



## 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

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in cooperation with the  
Federal Highway Administration and the  
Texas Department of Transportation  
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16. Abstract <p>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.</p> <p>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.</p> <p>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.</p> <p>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.</p>					
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# **ANALYSIS OF 54-INCH TALL SINGLE SLOPE CONCRETE BARRIER ON A STRUCTURALLY INDEPENDENT FOUNDATION**

by

Nauman M. Sheikh, P.E.  
Associate 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

and

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

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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 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.

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## REPORT AUTHORIZATION

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DocuSigned by:

*Bill Griffith*

44A122CB271845B...

---

Bill L. Griffith, Research Specialist  
Deputy Quality Manager

DocuSigned by:

*Matt Robinson*

EAA22BFA5BFD417...

---

Matthew N. Robinson, Research Specialist  
Test Facility Manager & Technical Manager

DocuSigned by:

*Darrell L. Kuhn*

D4CC23E85D5B4E7...

---

Darrell L. Kuhn, P.E., Research Specialist  
Quality Manager

DocuSigned by:

*Nauman M. Sheikh*

662F8286A604403...

---

Nauman M. Sheikh  
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
<b>LENGTH</b>				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	645.2	square millimeters	mm <sup>2</sup>
ft <sup>2</sup>	square feet	0.093	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.836	square meters	m <sup>2</sup>
ac	acres	0.405	hectares	ha
mi <sup>2</sup>	square miles	2.59	square kilometers	km <sup>2</sup>
<b>VOLUME</b>				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft <sup>3</sup>	cubic feet	0.028	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.765	cubic meters	m <sup>3</sup>
NOTE: volumes greater than 1000L shall be shown in m <sup>3</sup>				
<b>MASS</b>				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or metric ton <sup>†</sup> )	Mg (or "t")
<b>TEMPERATURE (exact degrees)</b>				
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
<b>FORCE and PRESSURE or STRESS</b>				
lbf	poundforce	4.45	newtons	N
lbf/in <sup>2</sup>	poundforce per square inch	6.89	kilopascals	kPa

### APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
<b>AREA</b>				
mm <sup>2</sup>	square millimeters	0.0016	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	10.764	square feet	ft <sup>2</sup>
m <sup>2</sup>	square meters	1.195	square yards	yd <sup>2</sup>
ha	hectares	2.47	acres	ac
km <sup>2</sup>	Square kilometers	0.386	square miles	mi <sup>2</sup>
<b>VOLUME</b>				
mL	milliliters	0.034	fluid ounces	oz
L	liters	0.264	gallons	gal
m <sup>3</sup>	cubic meters	35.314	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.307	cubic yards	yd <sup>3</sup>
<b>MASS</b>				
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
<b>TEMPERATURE (exact degrees)</b>				
°C	Celsius	1.8C+32	Fahrenheit	°F
<b>FORCE and PRESSURE or STRESS</b>				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in <sup>2</sup>

\*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 (I). 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\*

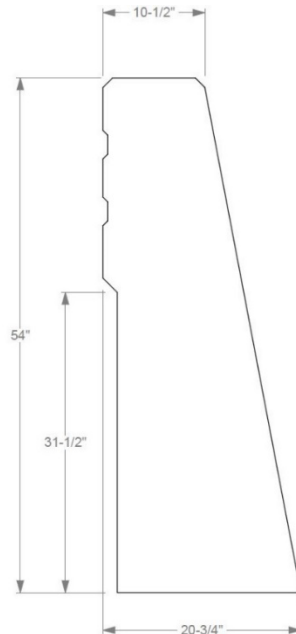
Researchers developed seven preliminary barrier foundation design concepts for TxDOT's review. Of these seven preliminary concepts, three were selected for further development. These included a shallow moment slab foundation, a drilled shaft foundation, and a vertical beam foundation.

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.

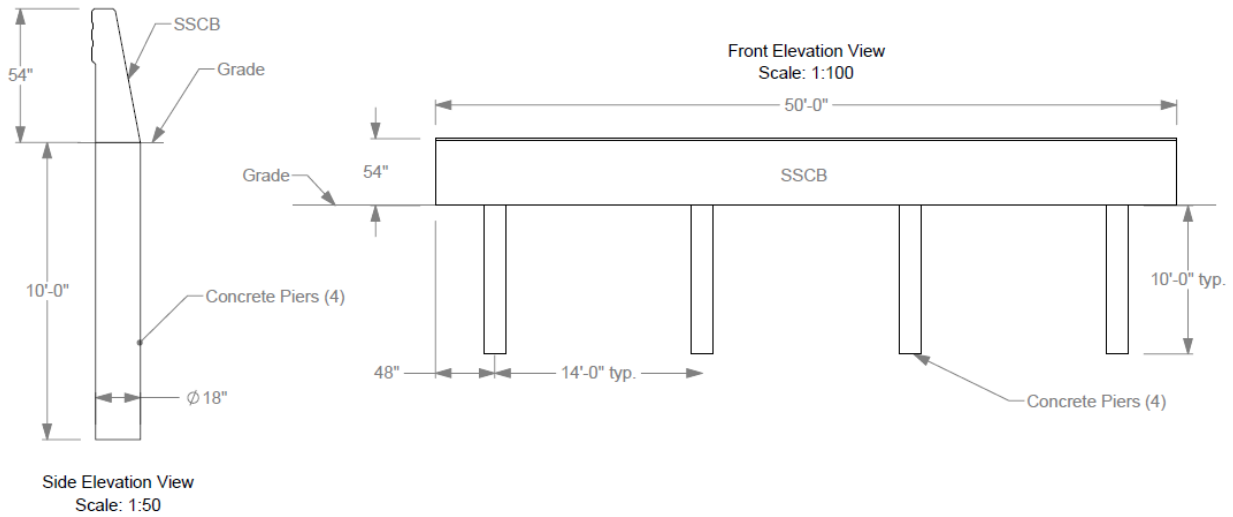


**Figure 2.1. 54-Inch Tall Single Slope Barrier Profile.**

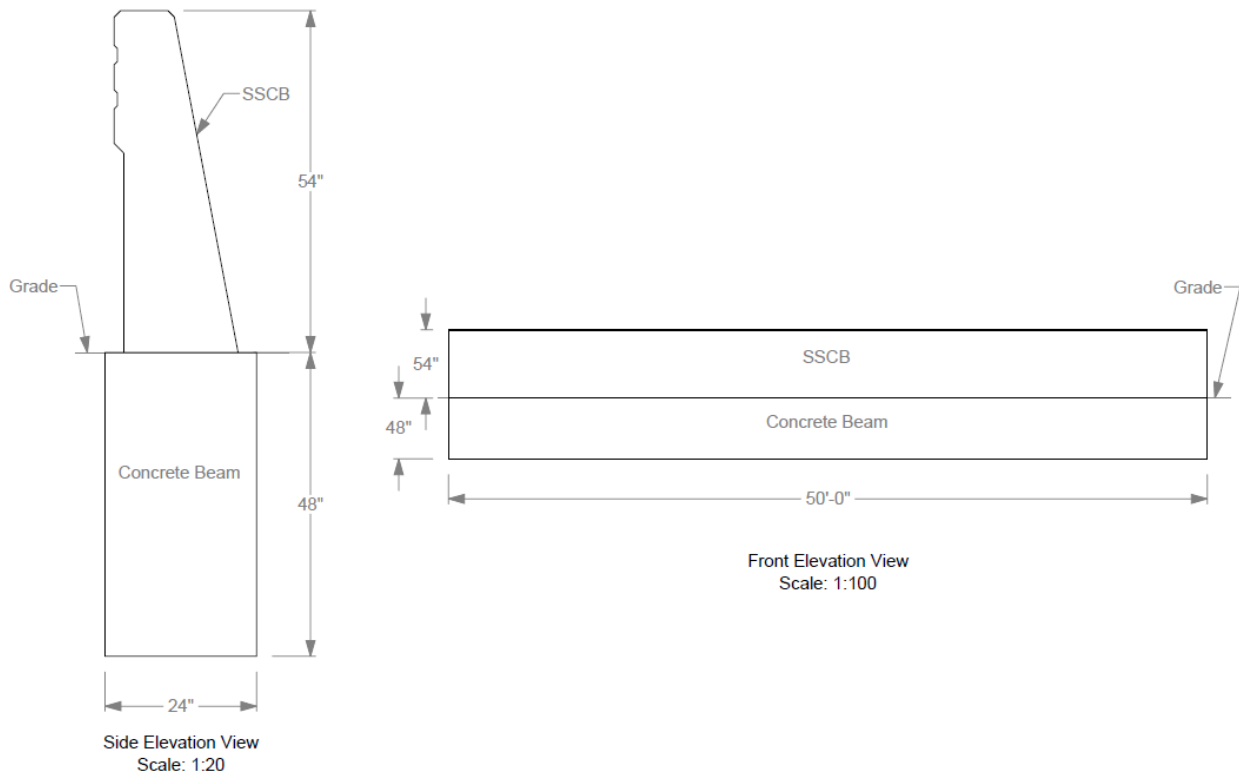
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\* The opinions/interpretations identified/expressed in this section of the report are outside the scope of TTI Proving Ground's A2LA Accreditation.

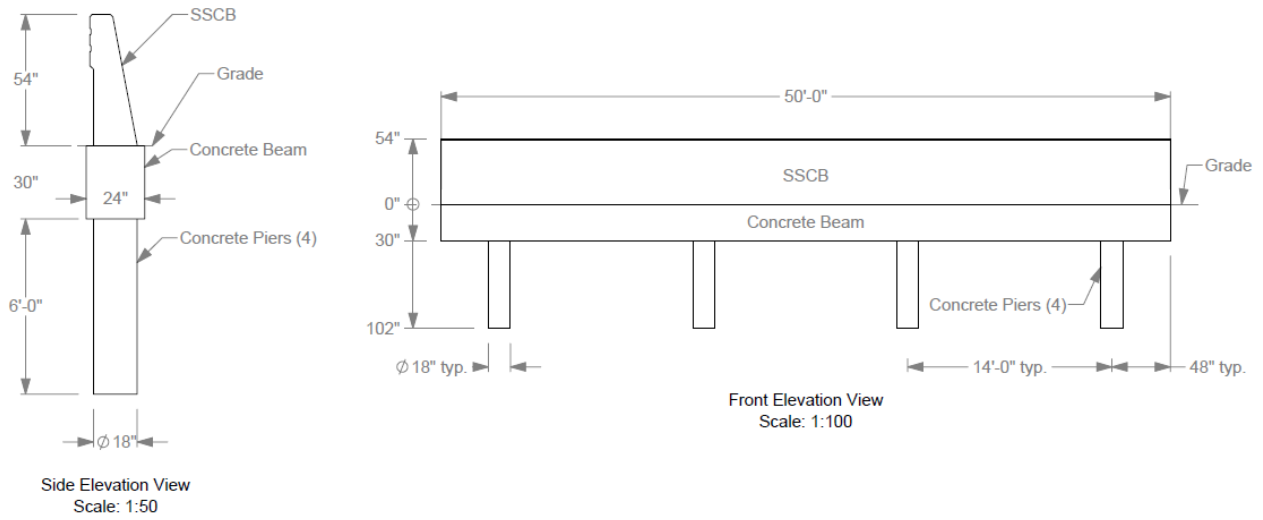
An initial engineering analysis accounted for the static load resistance provided by the soil and the weight of the foundation and barrier system. This approach provides conservative foundation designs because it does not take dynamic inertial effects into account. These designs were later optimized 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.



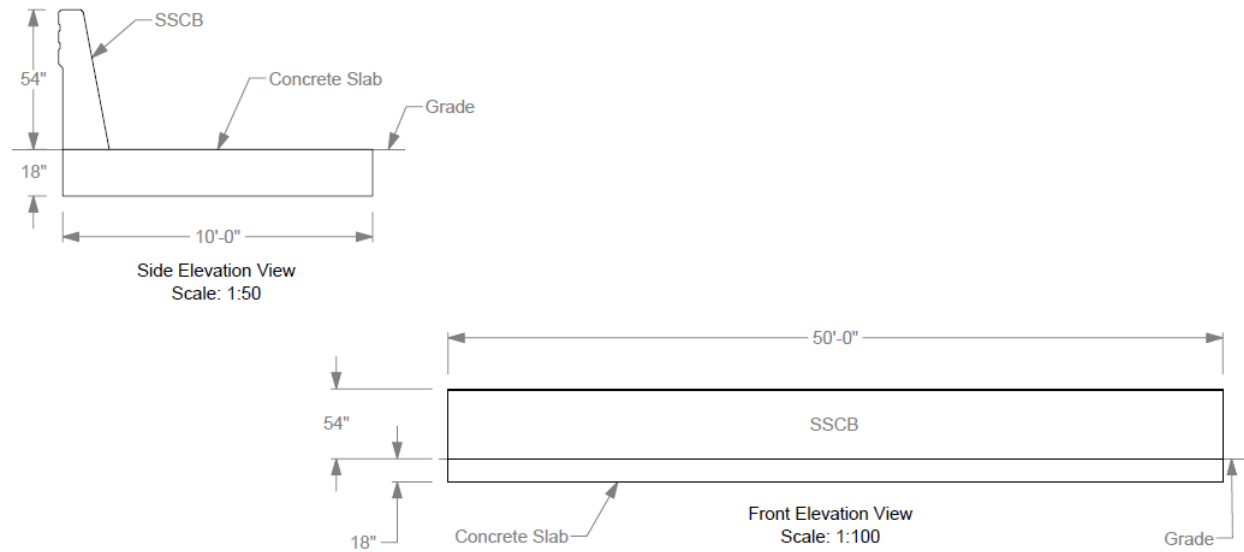
**Figure 2.2. Concept 1 – Drilled Shaft Design.**



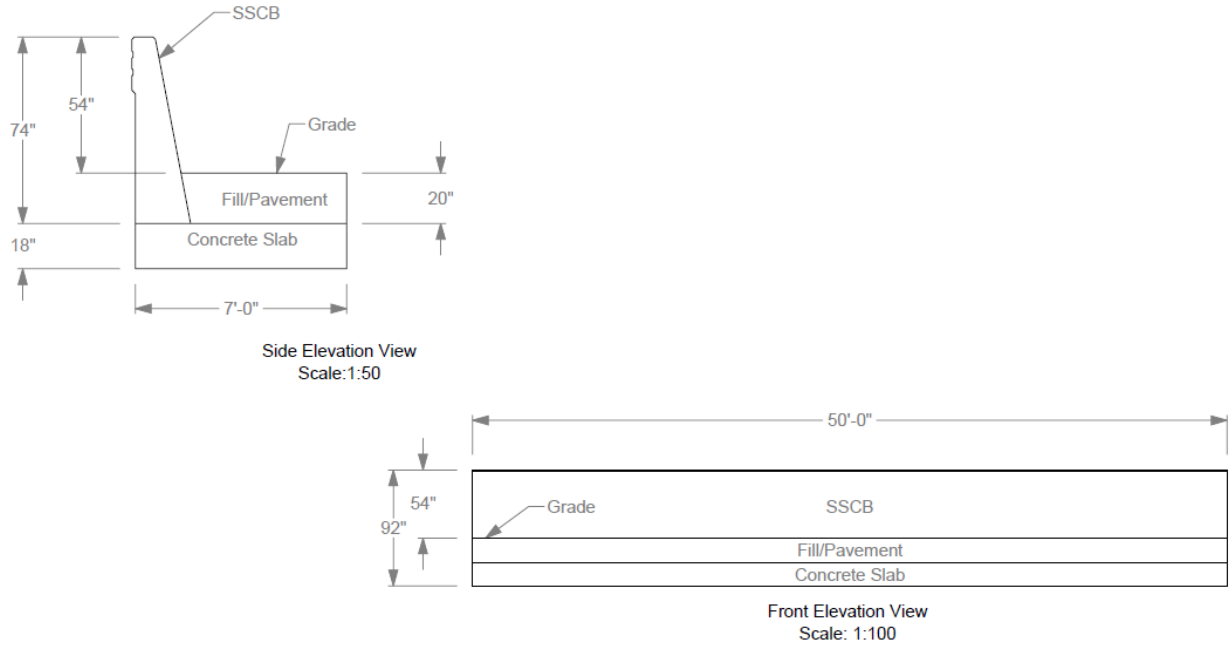
**Figure 2.3. Concept 2 – Concrete Beam Design.**



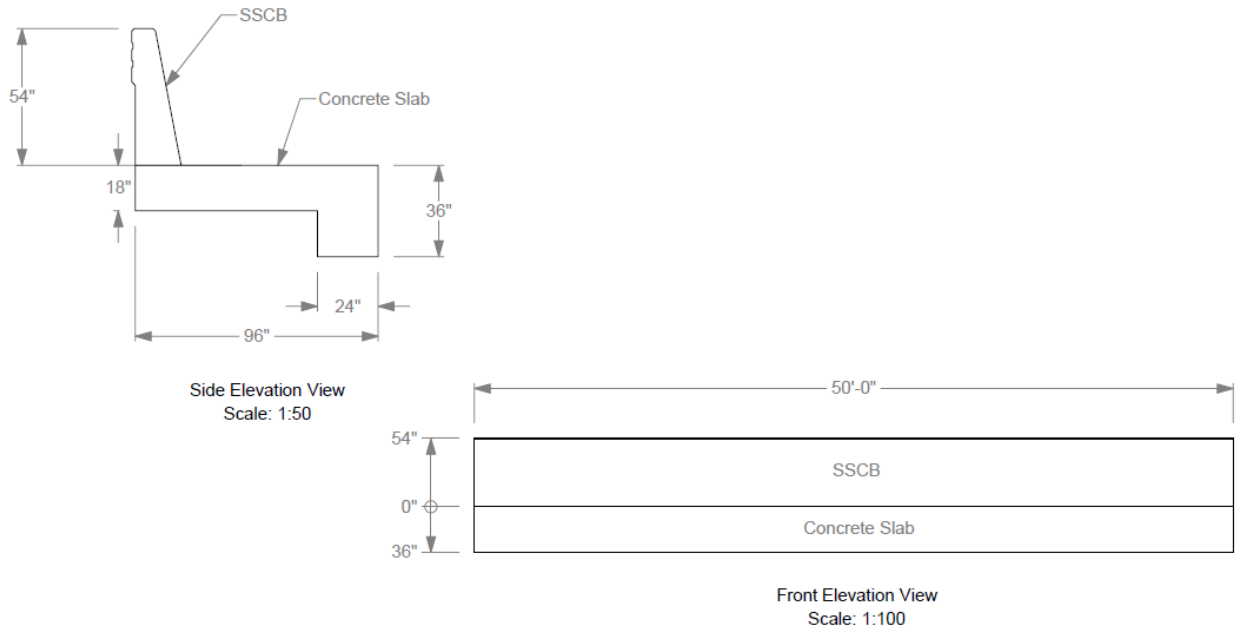
**Figure 2.4. Concept 3 – Drilled Shaft with Concrete Beam Design.**



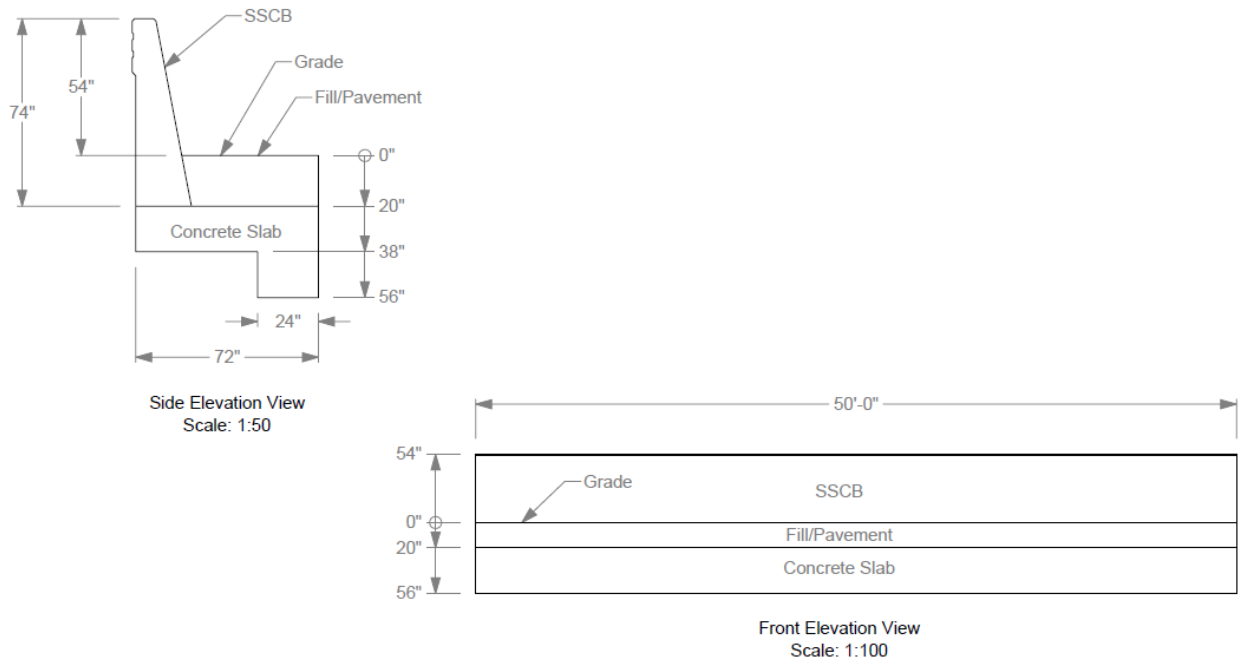
**Figure 2.5. Concept 4 – Moment Slab Design.**



**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.

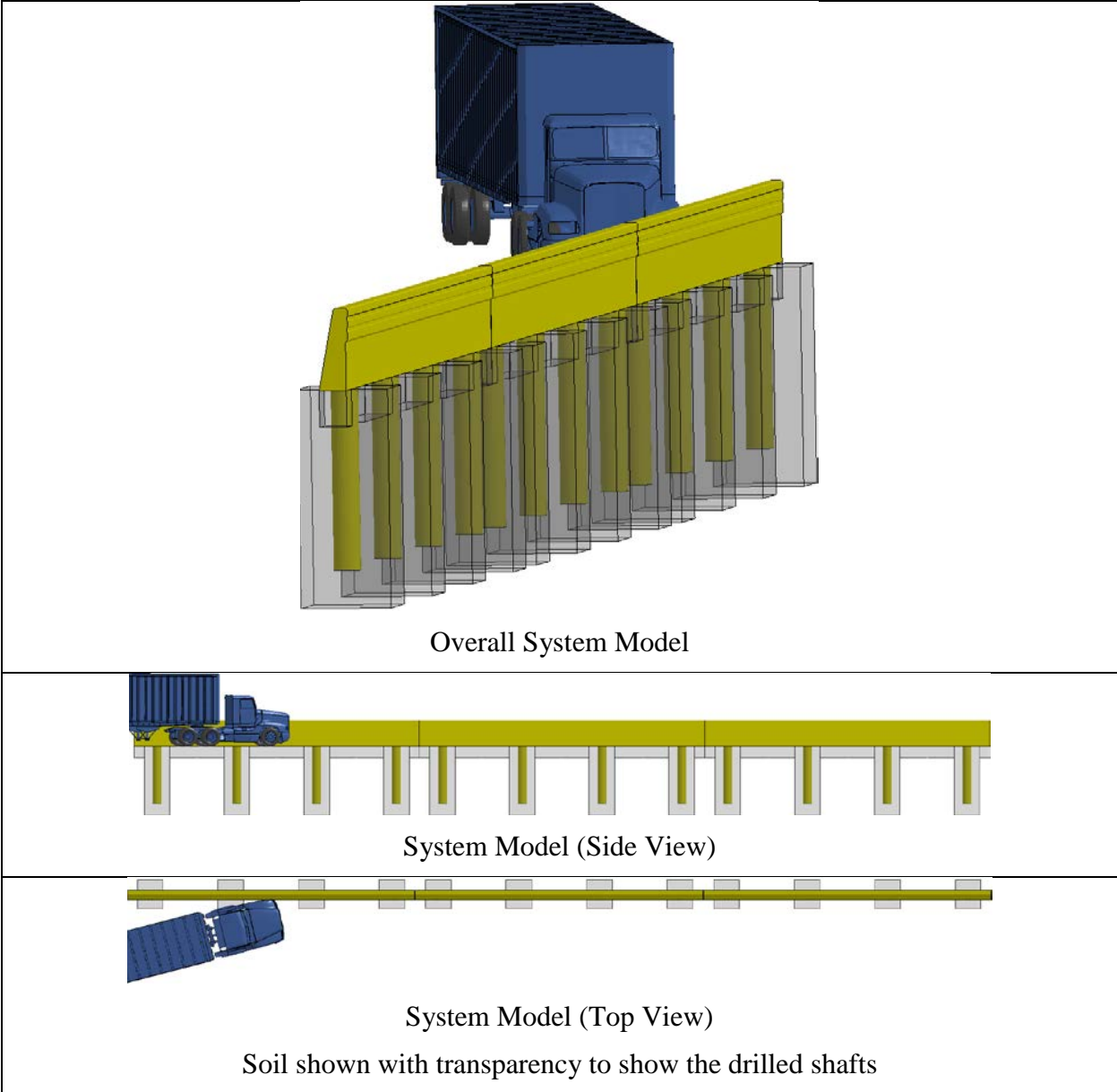
Images of the models for the various foundation designs and results of the impact analyses are presented next.

### **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.

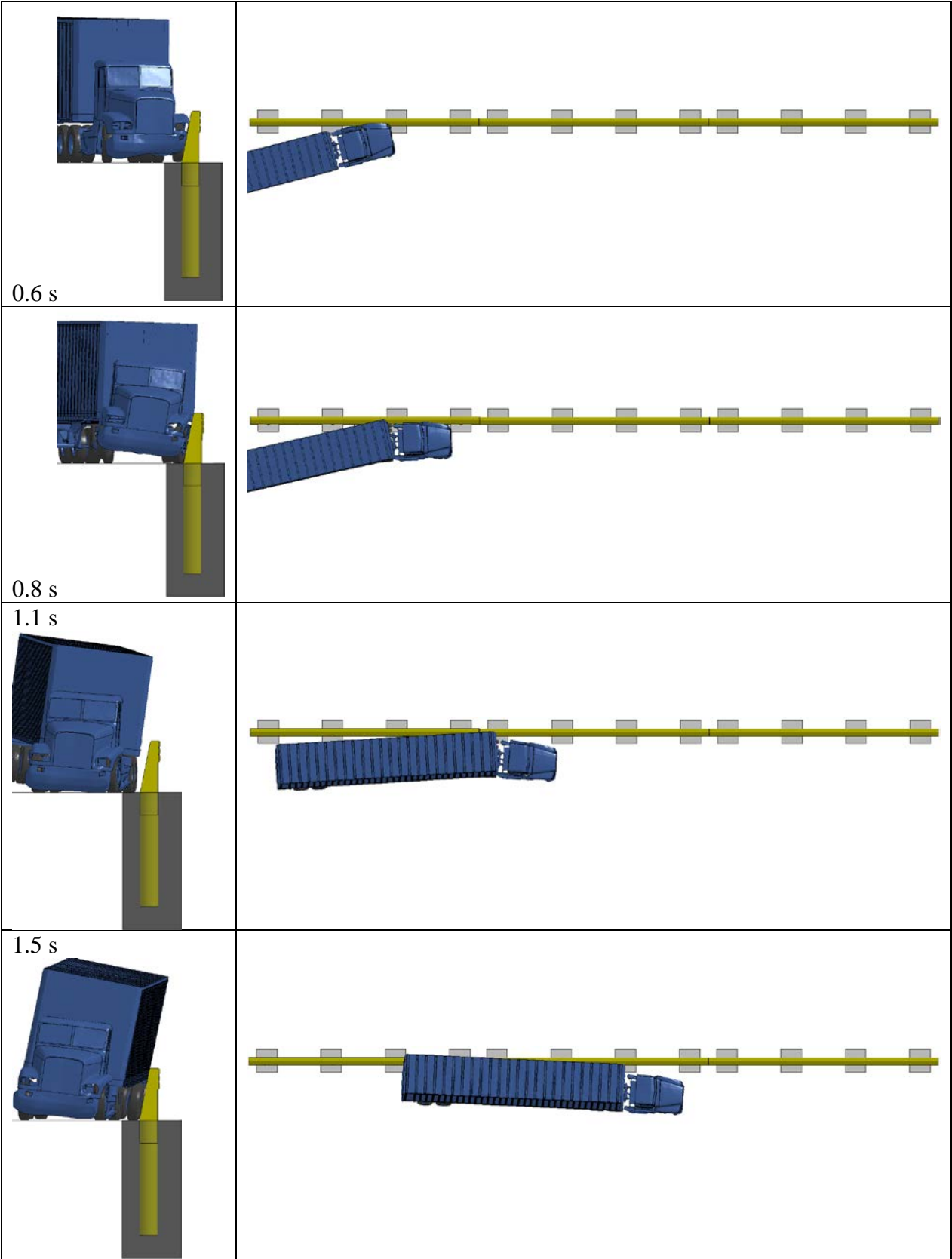
Figure 2.9 shows the FE model of this barrier and foundation. Figure 2.10 shows the results of *MASH* Test 5-12 impact simulation with the tractor trailer vehicle model. The vehicle was successfully contained and redirected by the barrier and the foundation system. There was very little movement of the 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.

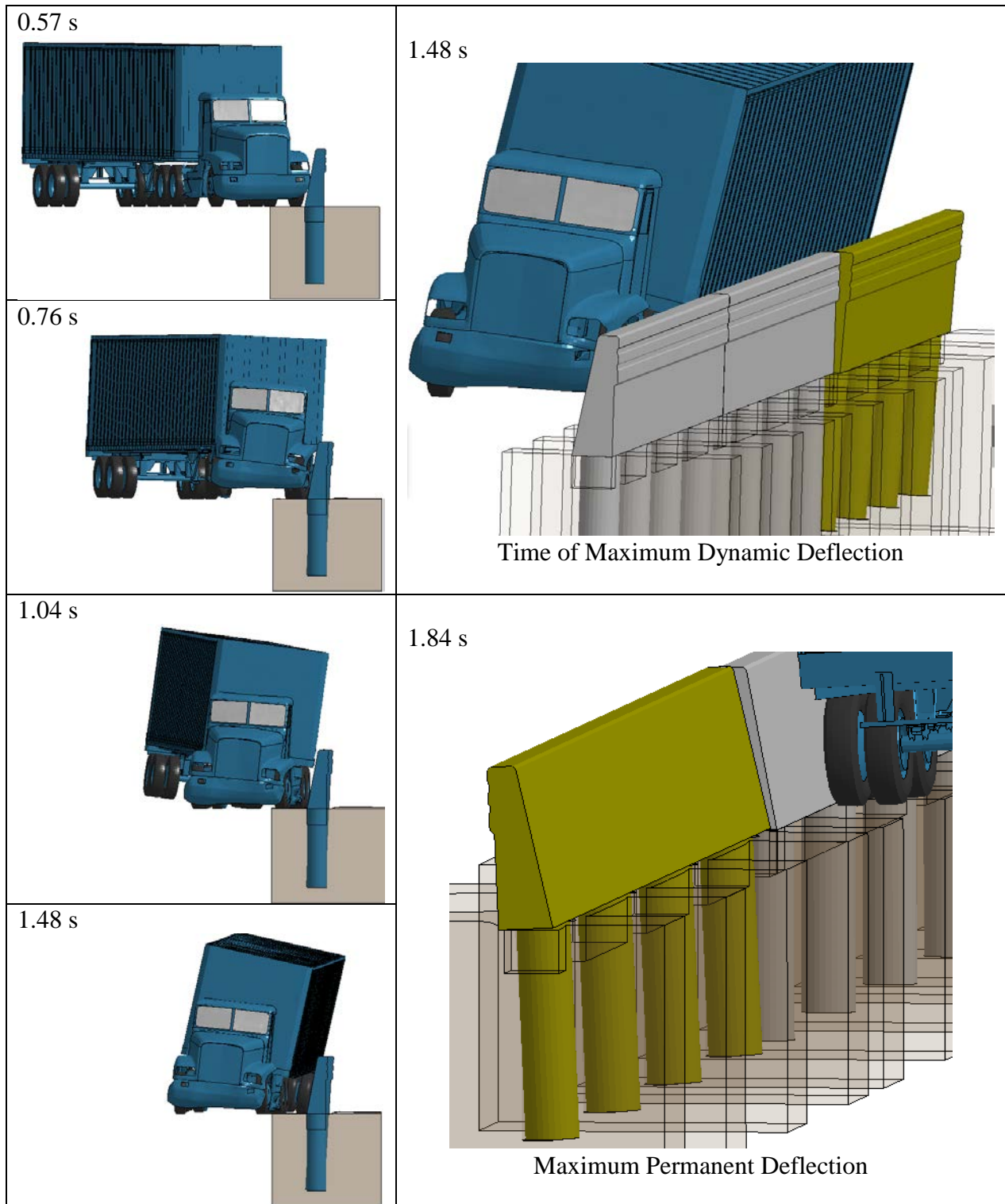


**Figure 2.9. Drilled Shaft Foundation Simulation Model Details (10-Ft Deep Shafts).**





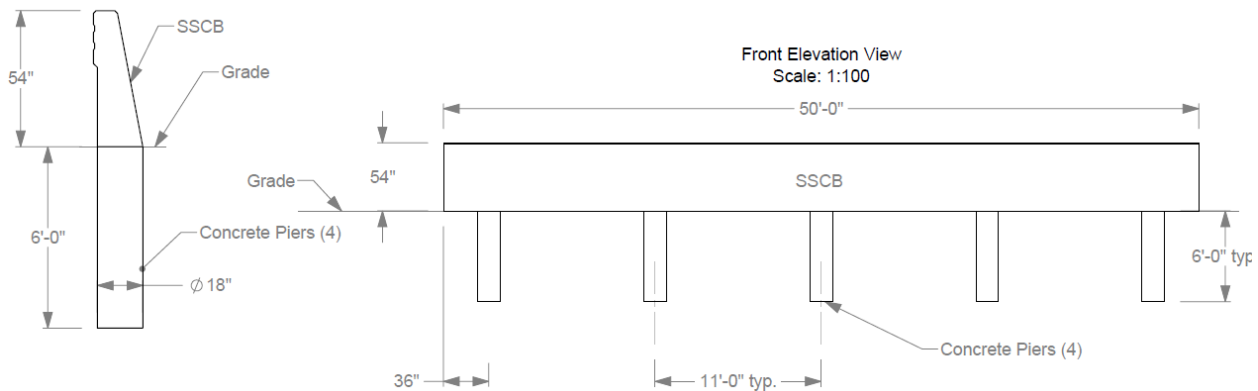
**Figure 2.10. Impact Simulation for Drilled Shaft Foundation with 10-Ft Deep Shafts.**



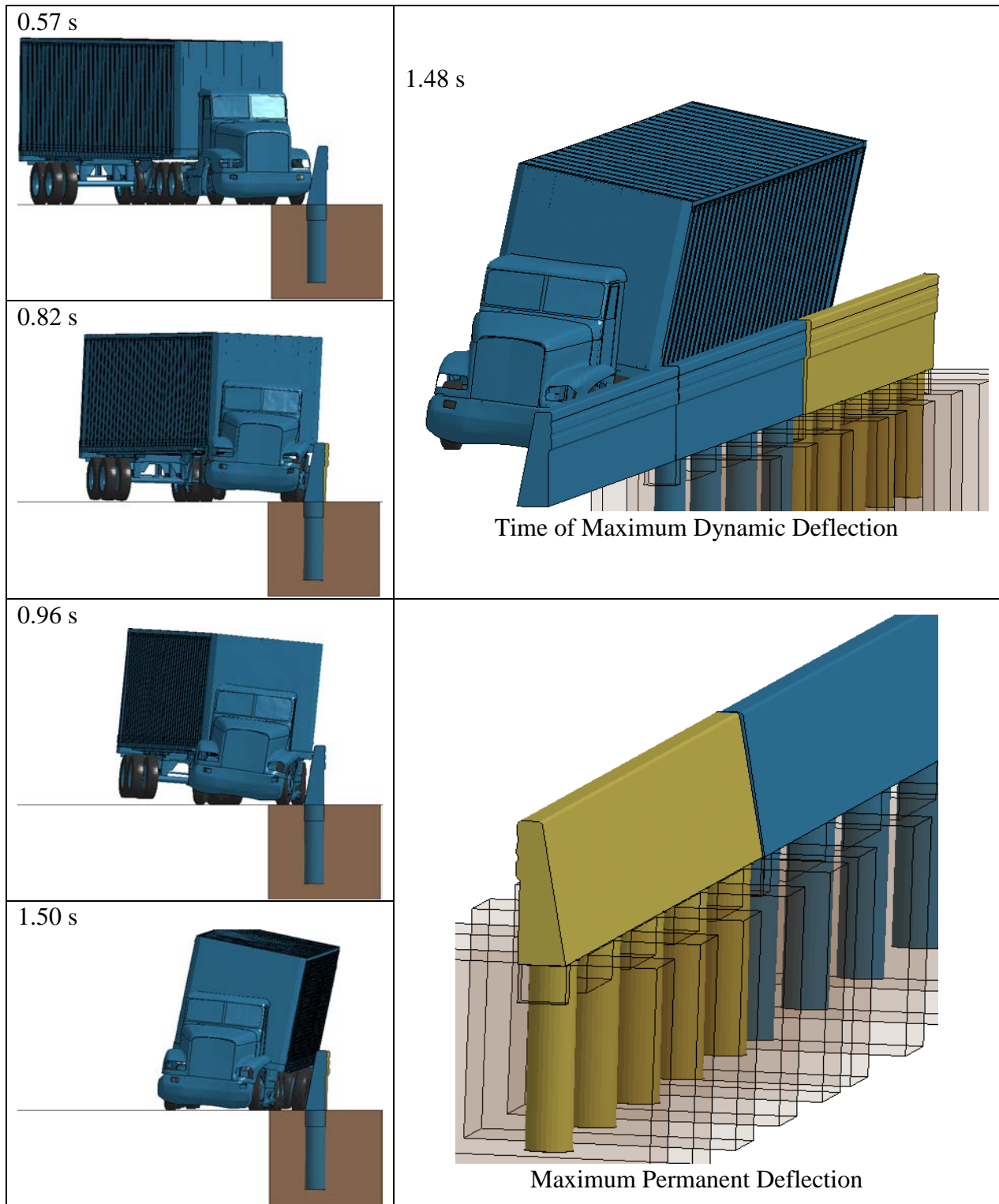
**Figure 2.11. Impact Simulation for Drilled Shaft Foundation Design with Four 6-Ft Deep Drilled Shafts.**

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.**

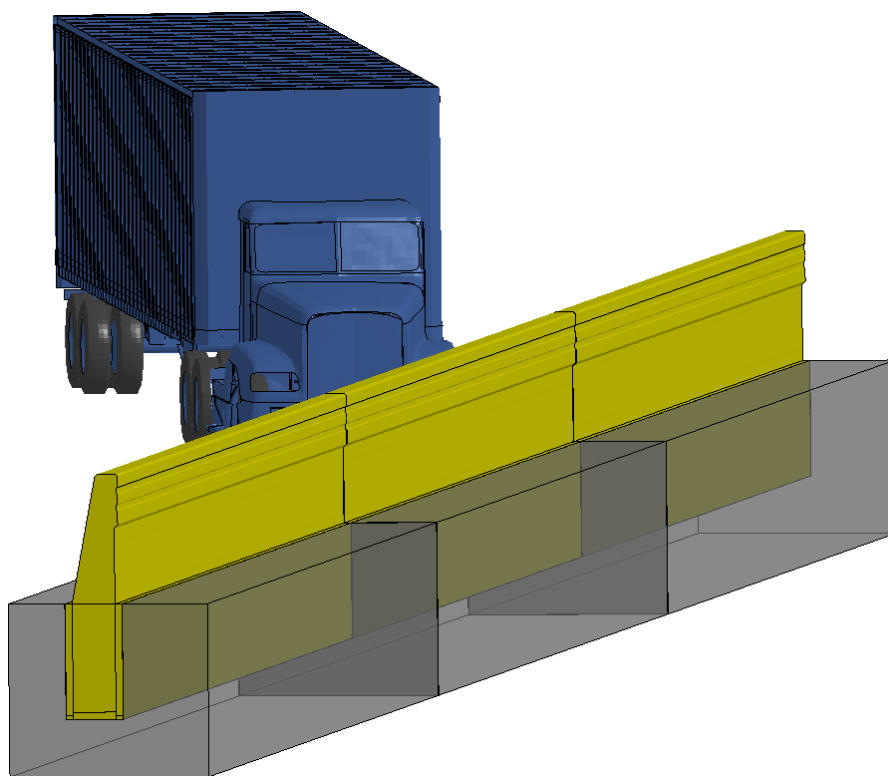


**Figure 2.13. Impact Simulation of Drilled Shaft Foundation with Five 6-Ft Deep Drilled Shafts.**

## 2.2.2 Concrete Beam Foundation Design

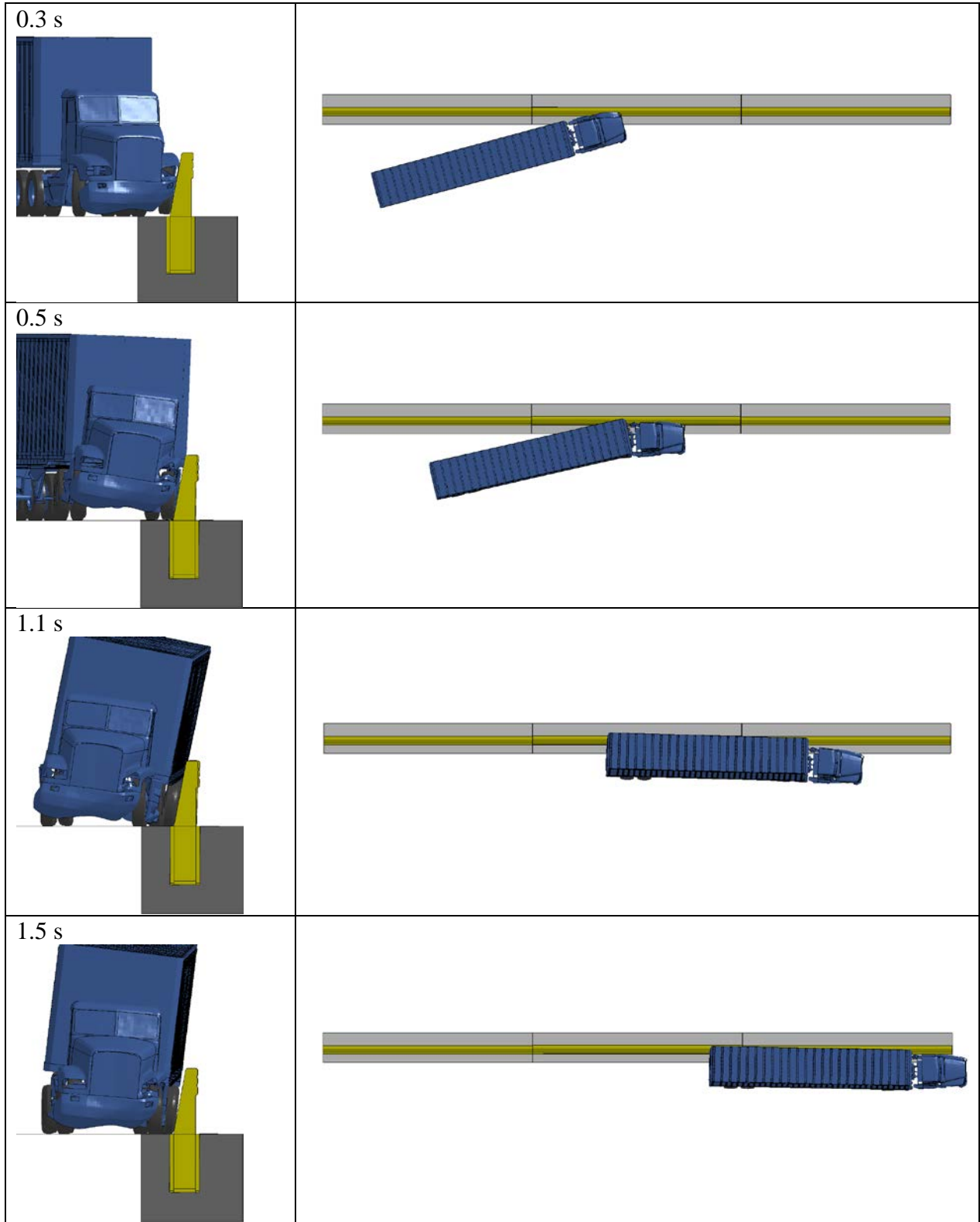
As shown in Figure 2.3, this foundation design was comprised of a 48-inch deep, 24-inch wide concrete beam that was attached to the base of the single slope barrier along the entire length of the 50-ft segment.

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.

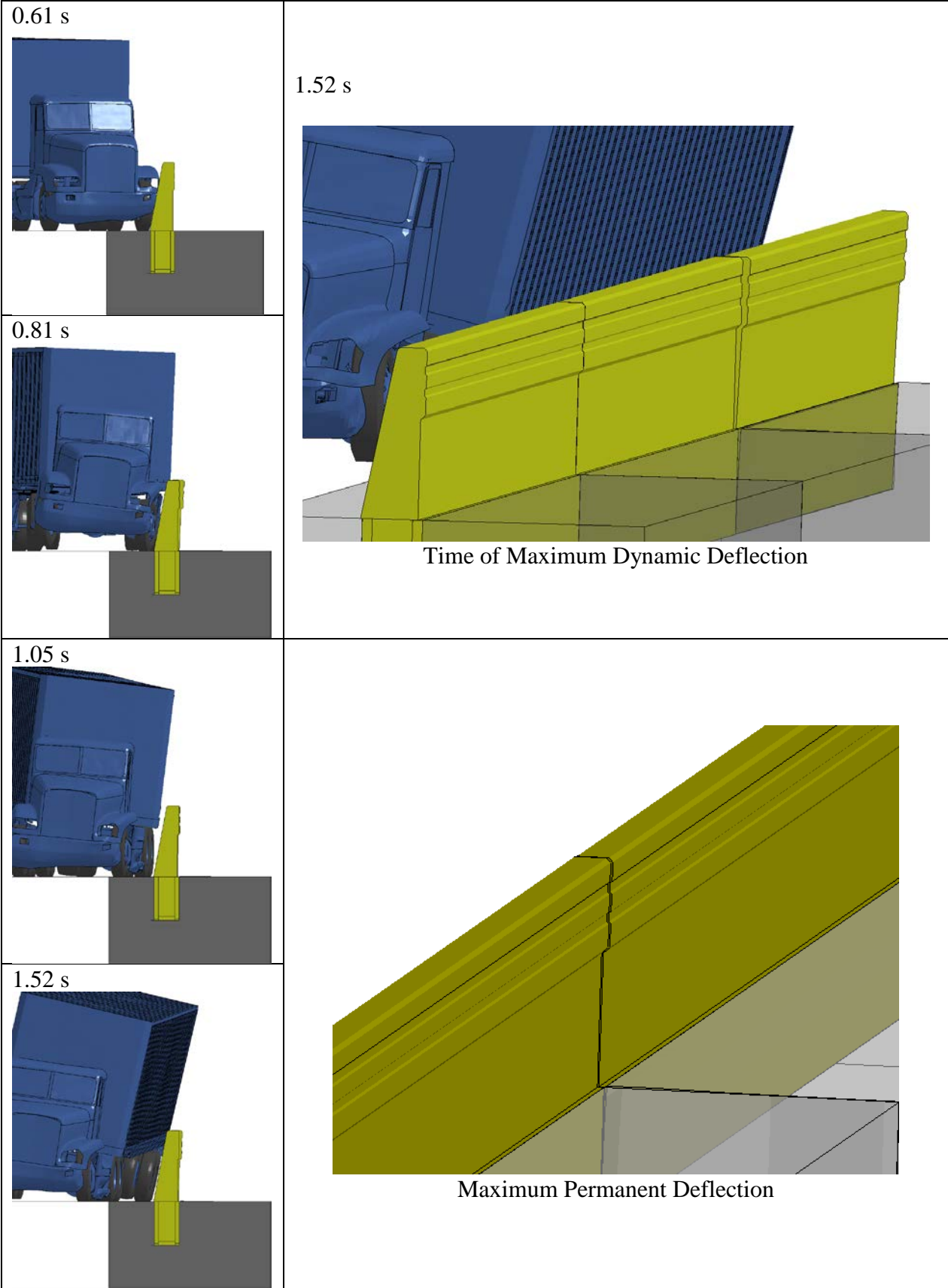
### **2.2.3 Moment Slab Foundation Design**

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.

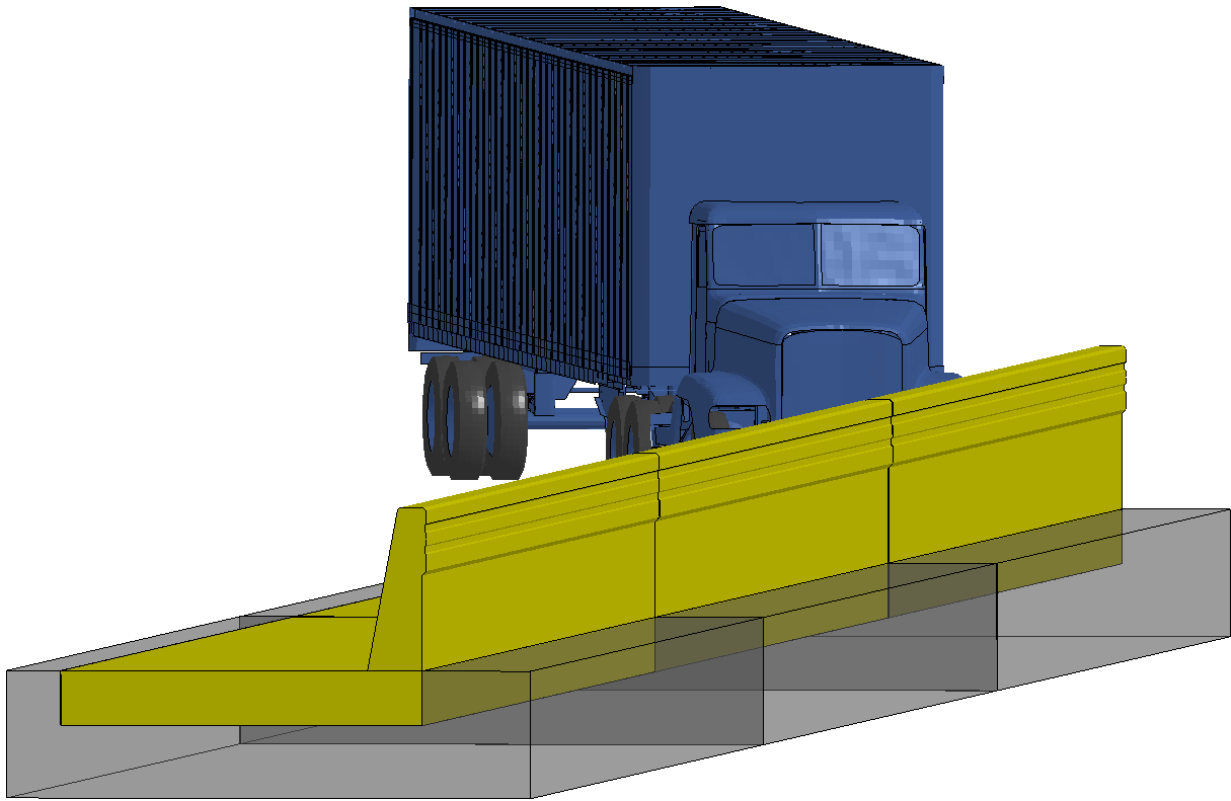
Due to the low deflection of the foundation design observed in the simulation, TTI researchers reduced the width of the moment slab to 6 ft, while keeping the same 18-inch depth. A finite element model of this modified foundation was developed, and the results of the impact simulation are shown in Figure 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.



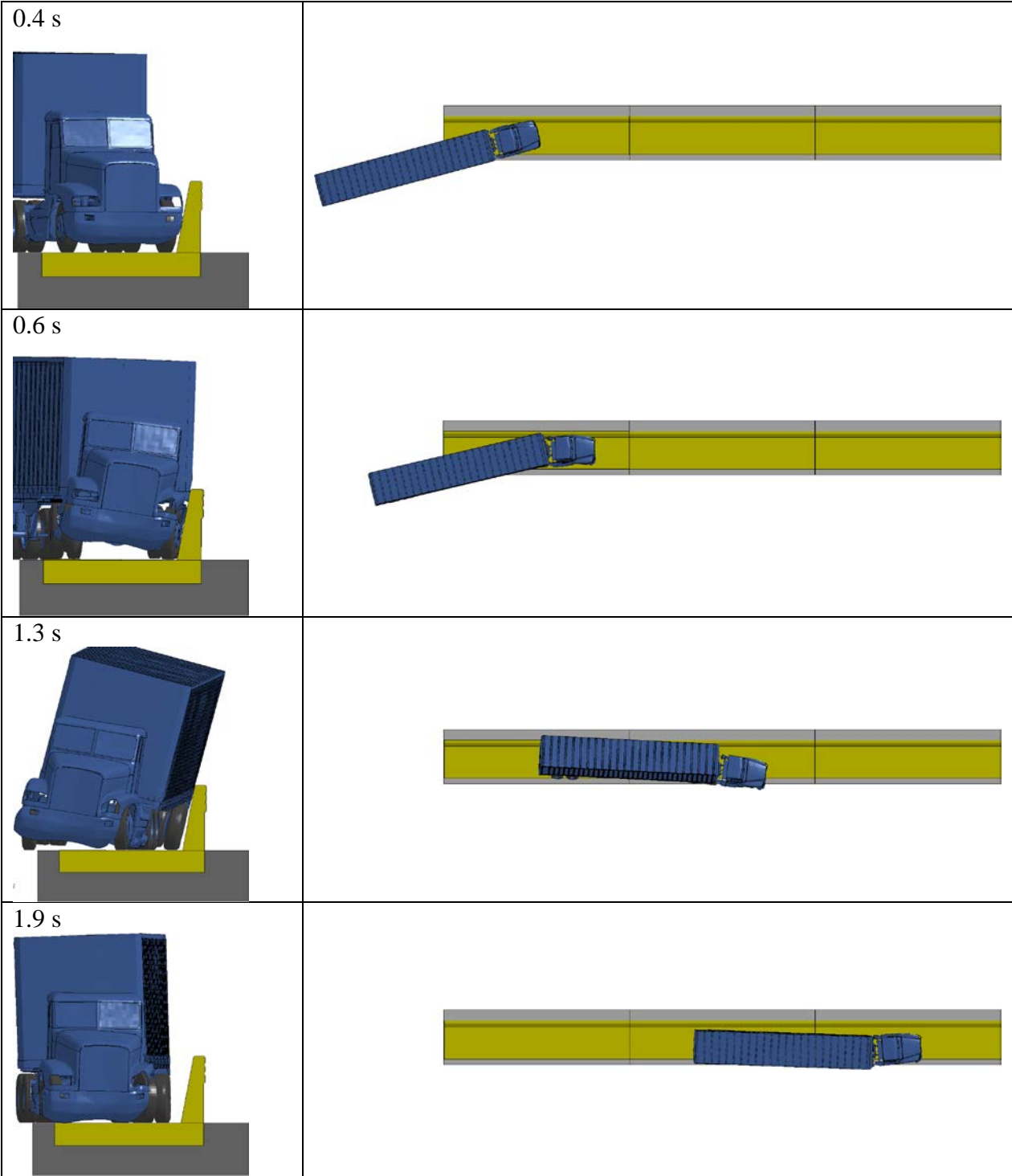
**Figure 2.16. Impact Simulation with Standard TxDOT Traffic Rail Foundation.**



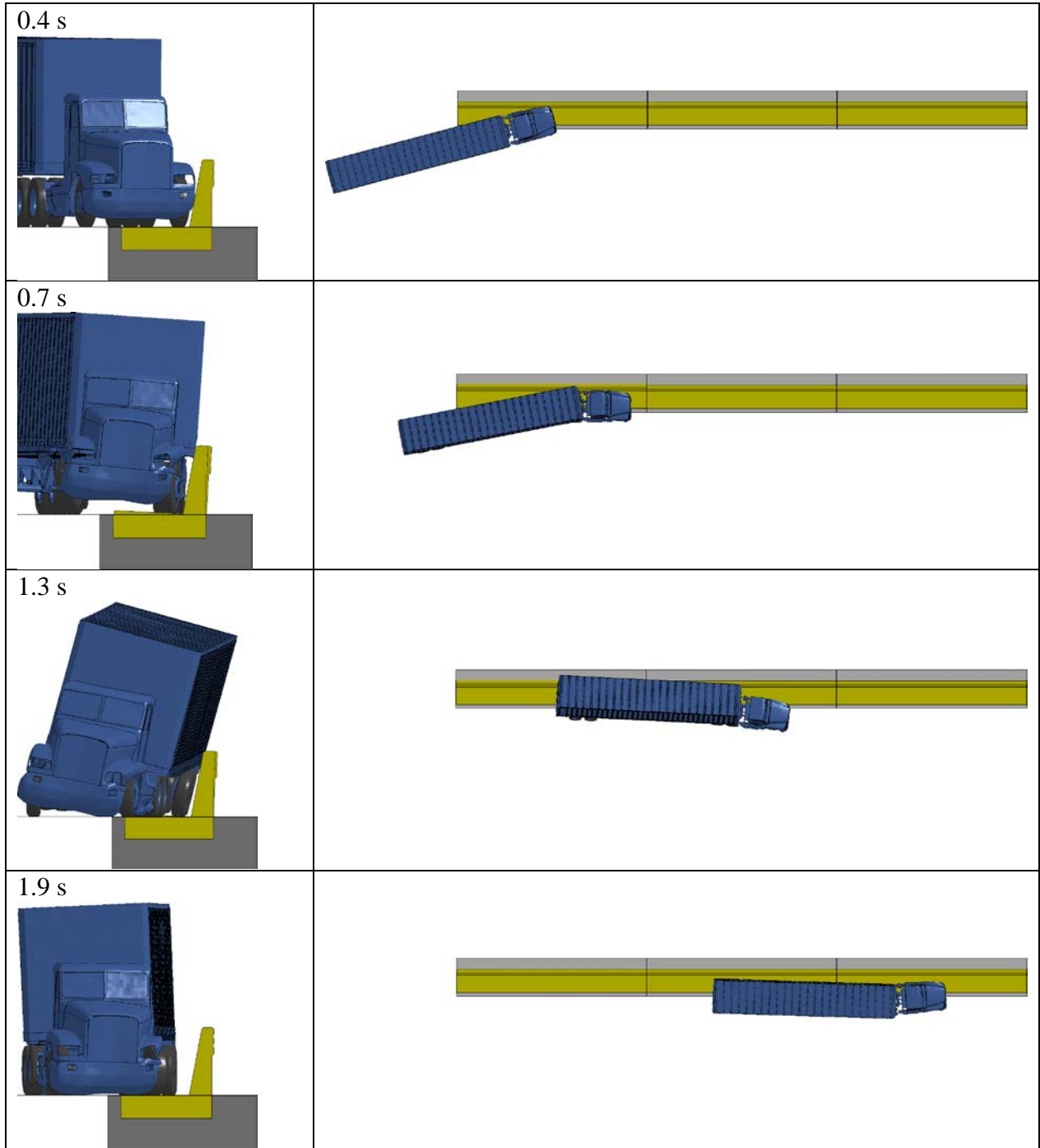


Soil shown with transparency to show foundation.

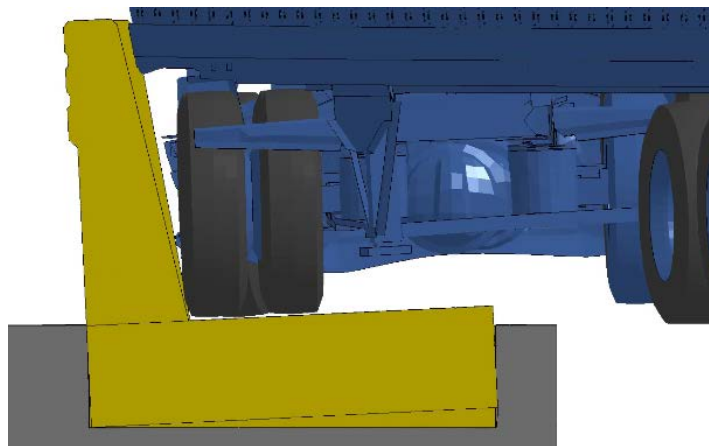
**Figure 2.17. 10-Ft Wide Moment Slab Foundation Simulation Model.**



**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.**

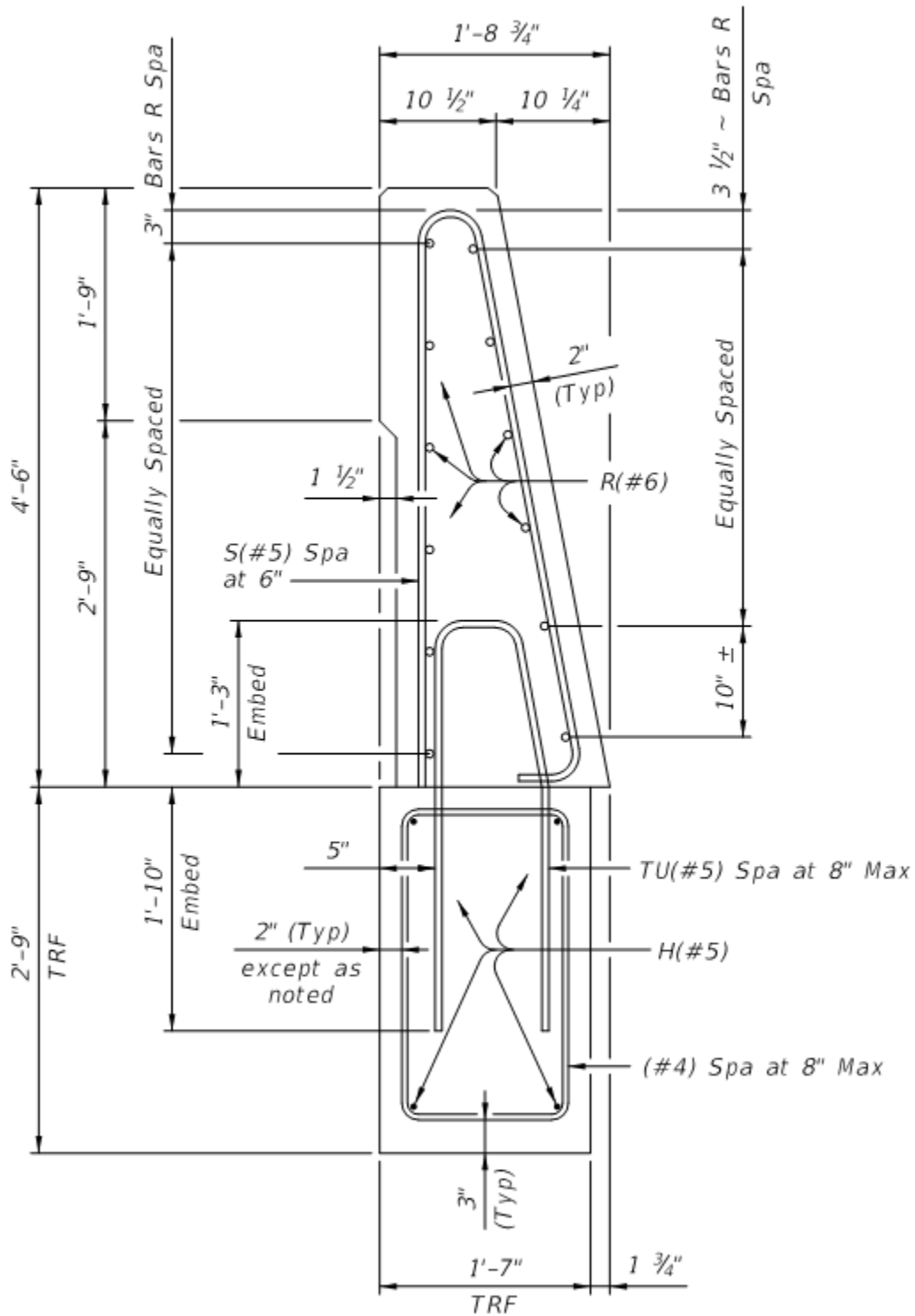
Foundation Type	Permanent Deflection (inches)	Maximum Dynamic Deflection (inches)	Working Width (inches)	Working Width Height (inches)
<b>Drilled Shaft</b> Five 6-ft long shafts	1.22	3.75	31.8	148.6
<b>Concrete Beam</b> TRF 19 inch × 33 inch	0.35	3.6	34.2	149.2
<b>Moment Slab</b> 18 inch × 10 ft	0.0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

## 2.3 REINFORCEMENT DESIGN

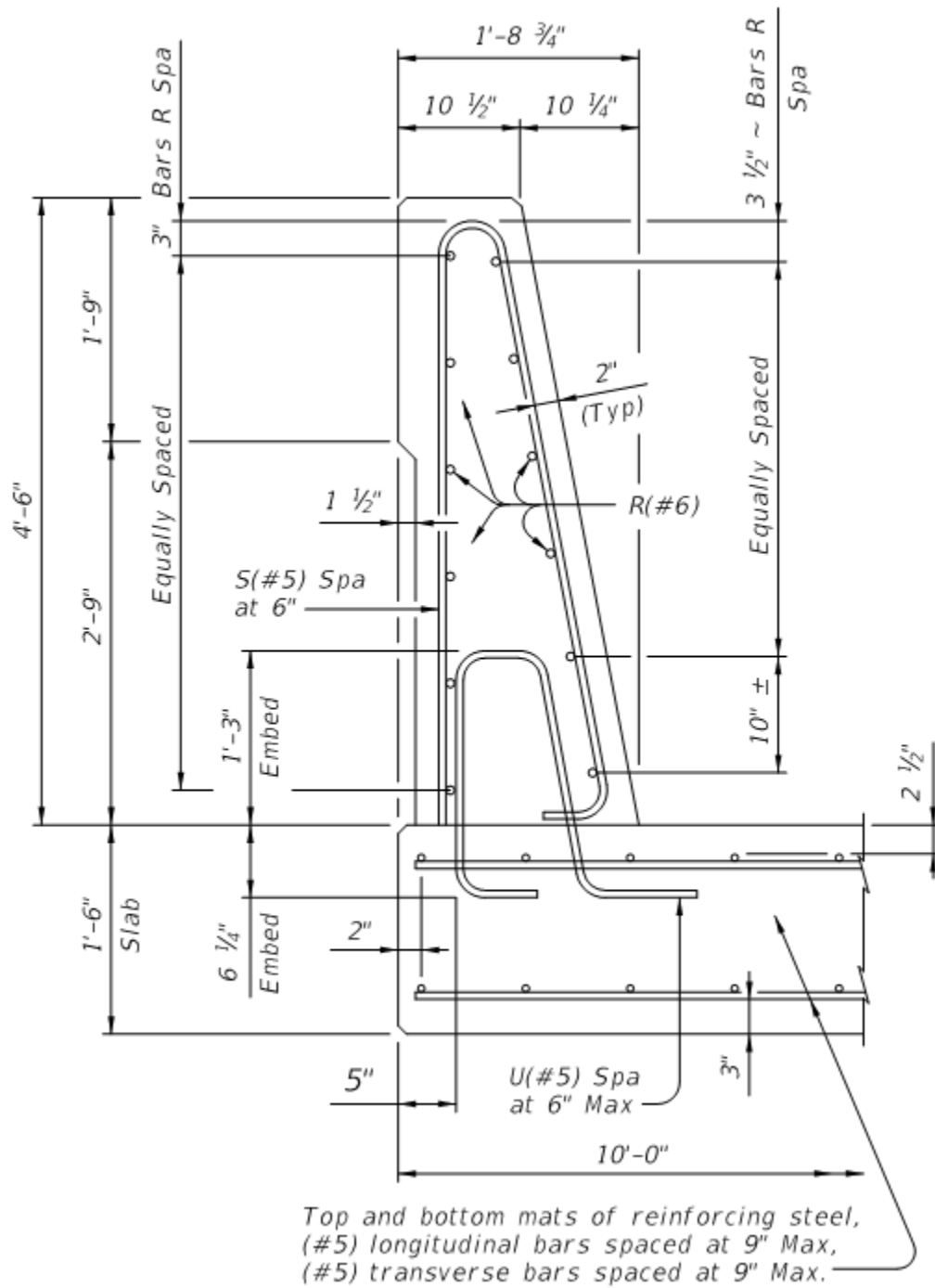
Once the basic geometric designs of the foundations were finalized using the FE analyses, TTI researchers developed reinforcement details of the 54-inch tall single slope barrier and the three selected foundations. The designs were reviewed and revised by TxDOT, and the final details are presented in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

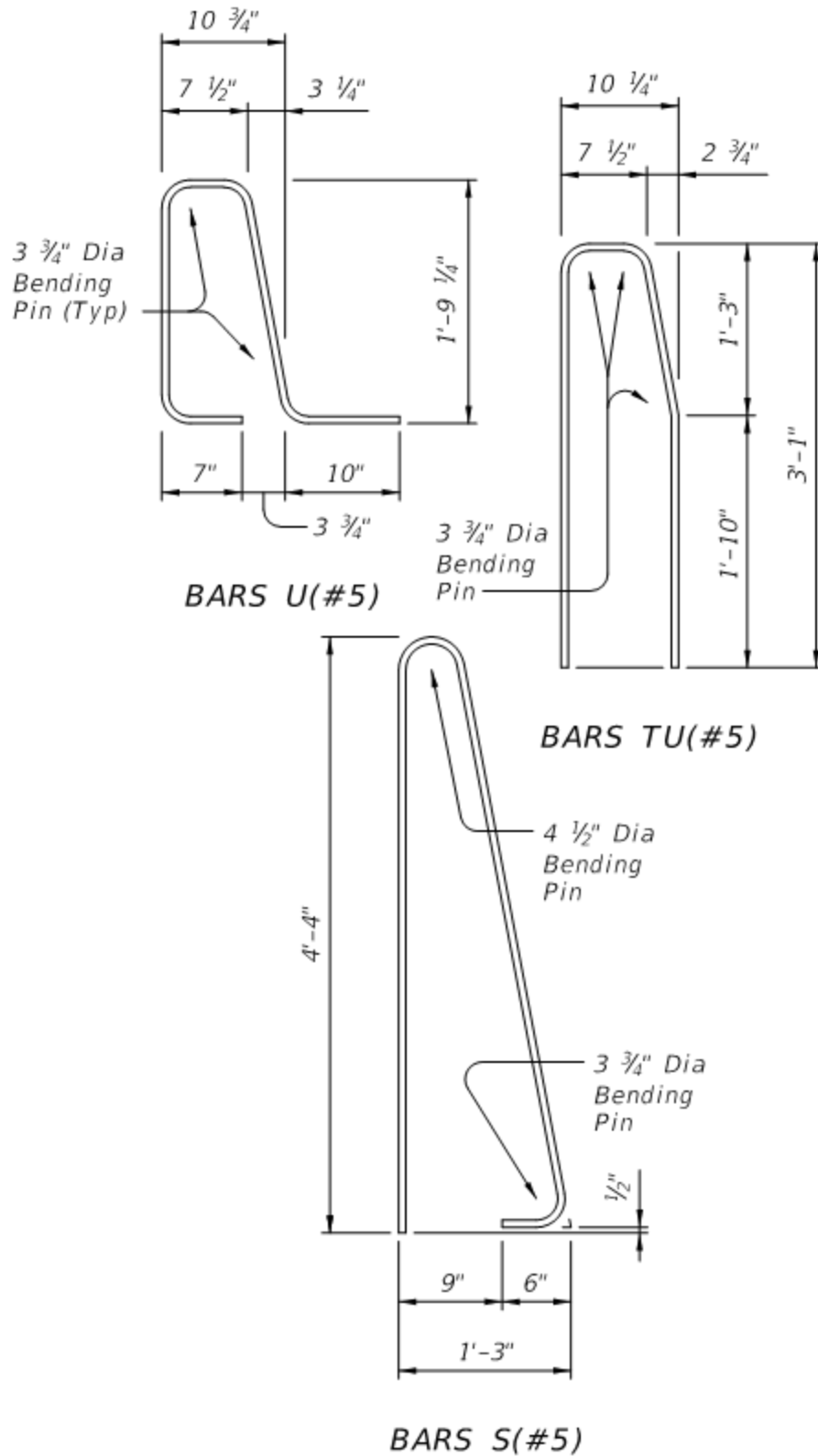


Figure 2.23. Details of Stirrups Used in Barrier and Foundation Designs.





## **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.

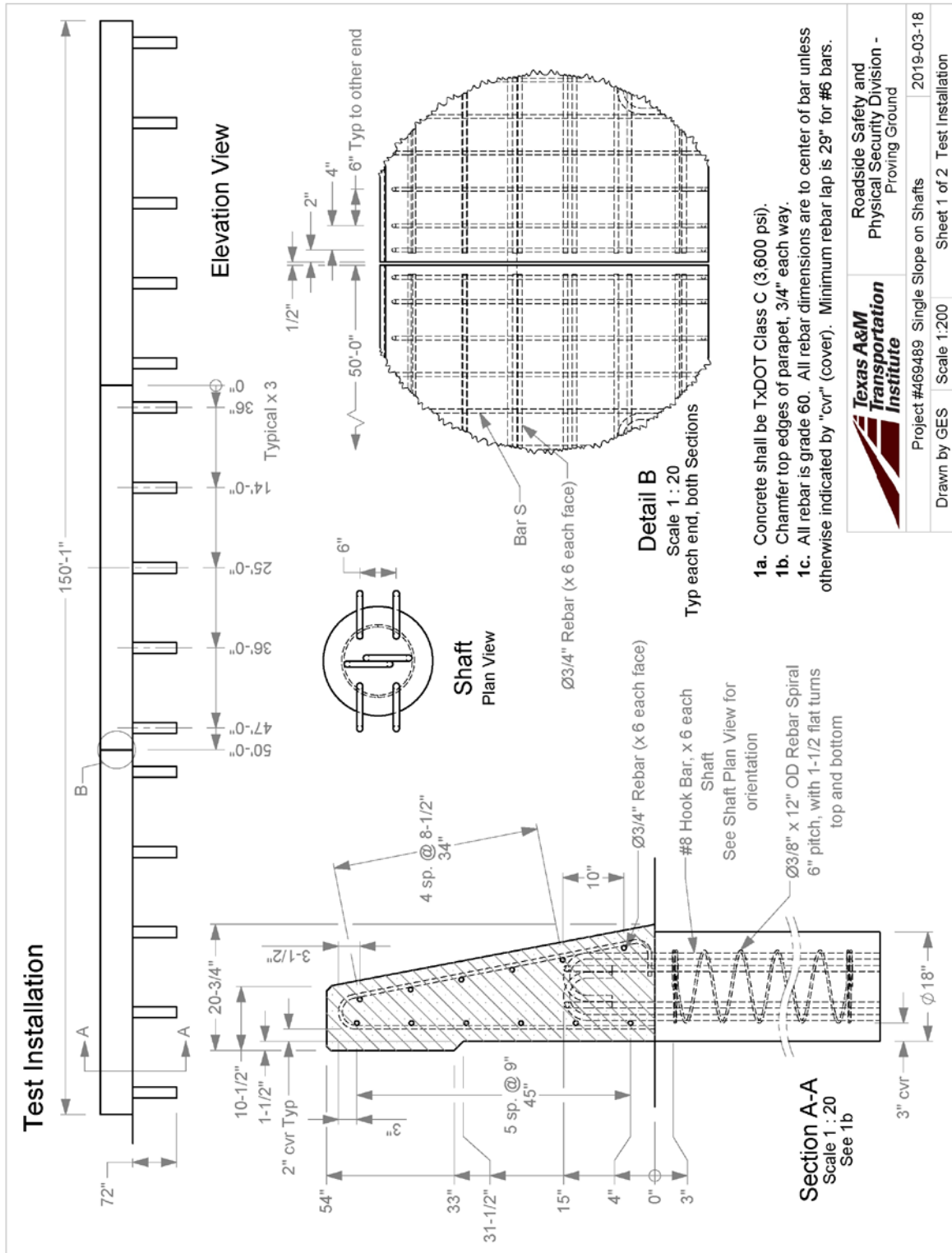
Figure 3.1 presents overall information on the SSCB with the drilled shaft foundation, and Figures 3.2 and 3.3 provide photographs of the installation. Appendix A provides further details of the installation.

### **3.2 DESIGN MODIFICATIONS DURING TESTS**

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

### **3.3 MATERIAL SPECIFICATIONS**

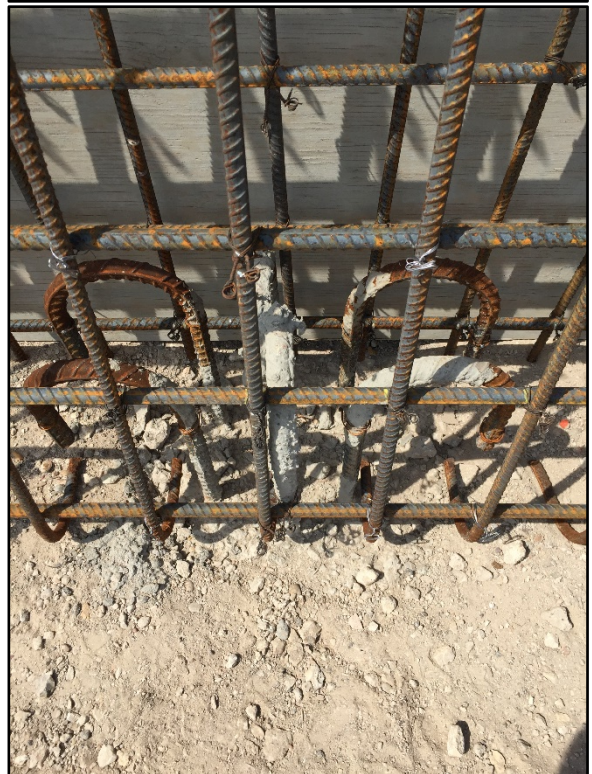
Appendix B provides material certification documents for the materials used to install/construct the SSCB with the drilled shaft foundation.



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

	Roadside Safety and Physical Security Division - Proving Ground	2019-03-18
	Project #469489 Single Slope on Shafts	2019-03-18
Drawn by GES	Scale 1:200 Sheet 1 of 2 Test Installation	



**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

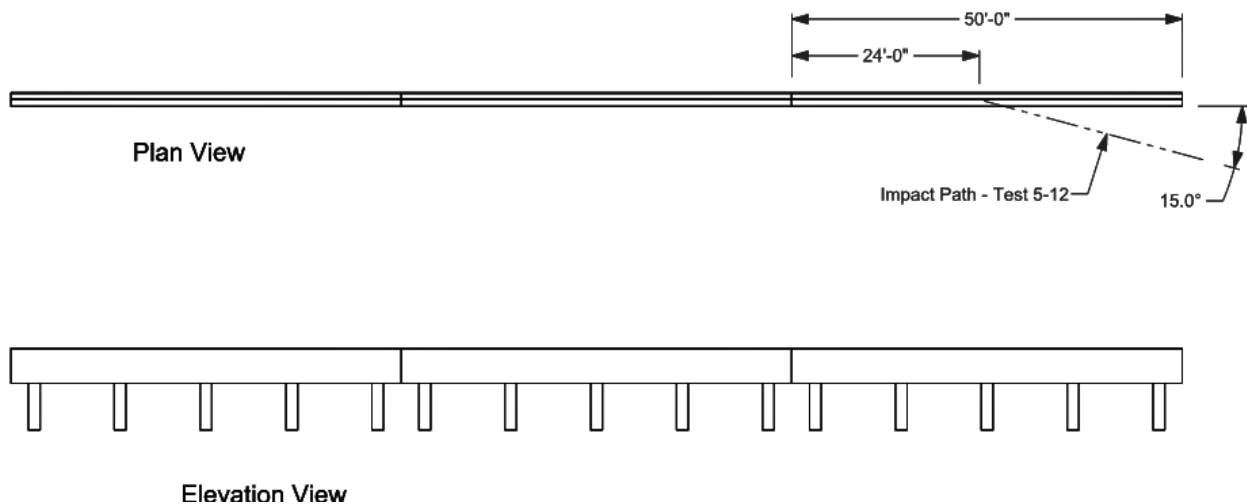
### 4.1 CRASH TEST MATRIX

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  $\pm$ 1100 lb impacting the critical impact point (CIP) of the barrier at an impact speed of 50 mi/h  $\pm$ 2.5 mi/h and an impact angle of 15°  $\pm$ 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.**

<b>Evaluation Factors</b>	<b>Evaluation Criteria</b>
<b>Structural Adequacy</b>	A. <i>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.</i>
<b>Occupant Risk</b>	D. <i>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.</i>  <i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</i>
	G. <i>It is preferable, although not essential, that the vehicle remain upright during and after the collision.</i>

## **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  $\pm 1.7$  percent at a confidence factor of 95 percent ( $k=2$ ).

TRAP uses the data from the TDAS Pro to compute occupant/compartiment impact velocities, time of occupant/compartiment 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.

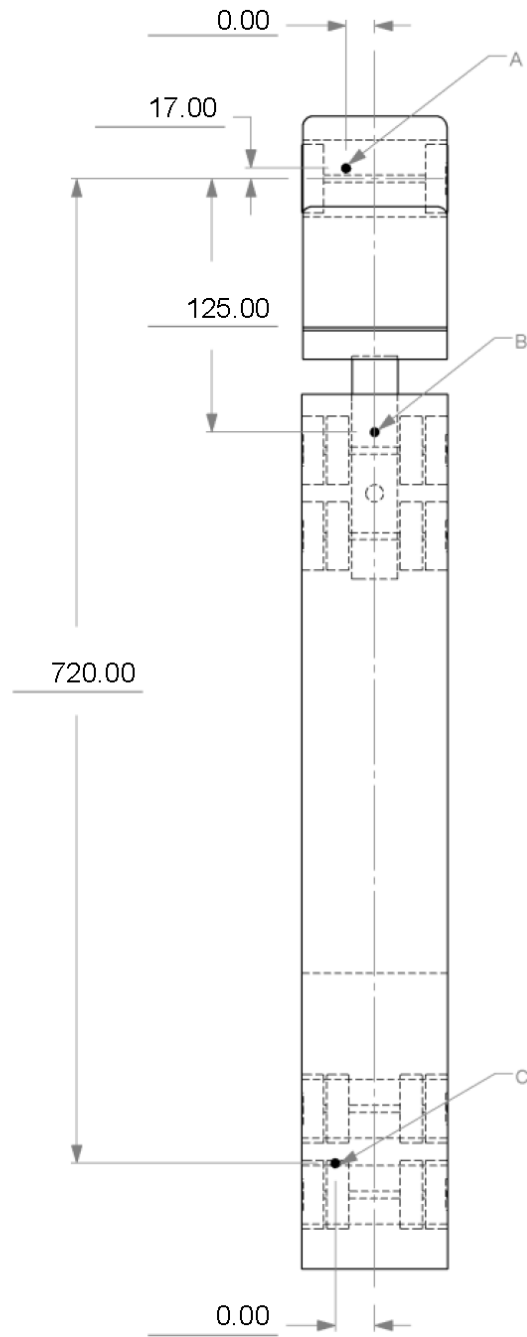
TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals, then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact. Rate of rotation data is measured with an expanded uncertainty of  $\pm 0.7$  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.



Height above ground:  
 A: 32.00 inches  
 B: 36.00 inches  
 C: 50.00 inches



**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  $\pm$ 1100 lb impacting the CIP of the test article at an impact speed of 50 mi/h  $\pm$ 2.5 mi/h and an impact angle of 15°  $\pm$ 1.5°. The CIP for *MASH* Test 5-12 on the SSCB with the drilled shaft foundation was 24 ft  $\pm$ 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.

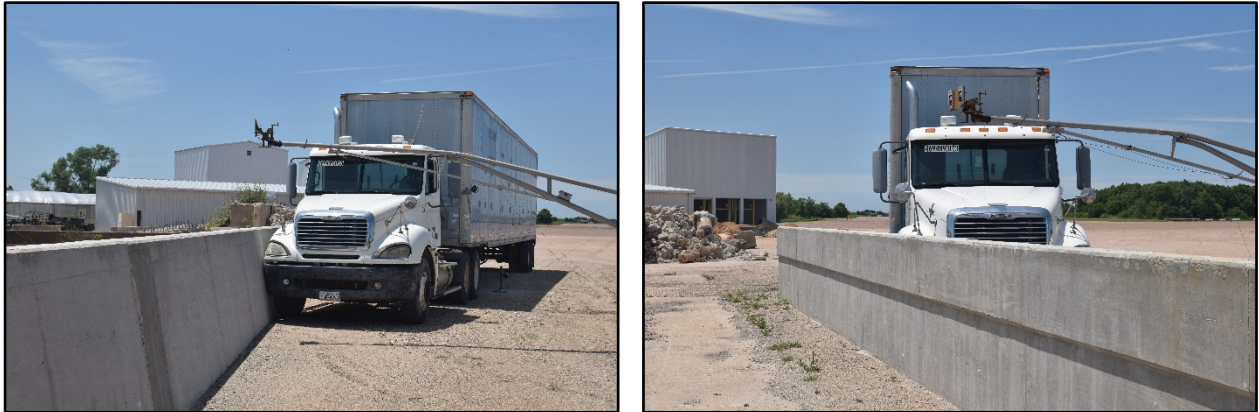
The 2006 Freightliner TR tractor with 1999 TRL VN 53 trailer used in the test weighed 80,170 lb, and the actual impact speed and angle were 48.9 mi/h and 15.0°, respectively. The actual impact point was 24.9 ft upstream of the centerline of the joint between barrier segments 1 and 2. Minimum target impact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

<b>TIME (s)</b>	<b>EVENTS</b>
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<sup>†</sup> 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.

---

<sup>†</sup> 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.

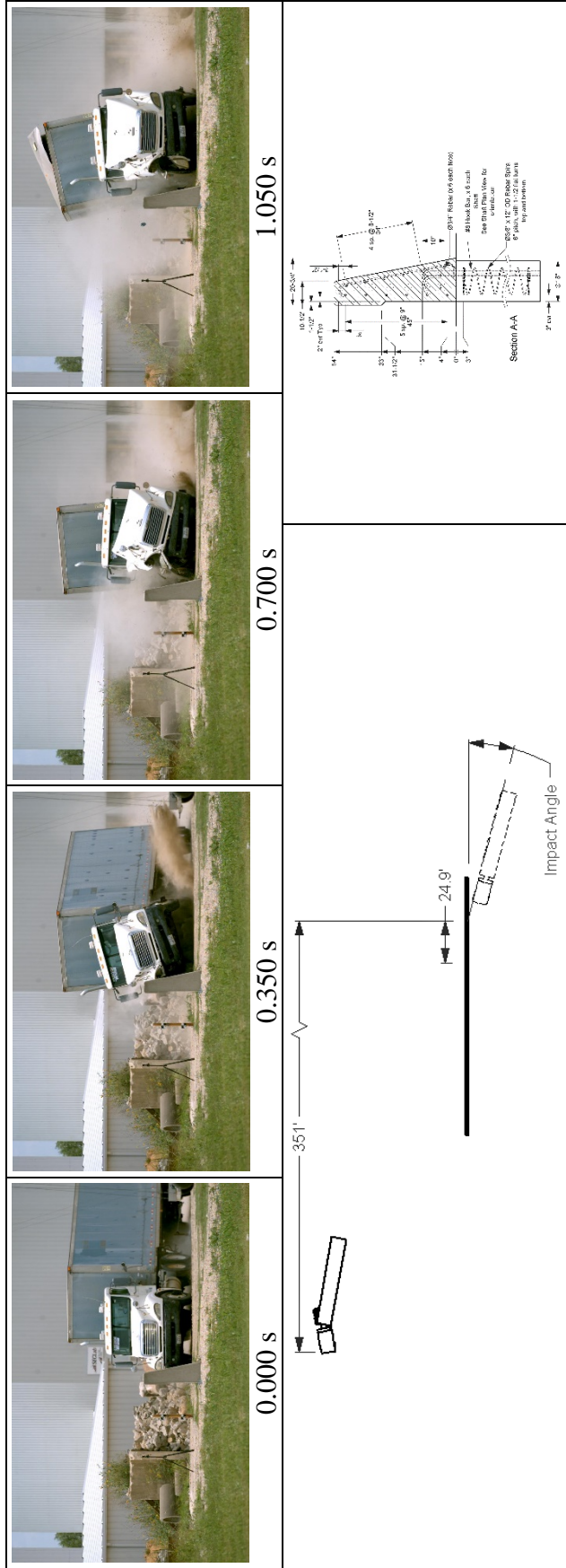
Data from the accelerometer at location B in Figure 5.1 were digitized for evaluation of occupant risk for informational purposes only, and the results are shown in Table 6.2. Figure 6.6 summarizes these data and other pertinent information from the test. Figure C.3 in

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.**

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





<b>General Information</b>				
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			
<b>Test Article</b>				
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			
<b>Soil Type and Condition</b> .....	Native soil			
<b>Test Vehicle</b>				
Type/Designation.....	36000V			
Make and Model .....	2006 Freightliner w/1999 TRL Trailer			
Curb.....	30,700 lb			
Test Inertial .....	80,170 lb			
Dummy .....	No dummy			
Gross Static .....	80,170 lb			
<b>Impact Conditions</b>				
Speed .....	48.9 mi/h			
Angle .....	15.0°			
Location/Orientation .....	24.9 ft up/stnm of joint btwn seg. 1&2			
<b>Impact Severity</b> .....	429 kip-ft			
<b>Exit Conditions</b>				
Speed .....	Not obtainable			
Angle .....	Not obtainable			
<b>Occupant Risk Values</b>				
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			
<b>Post-Impact Trajectory</b>				
Stopping Distance.....	351 ft downstream 82 ft twd field side			
<b>Vehicle Stability</b>				
Maximum Yaw Angle .....	32°			
Maximum Pitch Angle .....	3°			
Maximum Roll Angle .....	11°			
Vehicle Snagging.....	No			
Vehicle Pocketing .....	No			
<b>Test Article Deflections</b>				
Dynamic.....	2.9 inches			
Permanent.....	0.6 inch			
Working Width.....	40.2 inches			
Vehicle Intrusion .....	147.1 inches			
<b>Vehicle Damage</b>				
VDS .....	NA			
CDC .....	NA			
Max. Exterior Deformation.....	16.0 inches			
OCDI.....	FS000000			
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
<b>MASH Test Evaluation Criteria</b>		<b>Test Results</b>	<b>Assessment</b>
<u>Structural Adequacy</u>			
A. <i>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</i>		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. <i>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.</i>		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
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</i>		No occupant compartment deformation or intrusion occurred.	
G. <i>It is preferable, although not essential, that the vehicle remain upright during and after collision.</i>		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<sup>‡</sup>

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

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<sup>‡</sup> 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

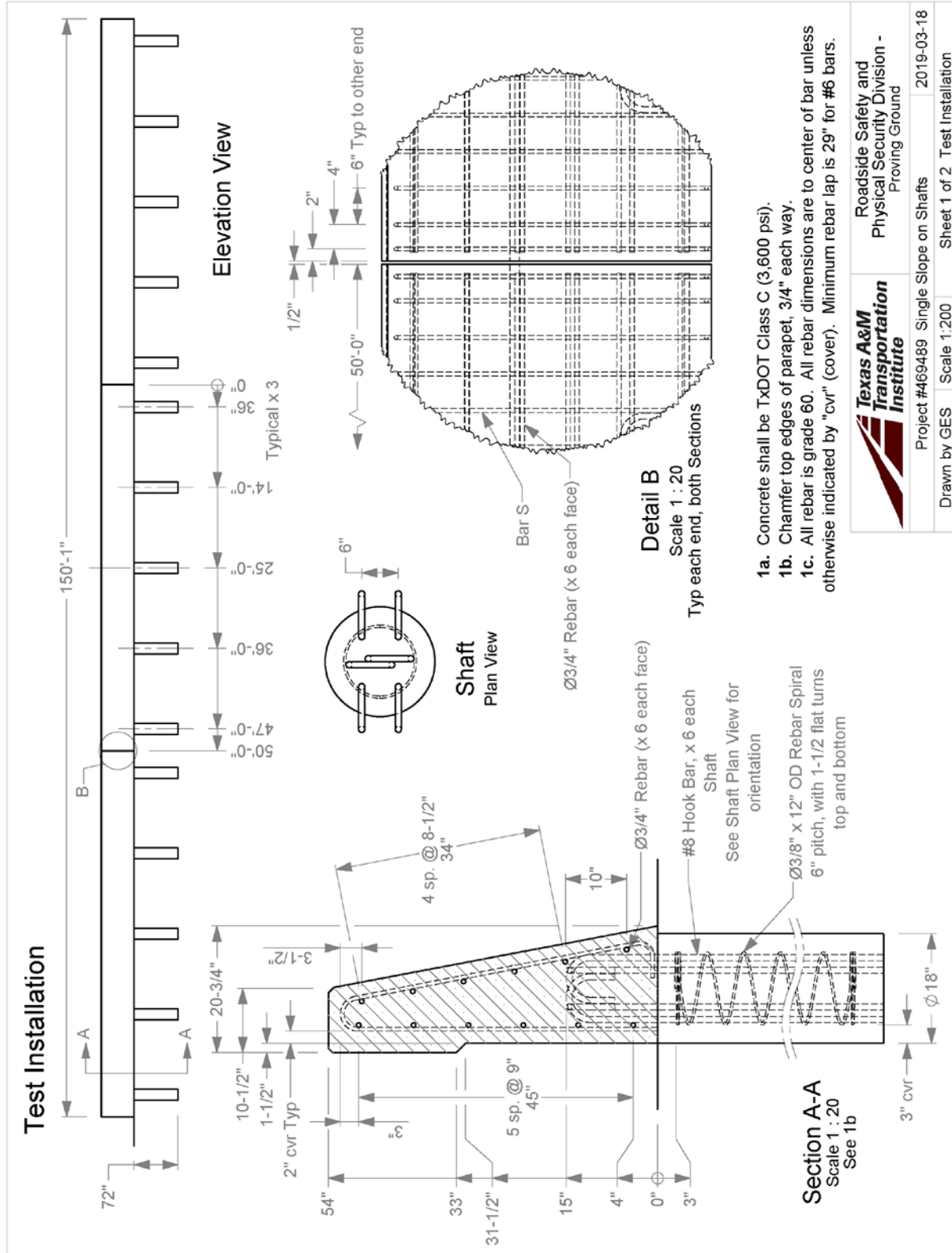
1. AASHTO. *Manual for Assessing Roadside Safety Hardware*. Second Edition, 2016, American Association of State Highway and Transportation Officials: Washington, DC.
2. Livermore Software Technology Corporation, *LS-DYNA Keyword User's Manual*, 2016, Livermore, California.
3. Livermore Software Technology 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.





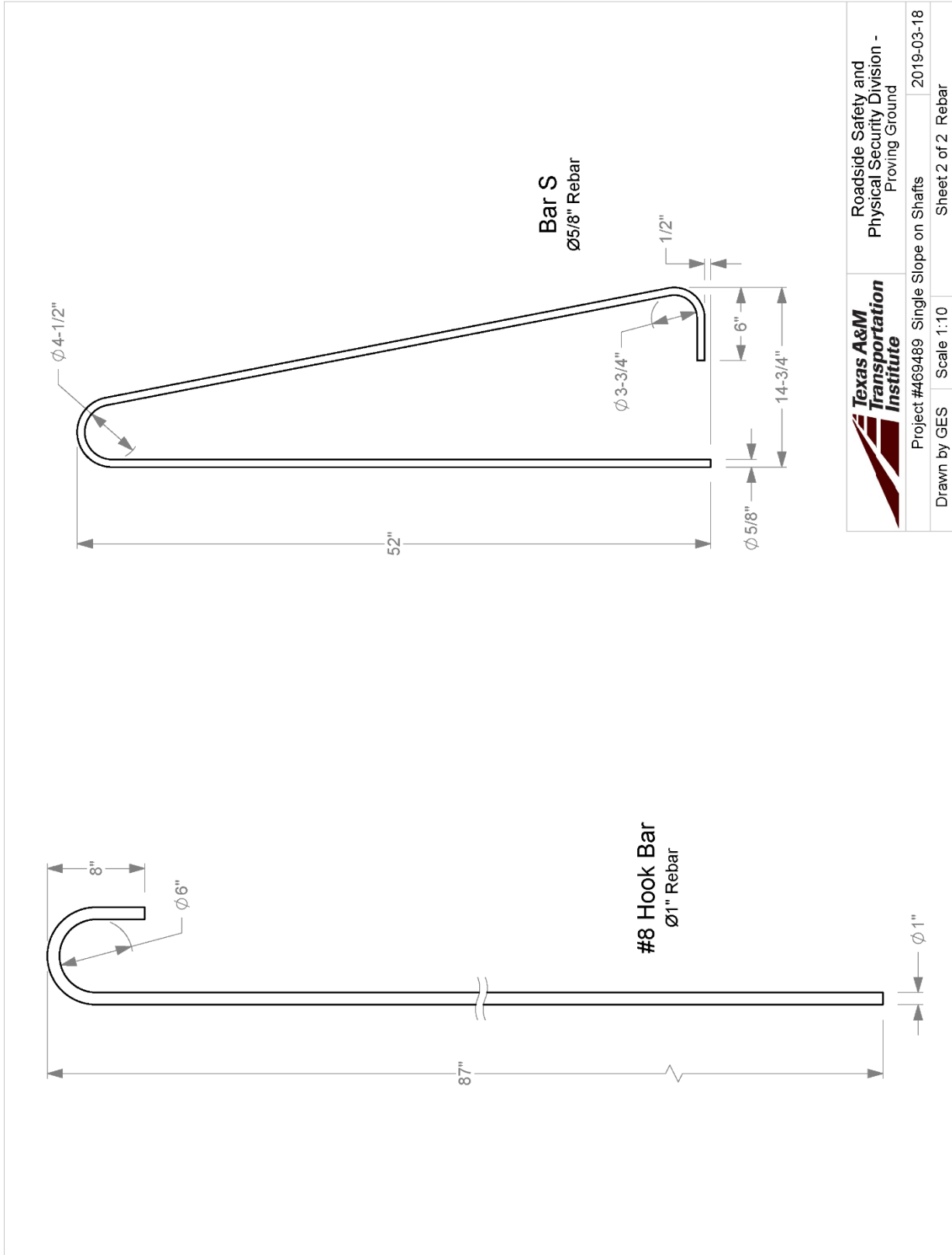
# APPENDIX A. DETAILS OF SSCB WITH DRILLED SHAFT FOUNDATION

T:\1-ProjectFiles\469489-TXDOT-Sheikh\Drafting\_469489\469489 Drawing



- 1a. Concrete shall be TxDOT Class C (3,600 psi).
- 1b. Chamfer top edges of parapet, 3/4" each way.
- 1c. All rebar is grade 60. All rebar dimensions are to center of bar unless otherwise indicated by "cvt" (cover). Minimum rebar lap is 29" for #6 bars.

	Roadside Safety and Physical Security Division - Proving Ground	2019-03-18
	Project #469489 Single Slope on Shafts	Sheet 1 of 2 Test Installation
Drawn by GES	Scale 1:200	



	Roadside Safety and Physical Security Division - Proving Ground
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 467489

**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

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



*Rolando A. Davila*  
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	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#: 82597572 BOL#: 72796067 CUST PO#: 804636 CUST P/N: DLVRY LBS / HEAT: 23496.000 LB DLVRY PCS / HEAT: 440 EA																																							
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 50%;">Characteristic</th> <th style="width: 50%;">Value</th> </tr> </thead> <tbody> <tr><td>C</td><td>0.41%</td></tr> <tr><td>Mn</td><td>1.11%</td></tr> <tr><td>P</td><td>0.012%</td></tr> <tr><td>S</td><td>0.043%</td></tr> <tr><td>Si</td><td>0.23%</td></tr> <tr><td>Cu</td><td>0.30%</td></tr> <tr><td>Cr</td><td>0.08%</td></tr> <tr><td>Ni</td><td>0.23%</td></tr> <tr><td>Mo</td><td>0.088%</td></tr> <tr><td>V</td><td>0.005%</td></tr> <tr><td>Cb</td><td>0.002%</td></tr> <tr><td>Sn</td><td>0.011%</td></tr> <tr><td>Al</td><td>0.001%</td></tr> <tr><td>Yield Strength test 1</td><td>68.4ksi</td></tr> <tr><td>Tensile Strength test 1</td><td>108.8ksi</td></tr> <tr><td>Elongation test 1</td><td>14%</td></tr> <tr><td>Elongation Gage Lgth test 1</td><td>8IN</td></tr> <tr><td>Bend Test Diameter</td><td>5.000IN</td></tr> <tr><td>Bend Test 1</td><td>Passed</td></tr> </tbody> </table>	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	Characteristic Value	Characteristic Value
Characteristic	Value																																									
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Elongation Gage Lgth test 1	8IN																																									
Bend Test Diameter	5.000IN																																									
Bend Test 1	Passed																																									
REMARKS :		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																																								



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SEGUIN TX 78155-7510

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830-372-8771

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

*Rolando A Devila*  
Rolando A Devila  
Quality Assurance Manager

S O L D T O		S H I P T O		S H I P T O	
Characteristic	Value	Characteristic	Value	Characteristic	Value
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					
CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900		CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900		Delivery#: 82641991 BOL#: 72864829 CUST PO#: 808744 CUST P/N: DLVRY LBS / HEAT: 37230.000 LB DLVRY PCS / HEAT: 1785 EA	
C	0.41%	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			
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				

REMARKS :



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Rolando A. Devilla

Quality Assurance Manager

S O L D T O		S H I P T O		S O L D T O		S H I P T O	
HEAT NO.: 3083348		CMC Construction Svcs College Stati		CMC Construction Svcs College Stati		CMC Construction Svcs College Stati	
SECTION: REBAR 19MM (#6) 20'0" 420/60		10650 State Hwy 30		10650 State Hwy 30		10650 State Hwy 30	
GRADE: ASTM A615-16 Gr 420/60		College Station TX		College Station TX		College Station TX	
ROLL DATE: 09/25/2018		US 77845-7950		US 77845-7950		US 77845-7950	
MELT DATE: 09/21/2018		979 774 5900		979 774 5900		979 774 5900	
Cert. No.: 82580173 / 083348A619							
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	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						
<b>REMARKS :</b> 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 <a href="http://www.P65Warnings.ca.gov">www.P65Warnings.ca.gov</a>							

 <b>Texas A&amp;M Transportation Institute</b> <small>Proving-Ground: 3100 SH-47, Bldg. 7091, Bryan, TX 77807          Texas A&amp;M University: College Station, TX 77843          Phone 979-545-8375</small>	<b>QF-7.3-01 Concrete Sampling</b>	Doc. No. <b>QF-7.3-01</b>	Issue Date: <b>2018-06-18</b>
		<b>Quality Form</b>	Prepared by: <b>Wanda L. Menges</b> Approved by: <b>Darrell L. Kuhn</b>

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

Project No: 469429-01 Casting Date: 2019-05-20 Mix Design (psi): 3500 psi

Name of Technician Taking Sample: B. H. Griffith Name of Technician Breaking Sample: B. H. Griffith  
 Signature of Technician Taking Sample: [Signature] Signature of Technician Breaking Sample: [Signature]

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 Break 2019-07-11		
			151000	5341	5223
			149000	5270	



CUSTOMER'S COPY

# Martin Marietta

1503 LBJ Freeway  
Suite 400  
Dallas, Tx 75234

TICKET NO.

5408937



LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
12:56	:	:	15:10 : 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

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

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

CUSTOMER NAME AND DELIVERY ADDRESS	PLANT	TRUCK	ORDER NO.	SLUMP	P.O. #/JOB/LOT	GRID
TEXAS A & M UNIVERSITY TTI-Riverside Campus	617	7030	2015	5.0	469468	
	DRIVER NAME		DATE			
	Carlos Bretherton		5/20/19			
	CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY		
	783659	79346	9.00	9.00		

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

469489-01-3


SPECIAL DELIVERY INSTRUCTIONS: SOUTH 2810, 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	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%			
H2O	250 lb	1546 lb	1540 lb	0.10%			
ZY-610	12 oz	107 oz	106 oz	-1.19%		186 gl	
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/	CVD	

 Proving Ground: 3100 SH-47, Bldg. 70911, Bryan, TX 77807 Texas A&M University: College Station, TX 77843 Phone: 979-545-6376	<b>QF-7.3-01 Concrete Sampling</b>	Doc. No. <input type="checkbox"/>	Issue Date: <input type="checkbox"/>
		QF-7.3-01 <input type="checkbox"/>	2018-06-18 <input type="checkbox"/>
<b>Quality Form</b>	Prepared by: Wanda L. Menges <input type="checkbox"/>	Revision: <input type="checkbox"/>	Page: <input type="checkbox"/>
	Approved by: Darrell L. Kuhn <input type="checkbox"/>	6 <input type="checkbox"/>	1 of 1 <input type="checkbox"/>

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

Project No: 469489023 Casting Date: 2019-05-20 Mix Design (psi): 3600

Name of Technician Taking Sample: Bill G. Ruhl Name of Technician Breaking Sample: Bill G. Ruhl  
 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 Street South Lead
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	1
1	1	1	156000	5518	5824
			167000	5907	1
T2	2019-07-11	44 days	171000	6048	1
			160000	5659	5906
			170000	6013	1





# Martin Marietta

1503 LBJ Freeway  
Suite 400  
Dallas, Tx 75234

TICKET NO.

5423724



LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
1:08	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

CUSTOMER SIGNATURE

X

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

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

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

PLANT	TRUCK	ORDER NO.	SLUMP	P.O. #/JOB/LOT	GRID
617	8120	2031	5.0	469488	
DRIVER NAME		DATE			
Matthew Wenzel		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		

469489-013

**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

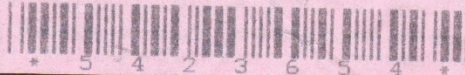
Truck	Driver	User	Disp	Ticket Num	Ticket ID	Time	Date
8120	946451	user	5423724	76301		12:08	5/28/19
Load	Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
6.00	CYDS	BDOTCC00				D	77324
Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat	
WCS	1845 lb	11682 lb	11680 lb	-0.01%	0.10% M	1 gl	
SAND-1	1269 lb	7849 lb	7840 lb	-0.12%	3.00% M	28 gl	
CMT-1/II	358 lb	2148 lb	2130 lb	-0.84%			
FLYASH-C	193 lb	1150 lb	1150 lb	-0.63%			
H2O	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



LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
1:56	12:10	12:30	:	:	11:40	:

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

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

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

CUSTOMER NAME AND DELIVERY ADDRESS		PLANT	TRUCK	ORDER NO.	SLUMP	P.O. #/JOB/LOT	GRID
TEXAS A & M UNIVERSITY TTI-Riverside Campus		617	8102	2031	5.0	469488	
T1 2019-02-11 44 days		DRIVER NAME	DATE				
		CHARLES BALANGA	5/28/19				
CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY				
703659	79546	7.00	13.00				

LOAD QUANTITY	PRODUCT CODE	DESCRIPTION	UNIT PRICE	AMOUNT
7.00	CYDS	BDOTCC00 DOT CLASS 171000	590.7	4133.1
1.00	ea	12987 FREIGHT CHARGE	590.6	590.6
T2 2019-02-11 44 days		170000	6013	102221

469489-01-3


SPECIAL DELIVERY INSTRUCTIONS  
 SOUTH 2810, 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.

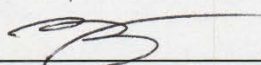

FOR OFFICE USE ONLY FORM: 2662696

Truck	Driver	User	Disp	Ticket Num	Ticket ID	Time	Date
8102	916114	user	5423654	76300	77323	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% W	2 gl	
SAND-1	1269 lb	9158 lb	9160 lb	0.02%	3.00% W	33 gl	
CMT-1/11	358 lb	2506 lb	2500 lb	-0.24%			
FLYASH-C	193 lb	1351 lb	1340 lb	-0.81%			
H2O	250 lb	1321 lb	1314 lb	-0.50%			
ZY-610	12 oz	83 oz	83 oz	-0.53%		157 gl	
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	True Water: -1.7 gl/ CYD		

 <b>Texas A&amp;M Transportation Institute</b> <small>Proving Ground 3100 SH-47, Bldg. 709 Bryan, TX 77807</small>	<b>QF-7.3-01 Concrete Sampling</b>	Doc. No. <input type="checkbox"/>	Issue Date: <input type="checkbox"/>
		QF-7.3-01	2018-06-18
<b>Quality Form</b>	Prepared by: Wanda L. Menges Approved by: Darrell L. Kuhn	Revision: <input type="checkbox"/>	Page: <input type="checkbox"/>
		6	1 of 1

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

Project No: 465489-01-3 Casting Date: 2019-06-08 <sup>07 1366</sup> <sup>2019-06-07</sup> Mix Design (psi): 3600

Name of Technician Taking Sample: Billy G. Ford Name of Technician Breaking Sample: B. H. Ford  
 Signature of Technician Taking Sample:  Signature of Technician Breaking Sample: 

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	1
			156000	5518	5494
			153000	5412	1
T2	2019-07-11	34 days	146000	5164	1
			141000	4987	5164
			151000	5341	1



CUSTOMER'S COPY  
**Martin Marietta**

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TICKET NO.

5445414



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

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

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

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

CUSTOMER NAME AND DELIVERY ADDRESS	PLANT	TRUCK	ORDER NO.	SLUMP	P.O. #/JOB/LOT	GRID
TEXAS A & M UNIVERSITY TTI-Riverside Campus	617	7102	2015	5.0	469689	
	DRIVER NAME	DATE				
	RAYMOND ORTIZ	6/7/19				
	CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY		
	783659	75546	12.00	12.00		

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

SPECIAL DELIVERY INSTRUCTIONS  
 2818 RT ON LEONARD RT ON HWY-47-LFT INTO RELLIS CAMPUS GO AROUND THE ROUND ABOUT AND THEY WILL MEET AT GATE  
 SALES TAX  
 TOTAL

46948 7.01-3

**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	75516		10:48	6/7/19
Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID	
6.00	CYDS BDOTCC00				D	77541	
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	30 gl	
CMT-1/II	358 lb	2148 lb	2130 lb	-0.09%			
FLYASH-C	193 lb	1158 lb	1150 lb	-0.69%			
H2O	250 lb	1029 lb	1032 lb	0.27%			
ZY-610	12 oz	72 oz	71 oz	-0.73%		124 gl	
Actual	Num Batches: 1						
Load Total:	23976 lb	Design 0.454	Water/Cement 0.455	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	Tris Water: -2.0 gl	/ CYD	



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 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

CUSTOMER SIGNATURE

X

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

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

CUSTOMER NAME AND DELIVERY ADDRESS

TEXAS A & M UNIVERSITY  
 TTI-Riverside Campus

PLANT TRUCK ORDER NO. SLUMP P.O. #/JOB/LOT GRID

617 7165 2015 5.0 469689

DRIVER NAME DATE

Carlos Brotherton 5/27/19

CUSTOMER NUMBER PROJECT CUM. QTY ORDERED QTY

7036594 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	1
1		146000	4987	5164
1		151000	5041	1

SPECIAL DELIVERY INSTRUCTIONS

2818-RT ON LEONARD RT ON HWY-47-LFT INTO RELLIS  
 CAMPUS GO AROUND THE 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	77638	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	1345 lb	11682 lb	11600 lb	-0.01%	0.10% M	1 gl	
SAND-1	1269 lb	7931 lb	7960 lb	0.36%	4.00% M	38 gl	
CMT-1/11	359 lb	2140 lb	2160 lb	0.56%			
FLYASH-C	193 lb	1158 lb	1150 lb	-0.69%			
H2O	250 lb	1023 lb	1032 lb	0.27%		124 gl	
W-610	12 oz	72 oz	71 oz	-0.75%			
Actual	Num Batches: 1						
Lead 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		

 <b>Texas A&amp;M Transportation Institute</b> <small>Proving Ground 3100-SH-47, Bldg. 700 Brvan, TX 77807</small> <small>Texas A&amp;M University College Station, TX 77843 Phone 979-845-8376</small>	<b>QF-7.3-01 Concrete Sampling</b>	Doc. No. <u>QF-7.3-01</u>	Issue Date: <u>2018-06-18</u>
		<b>Quality Form</b> <small>The information contained in this document is confidential to TTI Proving Ground</small>	Prepared by: <u>Wanda L. Menges</u> Approved by: <u>Darrell L. Kuhn</u>

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: B. H. Fickel

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

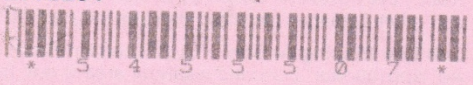
Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average
T1	2019-06-24	12 days	138000	4880	
T2	2019-06-24	12 days	124500	4400	
T1	2019-07-11	29 days	160000	5660	1
"	"	"	157000	5553	5577
"	"	"	156000	5518	1
T2	2019-07-11	29 days	154000	5447	1
			160000	5660	5529
			155000	5482	1



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**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

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

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

CUSTOMER NAME AND DELIVERY ADDRESS  
 TTI-Riverside Campus

PLANT	TRUCK	ORDER NO.	SLUMP	P.O. #/JOB/LOT	GRID
817	8164	2020	5.0	409005	
DRIVER NAME	DATE				
BOBY BYER	6/12/19				
CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY		
783659	79546	6.00	10.00		

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

469409-01-3

SPECIAL DELIVERY INSTRUCTIONS: ONWARD RT ON HWY-47-LFT INTO RELLIS CAMPUS GO AROUND THE 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	Plant	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%	3.58% M	33 gl	
CMT-1/11	358 lb	2148 lb	2130 lb	-0.84%			
FLYASH-C	193 lb	1158 lb	1150 lb	-0.69%			
H2O	250 lb	1085 lb	1085 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		Design 179.7	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	

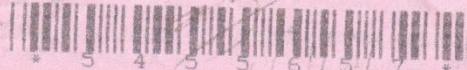


# Martin Marietta

1503 LBJ Freeway  
Suite 400  
Dallas, Tx 75234

TICKET NO.

5455657



LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
9:59	16:12	16:27	:	:	:	:

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

CUSTOMER SIGNATURE

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

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

CUSTOMER NAME AND DELIVERY ADDRESS  
TEXAS A & M UNIVERSITY  
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		
7836590	794590	13.00	13.00		

LOAD QUANTITY	PRODUCT CODE	DESCRIPTION	UNIT PRICE	AMOUNT
7.00	CYDS	B00TCC00 DOT CLASS		
1.00	ea	12987 FREIGHT CHARGE		

SPECIAL DELIVERY INSTRUCTIONS

2018 RT ON LEONARD RT ON HWY-47-LFT INTO RELLIS CAMPUS GO AROUND THE 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 B00TCC00				D	77787	
Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat	
1"CS	1945 lb	13629 lb	13640 lb	0.00%	0.10% M	2 gl	
SAND-1	1269 lb	3205 lb	3200 lb	-0.06%	3.50% M	39 gl	
CNT-1/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%			
ZY-610	12 oz	83 oz	84 oz	0.67%		152 gl	
Actual	Num Batches: 1						
Load Total:	27941 lb	Design 0.454 Water/Cement 0.452 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**

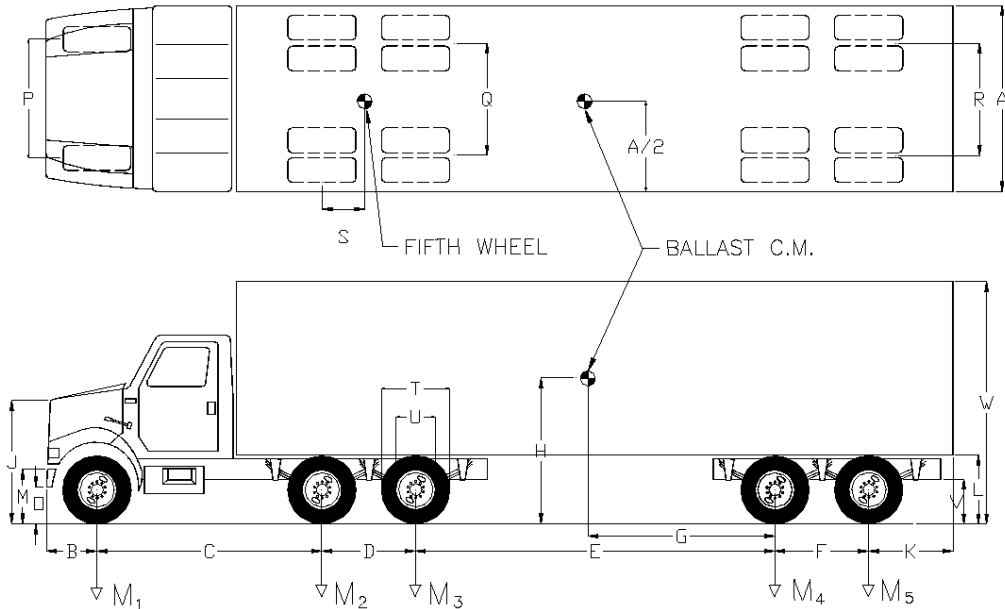
**YEAR:** 2006 **MAKE:** Freightliner **MODEL:** TR

**VIN No.:** IFUJA6CK46PV52093 **ODOMETER:** 776675

**TRAILER**

**YEAR:** 1999 **MAKE:** TRL **MODEL:** VN 53'

**VIN No.:** 1JJV532W2XL465292



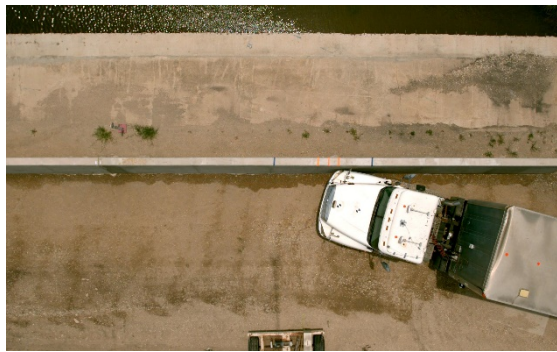
**GEOMETRY ( inches )**

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

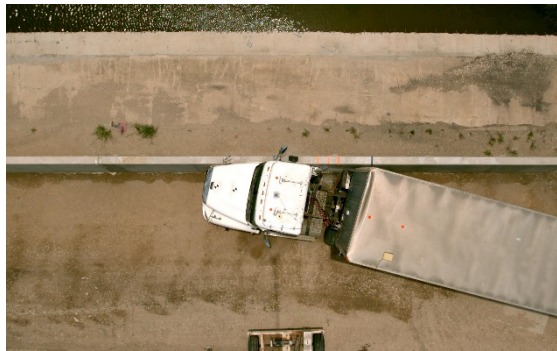
Allowable Range: C = 200 inches max.; L = 50 ±2 inches; Overall Trailer Length = 636 inches max.; Overall Combination Length = 780 inches max.; Trailer Overhang = 87 inches max.; Ballast Center of Mass Ht = 73 ±2 inches above ground;

MASS ( lb )	CURB	TEST INERTIAL
M <sub>1</sub>	9130	10190
M <sub>2</sub>	4320	13070
M <sub>3</sub>	7660	21850
M <sub>4</sub>	4840	17520
M <sub>5</sub>	4750	17540
M <sub>Total</sub>	30700	80170
	29,000 ±3100 lb	79,300 ±1100 lb

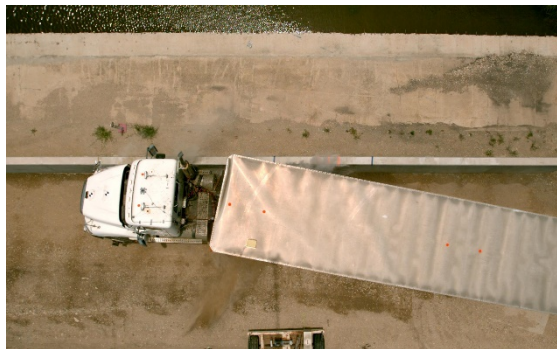
## C.2 SEQUENTIAL PHOTOGRAPHS



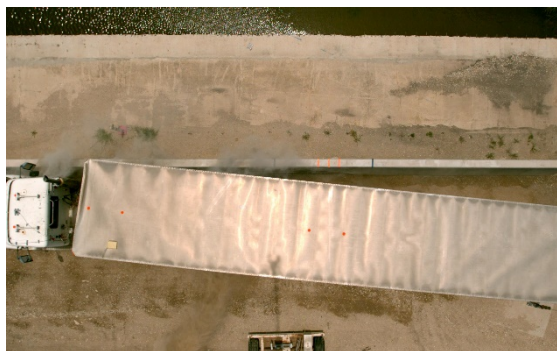
0.000 s



0.175 s



0.350 s



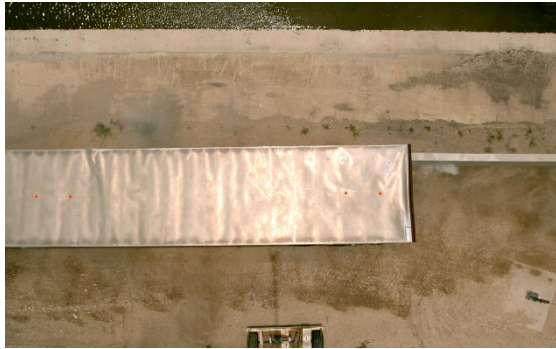
0.525 s



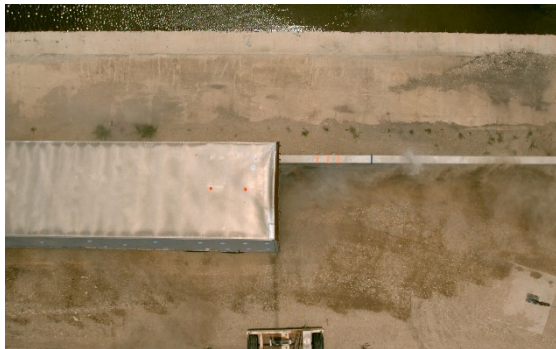
**Figure C.1. Sequential Photographs for Test No. 469489-01-3 (Overhead and Frontal Views).**



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).**



0.700 s



0.875 s



1.050 s



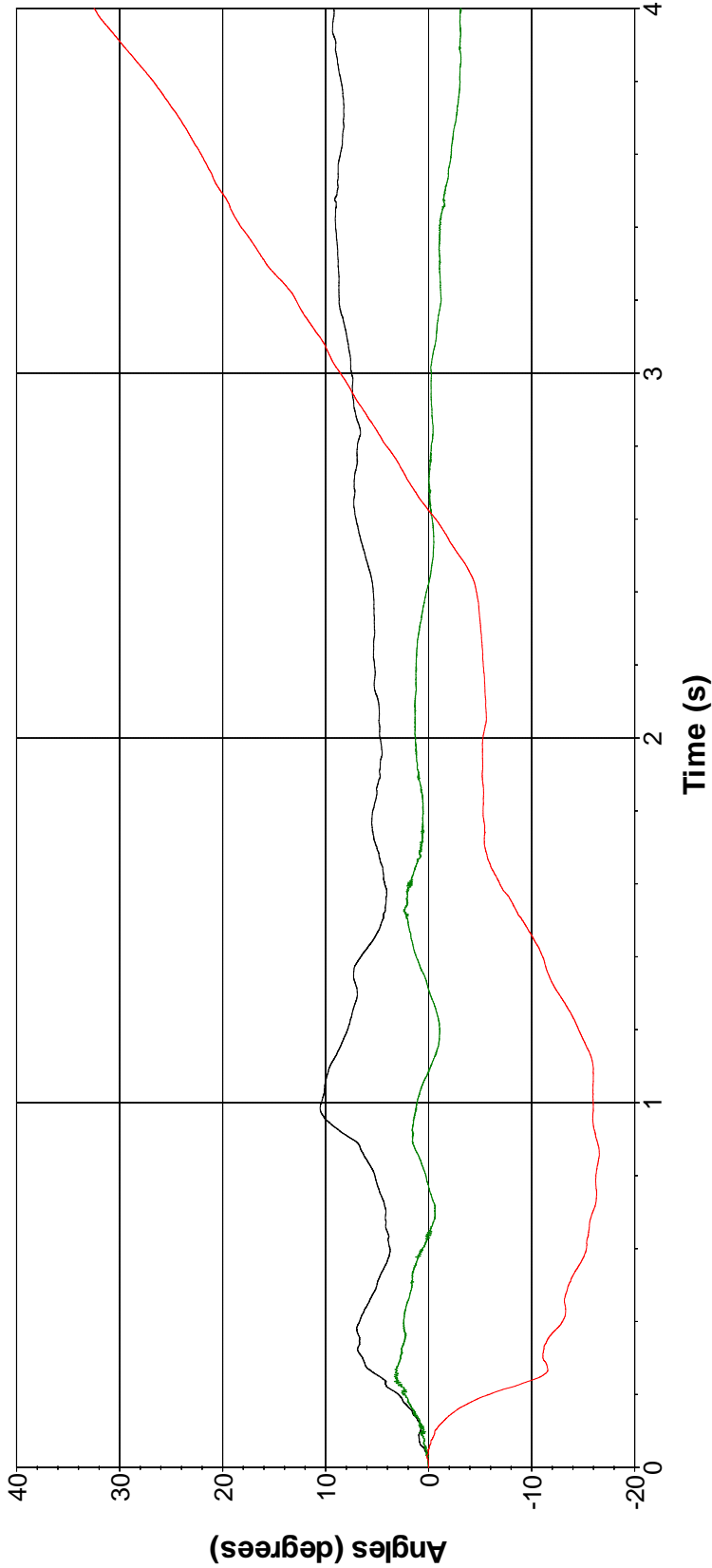
1.225 s



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

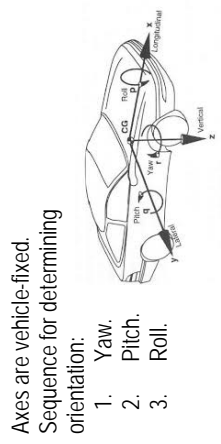
C.3 VEHICLE ANGULAR DISPLACEMENT

**Roll, Pitch, and Yaw Angles**



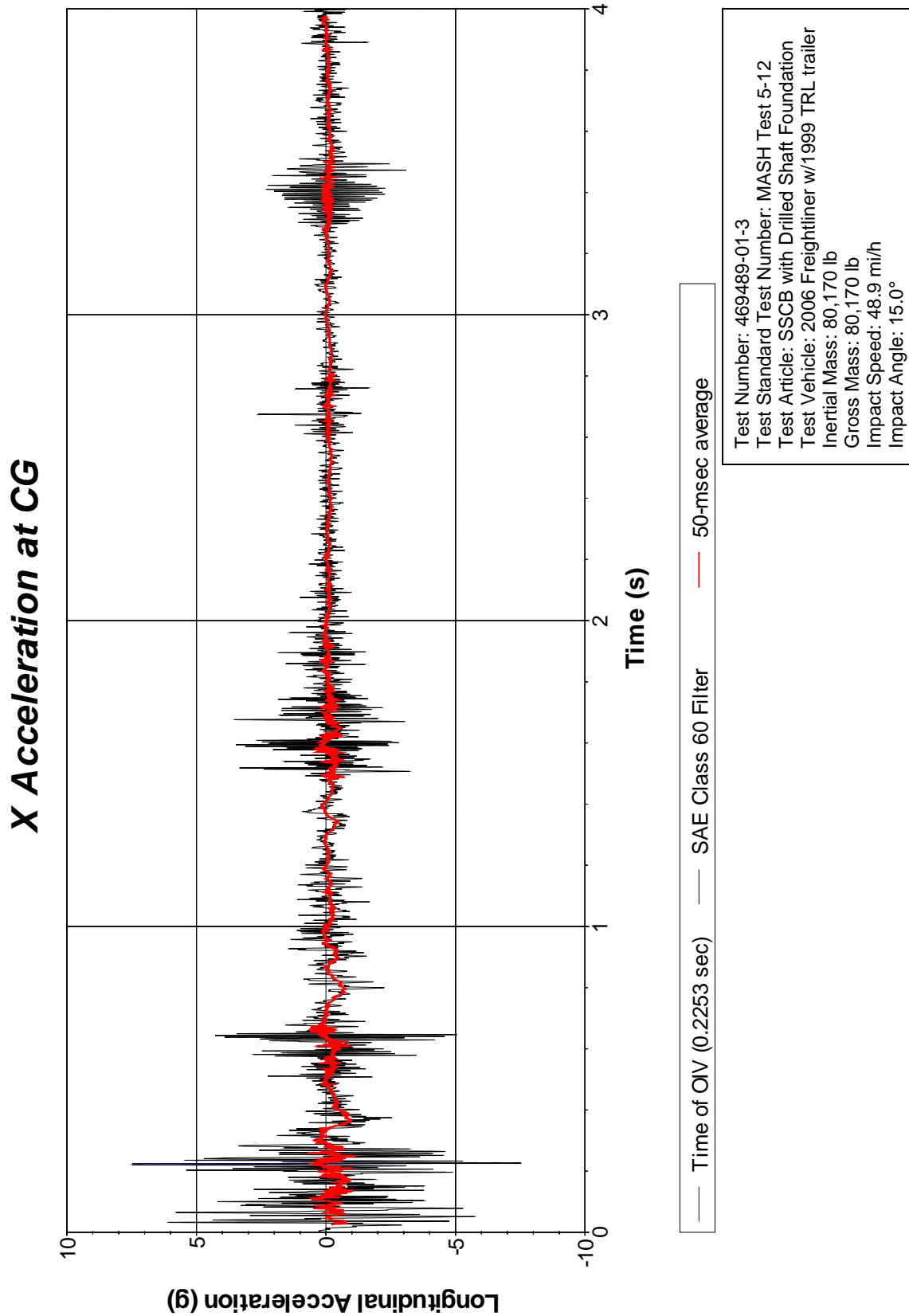
— Roll — Pitch — Yaw

Test Number: 469489-01-3  
 Test Standard: Test Number: MASH Test 5-12  
 Test Article: SSCB with Drilled Shaft Foundation  
 Test Vehicle: 2006 Freightliner w/1999 TRL trailer  
 Inertial Mass: 80,170 lb  
 Gross Mass: 80,170 lb  
 Impact Speed: 48.9 mi/h  
 Impact Angle: 15.0°



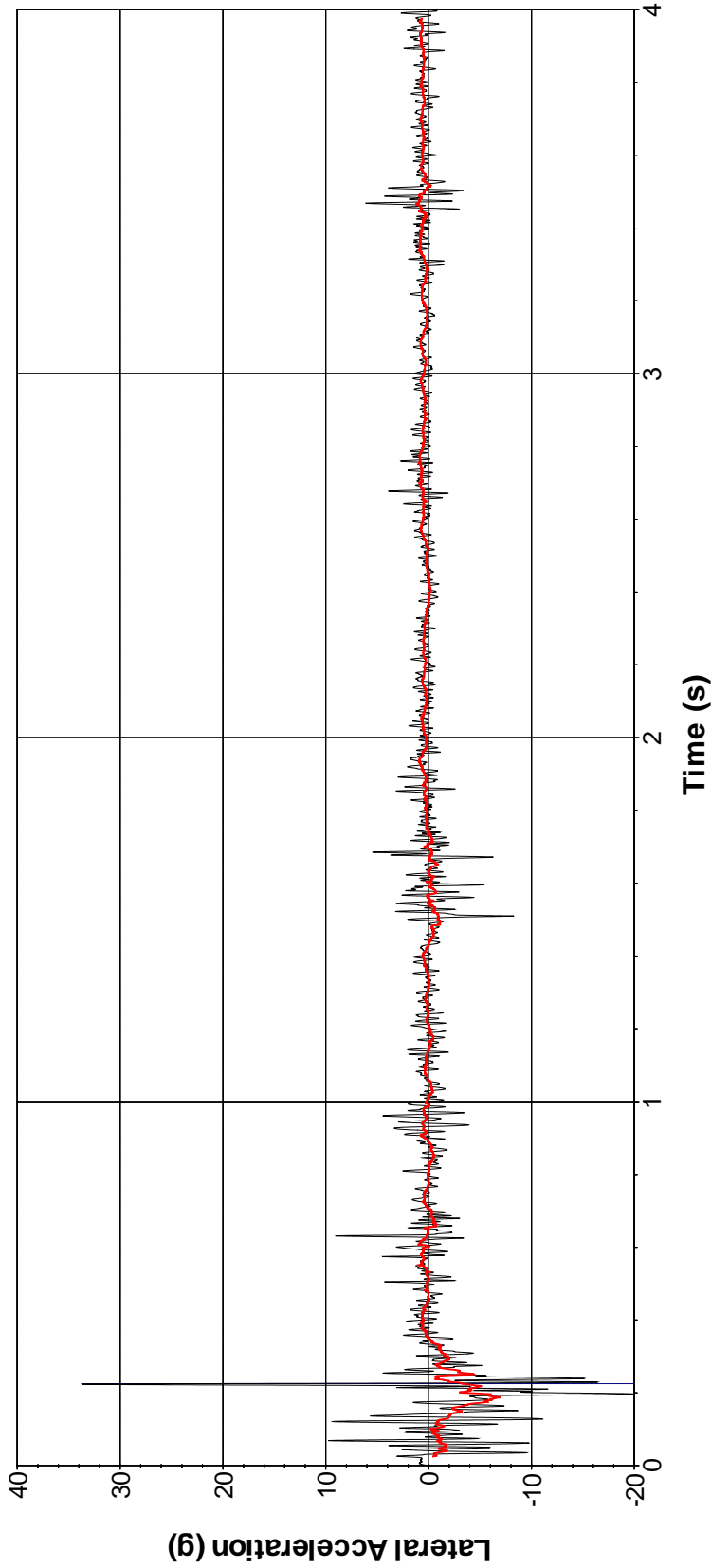
**Figure C.3. Vehicle Angular Displacements for Test No. 469489-01-3.**

## 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).

# Y Acceleration at CG



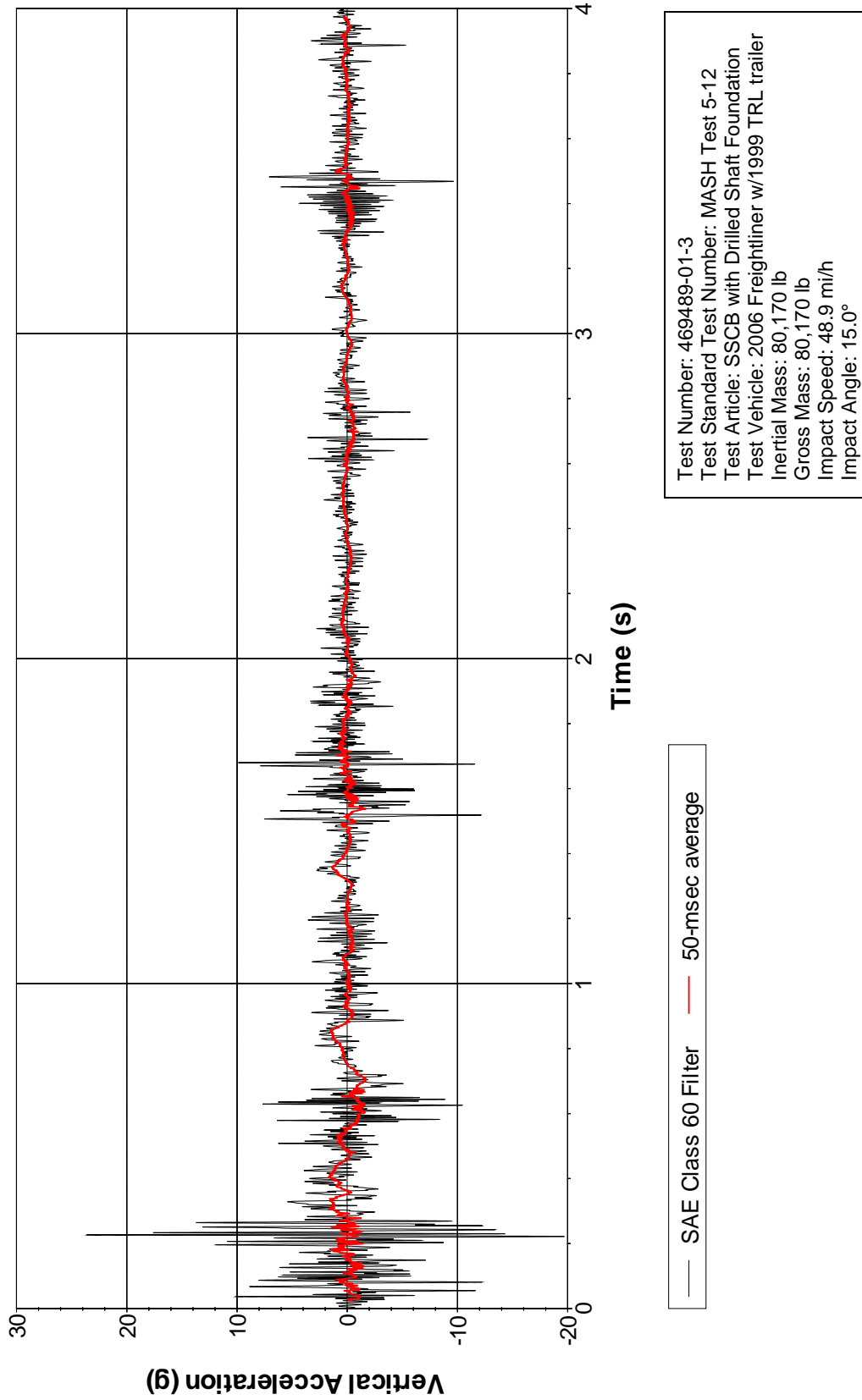
— Time of OIV (0.2253 sec)    — SAE Class 60 Filter    — 50-msec average

Test Number: 469489-01-3  
 Test Standard Test Number: MASH Test 5-12  
 Test Article: SSCB with Drilled Shaft Foundation  
 Test Vehicle: 2006 Freightliner w/1999 TRL trailer  
 Inertial Mass: 80,170 lb  
 Gross Mass: 80,170 lb  
 Impact Speed: 48.9 mi/h  
 Impact Angle: 15.0°

**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).**



# Z Acceleration at CG



**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).**

# X Acceleration Rear of CG

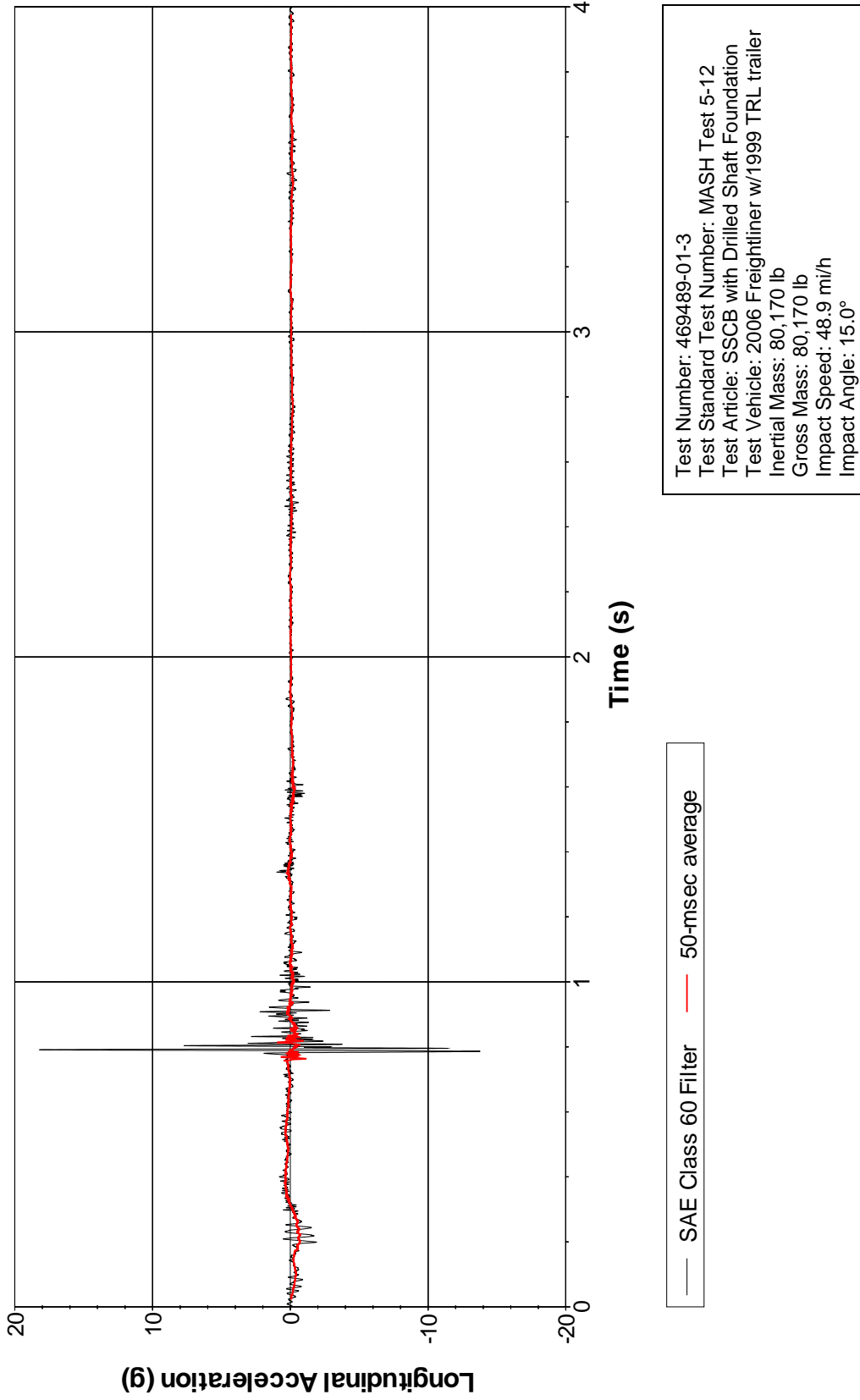
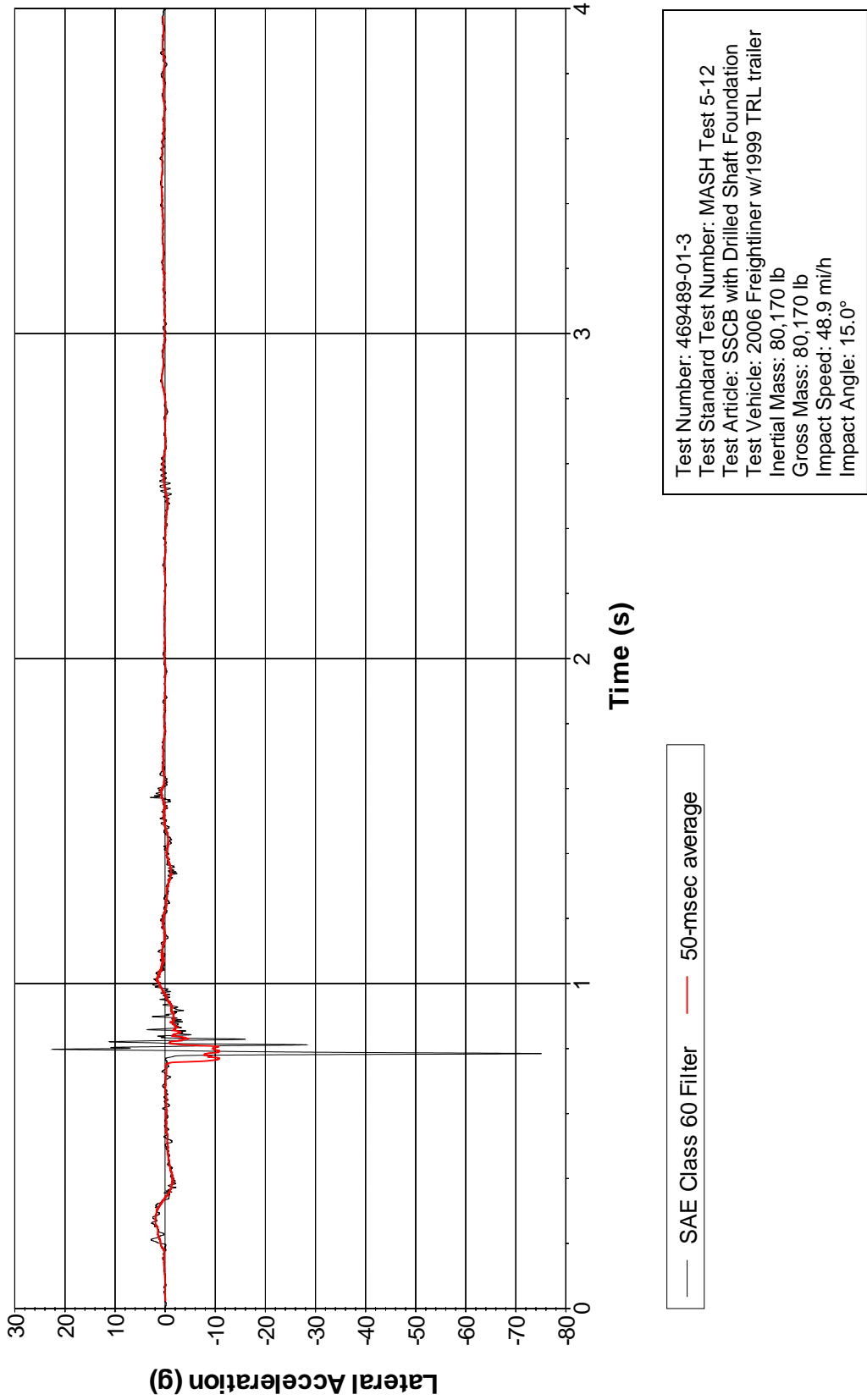


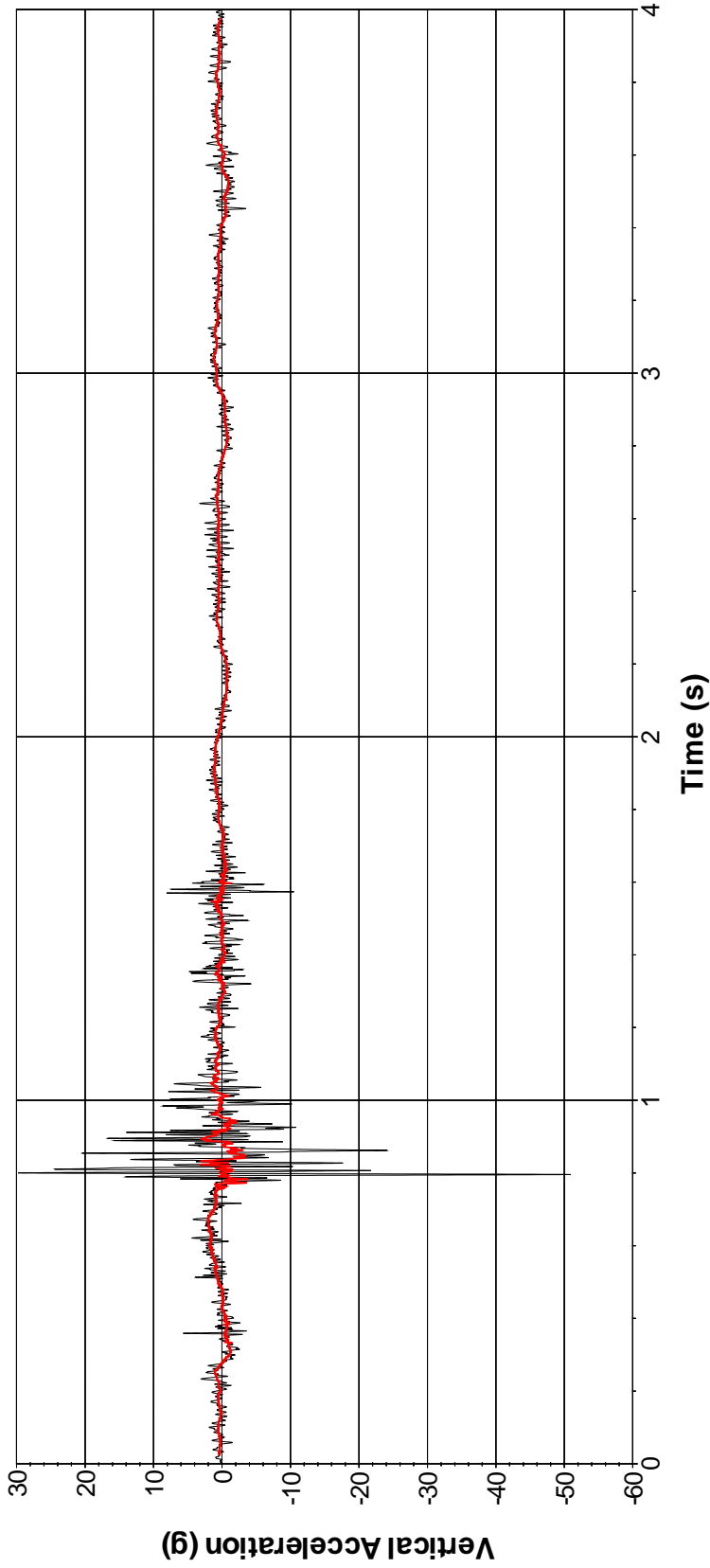
Figure C.7. Vehicle Longitudinal Accelerometer Trace for Test No. 469489-01-3 (Accelerometer Located Rear of Center of Gravity, Location C in Figure 5.1).

# Y Acceleration Rear of CG



**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).**

# Z Acceleration Rear of CG



— SAE Class 60 Filter    — 50-msec average

Test Number: 469489-01-3  
 Test Standard Test Number: MASH Test 5-12  
 Test Article: SSCB with Drilled Shaft Foundation  
 Test Vehicle: 2006 Freightliner w/1999 TRL trailer  
 Inertial Mass: 80,170 lb  
 Gross Mass: 80,170 lb  
 Impact Speed: 48.9 mi/h  
 Impact Angle: 15.0°

**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).**