TTI Test No.	469489-01-3
Test Date	2019-07-12

Test Article

Type	Longitudinal Barrier – Bridge Rail
Name	SSCB on Drilled Shafts
Installation Length	150 ft
Material or Key Elements	3 segments of 50 ft long x 54-inch tall reinforced SSCB each with 5 shafts 18 inches in diameter and 6 ft deep, spaced at 3, 14, 25, 36, and 47 ft

Soil Type and Condition ..... Native soil

Test Vehicle 36000V

Type/Designation	2006 Freightliner w/1999 TRL Trailer
Make and Model	30,700 lb
Curb	80,170 lb
Test Inertial	No dummy
Dummy	80,170 lb
Gross Static	

Impact Conditions

Speed	48.9 mi/h
Angle	15.0°
Location/Orientation	24.9 ft up/strm of joint btwn seg. 1&2

Impact Severity ..... 429 kip-ft

Exit Conditions

Speed	Not obtainable
Angle	Not obtainable

Occupant Risk Values

Longitudinal OIV	1.3 ft/s
Lateral OIV	12.1 ft/s
Longitudinal Ridedown	6.0 g
Lateral Ridedown	10.4 g
THIV	16.8 km/h
PHD	11.9 g
ASI	0.75
Max. 0.050-s Average	
Longitudinal	−1.1 g
Lateral	−7.0 g
Vertical	−1.7 g

Post-Impact Trajectory

Stopping Distance	351 ft downstream 82 ft twd field side

Vehicle Stability

Maximum Yaw Angle	32°
Maximum Pitch Angle	3°
Maximum Roll Angle	11°
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	2.9 inches
Permanent	0.6 inch
Working Width	40.2 inches
Vehicle Intrusion	147.1 inches

Vehicle Damage

VDS	NA
CDC	NA
Max. Exterior Deformation	16.0 inches
OCDI	FS0000000
Max. Occupant Compartment Deformation	None

Figure 6.6. Summary of Results for *MASH* Test 5-12 on SSCB with the Drilled Shaft Foundation.

CHAPTER 7:
SUMMARY AND CONCLUSIONS

7.1 SUMMARY OF RESULTS

An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 5-12 is provided in Table 7.1.

7.2 CONCLUSIONS

The 54-inch tall SSCB with the drilled shaft foundation performed acceptably for *MASH* Test 5-12.

Table 7.1. Performance Evaluation Summary for *MASH* Test 5-12 on SSCB with the Drilled Shaft Foundation.

Test Agency: Texas A&M Transportation Institute — Test No.: 469489-01-3 — Test Date: 2019-07-12

***MASH* Test 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 54-inch tall SSCB with the drilled shaft foundation contained and redirected the 36000V vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 2.9 inches.	Pass
<u>Occupant Risk</u> *D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, 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.	No occupant compartment deformation or intrusion occurred.	
G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	The 36000V vehicle remained upright during and after the collisions event.	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 65.6 ft for the 36000V vehicle), and should be documented.	The 36000V vehicle exited within the exit box criteria.	Documentation only

CHAPTER 8: IMPLEMENTATION‡

Based on the results of the testing and evaluation reported herein, the 54-inch tall single slope concrete barrier with drilled shaft foundation is considered suitable for implementation as a *MASH* TL-5 barrier system.

Comparing results of the crash tested drilled shaft foundation with the simulation of the same system, it can be observed that the simulation had slightly higher permanent and dynamic deflection, and was thus more conservative in predicting the movement of the barrier in soil (see Table 8.1). However, the working width of the barrier was under-predicted by 26.4 percent. The height of the working width was similar in both test and simulation.

Table 8.1. Simulation and Test Results Comparison for Drilled Shaft Foundation Design.

	Test	Simulation
Permanent Deflection	0.6 inch	1.22 inches
Maximum Dynamic Deflection	2.9 inches	3.75 inches
Working Width	40.2 inches	31.8 inches
Working Width Height	147.1 inches	148.6 inches

One of the objectives of this project was to develop guidance on the distance that should be maintained between the 54-inch tall SSCB and the bridge columns supporting an overpass. To protect the bridge columns from any impact from the tractor trailer, they should be placed at an offset equivalent to or greater than the working width of the barrier and foundation system. While the working width of the drilled shaft foundation is known from crash testing, it can be reasonably determined for the moment slab and concrete beam foundations by scaling up the working width results from the simulations (Table 2.1) to compensate for the 26.4 percent under-prediction. Doing so leads to the adjusted working widths presented in Table 8.2.

Table 8.2. Working Widths for Three Foundation Systems of SSCB.

	Working Width (inches)	Offset Behind Barrier (inches)
Moment Slab Foundation	45.9	25.15
Concrete Beam Foundation	43.2	22.45
Drilled Shaft Foundation	40.2	19.45

Working width in *MASH* is measured from the outermost point of the pre-impact traffic-side face of the barrier. Thus, in calculating the offset needed for the shielded bridge columns

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

behind the 54-inch tall SSCB, its width (20.75 inches) is subtracted from the working width. The resulting offset values for the three foundation types are shown in Table 8.2. In the interest of simplifying implementation, a minimum 2-ft offset behind the barrier may be recommended for all three foundation systems.

Statewide implementation of the 54-inch tall SSCB 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 2.21 through 2.23 can be used for this purpose.

REFERENCES

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

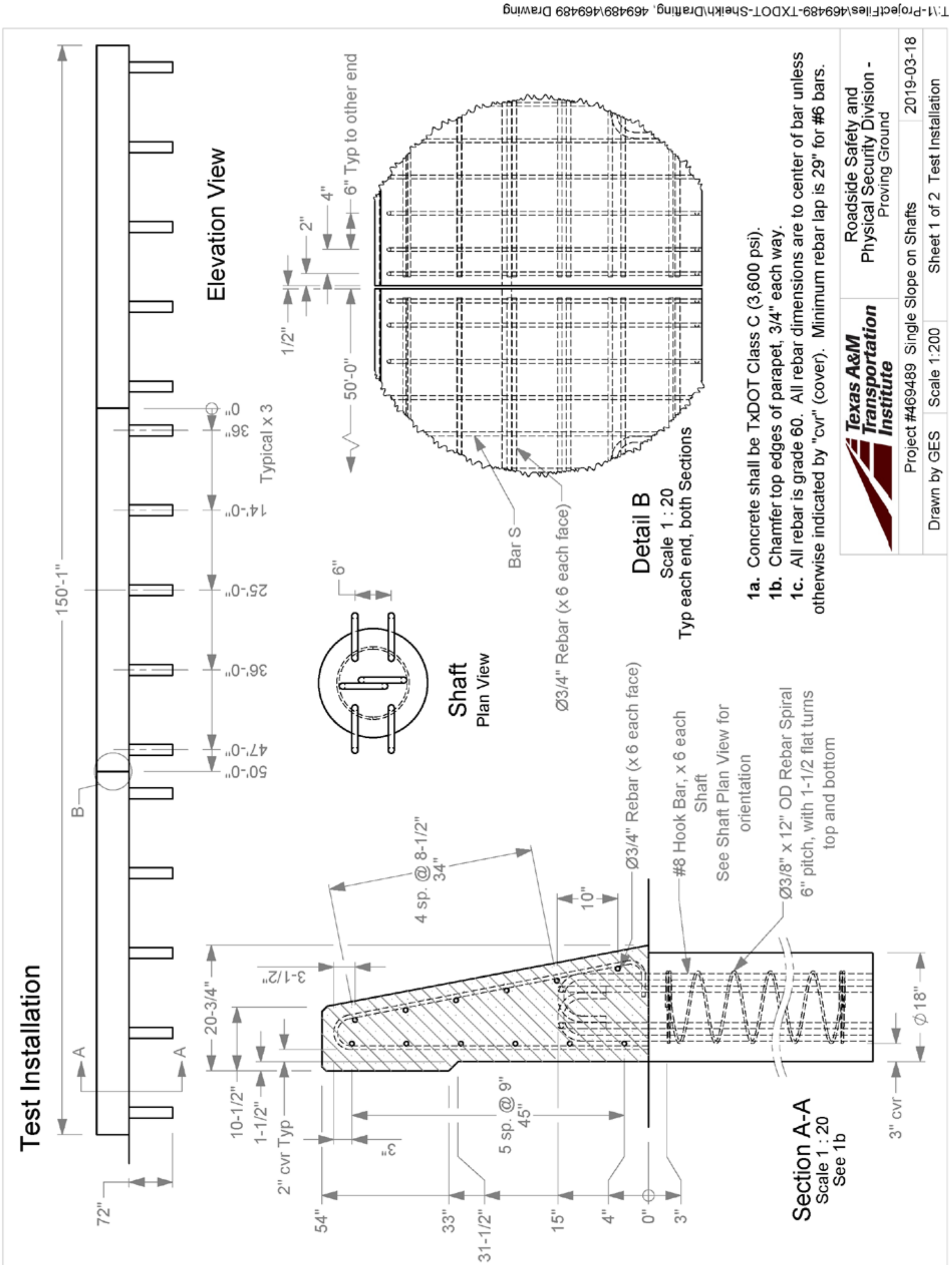
2. Livermore Software Technology Corporation, *LS-DYNA Keyword User's Manual*, 2016, Livermore, California.

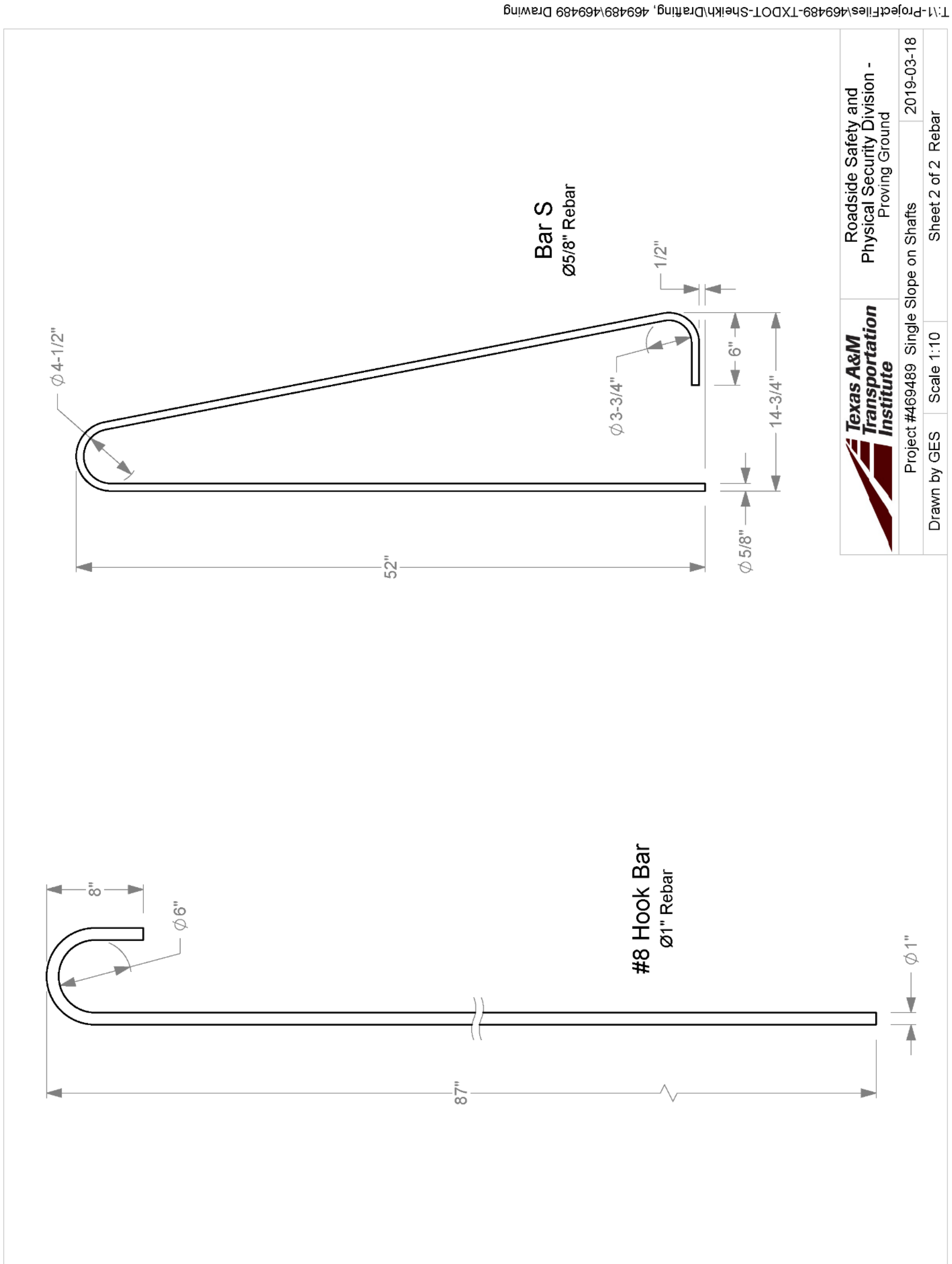
3. Livermore Software Technology Corporation, *LS-DYNA Theory Manual*, 2019, Livermore, California.

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 SSCB WITH DRILLED SHAFT FOUNDATION




T:\1-ProjectFiles\469489-TXDOT-Sheikh\Drafting, 469489\469489 Drawing
Bar S
Ø5/8" Rebar
Ø4-1/2"
Ø3-3/4"
1/2"
6"
14-3/4"
Ø5/8"
52"
#8 Hook Bar
Ø1" Rebar
8"
Ø6"
Ø1"
87"
Roadside Safety and Physical Security Division - Proving Ground
Texas A&M Transportation Institute
Project #469489 Single Slope on Shafts
2019-03-18
Drawn by GES
Scale 1:10
Sheet 2 of 2 Rebar

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

469488-2 469489

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.:3085562 SECTION: REBAR 25MM (#8) 20'0" 420/60 GRADE: ASTM A615-18e1 Gr 420/60 ROLL DATE: 01/11/2019 MELT DATE: 01/05/2019 Cert. No.: 82597572 / 085562A041	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#: 82597572 BOL#: 72796067 CUST PO#: 804636 CUST P/N: DLVRY LBS / HEAT: 23496.000 LB DLVRY PCS / HEAT: 440 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.41%				
Mn	1.11%				
P	0.012%				
S	0.043%				
Si	0.23%				
Cu	0.30%				
Cr	0.08%				
Ni	0.23%				
Mo	0.088%				
V	0.005%				
Cb	0.002%				
Sn	0.011%				
Al	0.001%				
Yield Strength test 1	68.4ksi				
Tensile Strength test 1	108.8ksi				
Elongation test 1	14%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	5.000IN				
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 :

01/28/2019 16:05:34
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.:3086199 SECTION: REBAR 16MM (#5) 20'0" 420/60 GRADE: ASTM A615-18e1 Gr 420/60 ROLL DATE: 02/04/2019 MELT DATE: 01/30/2019 Cert. No.: 82641991 / 086199A371	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#: 82641991 BOL#: 72864829 CUST PO#: 808744 CUST P/N: DLVRY LBS / HEAT: 37230.000 LB DLVRY PCS / HEAT: 1785 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.41%				
Mn	0.86%				
P	0.014%				
S	0.044%				
Si	0.17%				
Cu	0.31%				
Cr	0.19%				
Ni	0.19%				
Mo	0.070%				
V	0.001%				
Cb	0.000%				
Sn	0.014%				
Al	0.000%				
Yield Strength test 1	68.1ksi				
Tensile Strength test 1	105.4ksi				
Elongation test 1	16%				
Elongation Gage Lgth test 1	8IN				
Bend Test 1	Passed				
Bend Test Diameter	2.188IN				

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 :

03/11/2019 11:50:13
Page 1 OF 1

CMC

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.:3083348 SECTION: REBAR 19MM (#6) 20'0" 420/60 GRADE: ASTM A615-16 Gr 420/60 ROLL DATE: 09/25/2018 MELT DATE: 09/21/2018 Cert. No.: 82580173 / 083348A619	S O L D T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	S H I P T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 82580173 BOL#: 72771353 CUST PO#: 802555 CUST P/N: DLVRY LBS / HEAT: 47586.000 LB DLVRY PCS / HEAT: 1584 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.43%				
Mn	0.75%				
P	0.012%				
S	0.047%				
Si	0.17%				
Cu	0.33%				
Cr	0.15%				
Ni	0.21%				
Mo	0.090%				
V	0.000%				
Cb	0.002%				
Sn	0.013%				
Al	0.001%				
Yield Strength test 1	63.0ksi				
Tensile Strength test 1	102.7ksi				
Elongation test 1	17%				
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 :

01/09/2019 12:53:42
Page 1 OF 1

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: 469489-01 **Casting Date:** 2019-05-20 **Mix Design (psi):** 3500psi

Name of Technician Taking Sample: Bill Griffith

Name of Technician Breaking Sample: Bill Griffith

Signature of Technician Taking Sample:

Signature of Technician Breaking Sample:

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	7030	5408937	All Piles

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
T1	2019-06-24	35 days	119000	4209	
T1	2019-07-11	52 days	143000	5058	
			~~161000~~ BLG 2019-07-11		
			151000	5341	5223
			149000	5270	

CUSTOMER'S COPY

Martin Marietta

1503 LBJ Freeway
Suite 400
Dallas, Tx 75234

TICKET NO. 5408937

* 5 4 0 8 9 3 7 *

LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
12:56	:	: 30	1540 : 42	:	:	:

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 17.8 GAL.
ALLOWABLE WATER (withheld from batch) ________ 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	7030	2015	5.0	469488	

DRIVER NAME: Carlos Bretherton — DATE: 5/20/19

CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY
783659	79546	9.00	9.00

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

465485.01.3

SPECIAL DELIVERY INSTRUCTIONS
SOUTH 2818, RIGHT ON LEONARD RIGHT ON HWY-47-LEFT INTO RELLIS CAMPUS WILL MEET YOU AT GATE STRAIGHT BACK FROM ROUNDABOUT

SALES TAX

TOTAL

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

FOR OFFICE USE ONLY **FORM:** 2662499

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
7030	946310	user	5408937	76104	12:56	5/20/19

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
9.00 CYDS	BDOTCC00				D	77125

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
1"CS	1945 lb	17558 lb	17640 lb	0.47%	0.30% M	6 gl
SAND-1	1269 lb	11922 lb	11920 lb	-0.01%	4.20% M	60 gl
CMT-I/II	358 lb	3222 lb	3210 lb	-0.37%		
FLYASH-C	193 lb	1737 lb	1740 lb	0.17%		
H20	250 lb	1546 lb	1548 lb	0.10%		186 gl
ZY-610	12 oz	107 oz	106 oz	-1.19%		

Actual Num Batches: 1
Load Total: 36065 lb Design 0.454 Water/Cement 0.455 T Design 269.6 gl Actual 251.8 gl To Add: 17.8 gl
Slump: 5.00 in Water in Truck: 0.0 gl Adjust Water: 0.0 gl / Load Trim Water: -2.0 gl/ CYD

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: 469489OL-3 **Casting Date:** 2019-05-28 **Mix Design (psi):** 3600

Name of Technician Taking Sample: Bill Griffith

Name of Technician Breaking Sample: Bill Griffith

Signature of Technician Taking Sample: [signature]

Signature of Technician Breaking Sample: [signature]

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	8102	5423654	Northern Most Segment Start South end
T2	8120	5423724	Northern Most Segment Top Half

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
T1	2019-07-11	44 days	171000	6048	|
|	|	|	156000	5518	5824
|	|	|	167000	5907	|
T2	2019-07-11	44 days	171000	6048	|
			160000	5659	5906
			170000	6013	|

CUSTOMER'S COPY

Martin Marietta

1503 LBJ Freeway
Suite 400
Dallas, Tx 75234

TICKET NO. 5423724

5423724

LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
12:08	12:19	12:40	:	:	:	:

WATER ADDED ON JOB AT CUSTOMER'S REQUEST ________ GAL.
ALLOWABLE WATER (withheld from batch) ________ 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[D] CONDITIONS ON THE REVERSE SIDE HEREOF AS ACCEPTED B[Y] 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	8120	2031	5.0	469488	

DRIVER NAME: Matthew Wenzel
DATE: 5/28/19

CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY
783659	79546	13.00	13.00

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

469489-01-3

SPECIAL DELIVERY INSTRUCTIONS
SOUTH 2818, RIGHT ON LEONARD RIGHT ON HWY-47-LEFT INTO RELLIS CAMPUS WILL MEET YOU AT GATE STRAIGHT BACK FROM ROUNDABOUT

SALES TAX

TOTAL

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

FOR OFFICE USE ONLY **FORM:** 2662697

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
8120	946451	user	5423724	76301	12:08	5/28/19

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
6.00 CYDS	BDOTCC00				D	77324

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
1"CS	1945 lb	11682 lb	11680 lb	-0.01%	0.10% M	1 gl
SAND-1	1269 lb	7849 lb	7840 lb	-0.12%	3.00% M	28 gl
CMT-I/II	358 lb	2148 lb	2130 lb	-0.84%		
FLYASH-C	193 lb	1158 lb	1150 lb	-0.69%		
H20	250 lb	1126 lb	1122 lb	-0.35%		
ZY-610	12 oz	72 oz	71 oz	-0.73%		134 gl

Actual Num Batches: 1
Load Total: 23926 lb Design 0.454 Water/Cement 0.457 T Design 179.7 gl Actual 164.0 gl To Add: 10.7 gl
Slump: 5.00 in Water in Truck: 5.0 gl Adjust Water: 0.0 gl / Load Trim Water: -1.7 gl/ CYD

CUSTOMER'S COPY

Martin Marietta

1503 LBJ Freeway
Suite 400
Dallas, Tx 75234

TICKET NO. 5423654

5423654

LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
11:56	12:10	12:30	:	:	:	:

WATER ADDED ON JOB AT CUSTOMER'S REQUEST ______ GAL.
ALLOWABLE WATER (withheld from batch) ______ 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
T1 2019-07-11 44 days

PLANT	TRUCK	ORDER NO.	SLUMP	P.O. #/JOB/LOT	GRID
617	8102	2031	5.0	469488	

DRIVER NAME	DATE
CHARLES BALANGA	5/28/19

CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY
783659	79546	7.00	13.00

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

T2 2019-07-11 44 days 171000 ... 169000 5659 5906 170000 6013

469489-01-3

SPECIAL DELIVERY INSTRUCTIONS
SOUTH 2818, RIGHT ON LEONARD RIGHT ON HWY-47-LEFT INTO RELLIS CAMPUS WILL MEET YOU AT GATE STRAIGHT BACK FROM ROUNDABOUT

SALES TAX

TOTAL

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

FOR OFFICE USE ONLY **FORM:** 2662696

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time Date
8102	916114	user	5423654	76300	11:56 5/28/19

Load Size	Mix Code	Returned Qty	Mix Age	Seq	Load ID
7.00 CYDS	BDOTCC00			D	77323

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
1"CS	1945 lb	13629 lb	13600 lb	-0.21%	0.10% M	2 gl
SAND-1	1269 lb	9158 lb	9160 lb	0.02%	3.00% M	33 gl
CMT-I/II	358 lb	2506 lb	2500 lb	-0.24%		
FLYASH-C	193 lb	1351 lb	1340 lb	-0.81%		
H20	250 lb	1321 lb	1314 lb	-0.50%		157 gl
ZY-610	12 oz	83 oz	83 oz	-0.53%		

Actual Num Batches: 1
Load Total: 27919 lb Design 0.454 Water/Cement 0.456 T Design 209.7 gl Actual 192.0 gl To Add: 12.7 gl
Slump: 5.00 in Water in Truck: 5.0 gl Adjust Water: 0.0 gl / Load Trim Water: -1.7 gl/ CYD

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

Texas A&M Transportation Institute	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: 469489-01-3 **Casting Date:** 2019-06-07 **Mix Design (psi):** 3600

Name of Technician Taking Sample: Billy Griffith

Name of Technician Breaking Sample: Bill Griffith

Signature of Technician Taking Sample: [signature]

Signature of Technician Breaking Sample: [signature]

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	7165	5445292	Second Segment from North, Bottom
T2	7102	5445414	Second Segment from North, Top

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
T1	2019-07-11	34 days	157000	5553	
			156000	5518	5494
			153000	5412	
T2	2019-07-11	34 days	146000	5164	
			141000	4987	5164
			151000	5341	

CUSTOMER'S COPY

Martin Marietta

1503 LBJ Freeway
Suite 400
Dallas, Tx 75234

TICKET NO.
5445414

5445414

LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
10:48	11:00	11:05	:	:	:	:

WATER ADDED ON JOB AT CUSTOMER'S REQUEST ________ GAL.
ALLOWABLE WATER (withheld from batch) ________ 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	7102	2015	5.0	469689	

DRIVER NAME: RAYMOND ORTIZ — DATE: 6/7/19

CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY
783659	79546	12.00	12.00

LOAD QUANTITY	PRODUCT CODE	DESCRIPTION	UNIT PRICE	AMOUNT
6.00	CYDS	BDOTCC00 DOT-CLASS C		
1.00	ea	12987 FREIGHT CHARGE		

SPECIAL DELIVERY INSTRUCTIONS
2818-RT ON LEONARD RT ON HWY-47-LFT INTO RELLIS CAMPUS GO AROUNDTHE ROUND ABOUT AND THEY WILL MEET AT GATE

SALES TAX

46948 9-01-3

TOTAL

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

FOR OFFICE USE ONLY **FORM:** 2663019

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
7102	940107	user	5445414	76616	10:48	6/7/19

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
6.00 CYDS	BDOTCC00				D	77641

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
1"CS	1945 lb	11682 lb	11680 lb	-0.01%	0.10% M	1 gl
SAND-1	1269 lb	7931 lb	7960 lb	0.36%	4.00% M	38 gl
CMT-I/II	358 lb	2148 lb	2150 lb	0.09%		
FLYASH-C	193 lb	1158 lb	1150 lb	-0.69%		
H20	250 lb	1029 lb	1032 lb	0.27%		124 gl
ZY-610	12 oz	72 oz	71 oz	-0.73%		

Actual Num Batches: 1
Load Total: 23976 lb Design 0.454 Water/Cement 0.455 T Design 179.7 gl / Load Actual 163.2 gl To Add: 11.5 gl
Slump: 5.00 in Water in Truck: 5.0 gl Adjust Water: 0.0 gl Trim Water: -2.0 gl/ CYD

CUSTOMER'S COPY

Martin Marietta

1503 LBJ Freeway
Suite 400
Dallas, Tx 75234

TICKET NO. 5445292

LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
10:20	10:33	10:48	10:55	:	:	:

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 10 GAL.
ALLOWABLE WATER (withheld from batch) 11.5 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
T1 2019-07-

PLANT	TRUCK	ORDER NO.	SLUMP	P.O. #/JOB/LOT	GRID
617	7165	2015	5.0	469689	

DRIVER NAME: Carlos Bretherton
DATE: 6/7/19

CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY
783658	279546	6.00	12.00

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

T2 2019-07-11 34 days 146000 5164
141000 4987 5164
151000 5341

SPECIAL DELIVERY INSTRUCTIONS
2818-RT ON LEONARD RT ON HWY-47-LFT INTO RELLIS CAMPUS GO AROUNDTHE ROUND ABOUT AND THEY WILL MEET AT GATE

SALES TAX
TOTAL

469489-01-3

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

FOR OFFICE USE ONLY **FORM:** 2663016

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
7165	946310	user	5445292	76613	10:20	6/7/19

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
6.00 CYDS	BDOTCC00				D	77638

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
1"CS	1945 lb	11682 lb	11680 lb	-0.01%	0.10% M	1 gl
SAND-1	1269 lb	7931 lb	7960 lb	0.36%	4.00% M	38 gl
CMT-I/II	358 lb	2148 lb	2160 lb	0.56%		
FLYASH-C	193 lb	1158 lb	1150 lb	-0.69%		
H20	250 lb	1029 lb	1032 lb	0.27%		124 gl
ZY-610	12 oz	72 oz	71 oz	-0.73%		

Actual Num Batches: 1
Load Total: 23986 lb Design 0.454 Water/Cement 0.453 T Design 179.7 gl Actual 163.2 gl To Add: 11.5 gl
Slump: 5.00 in Water in Truck: 5.0 gl Adjust Water: 0.0 gl / Load Trim Water: -2.0 gl/ CYD

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: 469489-01-3 **Casting Date:** 6-12-19 **Mix Design (psi):** 3600

Name of Technician Taking Sample: Matt Robinson

Name of Technician Breaking Sample: [signature]

Signature of Technician Taking Sample: [signature]

Signature of Technician Breaking Sample: Bill Griffith

Load No.	Truck No.	Ticket No.	Location (from concrete map)
	1	5455507	South
	2	5455657	mid-South

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
T1	2019-06-24	12 days	138000	4880	
T2	2019-06-24	12 days	124500	4400	
T1	2019-07-11	29 days	160000	5660	
"	"	"	157000	5553	5577
"	"	"	156000	5518	
T2	2019-07-11	29 days	154000	5447	
			160000	5660	5529
			155000	5482	

CUSTOMER'S COPY

Martin Marietta
1503 LBJ Freeway
Suite 400
Dallas, Tx 75234

TICKET NO. 5455507

LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
9:30	9:44	10:09	10:16	10:30	:	:

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 10 GAL.
ALLOWABLE WATER (withheld from batch) 10.2 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 617 TRUCK 8164 ORDER NO. 2020 SLUMP 5.0 P.O. #/JOB/LOT 465489 GRID
DRIVER NAME JOSH BYER DATE 6/12/19
CUSTOMER NUMBER 783659 PROJECT 79546 CUM. QTY 6.00 ORDERED QTY 13.00

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

465489-01-3

SPECIAL DELIVERY INSTRUCTIONS LEONARD RT ON HWY-47-LFT INTO RELLIS CAMPUS GO AROUNDTHE ROUND ABOUT AND THEY WILL MEET AT GATE

SALES TAX

TOTAL

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

FOR OFFICE USE ONLY **FORM:** 2663158

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
8164	901812	user	5455507	76755	9:30	6/12/19

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
6.00 CYDS	BDOTCC00				D	77783

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
1"CS	1945 lb	11682 lb	11680 lb	-0.01%	0.10% M	1 gl
SAND-1	1269 lb	7890 lb	7880 lb	-0.13%	3.50% M	33 gl
CMT-I/II	358 lb	2148 lb	2130 lb	-0.84%		
FLYASH-C	193 lb	1158 lb	1150 lb	-0.69%		
H20	250 lb	1085 lb	1086 lb	0.06%		130 gl
ZY-610	12 oz	72 oz	72 oz	0.67%		

Actual Num Batches: 1
Load Total: 23931 lb Design 0.454 Water/Cement 0.457 T Design 179.7 gl Actual 164.6 gl To Add: 10.2 gl
Slump: 5.00 in Water in Truck: 5.0 gl Adjust Water: 0.0 gl / Load Trim Water: -1.7 gl/ CYD

CUSTOMER'S COPY

Martin Marietta

1503 LBJ Freeway
Suite 400
Dallas, Tx 75234

TICKET NO. 5455657

5455657

LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
9:59	10:12	10:22	:	:	:	:

WATER ADDED ON JOB AT CUSTOMER'S REQUEST ______ GAL.
ALLOWABLE WATER (withheld from batch) ______ 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
617	7165	2020	5.0	469689	

DRIVER NAME	DATE
ANDRA DARNELL	6/12/19

CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY
7836990	795460	13.00	13.00

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

465489-01-3

SPECIAL DELIVERY INSTRUCTIONS
2818-RT ON LEONARD RT ON HWY-47-LFT INTO RELLIS CAMPUS GO AROUNDTHE ROUND ABOUT AND THEY WILL MEET AT GATE

SALES TAX

TOTAL

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

FOR OFFICE USE ONLY **FORM:** 2663162

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
7165	746154	user	5455657	76759	9:59	6/12/19

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
7.00 CYDS	BDOTCC00				D	77787

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
1"CS	1945 lb	13629 lb	13640 lb	0.08%	0.10% M	2 gl
SAND-1	1269 lb	9205 lb	9200 lb	-0.06%	3.50% M	39 gl
CMT-I/II	358 lb	2506 lb	2490 lb	-0.64%		
FLYASH-C	193 lb	1351 lb	1340 lb	-0.81%		
H2O	250 lb	1273 lb	1266 lb	-0.56%		152 gl
ZY-610	12 oz	83 oz	84 oz	0.67%		
Actual	Num Batches: 1					

Load Total: 27941 lb Design 0.454 Water/Cement 0.457 T Design 209.7 gl Actual 191.9 gl To Add: 12.8 gl
Slump: 5.00 in Water in Truck: 5.0 gl Adjust Water: 0.0 gl / Load Trim Water: -1.7 gl/ CYD

APPENDIX C. *MASH* TEST 5-12 (CRASH TEST NO. 469489-01-3)

C.1 VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 469489-01-3.

DATE: 2019-07-12 **TEST NO.:** 469489-1

TRACTOR

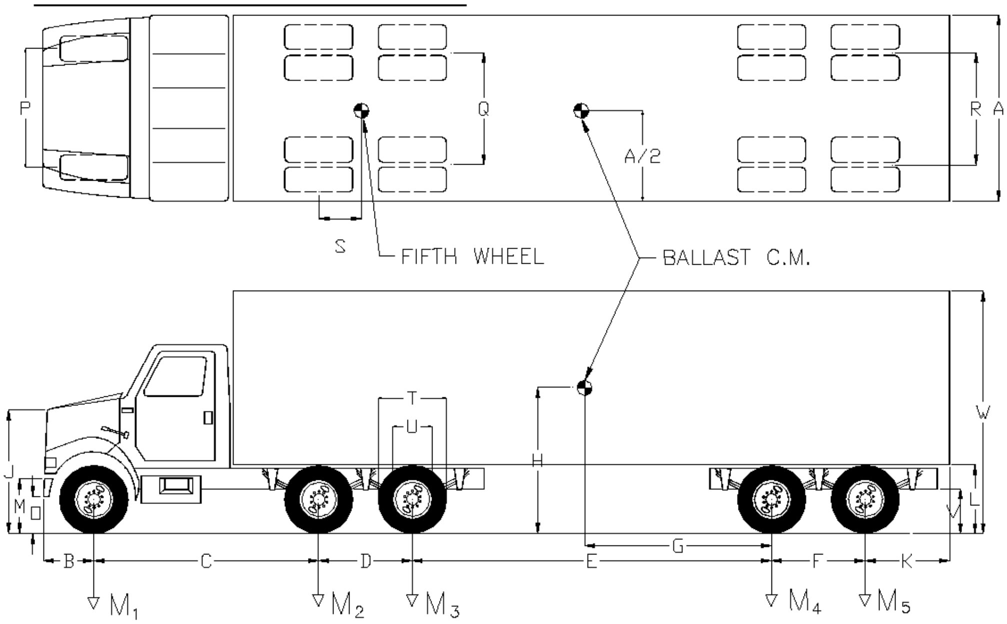
YEAR: 2006 MAKE: Freightliner MODEL: TR

VIN No.: IFUJA6CK46PV52093 ODOMETER: 776675

TRAILER

YEAR: 1999 MAKE: TRL MODEL: VN 53'

VIN No.: 1JJV532W2XL465292



GEOMETRY (inches)

A	102.00	D	50.00	G		K	62.00	O	17.50	R	73.00	U	23.00
B	118.00	E	456.00	H	71.75	L	50.00	P	79.50	S	25.00	V	38.00
C	148.00	F	50.00	J	68.75	M	34.00	Q	73.00	T	40.00	W	160.00

Allowable Range: C = 200 inches max.; L = 50 ±2 inches; Overall Trailer Length = 636 inches max.; Overall Combination Length = 780 inches max.; Trailer Overhang = 87 inches max.; Ballast Center of Mass Ht = 73 ±2 inches above ground;

MASS (lb)	CURB		TEST INERTIAL	
M_1	9130		10190	
M_2	4320		13070	
M_3	7660		21850	
M_4	4840		17520	
M_5	4750	Allowable Range	17540	Allowable Range
M_{Total}	30700	29,000 ±3100 lb	80170	79,300 ±1100 lb

C.2 SEQUENTIAL PHOTOGRAPHS

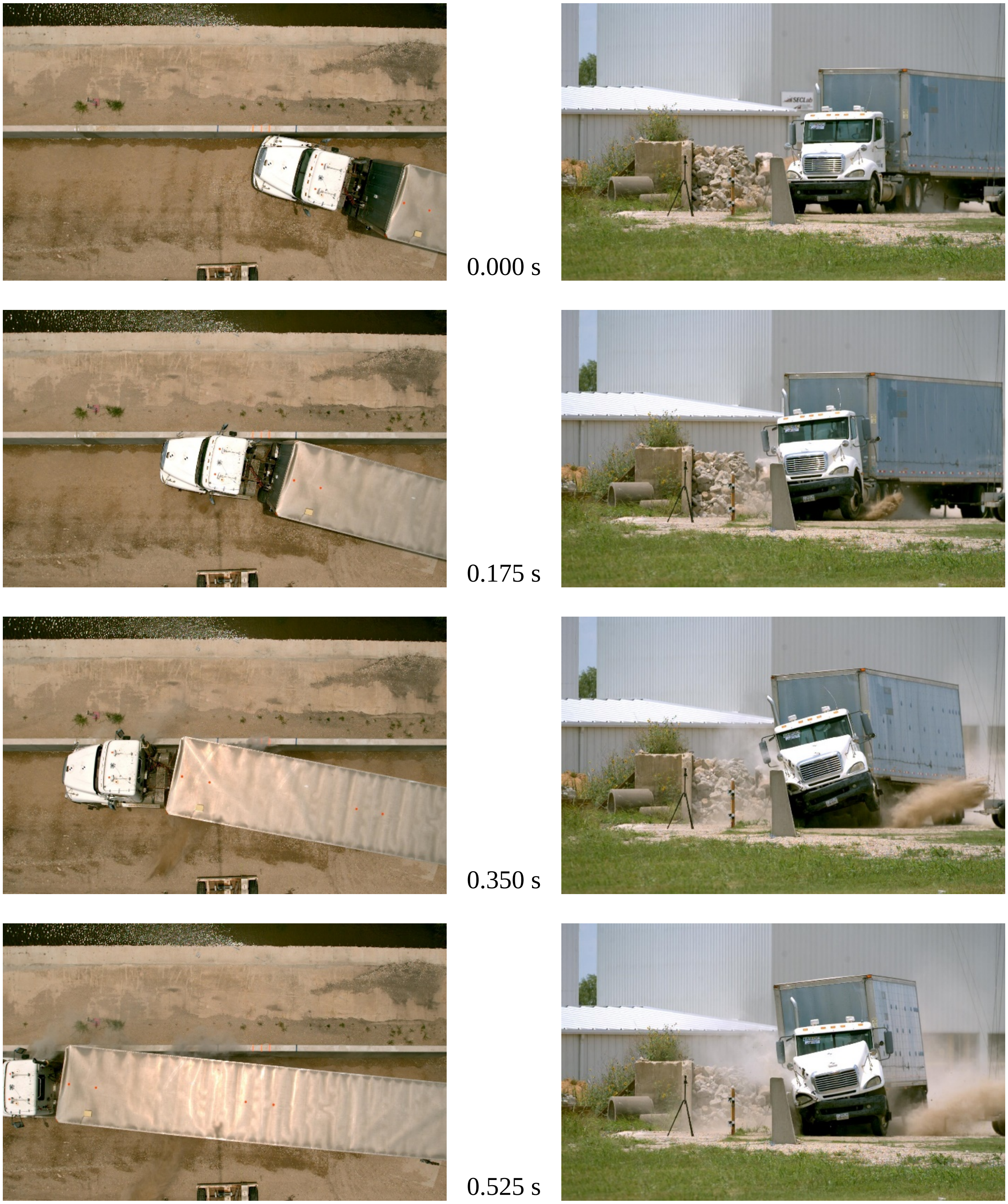


Figure C.1. Sequential Photographs for Test No. 469489-01-3 (Overhead and Frontal Views).

0.700 s

0.875 s

1.050 s

1.225 s

Figure C.1. Sequential Photographs for Test No. 469489-01-3 (Overhead and Frontal Views) (Continued).

0.000 s

0.175 s

0.350 s

0.525 s

Figure C.2. Sequential Photographs for Test No. 469489-01-3 (Rear Views).

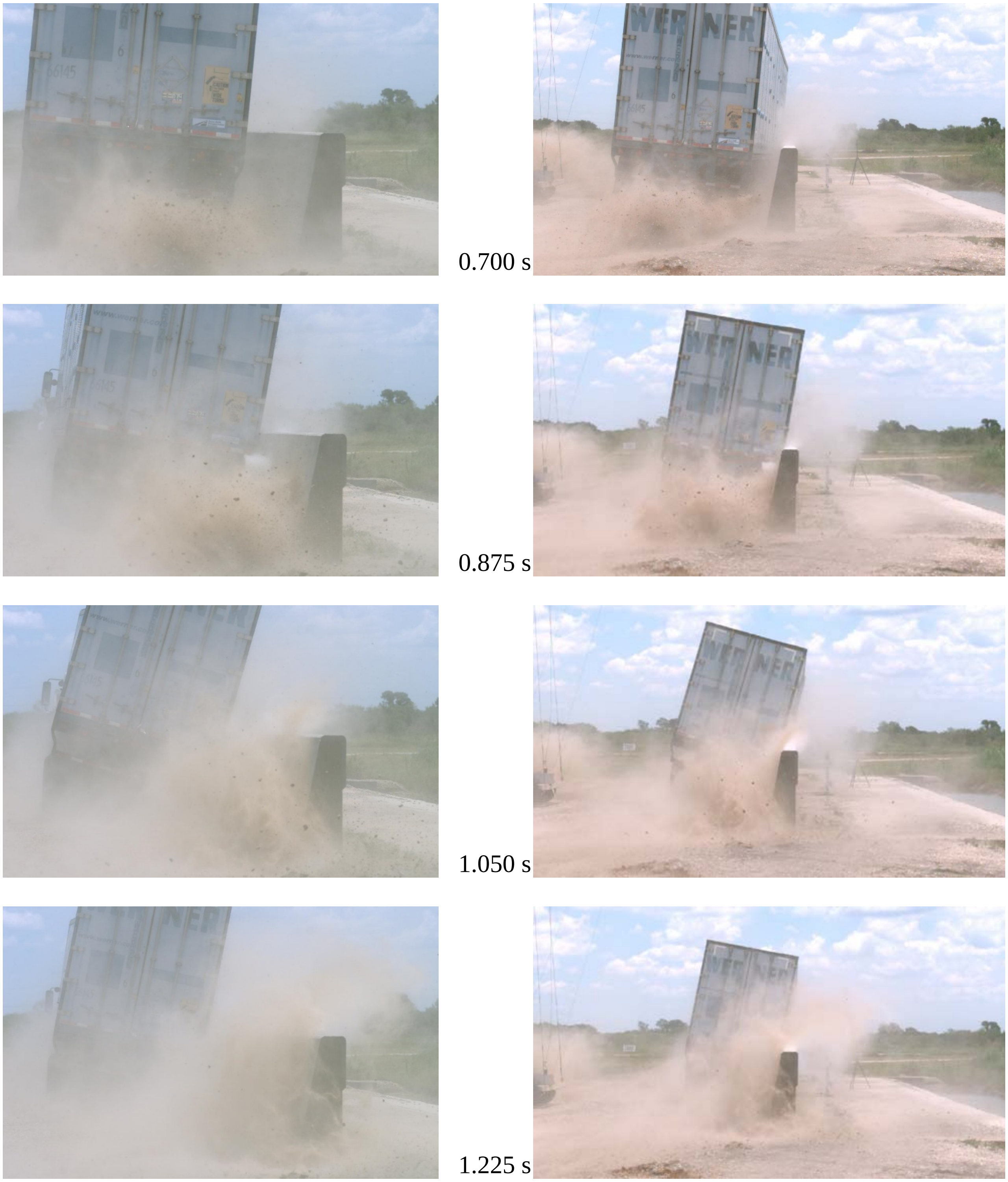


Figure C.2. Sequential Photographs for Test No. 469489-01-3 (Overhead and Frontal Views) (Continued).

C.3 VEHICLE ANGULAR DISPLACEMENT

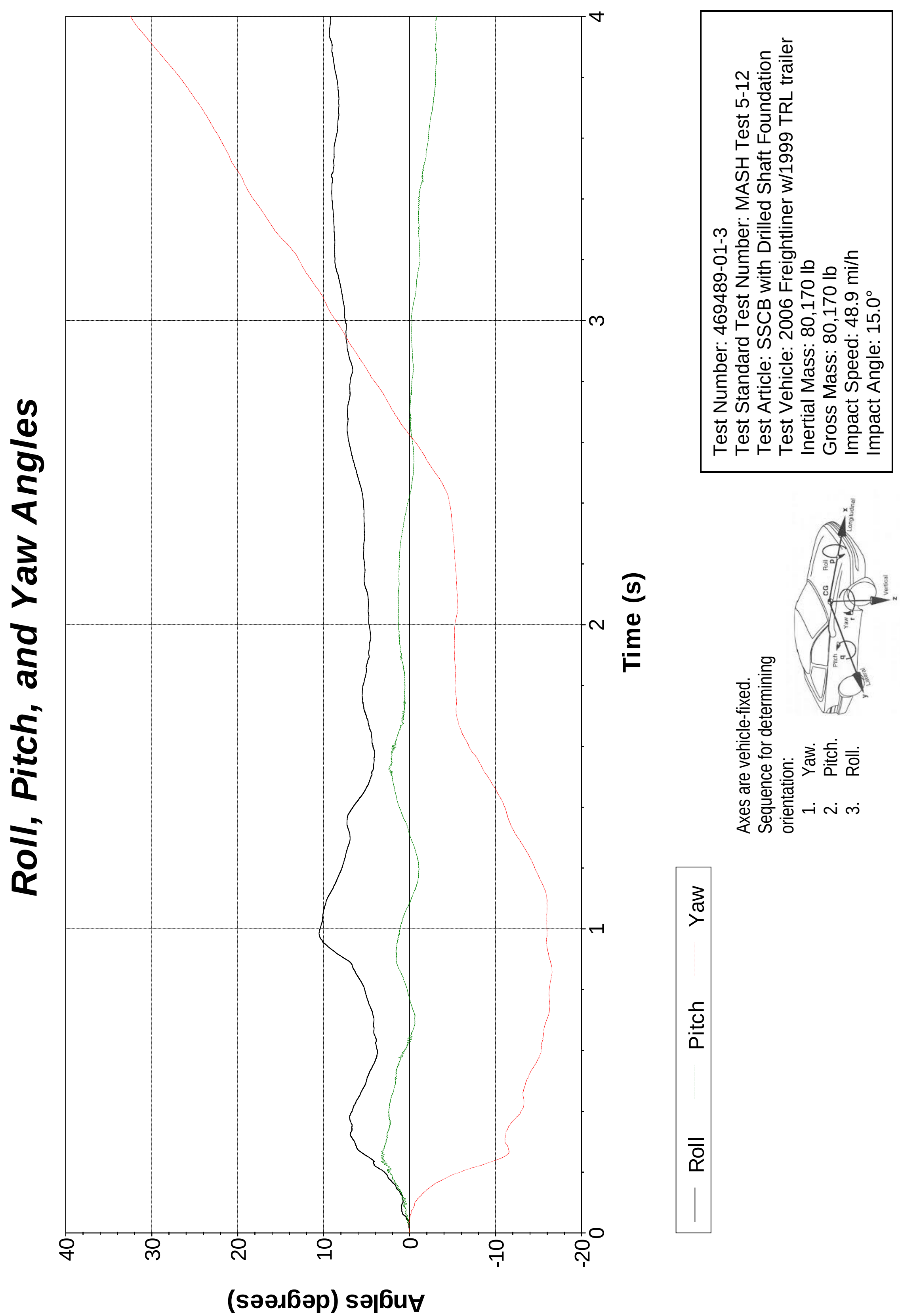


Figure C.3. Vehicle Angular Displacements for Test No. 469489-01-3.

C.4 VEHICLE ACCELERATIONS

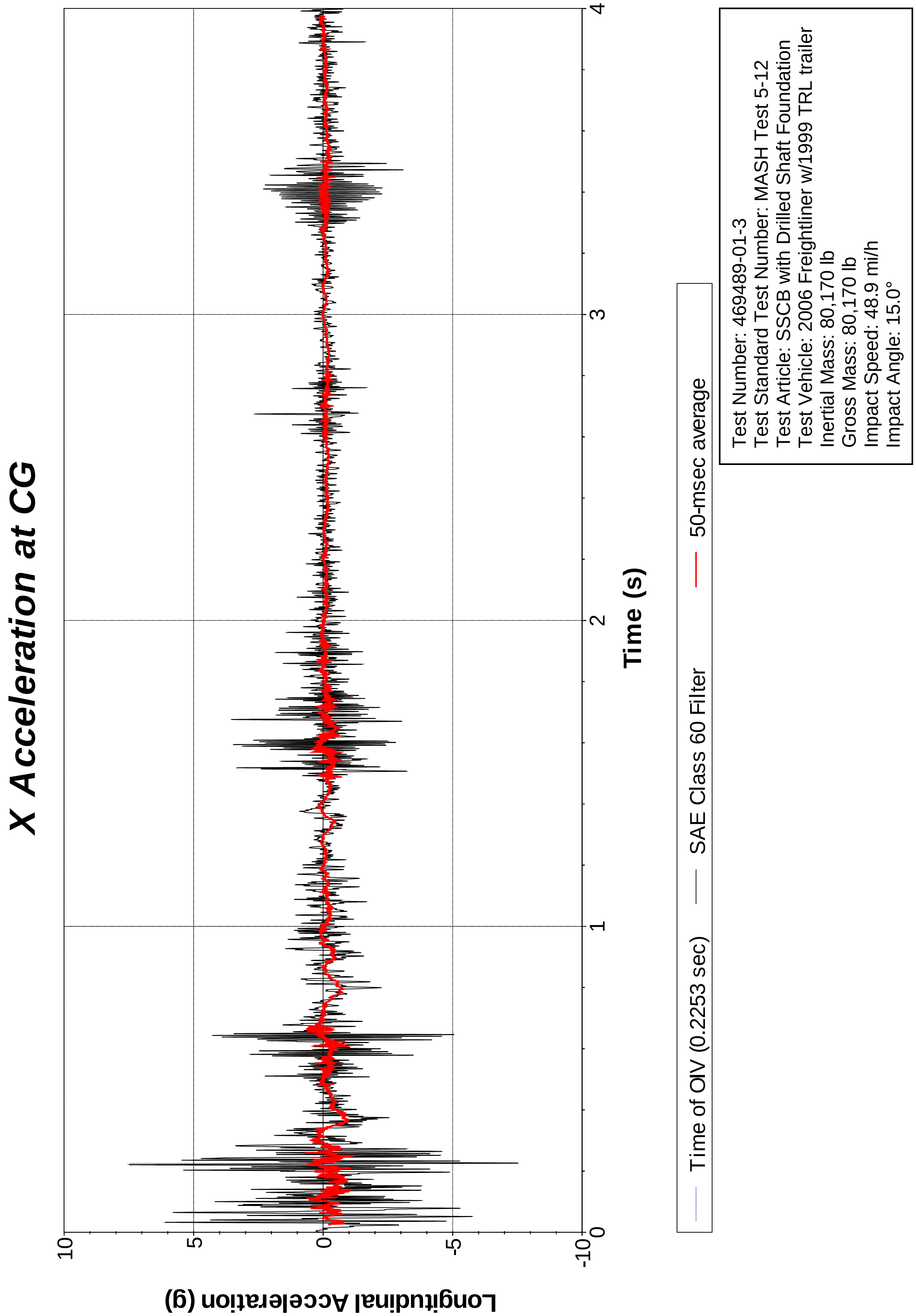


Figure C.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469489-01-3 (Accelerometer Located at Center of Gravity, Location B in Figure 5.1).

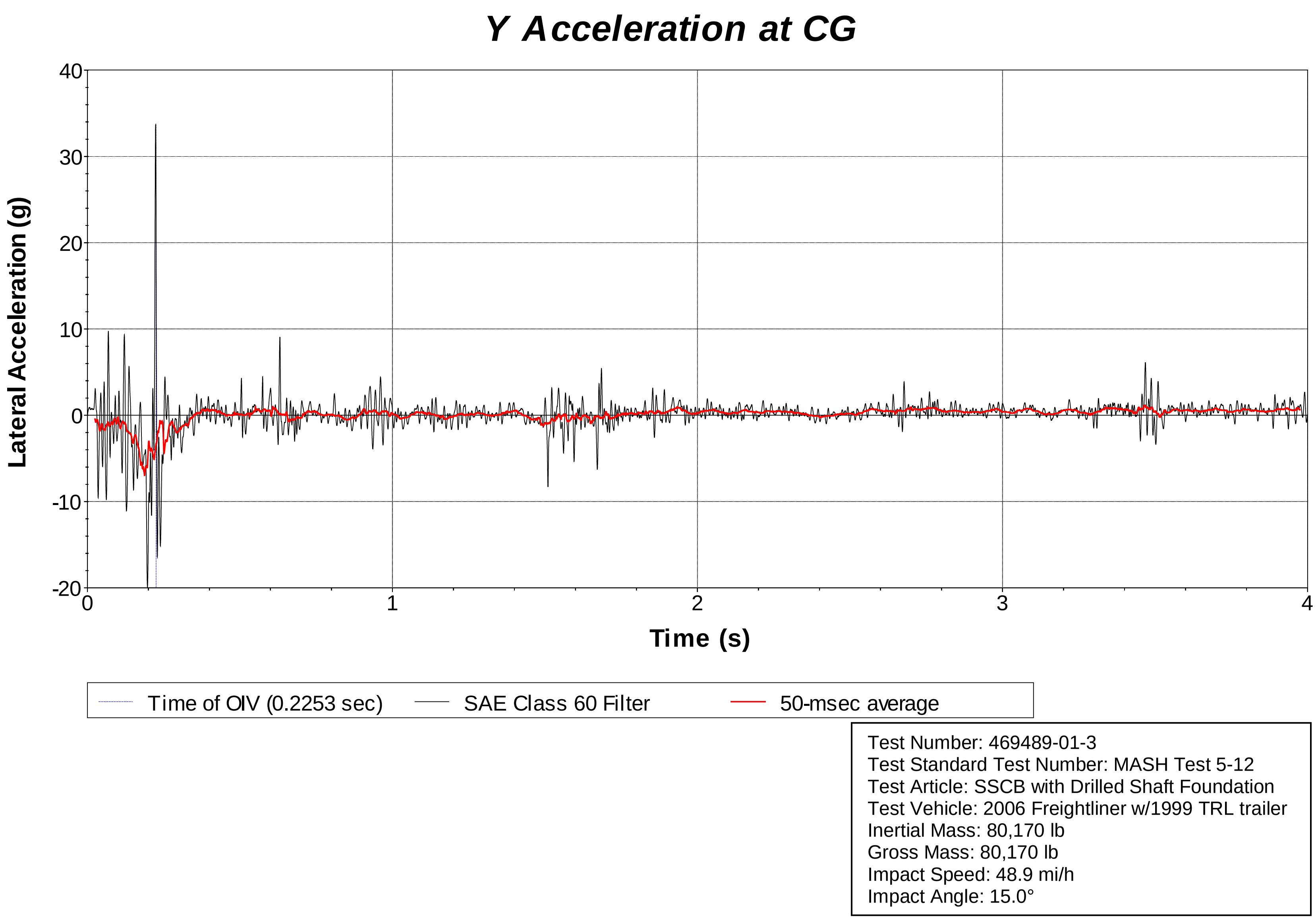


Figure C.5. Vehicle Lateral Accelerometer Trace for Test No. 469489-01-3 (Accelerometer Located at Center of Gravity, Location B in Figure 5.1).

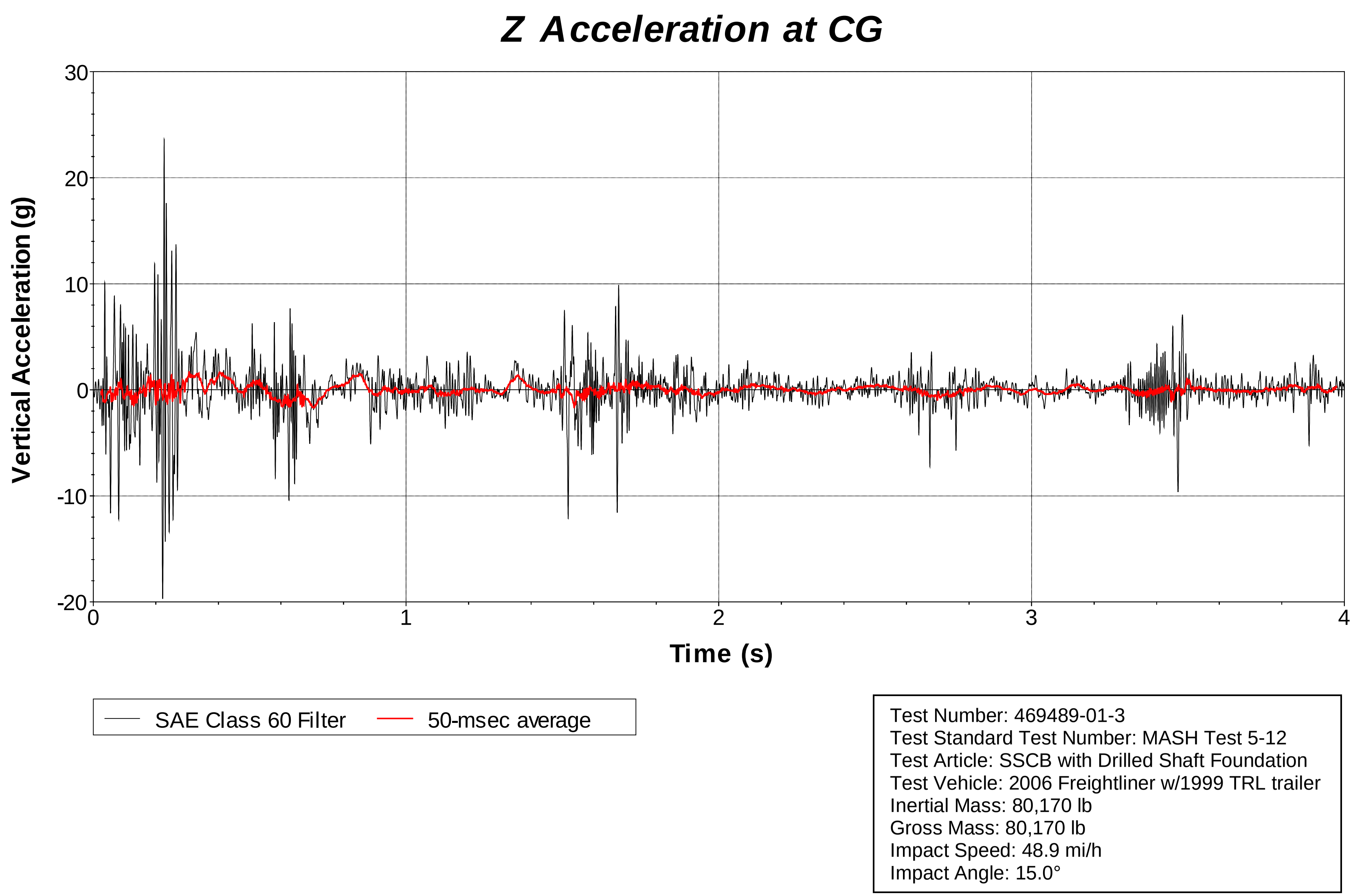


Figure C.6. Vehicle Vertical Accelerometer Trace for Test No. 469489-01-3 (Accelerometer Located at Center of Gravity, Location B in Figure 5.1).

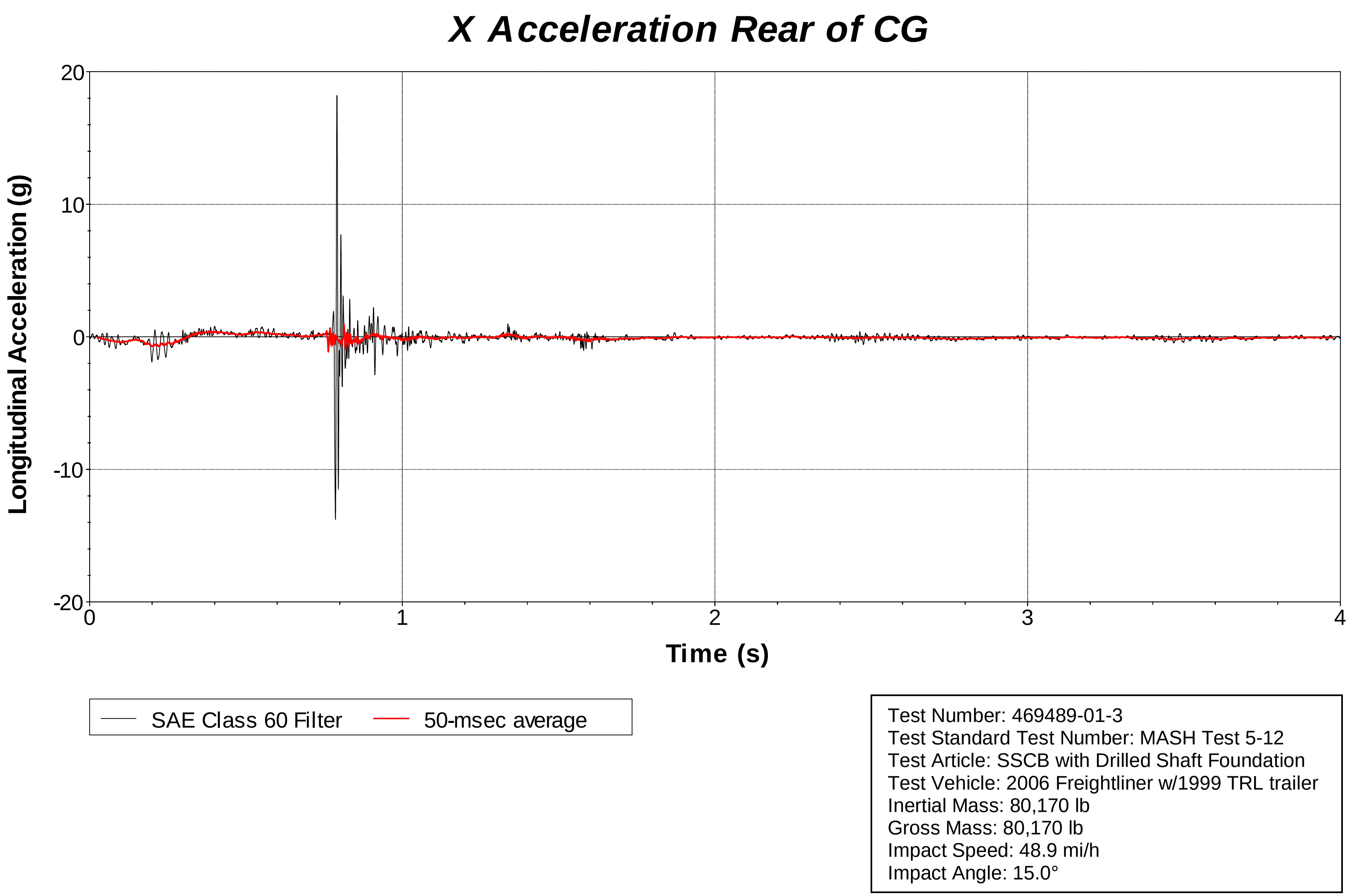


Figure C.7. Vehicle Longitudinal Accelerometer Trace for Test No. 469489-01-3 (Accelerometer Located Rear of Center of Gravity, Location C in Figure 5.1).

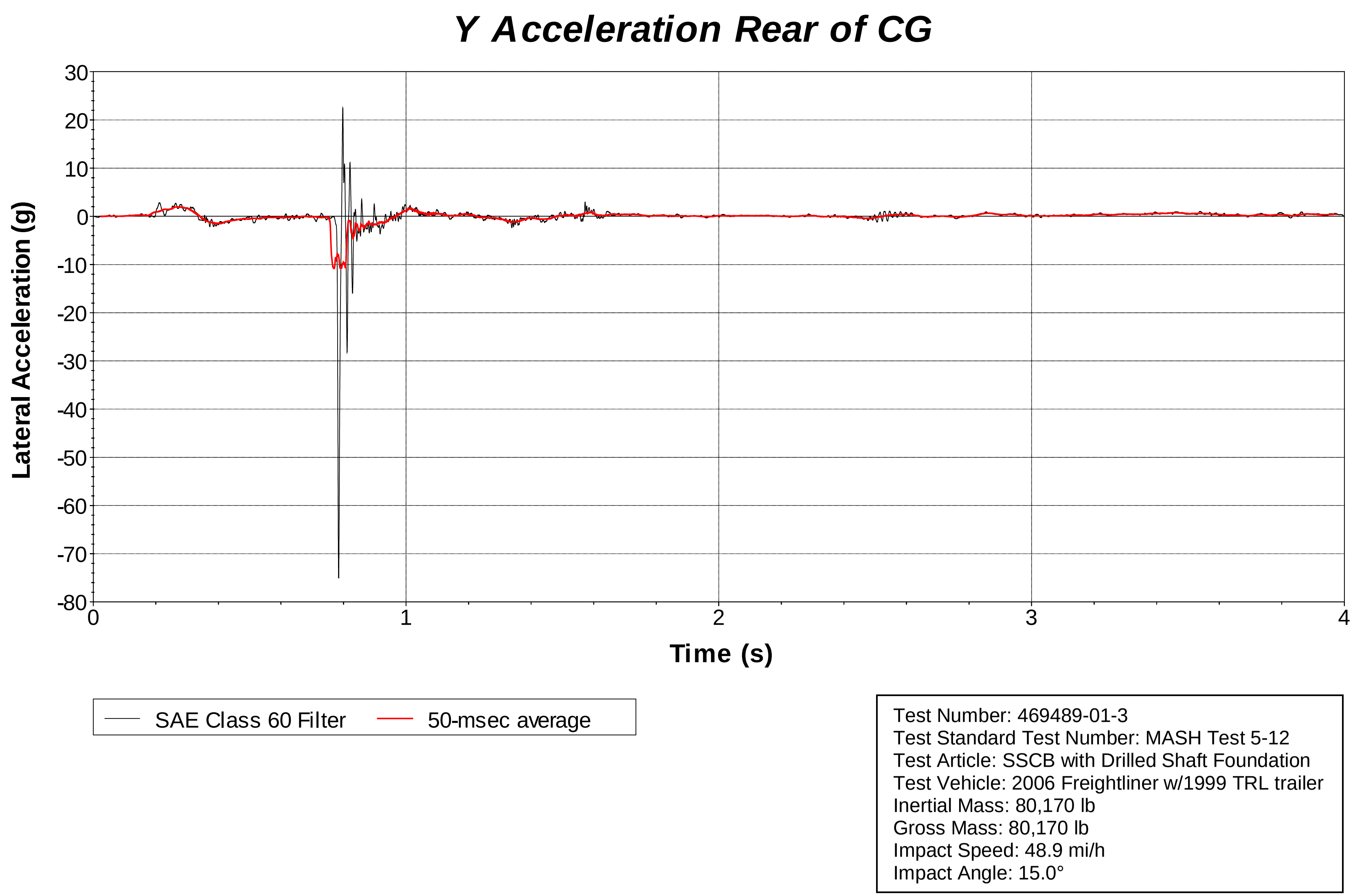


Figure C.8. Vehicle Lateral Accelerometer Trace for Test No. 469489-01-3 (Accelerometer Located Rear of Center of Gravity, Location C in Figure 5.1).

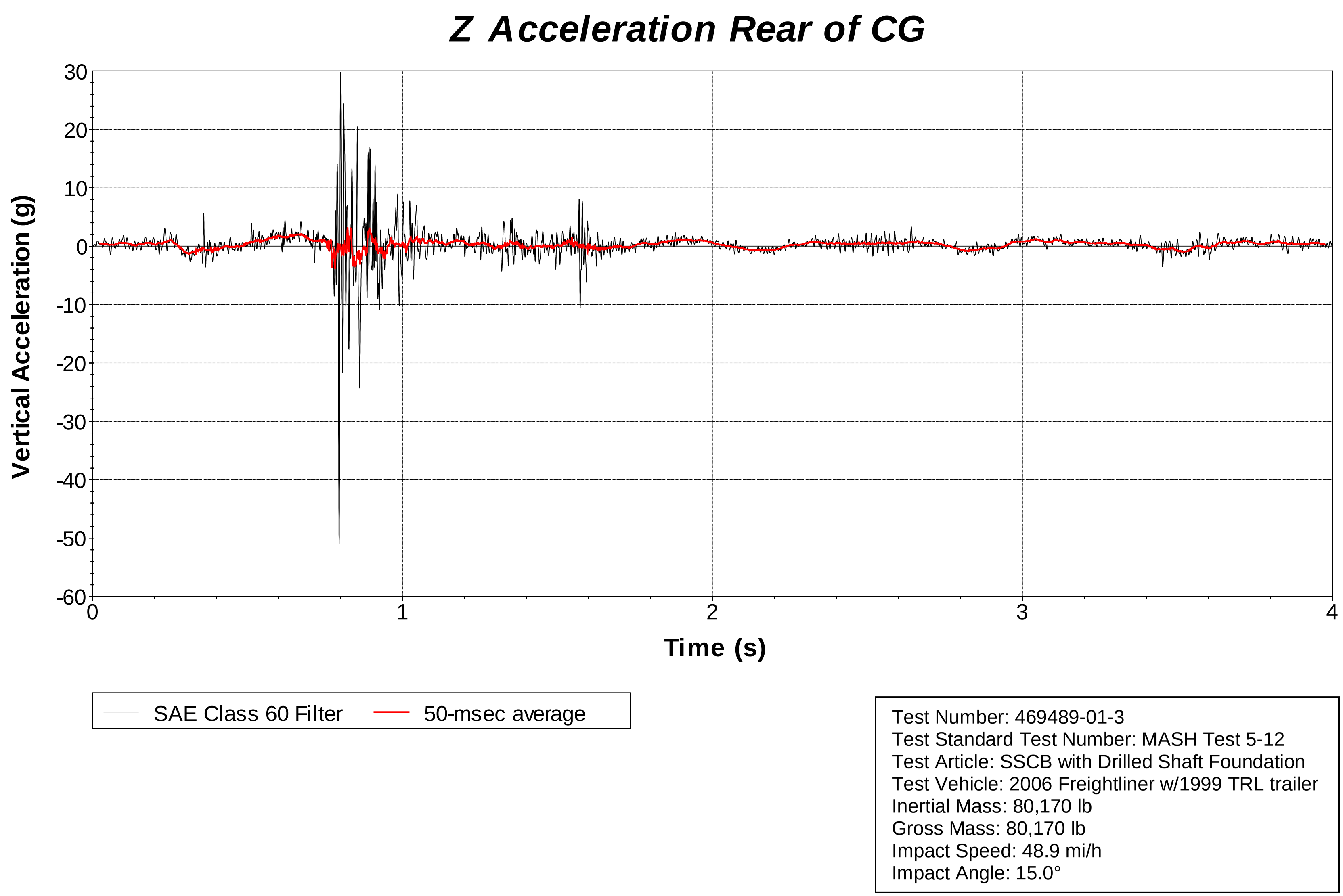


Figure C.9. Vehicle Vertical Accelerometer Trace for Test No. 469489-01-3 (Accelerometer Located Rear of Center of Gravity, Location C in Figure 5.1).