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DEVELOPMENT AND TESTING OF ANCHORED TEMPORARY CONCRETE BARRIER FOR USE ON ASPHALT

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16. Abstract

In 2008, Texas Transportation Institute developed a pinned down anchored temporary concrete barrier system for use on concrete bridge decks and pavements. This F-shape barrier with pin-and-loop connections was anchored using steel pins that passed through inclined holes cast in the toe of the barrier, and continued a short distance into the underlying concrete pavement or deck. The objective of the research presented in this report was to extend the use of the existing pinned down anchored barrier design for placement on asphalt with minimum modifications to the barrier design.

By performing a series of dynamic subcomponent tests and full-scale impact simulation analyses, the researchers developed an appropriate anchoring design for pinning the barrier to asphalt. This design involves placing the barrier on a 4 inch thick asphalt pad and pinning it to the ground using three steel pins per barrier segment. The pins are 1.5 inches in diameter and pass through slotted holes cast into the toe of the barrier at an inclination of 40 degrees from the ground.

A 151-ft long installation was built for *Manual for Assessing Safety Hardware (MASH)* test level 3 (TL-3) testing. This installation was comprised of 12 pinned down barrier segments and was placed adjacent to a 1.5H:1V slope with a 1-foot lateral offset. *MASH* test 3-11 was performed with a 2005 Dodge Ram 1500 pickup impacting the barrier at a nominal impact speed and angle of 62.2 mi/h and 25 degrees, respectively. The test vehicle was successfully contained and redirected by the pinned down anchored barrier system. The pinned down anchored barrier design was considered a pass according to *MASH* TL-3 criteria. Maximum dynamic and static deflections of the barrier system were 17.8 inches and 17 inches, respectively.

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APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^{2}	square inches	645.2	square millimeters	mm^{2}
ft^{2}	square feet	0.093	square meters	m^{2}
yd^{2}	square yard	0.836	square meters	m^{2}
ac	acres	0.405	hectares	ha
mi^{2}	square miles	2.59	square kilometers	km^{2}
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^{3}	cubic feet	0.028	cubic meters	m^{3}
yd^{3}	cubic yards	0.765	cubic meters	m^{3}
		NOTE: volumes greater than 1000 L shall be shown in m^{3}		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^{2}	cd/m^{2}
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^{2}	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^{2}	square millimeters	0.0016	square inches	in^{2}
m^{2}	square meters	10.764	square feet	ft^{2}
m^{2}	square meters	1.195	square yards	yd^{2}
ha	hectares	2.47	acres	ac
km^{2}	square kilometers	0.386	square miles	mi^{2}
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^{3}	cubic meters	35.314	cubic feet	ft^{3}
m^{3}	cubic meters	1.307	cubic yards	yd^{3}
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^{2}	candela/m^{2}	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^{2}

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
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1. INTRODUCTION

1.1 PROBLEM

Texas Transportation Institute (TTI) recently develop a pinned down F-shape temporary concrete barrier system that provides limited lateral deflection (less than 6 inches) and can be used for bridge or roadway applications (*1*). The design was developed for use on concrete pavements or bridge decks seven inches or thicker. In many situations, the anchored barrier system is needed for placement over asphalt pavement. Being specifically designed for concrete bridge decks or pavements, the current anchorage design cannot be used on asphalt. It is desired to extend the use of the pinned down barrier for placement on asphalt while maintaining consistent barrier designs. Consequently this project focuses on modifications to the pinning scheme.

1.2 BACKGROUND

In 2008, TTI developed a restrained F-shaped temporary concrete barrier design that was easy to install and minimized damage to the bridge deck or concrete pavement (*1*). This restraint mechanism was developed for use on concrete bridge decks and pavements. It used 1.5-inch diameter steel pins that were dropped into inclined holes cast in the toe of the barrier segments. The pins passed through the holes in the barrier and continued a short distance into the underlying concrete pavement, thus locking the barrier in place. The pinned-down barrier successfully passed the *National Cooperative Research Program (NCHRP) Report 350* Test Level 3 requirements (*2*). The maximum permanent and dynamic barrier deflections were 5.76 inches and 11.52 inches, respectively. There was no significant damage to the underlying concrete pavement. This design was developed for the Pooled Fund states and had the primary objective of being used on thin concrete decks. The design has now been adopted by some of the participating states and there is a desire to extend the restraint design for use on asphalt and soil, while keeping the same barrier design to the extent possible.

Among other anchored barrier designs, Midwest Roadside Safety Facility (MwRSF) developed a concrete bridge deck tie-down system for 12.5 ft long, F-shaped Kansas temporary barriers in 2003 (*3*). Three anchor bolts were passed through the holes in the barrier and fastened to the bridge deck on the traffic side of the barrier. The maximum static and dynamic deflections were 3.5 inches and 11.3 inches, respectively.

In 2005, MwRSF developed an *NCHRP Report 350* compliant tie down design for 12.5-ft long temporary concrete barriers with pin-and-loop type connection for use on asphalt pavements that are at least two inches thick (*4*). The barrier was installed at a 6-inch lateral offset from the edge of a ditch. This tie-down system used three 1.5-inch diameter, 36 inches long steel pins that were driven down vertically through holes cast in each barrier segment to pin them to the ground. The maximum static and dynamic deflections of this system in an *NCHRP Report 350* test 3-11 were 11.1 inches and 21.8 inches, respectively.

In this same study, MwRSF also developed a transition from the free-standing 12.5-ft long temporary concrete barrier to the anchored temporary concrete barrier design developed earlier in 2003. The transition section was comprised of four 12.5-ft long barrier segments in which steel pins were driven down through the holes in the barrier. The number of pins in the transition barrier segments was gradually reduced to transition from the anchored to the free standing barrier. Barrier segments in the transition section of the design were placed on a 2-inch thick asphalt layer. The barrier was installed at a 6 inch lateral offset from the edge of a ditch. The maximum static and dynamic deflections in the test were 5.25 inches and 18.39 inches, respectively.

In 1999, California Department of Transportation (Caltrans) developed a pinning/staking configuration for its 20-ft long, New Jersey profile concrete barriers connected with a pin-and-loop type connection (*5*). The configuration met *NCHRP Report 350* test level 3 evaluation criteria and consisted of four 1-inch diameter pins that were driven 16.5 inches vertically into the underlying asphalt pavement. Each barrier segment was pinned at its four corners. The barrier was tested in a median configuration and there was no ditch or slope behind the barrier. The maximum static and dynamic deflections of the system were 2.75 inches and 10 inches, respectively.

1.3 OBJECTIVES AND SCOPE OF RESEARCH

The objective of this research was to modify the anchoring design of the previously developed F-shaped pinned-down concrete barrier and extend its use for asphalt pavement and/or soil base. The new design was to be developed using subcomponent level testing, finite element (FE) analysis, and full-scale crash testing. The design was required to meet *MASH* test level 3 criteria.

As described in previous sections, this new design was intended to be an extension of the existing design developed by the researchers for use on a concrete deck or pavement. Thus the researchers were to maintain as many features from the previous design as possible. Unless it was determined that some modifications are necessary for a successful design, the researchers were to use the previously developed barrier design without modifications. The anchorage of the barrier was to be modified by changing the number and depth of the anchoring pins. The researchers were to develop an appropriate anchoring design using a series of subcomponent level pendulum testing and simulation analysis. A full-scale crash test was to be performed in the end as a final validation of the design. The design developed under this study was required to meet AASHTO *MASH* test level 3 criteria.

The testing reported herein assesses the performance of the pinned down anchored temporary concrete barrier design developed in this research according to the safety-performance evaluation guidelines included in *MASH*. The crash test for this design was in accordance with Test Level 3 (TL-3) of *MASH*, which involves the 2270P vehicle (a 5000-lb Quad Cab Pickup).

2. DESIGN AND SIMULATION ANALYSIS[1]

2.1 INTRODUCTION

The researchers performed several subcomponent level pull tests followed by finite element analyses to determine the appropriate pinning design for anchoring the temporary concrete barrier on asphalt. The pinning design emanating from these subcomponent tests and simulation analyses was subsequently evaluated by performing a full-scale crash test. Details of the subcomponent level testing and finite element analyses are presented in this chapter. Details of the full-scale crash test are presented in subsequent chapters.

2.2 PIN PULLOUT TESTS

One of the objectives of this research was to determine if a pinning design could be developed for anchoring the barrier on both asphalt and soil. If a successful pinning design could be achieved for anchoring the barriers placed on soil, the same design could be used for placement on asphalt. However, it needed to be determined if soil base alone could provide sufficient lateral restraint for anchoring the barriers.

To design the appropriate pinning scheme, the researchers first determined the lateral restraint force that could be achieved from a single anchoring pin. Dynamic pull tests were conducted with the pin installed in soil and asphalt. The results showed that sufficient lateral restraint cannot be achieved with a pin installed just in soil. Testing with a layer of asphalt on top of soil resulted in the desired lateral restraint and, therefore, the final design was developed for placement on asphalt only. Details of the pull tests are presented next.

2.2.1 Anchoring Pin in Soil

The researchers performed a series of pull-tests to determine the response of the inclined steel pins embedded in soil. The test plan included performing three tests with pins embedded at various depths in the soil. To apply the load at the correct height and orientation of the pins, a steel frame was built to match the toe profile of an F-shape barrier (as shown in figure 2.1). The soil was comprised of crush limestone road base material, which was compacted in 6-inch lifts.

The lateral pull load was applied on the pins using a 2000-lb drop pendulum. The pendulum was raised to a predetermined height and released such that it had the desired velocity at the bottom of its swing. The cable was attached to the rear of the pendulum which was also attached to the frame hosting the anchoring pin. A load cell was placed in line to measure the tensile load in the cable, thus measuring the dynamic load applied to the pins. The test setup is shown in figure 2.2.

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[1] The simulation analysis reported herein is not within the scope of TTI Proving Ground's A2LA accreditation.

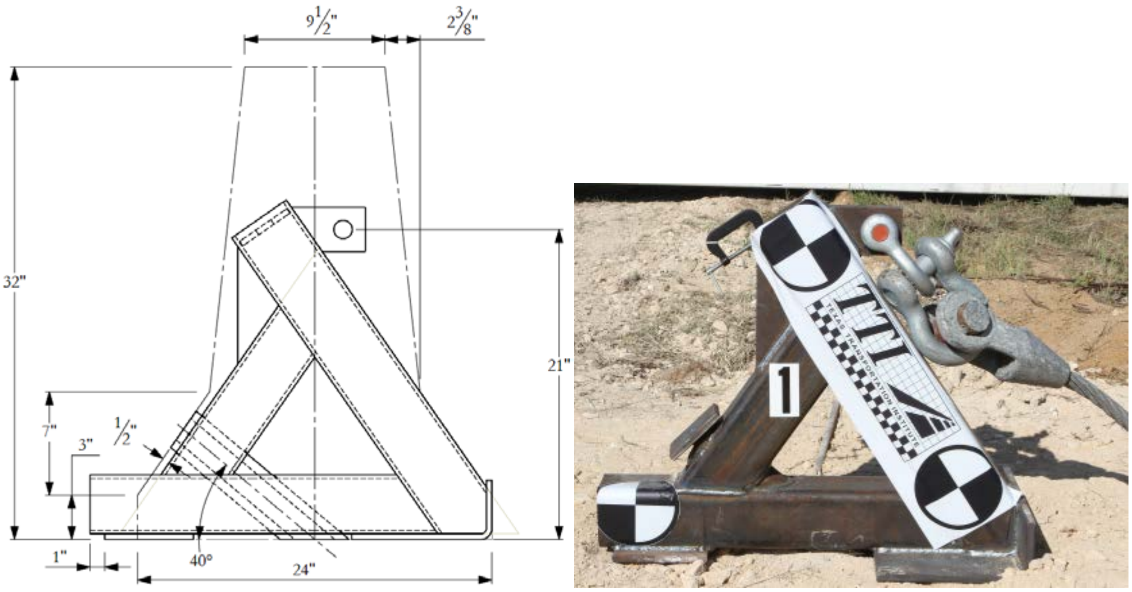


Figure 2.1. Frame built to hold anchoring pin at correct height and orientation.

Figure 2.2. Dynamic pull test setup.

The researchers had planned to perform three tests; with 48-inch, 42-inch, and 36-inch long pins installed at a 40-degree angle into the barrier toe. The 40-degree angle was previously determined to be most suitable for providing anchorage for the barriers when installed on concrete *(1)*. The first test was performed with the 48-inch long pin as this provided the greatest embedment of the pin in soil (37-inch embedment). The dynamic pull test generated a peak restraint force of 6 kips. The pin did not show any significant bending. It deflected approximately 36 inches in soil before being pulled out by the pendulum. The lateral restraint force of 6 kips and the corresponding large deflection of the pin was not considered suitable for the pinned down anchored barrier application. Even though more tests with shallower pin embedment were scheduled, they were not performed since reducing the pin embedment further was expected to result in even lower lateral restraint force and higher lateral deflection.

The angle at which the pin goes into the soil affects the lateral restraint force. To evaluate the range of this affect, the researchers performed another dynamic pull test with the pin installed directly in the soil (i.e. without the frame) perpendicular to the ground. The pull cable was attached directly to the top of the pin. The embedment of the pin was 34 inches. The peak lateral force obtained from this test was 12 kips. While this was an encouraging increase in the peak restraint force, the researchers noted that there were limitations on how much the angle of the pin could be varied. One of the objectives of this research was to use the existing pinned down anchored barrier design to the extent possible. While increasing the angle of the anchoring pin could potentially render some increase in lateral soil restraint, it should be noted that doing so significantly alters the performance of the barrier when it is placed on concrete. A previous test performed on concrete pavement with a 55-degree incline of the pins resulted in loss of lateral restraint. At this higher angle, the pins easily pulled out of the holes in the concrete pavement as the barrier rotated due to the vehicle impact *(1)*. Thus, the researchers did not find it feasible to increase the 40-degree incline of the pins currently being used in the pinned down anchored barrier design.

Due to the lack of adequate lateral restraint achievable with pins embedded in soil, further design development efforts focused on pinning the barrier through a top layer of asphalt.

2.2.1 Anchoring Pin in Asphalt

The researchers conducted further dynamic pull-tests with pins installed in different thickness of asphalt. The objective of these tests was to determine the resistance of the anchoring pins in different thicknesses of the asphalt pad, and to use the results in calibrating simulation models of the pin-asphalt-soil interaction. The testing also helped in selecting the appropriate asphalt thickness needed to provide sufficient lateral restraint for the pinned down anchored barrier.

Three 12-ft long and 5-ft wide asphalt pads with 2, 4, and 6-inch thickness were constructed. The pads were constructed over a 42-inch wide and 36-inch deep soil bucket that contained compacted crushed limestone road base. The pins were installed using the metal frame as in previous testing. A tractor was used to apply the load on the pins by pulling on a cable that was attached to the frame (see figure 2.3). A load cell was used to measure the dynamic tensile force in the cable.

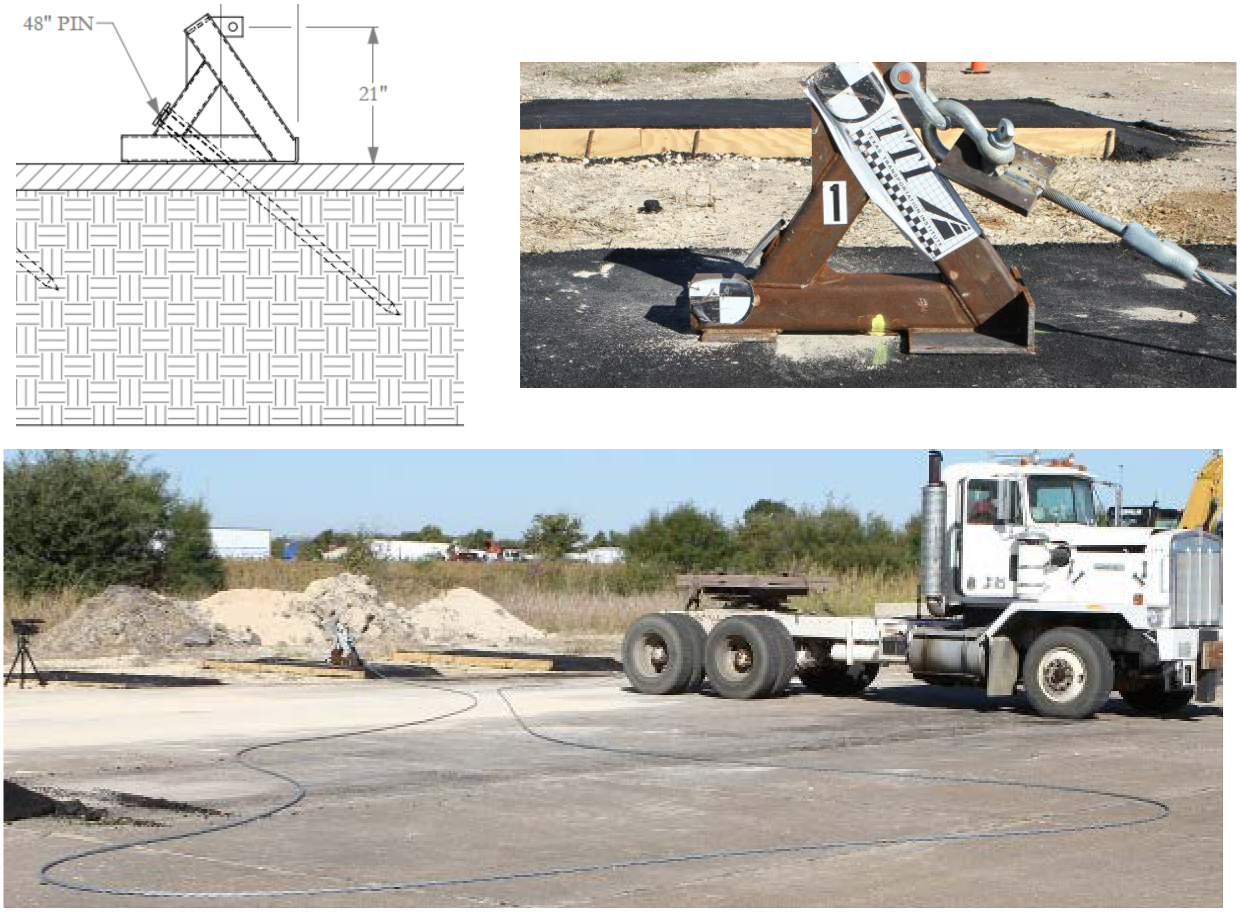


Figure 2.3. Test set up for dynamic pull testing of pins installed in asphalt.

The first test was performed with a 48-inch long pin installed in the 4-inch thick asphalt pad. The pin started to deform once the cable was taught and the pull vehicle was travelling at a speed of approximately 12 mi/h. After significant bending of the anchoring pin, the asphalt pad started to delaminate from the soil base and was pulled forward. Prior to the delamination, however, sufficient bending of the anchoring pin was achieved for the purposes of this design, and thus the load data was valid for further use. However, due to the delamination, a subsequent pull test to evaluate a shorter 42-inch long pin could not be performed.

A peak load of 22 kips was achieved from the 4-inch pad using the 48-inch pin (which was embedded 37 inches). This restraint level was considered sufficient to anchor the barrier in the final design. However, the researchers performed another test with the 2-inch thick pad to determine if the thinner pad could also achieve acceptable lateral restraint. The pull test with the 2-inch pad however resulted in significant tearing of the pad (approximately 30 inches) as the inclined anchor pin moved laterally. A comparison of the tear in the 4-inch and the 2-inch asphalt pads is shown in figure 2.4. The large lateral movement of the pin in the 2-inch pad implied a potential for large overall barrier deflection, which would be an unacceptable outcome. The peak restraint force achieved with the 2-inch thick pad was 7.6 kips. Thus, due to the high lateral deflection and lower lateral restrain force, the 2-inch pad was considered undesirable for the final anchoring design.

Figure 2.4. Tear in asphalt pad due to pin pullout. 4-inch pad (left), 2-inch pad (right).

Since the 4-inch pad had already yielded sufficient lateral strength, the test with the 6-inch pad was not performed. Any anchoring design that works with a 4-inch pad is expected to work successfully with greater asphalt thicknesses.

2.3 FINITE ELEMENT ANALYSIS

2.3.1 Asphalt-Pin Model

After obtaining the response of a single pin pullout, the researchers developed a finite element model of the pin installed in a 4-inch thick asphalt pad over soil base. Modeling the asphalt pad was somewhat challenging as it involved accommodating the tearing of the asphalt near the top surface of the pad. One approach to modeling the tear would have been to include material failure. However, this method would have significantly complicated the model validation process and could have reduced the robustness of the contact algorithm used to maintain contact between the pin and the asphalt in LS-DYNA. To avoid these complications, the asphalt pad was modeled with two material types. A top thin layer was comprised of Mohr-Coulomb material (MAT173 in LS-DYNA), which is typically used to represent granular materials and has a weaker response. The rest of the asphalt pad was modeled using viscoelastic material (MAT6 in LS-DYNA), which has a relatively stiffer response. The finite element model is shown in figure 2.5. Using this multi-material modeling approach, the researchers were able to sufficiently capture the dynamic force-deflection response of the pin in the pull test, as shown in figure 2.6. The force in the simulation started decreasing after 8.25 inches (210 mm) in comparison to the pull test. However, at this time, the pin has rotated more than what would be desirable for providing sufficient anchorage to the pinned barriers. Thus, the anchoring pin design is expected to stay well within the load range where simulation results are in good agreement with the test results.

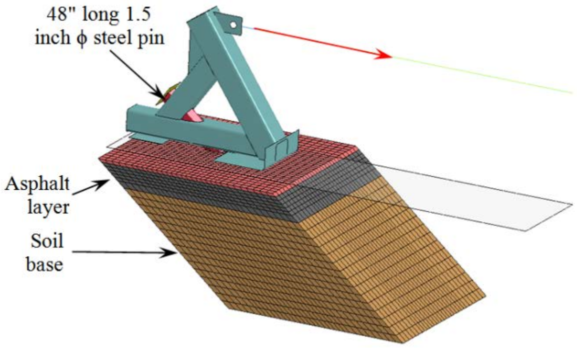


Figure 2.5. Finite element model of anchoring pin installed in asphalt pad and soil base.

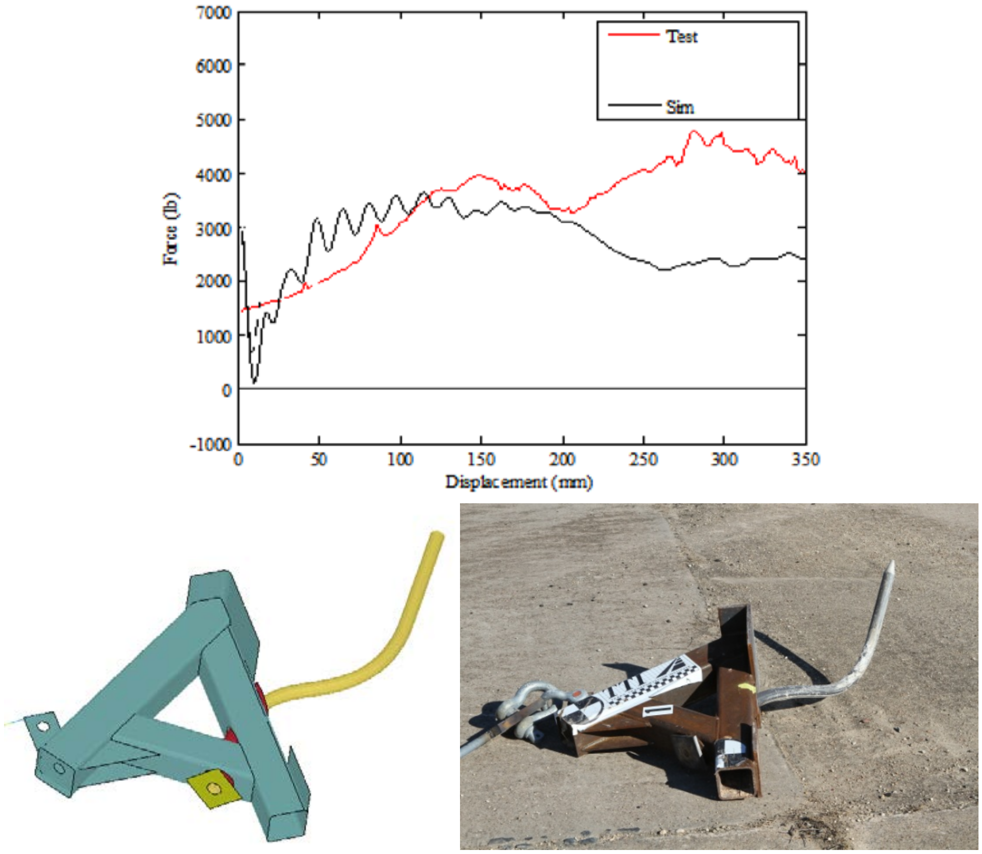


Figure 2.6. Test and simulation comparison of lateral pull force and pin deformation.

2.3.2 Barrier System Model

Having adequately validated the soil-asphalt-pin model, the researchers developed a full-scale 100-ft installation of F-shape concrete barrier pinned on asphalt. The model is shown in figure 2.7 and includes eight 12.5-ft long F-shape concrete barrier segments with pin-loop connections. The concrete barrier was modeled using rigid solid elements. Slotted holes (4-inch×1-7/8-inch) were built into the model to pass the anchoring pins through the toe of the barrier. A 1.5H:1V slope was also incorporated behind the barrier. The barrier was placed at a 1-

ft offset from the break point of the 1.5H:1V slope. The steel pins used to anchor the barrier were 1.5 inches in diameter and 48 inches in length, as used in the pull tests. Using this barrier system model, the researchers performed *MASH* test 3-11 vehicle impact simulations (i.e. 5000-lb pickup; impact speed 62.2 mi/h; and impact angle 25 degrees). The vehicle model used in the simulation was a reduced Chevrolet Silverado model developed by National Crash Analysis Center with funding from Federal Highway Administration (FHWA) and National Highway Traffic Safety Administration (NHTSA).

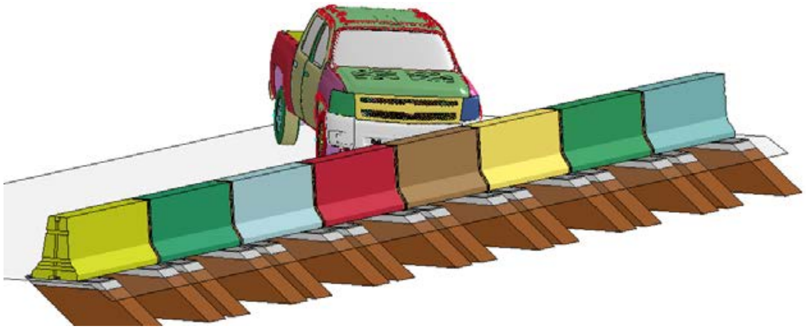


Figure 2.7. FE model for temporary concrete barrier anchored on asphalt and soil.

The researchers evaluated the performance of the pinned barrier using two variations of the pinning scheme. One involved using two anchoring pins per barrier segment (as in the existing pinned down barrier for use on concrete), and the other involved using three pins per barrier segment (with third pin in the center of the barrier segment). Results of both impact simulations are compared in figures 2.8 and 2.9.

It can be seen from the figures that the two-pin design has a slightly greater roll and pitch compared to the three-pin design. However, the results of the simulation analyses are very similar for both cases. The vehicle exhibits a high climb and vehicular instability during redirection, even though it redirects successfully in the simulations. It is important to note certain limitations of the simulation analyses. The finite element model of the asphalt does not incorporate cracking of the asphalt due to limitations of available asphalt material properties and numerical material models. In previous testing, cracking of the asphalt was observed in front of a pinned F-shape barrier due to the vehicle impact *(4)*. Such cracking can result in increased lateral barrier movement and barrier roll, which can consequently increase the climb and instability of the vehicle. Additionally, the finite element model does not account for the delamination of the asphalt pad from the underlying soil base. If such delamination occurs, it can also increase the lateral barrier movement and roll, and thus add to the instability of the vehicle.

After considering the slightly improved vehicular stability of the 3-pin design exhibited in the simulation analysis, and some of the limitations of the simulation models, the researchers recommend performing a crash test with the 3-pin anchoring design. Details of the final design, the test installation, and the full scale crash testing are presented in the following chapters.

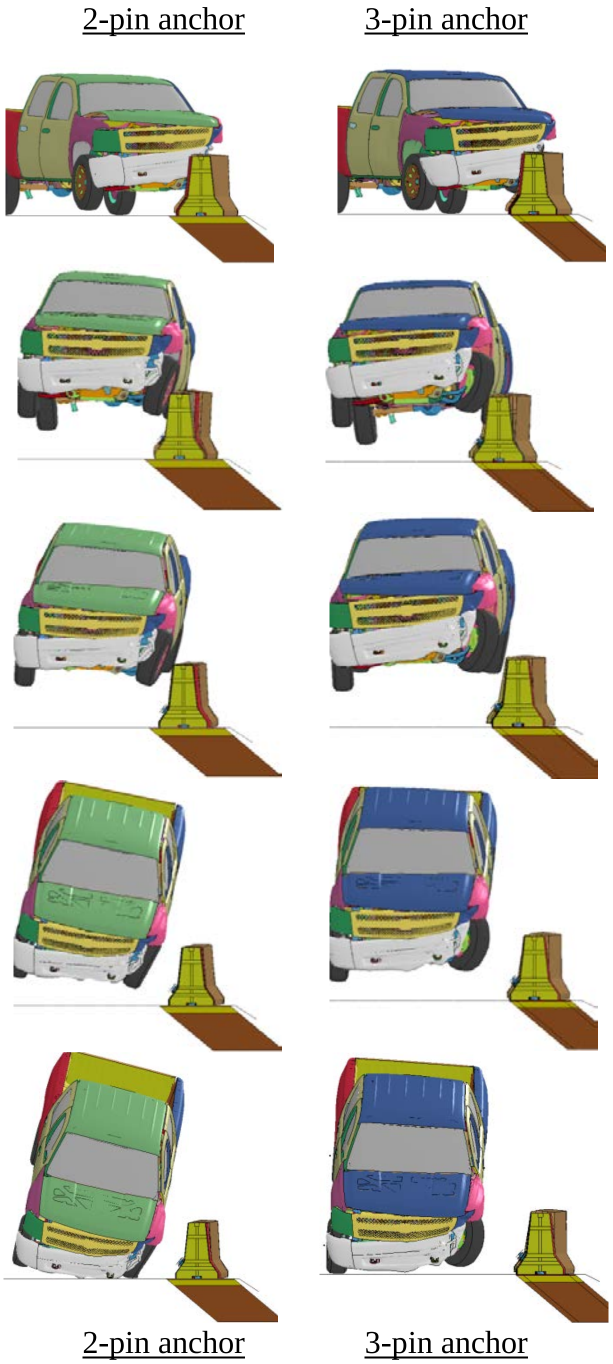
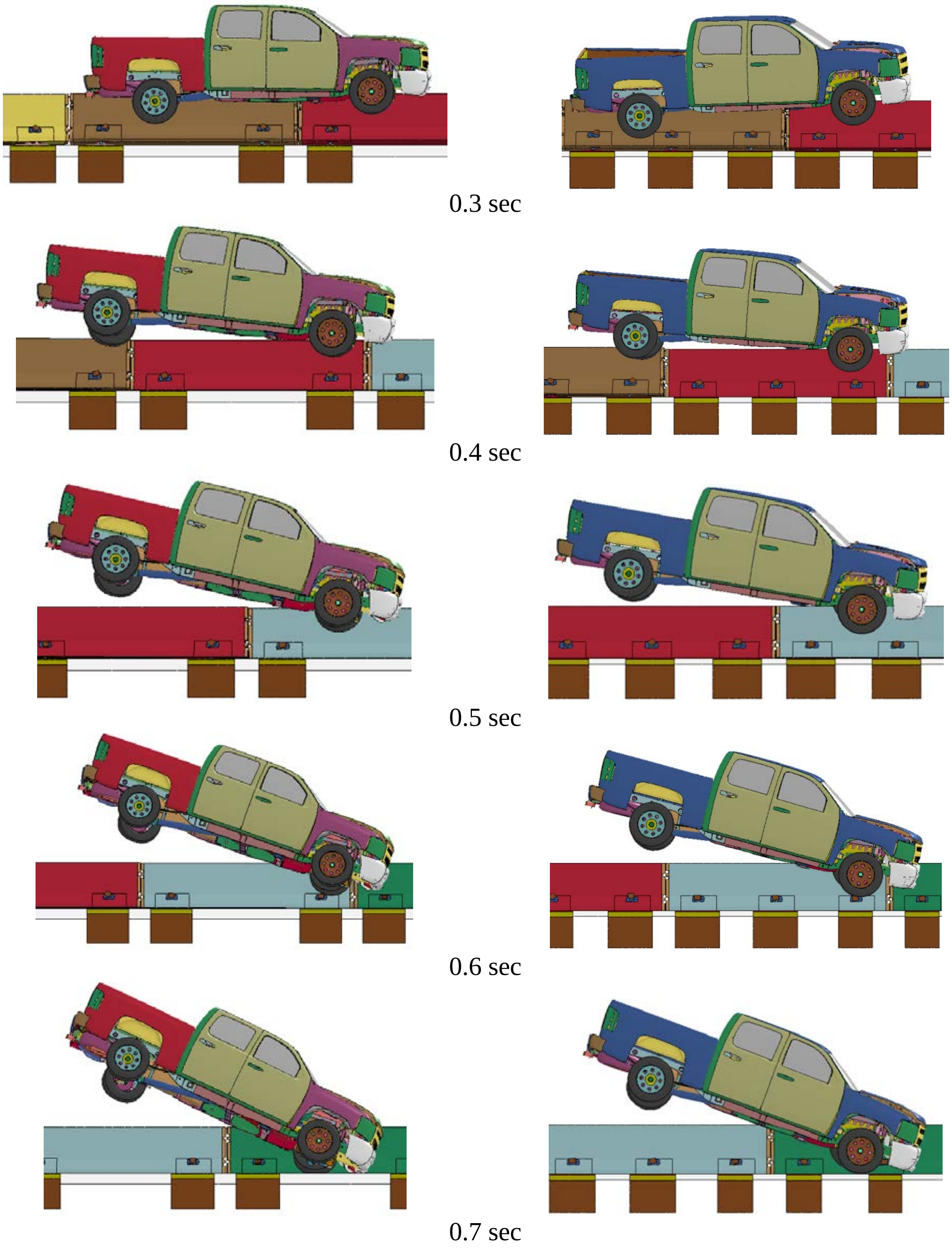


Figure 2.8. Comparison between two and three anchoring pins per segment.



(a) 2-pin anchorage on asphalt (b) 3-pin anchorage on asphalt

Figure 2.9. Comparison between two and three anchoring pins per segment.

3. SYSTEM DETAILS

3.1 TEST ARTICLE DESIGN AND CONSTRUCTION

The precast concrete segments used in this crash test were 12.5 ft long and had a standard "F" profile. The barriers were 32 inches tall, 24 inches wide at the base, and 9.5 inches wide at the top. Horizontal barrier reinforcement consisted of eight #4 bars spaced along the height of the barrier within the vertical reinforcement. Vertical barrier reinforcement consisted of rebar stirrups of #4 bars spaced 18 inches on centers. These vertical bars were bent to conform to the F-shape barrier profile and to provide sufficient concrete cover for the faces of the barrier and the drainage scupper at the base of the barrier. For the last two vertical stirrup bars adjacent to the ends of the barrier segments, the spacing was reduced to 17.875 inches and 7.875 inches, respectively.

Adjacent barrier segments were connected using a pin-and-loop type connection. The loops were made of 3/4-inch diameter round stock steel. The outer diameter of the loops was 3.5 inches and they extended 2 inches outside the end of the barrier segment. The barrier connection was comprised of two sets of three loops. When installed, the distance between adjacent barrier segments was 0.25 inches. A 1-inch diameter, 30-inch long connecting pin was inserted between the loops to establish the connection. A 2-inch diameter and 1/4-inch thick washer was welded 3/4 inch from the top of the connecting pin. The pin was held in place by resting the washer on insets built into the faces of adjacent barriers.

Three 1.875-inch wide and 4-inch long slotted holes, inclined 40 degrees from the ground, were cast into the toe of each barrier segment. These slotted holes started from the traffic face of the barrier and exited near its bottom centerline. Two of the slotted holes were positioned 16 inches away from each face of the barrier. The third slotted hole was positioned in the middle of the barrier segment.

The barriers were placed adjacent to a 1.5H:1V slope with a 12-inch offset from the slope break point. The underlying ground was comprised of 4-inch thick, 125-feet long, and 8-feet wide asphalt pad constructed on top of a 12 inch thick layer of crushed limestone road base (Type A, Grade 1), which was compacted to 95% of standard proctor density. A layer of asphalt binder (CSS-1H tack coat binder) was sprayed at the interface between the asphalt and soil surfaces. The asphalt used was hot mixed Type D with reclaimed asphalt pavement (RAP).

Once the barriers were positioned in place, the slotted holes in the barrier segments were used as a guide to drill pilot holes in the underlying asphalt and soil base. The pilot holes were drilled using a 1.5-inch diameter drill bit. After each pilot hole was drilled, a 1.5-inch diameter, 48-inch long anchoring pin was passed through the slotted hole in the barrier and driven into the asphalt-soil base. Thus, each barrier segment was anchored to the ground with three pins. The anchoring pin was fabricated with a 2-inch tip. The top of each anchoring pin had a ½-inch thick, 4-inch×4-inch A36 plate cover welded to it. The plate covers were welded at a 5-degree angle from the vertical so that they matched the profile of the barrier's toe when installed.

Inside the barrier segments, a 22-inch long U-shaped #4 bar was diagonally placed at the location of each slotted hole. The U-shaped bar circumvented the slot to reinforce the concrete around it and to resist pullout of the anchoring pin in the event of concrete failure in the vicinity of the slotted hole.

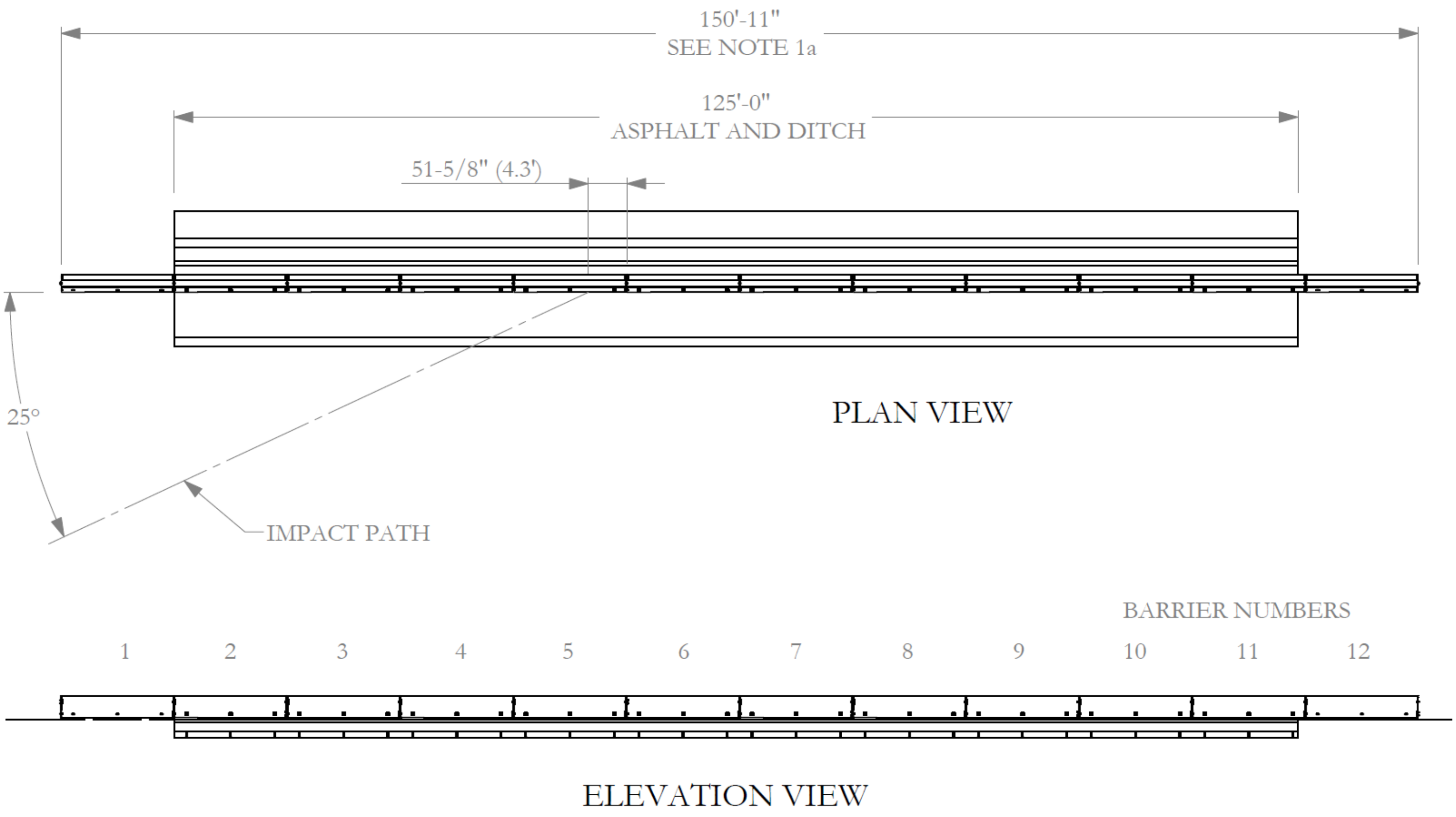
The completed test installation consisted of 12 barrier segments connected together for a total length of approximately 150 ft and 11 inches. The end barrier segments on each side of the installation were placed directly on native soil and were not anchored. The remaining 10 barrier segments were placed on the asphalt pad and were anchored as described above. Barrier segments used in the test installation were donated by WASKEY. Details of the barrier and the pin-down restraint are shown in figures 3.1 through 3.7. Figure 3.9 shows photographs of the completed test installation.

3.2 MATERIAL SPECIFICATIONS

The specified compressive strength of the concrete for the barrier segments was 5000 psi. The compressive strength on the day of testing was 5520 psi. Results of the tests performed to determine the compressive strength are shown in appendix A.

All rebar reinforcement was grade 60 steel material. The loops for the connecting pin, the anchoring pins, and the washers welded on top of the anchoring pins were A36 steel. The connecting pin between adjacent barrier segments was A572 grade 50 steel.

TEST INSTALLATION



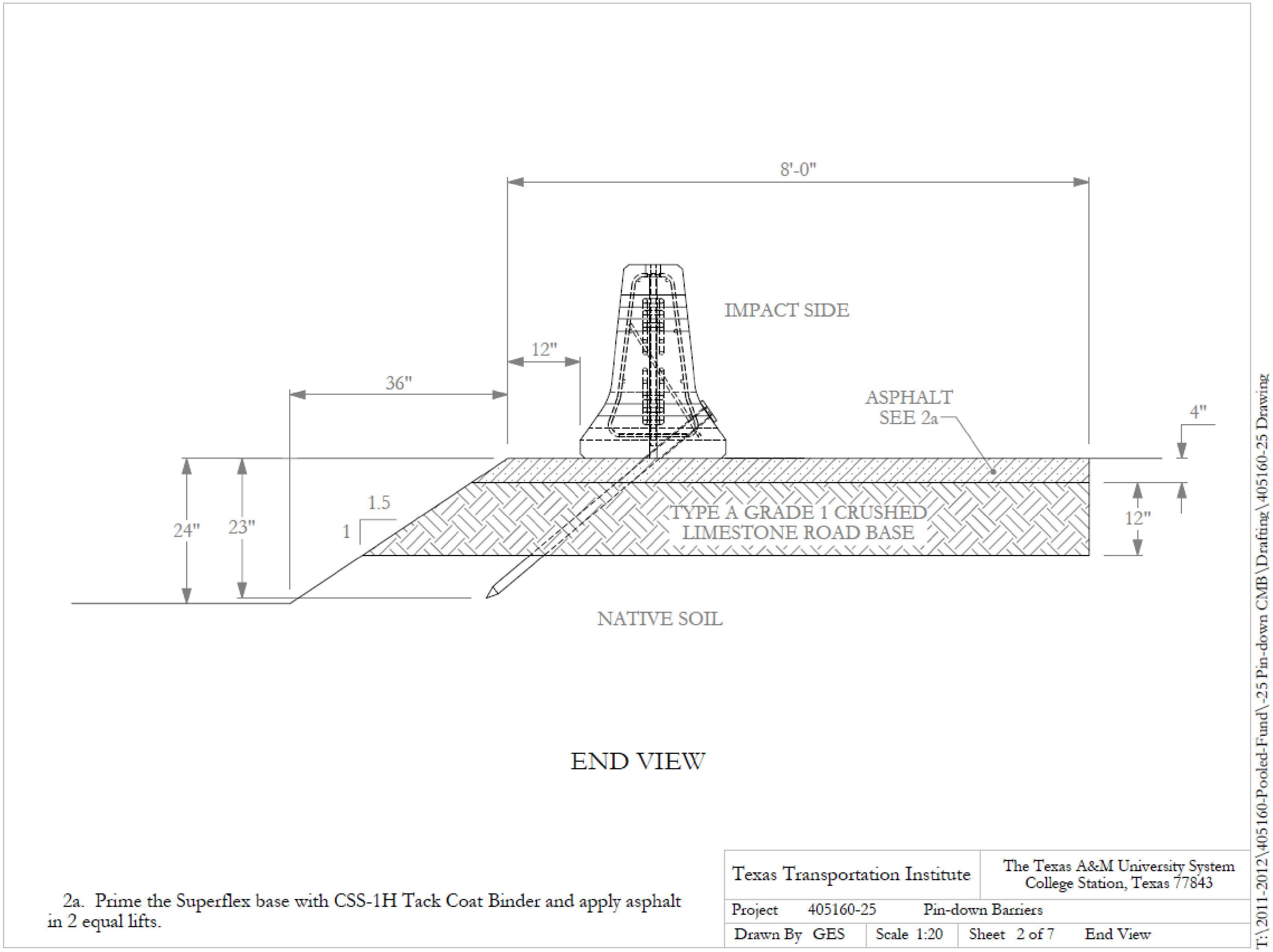
1a. Twelve barriers at 12'6" each with ≈1" space between barriers. Barriers 1and 12 are not pinned and may or may not have slots or holes for anchor pins.

1b. Installation instructions: Place barriers and insert connecting pins. Drill Ø1-3/4" holes, three per barrier, through asphalt with masonry bit and rotary percussion drill at Barriers 2 - 11, using sleeves as a guide. Insert Anchor Pins, and turn the pins if necessary so that the plate washers fit snug against the barriers.

Texas Transportation Institute		The Texas A&M University System College Station, Texas 77843	
Project	405160-25	Pin-down Barriers	
Drawn By GES	Scale 1:200	Sheet 1 of 7	Test Installation
Approved: Nauman Sheikh: Nauman M. Sheikh	Signature		Date: 2011-10-24

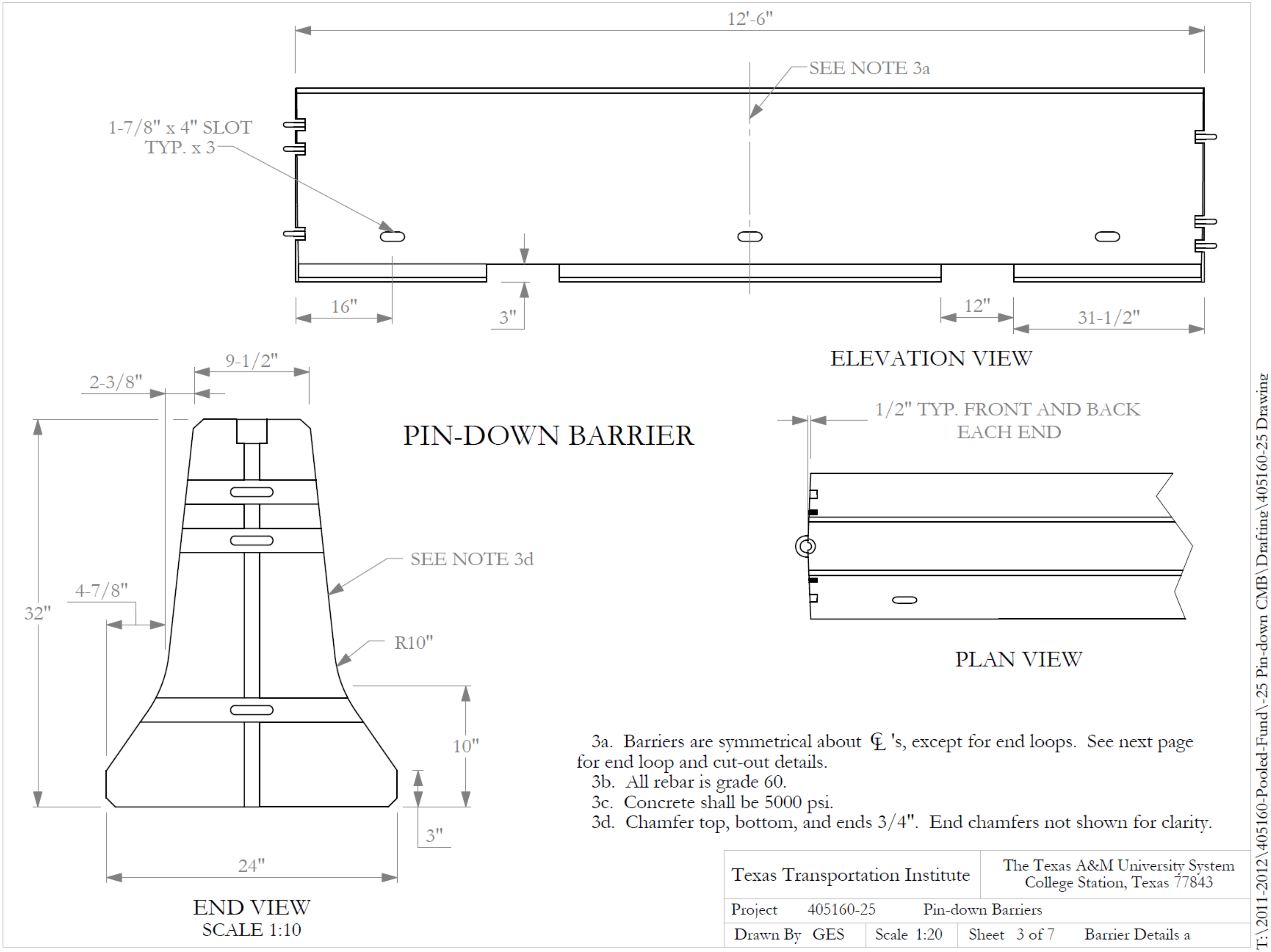
T:\2011-2012\405160-Pooled-Fund\-25 Pin-down CMB\Drafting\405160-25 Drawing

Figure 3.1. Overall layout of the Temporary Concrete Barrier Pinned on Asphalt.



2a. Prime the Superflex base with CSS-1H Tack Coat Binder and apply asphalt in 2 equal lifts.

Figure 3.2. Installation cross section for the Temporary Concrete Barrier Pinned on Asphalt.



3a. Barriers are symmetrical about ℄'s, except for end loops. See next page for end loop and cut-out details.
3b. All rebar is grade 60.
3c. Concrete shall be 5000 psi.
3d. Chamfer top, bottom, and ends 3/4". End chamfers not shown for clarity.

Texas Transportation Institute		The Texas A&M University System College Station, Texas 77843	
Project 405160-25		Pin-down Barriers	
Drawn By GES	Scale 1:20	Sheet 3 of 7	Barrier Details a

Figure 3.3. Barrier details for the Temporary Concrete Barrier Pinned on Asphalt.

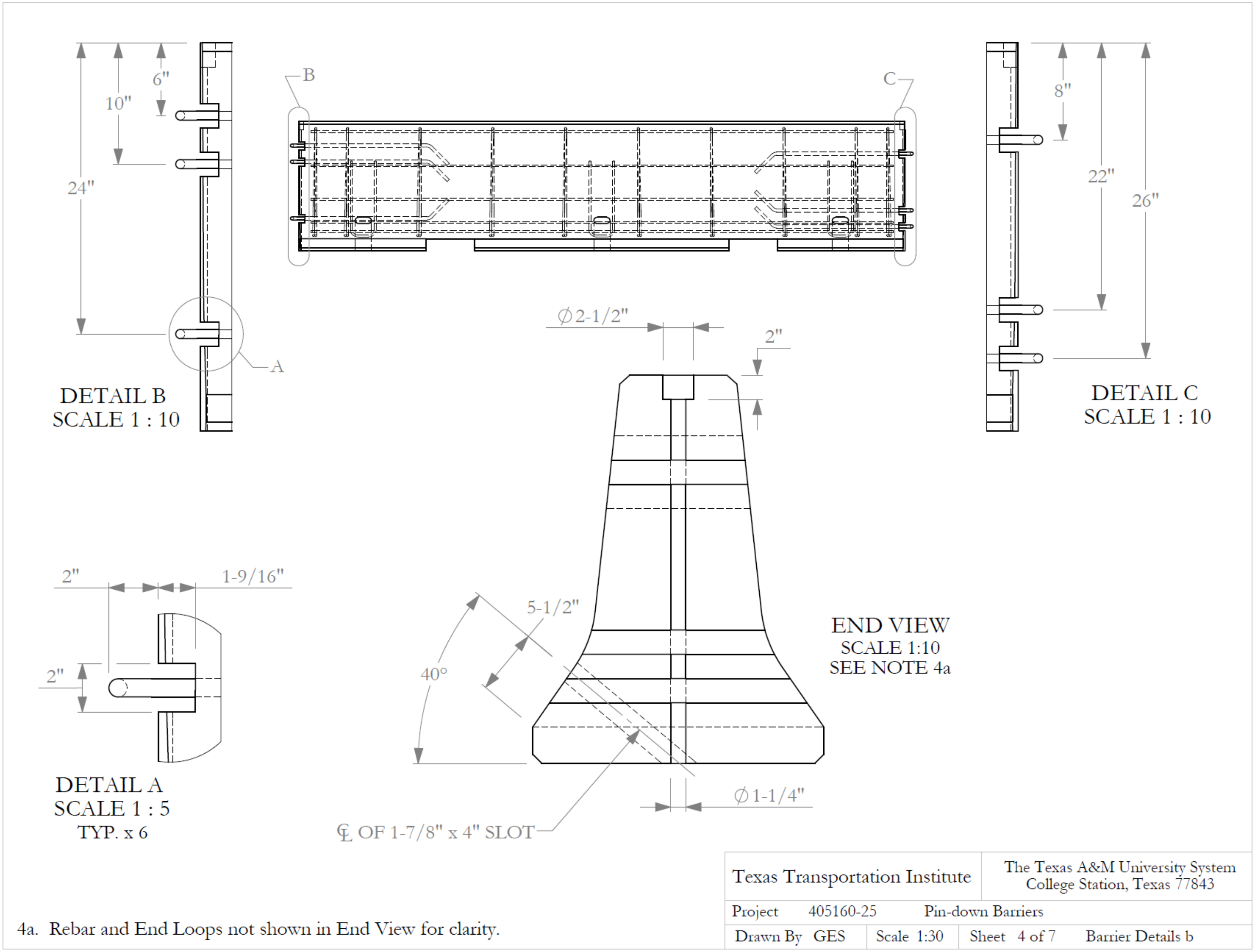


Figure 3.4. Connection details for the Temporary Concrete Barrier Pinned on Asphalt.

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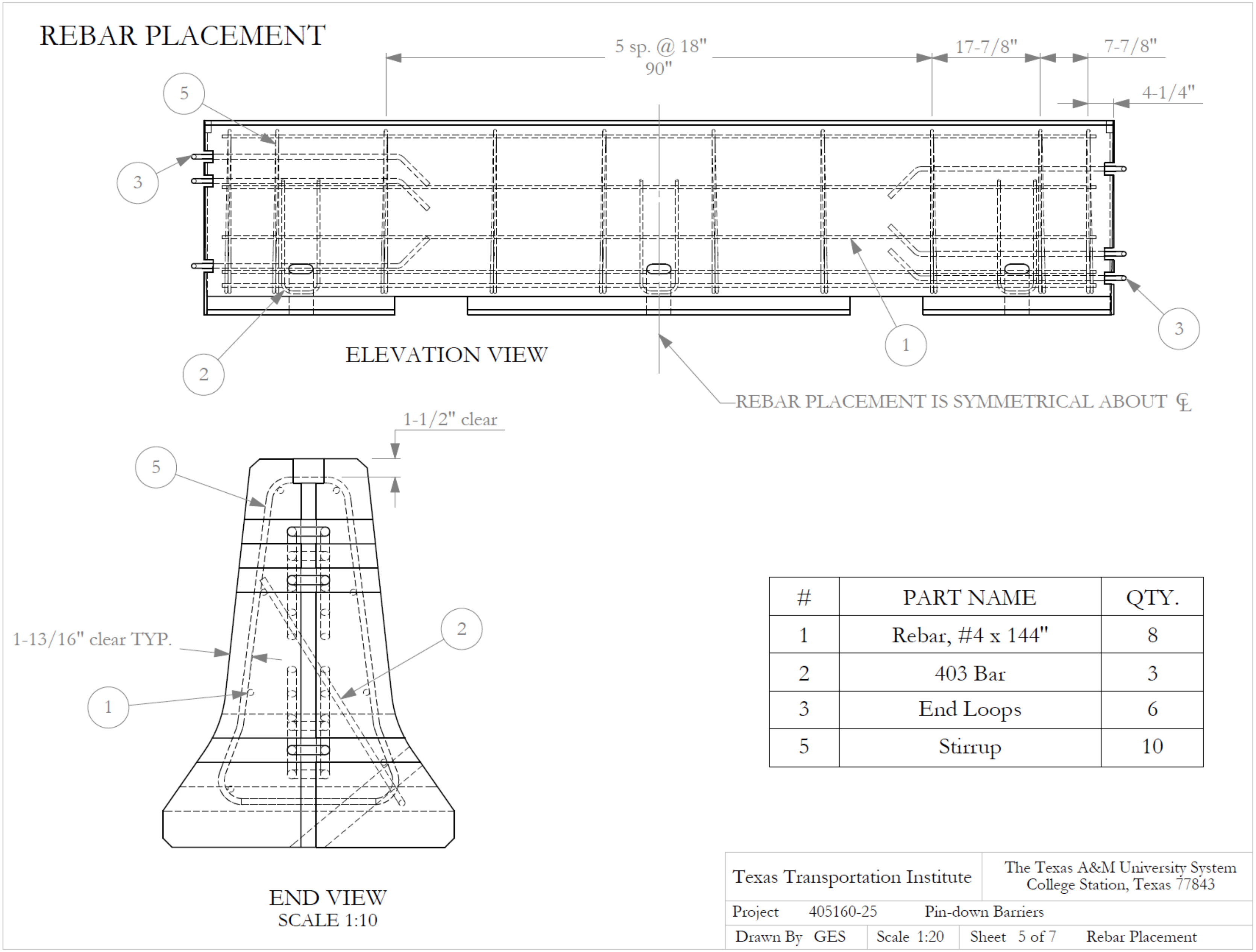

#	PART NAME	QTY.
1	Rebar, #4 x 144"	8
2	403 Bar	3
3	End Loops	6
5	Stirrup	10

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College Station, Texas 77843
Project 405160-25 Pin-down Barriers
Drawn By GES Scale 1:20 Sheet 5 of 7 Rebar Placement

Figure 3.5. Reinforcement details of the Temporary Concrete Barrier Pinned on Asphalt.

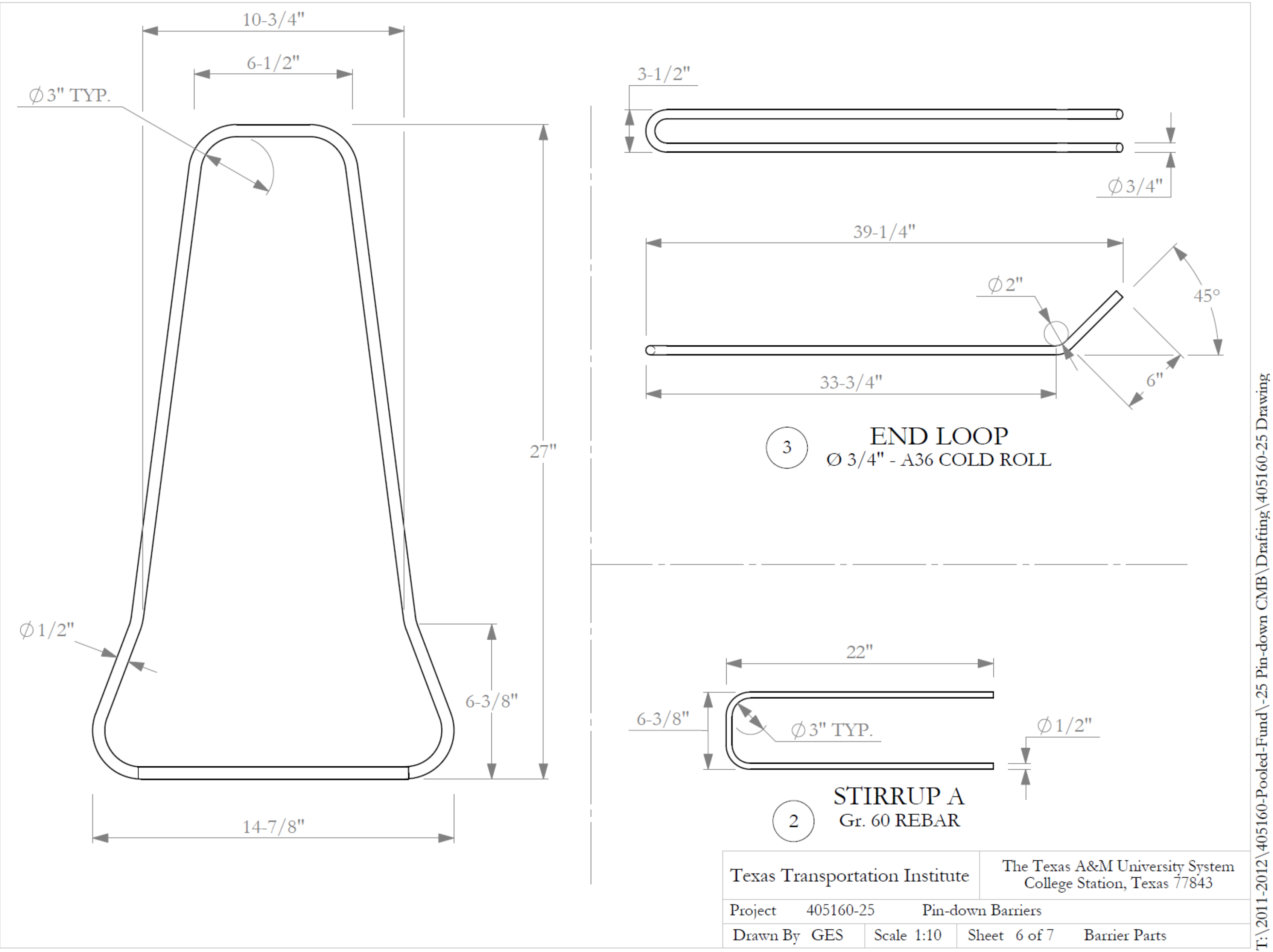


Figure 3.6. Rebar details for the Temporary Concrete Barrier Pinned on Asphalt.

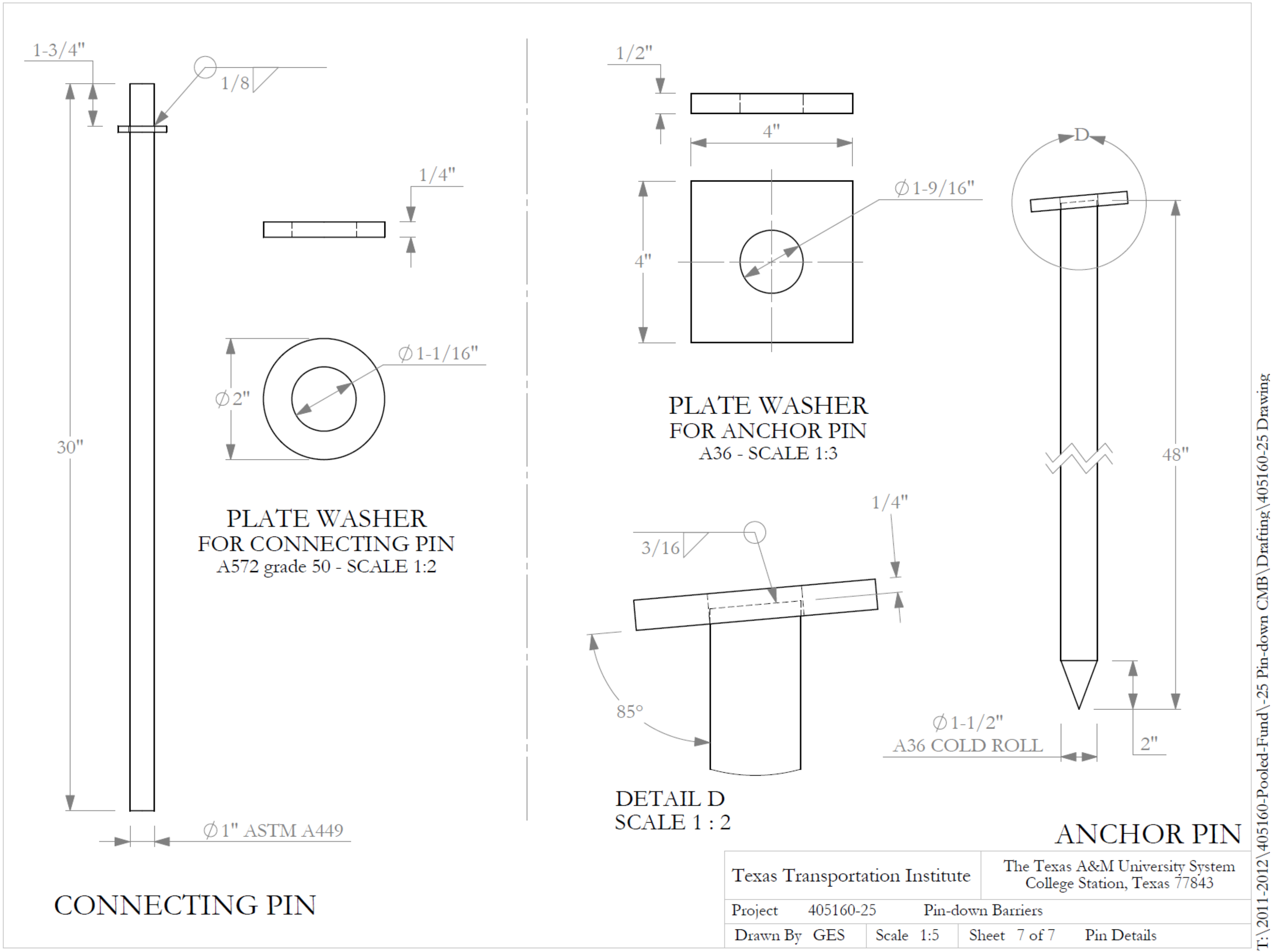


Figure 3.7. Anchor and connecting pin details for the Temporary Concrete Barrier Pinned on Asphalt.

Figure 3.8. Temporary concrete barrier pinned on asphalt prior to testing.

4. TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1 CRASH TEST MATRIX

According to *MASH,* two tests are recommended to evaluate longitudinal barriers to test level three (TL-3) and are as described below.

> ***MASH* Test Designation 3-10:** A 2425 lb vehicle impacting the critical impact point (CIP) of the length of need (LON) of the barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. This test investigates a barrier's ability to successfully contain and redirect a small passenger vehicle.
>
> ***MASH* Test Designation 3-11:** A 5000 lb pickup truck impacting the CIP of the LON of the barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. This test investigates a barrier's ability to successfully contain and redirect light trucks and sport utility vehicles.

The test reported herein corresponds to Test 3-11 of *MASH* (5000-lb pickup, 62 mi/h, 25 degrees). This test was deemed sufficient to evaluate the impact performance of the pinned-down barrier. It was argued that the test with the smaller 2425-lb was not needed. Due to higher impact energy, the test with the 5000-lb pickup truck will result in greater load on the anchoring pins, lateral barrier deflection, and vehicle instability. The barrier is expected to behave nearly rigidly when impacted by the lighter 2425-lb passenger car, and a rigid F-shape barrier has been successfully tested under *MASH* Test 3-10. Thus, only test 3-11 was conducted. 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 crash test was evaluated in accordance with the criteria presented in *MASH*. The performance of the temporary concrete barrier pinned on asphalt is judged on the basis of three factors: structural adequacy, occupant risk, and post impact vehicle trajectory. Structural adequacy is judged upon the ability of the pinned barrier to contain and redirect the vehicle, or bring the vehicle to a controlled stop in a predictable manner. Occupant risk criteria evaluates the potential risk of hazard to occupants in the impacting vehicle, and to some extent other traffic, pedestrians, or workers in construction zones, if applicable. Post impact vehicle trajectory is assessed to determine potential for secondary impact with other vehicles or fixed objects, creating further risk of injury to occupants of the impacting vehicle and/or risk of injury to occupants in other vehicles. The appropriate safety evaluation criteria from table 5.1 of *MASH* were used to evaluate the crash test reported herein, and are listed in further detail under the assessment of the crash test.

5. TEST CONDITIONS

5.1 TEST FACILITY

The full-scale crash test reported herein was performed at Texas Transportation Institute (TTI) Proving Ground. TTI Proving Ground is an International Standards Organization (ISO) 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 at the TTI Proving Ground consist of a 2000-acre complex of research and training facilities situated 10 miles northwest of the main campus of Texas A&M University. The site, formerly an Air Force 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 performance evaluation of roadside safety hardware. The site selected for the installation of the temporary concrete barrier pinned on asphalt was along the edge of a wide out-of-service apron. The apron consists of an unreinforced jointed concrete pavement in 12.5 ft × 15 ft blocks nominally 8-12 inches deep. The aprons are over 50 years old and the joints have some displacement, but are otherwise flat and level.

5.2 VEHICLE TOW AND GUIDANCE SYSTEM

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

5.3 DATA ACQUISITION SYSTEMS

5.3.1 Vehicle Instrumentation and Data Processing

The test vehicle was instrumented with a self-contained, on-board data acquisition system. The signal conditioning and acquisition system is a 16-channel, Tiny Data Acquisition System (TDAS) Pro manufactured by Diversified Technical Systems, Inc. The accelerometers that measure the x, y, and z axis of vehicle acceleration are strain gauge type with linear millivolt output proportional to the acceleration. Angular rate sensors measuring vehicle roll, pitch, and yaw rates are ultra-small size, solid state unit designs for crash test service. The TDAS Pro hardware and software conform to 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 recorded, the data are backed up inside the unit by internal batteries should the primary battery cable be severed. Initial contact of the pressure switch on the vehicle's bumper provides a time zero mark as well as initiating the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The raw data are then processed by the Test Risk Assessment Program (TRAP) software to produce detailed reports of the test results. Each of the TDAS Pro units is returned to the factory annually for complete recalibration. Accelerometers and rate transducers are also calibrated annually with traceability to the National Institute for Standards and Technology. Acceleration data is measured with an expanded uncertainty of ±1.7% at a confidence fracture of 95% (k=2).

TRAP uses the data from the TDAS Pro to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-millisecond (ms) average ridedown acceleration. TRAP calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz 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 and then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact. Rate of rotation data is measured with an expanded uncertainty of ±0.7% at a confidence factor of 95% (k=2).

5.3.2 Anthropomorphic Dummy Instrumentation

Use of a dummy in the 2270P vehicle is optional according to *MASH*, and there was no dummy used in this test.

5.3.3 Photographic Instrumentation and Data Processing

Photographic coverage of the test included three 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 activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked motion analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-DV camera and still cameras recorded and documented conditions of the test vehicle and installation before and after the test.

6. CRASH TEST 405160-25-1 (*MASH* TEST NO. 3-11)

6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

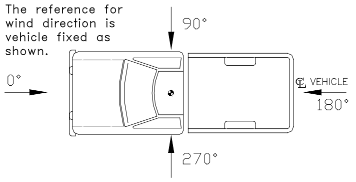
MASH test 3-11 involves a 2270P vehicle weighing 5000 lb ±100 lb and impacting the barrier installation at an impact speed of 62.2 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target impact point was 4.3 ft upstream of the joint between segments 5 and 6 of the installation. The 2005 Dodge Ram 1500 pickup used in the test weighed 5056 lb and the actual impact speed and angle were 62.2 mi/h and 24.8 degrees, respectively. The actual impact point was 3.9 ft upstream of the joint between segments 5 and 6 of the barrier.

6.2 TEST VEHICLE

A 2005 Dodge Ram 1500 pickup truck, shown in figures 6.1 and 6.2, was used for the crash test. Test inertia weight of the vehicle was 5056 lb, and its gross static weight was 5056 lb. The height to the lower edge of the vehicle front bumper was 13.5 inches, and the height to the upper edge of the front bumper was 26.0 inches. The height to the vehicle's center of gravity was 29.5 inches. Additional dimensions and information on the vehicle are given in appendix C, tables C1 and C2. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

6.3 WEATHER CONDITIONS

The crash test was performed the morning of November 18, 2011. Weather conditions at the time of testing were: Wind speed: 8 mi/h; wind direction: 153 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 62ºF; relative humidity: 62 percent.



6.4 TEST DESCRIPTION

The 2005 Dodge Ram 1500 pickup, traveling at an impact speed of 62.2 mi/h, impacted the temporary concrete barrier system pinned on asphalt 3.9 ft upstream of the joint between segments 5 and 6 at an impact angle of 24.8 degrees. At approximately 0.014 s, the vehicle began to redirect, and at 0.103 s, the left front tire blew out. The vehicle became airborne at 0.127 s. Maximum deflection of 17.8 inches occurred at 0.158 s. At 0.187 s, the vehicle began traveling parallel with the barrier at a speed of 52.4 mi/h. At 0.365 s, the vehicle lost contact with the barrier and was traveling at an exit speed and angle of 50.2 mi/h and 6.8 degrees, respectively. The vehicle touched ground at 0.514 s, and the brakes on the vehicle were applied at 1.925 s. The vehicle subsequently came to rest 225 ft downstream of impact and 39 ft toward traffic lanes from the traffic face of the barrier. Sequential photographs of the test period are shown in appendix C, figure C1.

Figure 6.1. Vehicle/installation geometrics for test 405160-25-1.

Figure 6.2. Vehicle before test 405160-25-1.

6.5 TEST ARTICLE AND COMPONENT DAMAGE

Damage to the barrier installation is shown in figures 6.3 and 6.4. The anchor pins on segments 5, 6 and 7 pulled upward as listed in table 6.1, and the pin on the upstream end of segment 5 was deformed. The downstream end of segment 3 moved 0.25 inch toward the traffic side. The concrete around the anchoring pin in the toe area of segment 5 failed and spalled off due to the impact. The upstream end of segment 6 moved 7.0 inches toward the field side, and the downstream end moved 1.5 inches toward traffic lanes. The upstream end of segment 7 moved 0.25 inch toward traffic lanes. Working width was 29.9 inches, maximum dynamic deflection during the test was 17.8 inches, and maximum permanent deformation was 17.0 inches.

Table 6.1. Distance pins pulled upward.

Barrier #	Pin #	Distance (inches)
5	1	1.0
	2	2.5
	3	4.0
6	1	2.5
	2	1.0
	3	1.0
7	1	1.5
	2	1.5
	3	nil

6.6 TEST VEHICLE DAMAGE

Figure 6.5 shows damage to the 2270P vehicle. The left front upper and lower A-arms, left tie rod end, left frame rail, left rear U-bolts, and drive shaft were damaged. Also damaged were the front bumper, left front fender, left front tire and wheel rim, left front and rear doors, left rear cab corner, left rear exterior bed, left rear tire and wheel rims, and rear bumper. Maximum exterior crush to the vehicle was 18.0 inches in the side plane at the left front corner at bumper height. Maximum occupant compartment deformation was 0.75 inch in the lateral area across the cab at driver’s hip height. Photographs of the interior of the vehicle are shown in figure 6.6. Exterior vehicle crush and occupant compartment measurements are shown in appendix C, tables C3 and C4.

Figure 6.3. Vehicle and installation positions after test 405160-25-1.

Figure 6.4. Installation after test 405160-25-1.

Figure 6.5. Vehicle after test 405160-25-1.

Before Test

After Test

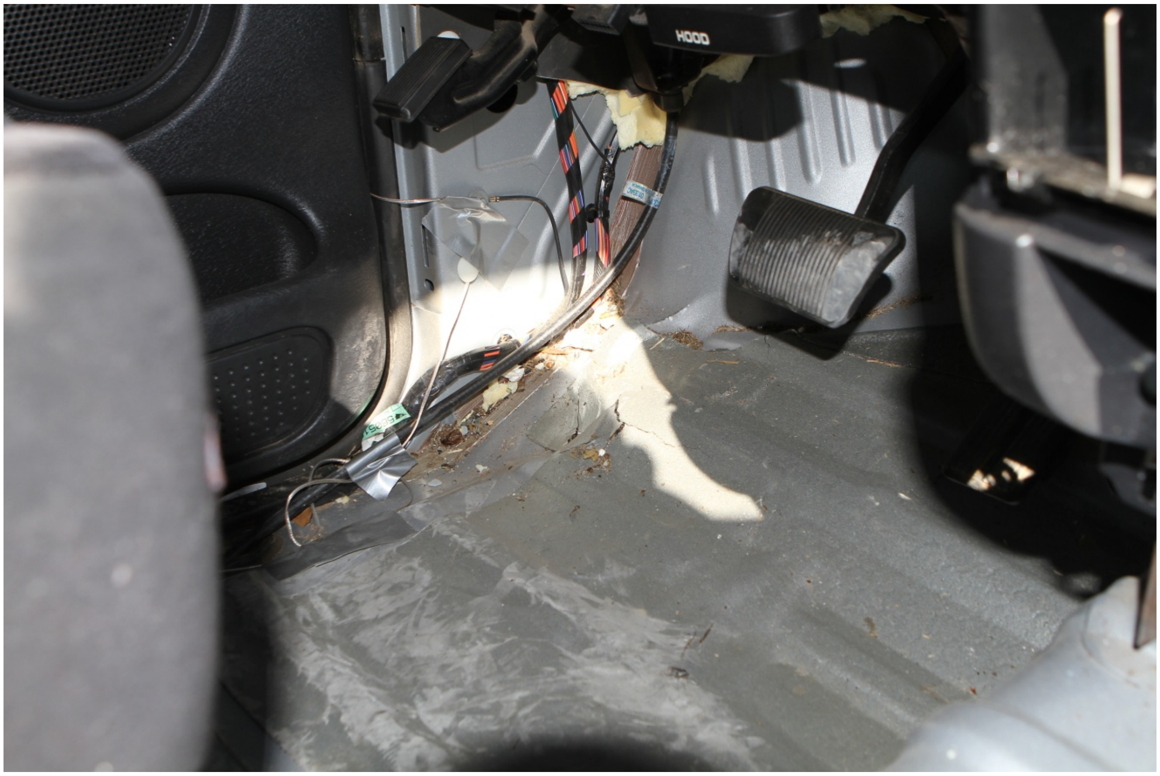


Figure 6.6. Interior of vehicle for test 405160-25-1.

6.7 OCCUPANT RISK VALUES

Data from the accelerometer, located at the vehicle's center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 15.1 ft/s at 0.099 s, the highest 0.010-s occupant ridedown acceleration was 4.1 Gs from 0.199 to 0.209 s, and the maximum 0.050-s average acceleration was -6.5 Gs between 0.025 and 0.075 s. In the lateral direction, the occupant impact velocity was 21.3 ft/s at 0.099 s, the highest 0.010-s occupant ridedown acceleration was 12.7 Gs from 0.213 to 0.223 s, and the maximum 0.050-s average was 10.9 Gs between 0.031 and 0.081 s. Theoretical Head Impact Velocity (THIV) was 28.0 km/h or 7.8 m/s at 0.096 s; Post-Impact Head Decelerations (PHD) was 12.7 Gs between 0.213 and 0.223 s; and Acceleration Severity Index (ASI) was 1.31 between 0.026 and 0.076 s. These data and other pertinent information from the test are summarized in figure 6.7. Vehicle angular displacements and accelerations versus time traces are presented in appendix C, figures C2 through C8.

6.8 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the following applicable *MASH* safety evaluation criteria is presented below.

6.8.1 Structural Adequacy

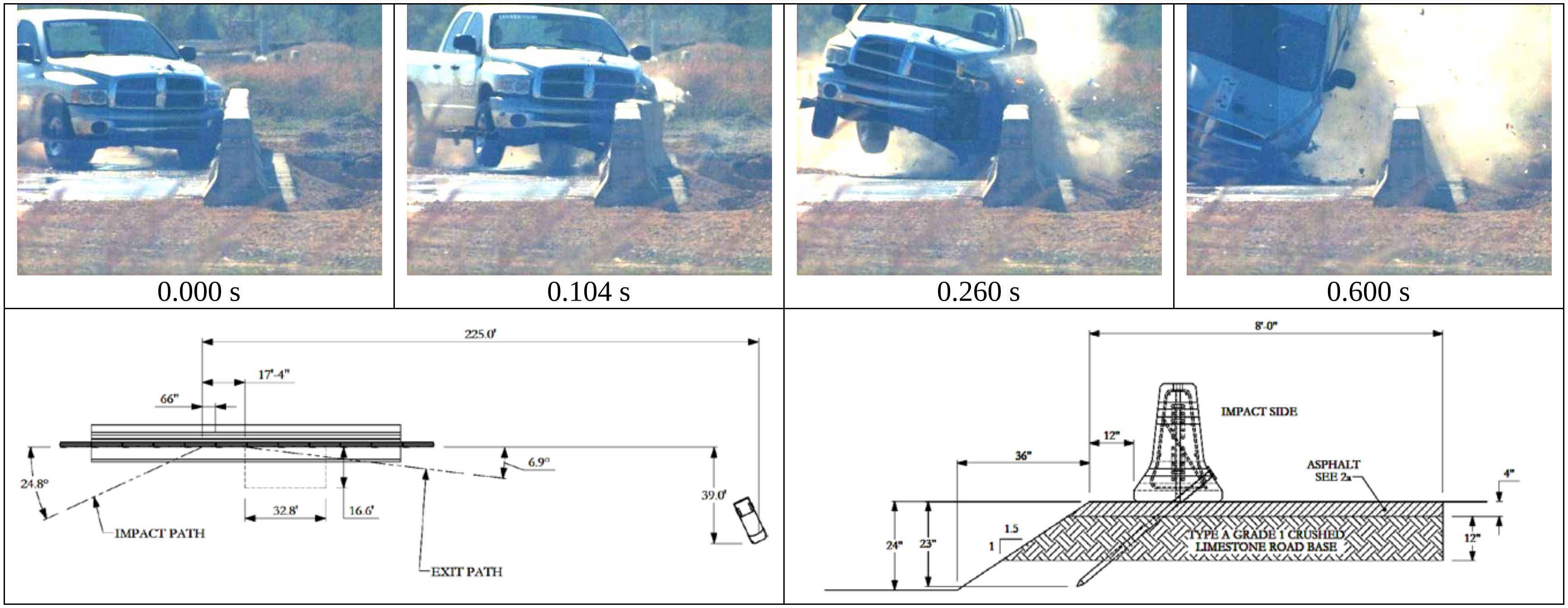
A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.

Results: The temporary concrete barrier pinned on asphalt contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the barrier during the test was 17.8 inches. (PASS)

6.8.2 Occupant Risk

D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.

Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 inches).



General Information	
Test Agency	Texas Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-11
TTI Test No.	405160-25-1
Date	November 18, 2011
Test Article	
Type	Portable Concrete Median Barrier (pinned)
Name	Temporary CMB pinned to asphalt
Installation Length	150.9 ft
Material or Key Elements	
Soil Type and Condition	Asphalt and Soil, Dry
Test Vehicle	
Type/Designation	2270P
Make and Model	2005 Dodge Ram 1500 Pickup
Curb	4834 lb
Test Inertial	5056 lb
Dummy	No dummy
Gross Static	5056 lb

Impact Conditions	
Speed	62.2 mph
Angle	24.8 degrees
Location/Orientation	
Impact Severity	115.0 kip-ft
Exit Conditions	
Speed	50.2 mi/h
Angle	6.8 degrees
Occupant Risk Values	
Impact Velocity	
Longitudinal	15.1 ft/s
Lateral	21.3 ft/s
Ridedown Accelerations	
Longitudinal	4.1 G
Lateral	12.7 G
THIV	28.0 km/h
PHD	12.7 G
ASI	1.31
Max. 0.050-s Average	
Longitudinal	-6.5 G
Lateral	10.9 G
Vertical	-4.5 G

Post-Impact Trajectory	
Stopping Distance	120 ft dwnstrm 39 ft twd traffic
Vehicle Stability	
Maximum Yaw Angle	41 degrees
Maximum Pitch Angle	20 degrees
Maximum Roll Angle	17 degrees
Vehicle Snagging	
Vehicle Pocketing	
Test Article Deflections	
Dynamic	17.8 inches
Permanent	17.0 inches
Working Width	29.9 inches
Vehicle Damage	
VDS	11LFQ6
CDC	11FLEW4
Max. Exterior Deformation	18.0 inches
OCDI	LF0000000
Max. Occupant Compartment Deformation	0.75 inch

Figure 6.7. Summary of results for *MASH* test 3-11 on Temporary Concrete Barrier Pinned on Asphalt and Soil.

Results: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area. (PASS)
Maximum occupant compartment deformation was 0.75 inch in the lateral area across the cab at passenger hip height. (PASS)

F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.

Results: The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 17 and 20 degrees, respectively. (PASS)

H. Occupant impact velocities should satisfy the following:

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
30 ft/s	*40 ft/s*

Results: Longitudinal occupant impact velocity was 15.1 ft/s, and lateral occupant impact velocity was 21.3 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Longitudinal ridedown acceleration was 4.1 Gs, and lateral ridedown acceleration was 12.7 Gs. (PASS)

6.8.3 Vehicle Trajectory

For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).

Result: The 2270P vehicle crossed the exit box at 102.7 ft. (PASS)

7. SUMMARY AND CONCLUSIONS

7.1 SUMMARY OF TEST RESULTS

The F-shape temporary concrete barrier pinned on asphalt contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the barrier during the test was 17.8 inches. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 0.75 inch in the lateral area across the cab at passenger hip height. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 17 and 20 degrees, respectively. The occupant risk factors were below the preferred values specified in *MASH*. The 2270P vehicle crossed the exit box at 102.7 ft.

7.2 CONCLUSIONS AND IMPLEMENTATION

7.2.1 Conclusions

Previously, TTI had developed a pinned down anchored temporary concrete barrier system for use on concrete bridge decks and pavements *(1)*. The objective of this research was to extend the use of the previously developed pinned down barrier design for placement on asphalt or soil base. The researchers were required to keep the existing design features to the extent possible.

To determine the appropriate pinning scheme, the researchers evaluated the response of a single anchoring pin when installed in soil and asphalt. A series of dynamic pull tests were performed to determine the lateral resistance and deflection response of a single anchoring pin when installed in soil and in different thicknesses of asphalt pad laid over soil base. These tests revealed that pinning the barrier directly on soil is not likely to yield enough lateral restraint to sufficiently anchor the barrier with two to three pins per barrier segment. However, installing the anchoring pin in a 4-inch thick asphalt pad can yield the required lateral restraint needed. Based on the findings of the dynamic pull tests, the pinned down anchored barrier design was developed for placement on a 4-inch thick asphalt pad.

The researchers performed finite element analyses to determine the performance of the pinned barrier system under *MASH* test 3-11 conditions. Analyses were performed with a 5000-lb pickup truck model impacting the barrier system restrained by two and three anchoring pins per barrier segment. Results of the FE analyses showed slightly better performance when three pins per segment were used to anchor the barrier. Furthermore, using three anchoring pins per barrier segment provided greater factor of safety against failure or cracking of asphalt, as well as variability in soil and asphalt properties in the field. The anchorage design with three pins per barrier segment was thus selected for further evaluation by full-scale crash testing.

A 151-ft test installation comprising of 12 barrier segments, connected using pin-and-loop connections, was built for *MASH* test level 3 testing. The barrier was placed adjacent to a 1.5H:1V slope at a lateral offset of 1 ft from the slope break point. The barrier was anchored using three 1.5-inch diameter steel pins per barrier segment. *MASH* test 3-11 was performed with a 2005 Dodge Ram 1500 pickup impacting the barrier at an impact speed and angle of 62.2 mi/h and 24.8 degrees, respectively. The test vehicle was successfully contained and redirected by the pinned down anchored barrier system. The pinned down anchored barrier design meets *MASH* test level 3 criteria, as shown in table 7.1. The maximum dynamic and static deflections of the barrier system were 17.8 inches and 17 inches, respectively.

7.2.2 Implementation

As described in this report, the test installation was comprised of a 12-inch thick Type-A Grade-1 crushed limestone road base, over which a 4-inch thick asphalt pavement was constructed. This road base was primarily used to meet *MASH* requirements for the type of soil that should be used for testing, and to be able to compact the 4-inch thick asphalt pavement on top. In a field installation, it may not always be feasible to have a 12-inch thick road base. Furthermore, native soil conditions may vary from one site to another. It should be noted that the primary resistance to the deflection of the barrier comes from the asphalt pavement. While differences in soil properties underneath the asphalt layer can have some influence on the lateral deflection of the barrier, their effect is expected to be minimal as long as the sub-base is stable enough to roll and compact the asphalt pavement on top of it. Thus smaller thickness of road base may also be used in combination with native soil if the sub-base can be stabilized to achieve proper compaction of the 4-inch thick asphalt pavement on top.

The width of the asphalt pavement constructed for the crash test performed in this research was 8 feet. Using this width eliminated the need to make equipment modifications while constructing the asphalt pavement, and was thus the most economical. However, a successful performance of the anchored barrier design developed in this research does not necessarily require the 8-ft width of the asphalt pad. A conservative estimate based on the amount of asphalt shear surface needed to resist the lateral impact load indicates a minimum width of 5 ft. As long as a 12-inch offset is maintained from the field side edge of the asphalt pad, the barrier may be placed anywhere on a 5-ft wide pad, including placing it flush to traffic side edge. Further research will be needed to determine a more precise minimum width.

The barrier in this research was placed adjacent to a 1.5H:1V slope with a 12-inch offset from the slope break point. These design conditions were agreed by the Pooled Fund states at the start of the project. The slope should not be increased without additional testing and/or modifications to the anchoring design. Similarly, the 12-inch lateral offset from the slope break point should not be decreased without further evaluation through crash testing.

The length of the barrier segments used in the test installation was 12.5 feet. This is the minimum segment length of the portable concrete barriers used among the participating Pooled Fund states. While the design was developed using the smallest barrier segment length, it can also be extended for use with longer barrier segments by adding additional anchoring pins if needed.

The connections between adjacent barrier segments are the weakest points in the system. Due to this, the distance of the anchoring pins adjacent to the connections should not be increased with respect to the connection. Doing so can alter the restraint characteristics of the barrier. Additional pins should therefore only be added to the mid span of the barrier segment without altering the location of the pins adjacent to the barrier connections.

A determination of the number of additional pins needed for longer segments can be made by estimating the number of pins needed per unit length of the barrier. Using the 12.5-ft design tested in this research, it can be estimated that one mid-span anchoring pin is needed for approximately five feet of barrier length (without moving the pins located adjacent to the barrier connections). It should also be noted that using longer segment lengths results in fewer number of barrier connections for a given length of the barrier system. Since rotation between adjacent barriers segments occurs at barrier connections, reducing the number of connections has a benefit of reducing the overall lateral deflection of the barrier. Thus a slightly greater barrier length per mid-span anchoring pin can be allowed for longer segments. Based on this, a 15-ft segment length should not need an additional mid-span anchoring pin. A 20-ft barrier segment length however will require a fourth anchoring pin (i.e. two pins spaced equally in the mid-span of the segment) to attain nearly the same level of anchorage.

Table 7.1. Performance evaluation summary for *MASH* test 3-11 on the Temporary Concrete Barrier Pinned on Asphalt and Soil.

Test Agency: Texas Transportation Institute | Test No.: 405160-25-1 | Test Date: 11/18/2006

***MASH* Test 3-11 Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable*	The Temporary Concrete Barrier Pinned on Asphalt and Soil contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the barrier during the test was 17.8 inches.	Pass
Occupant Risk D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 0.75 inch in the lateral area across the cab at passenger hip height.	Pass
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 17 and 20 degrees, respectively.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.*	Longitudinal occupant impact velocity was 15.1 ft/s, and lateral occupant impact velocity was 21.3 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.*	Longitudinal ridedown acceleration was 4.1 Gs, and lateral ridedown acceleration was 12.7 Gs.	Pass
Vehicle Trajectory *For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).*	The 2270P vehicle crossed the exit box at 102.7 ft.	Pass

REFERENCES

1. Sheikh, N.M., Bligh, R.P., and Menges, W.L. *Crash Testing and Evaluation of the 12 ft Pinned F-shape Temporary Barrier*. Texas Transportation Institute, College Station, TX, 2008.
2. Ross, Jr., H.E., Sicking, D.L., Zimmer, R.A. and Michie, J.D. *Recommended Procedures for the Safety Performance Evaluation of Highway Features.* National Cooperative Highway Research Program *Report 350*, Transportation Research Board, National Research Council, Washington, DC, 1993.
3. Polivka, K.A., Faller, R.K., Rohde, J.R., Holloway, J.C., Bielenberg, B.W., and Sicking, D.L. *Development and Evaluation of a Tie-Down System for the Redesigned F-Shape Concrete Temporary Barrier*. Midwest Roadside Safety Facility, Lincoln, NE, 2003.
4. Bielenberg, B.W., Reid, J.D., Faller, R.K., Rohde, J.R., and Sicking, D.L. *Tie-downs and Transitions for Temporary Concrete Barriers.* Transportation Research Record, *TRR 1984*, 2006.
5. Jewel, J., Weldon, G., and Peter, R. *Compliance Crash Testing of K-Rail Used in Semi-Permanent Installations Report No. 59-680838*, Division of Materials Engineering and Testing Services, CALTRANS, Sacramento, CA, 1999.
6. *AASHTO Manual for Assessing Safety Hardware.* American Association of State Highway and Transportation Officials, Washington, DC, 2010.

APPENDIX A. CONCRETE AND SOIL DOCUMENTATION

CONCRETE CORE TEST REPORT

Report Number: A1111007.0019
Service Date: 11/21/11
Report Date: 11/23/11
Task: PO #405160-25

Terracon
6198 Imperial Loop
College Station, TX 77845
979-846-3767 Reg No: F-3272

Client

Texas Transportation Institute
Attn: Gary Gerke
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1111007

Material Information

Specified Strength:

Specified Length:
Mix ID: Unknown
Nominal Maximum Size Aggregate: Unknown

Sample Information

Placement Date: Unknown
Date Tested: 11/22/11 **Time:** 0000
Sampled By: Matcek, James
Drill Directions: Vertical
Date Core Obtained: 11/22/11 **Time:** 0000
Date Ends Trimmed: 11/22/11 **Time:** 0000
Moisture Conditioning History: According to ASTM C-42

Laboratory Test Data

Core ID	Location	Cored Length (in)	Trim Length (in)	Capped Length (in)	Diam. (in)	Area (sq in)	Length / Diam. Ratio	Max Load (lbs)	Corr. Factor	Comp. Strength (psi)	Fracture Type	Density (pcf)
1	PO #405160-25	12.0	8.1	8.3	3.95	12.25	2.10	67640	1.000	5520	3	

Comments:

Services: Secure cores from concrete paving. Transport the cores to the laboratory for testing to determine length and compressive strength.
Terracon Rep.: Matcek, James
Reported To:
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Emailed

Started: 1000
Finished: 1200

Reviewed By:
Mark E.Dornak, E.I.T.
Project Manager

Test Methods: ASTM C42

FIELD DENSITY TEST REPORT

Report Number: A1111007.0018
Service Date: 11/07/11
Report Date: 11/10/11
Task: PO #405160-25

Terracon
6198 Imperial Loop
College Station, TX 77845
979-846-3767 Reg No: F-3272

Client

Texas Transportation Institute
Attn: Gary Gerke
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1111007

Material Information

				Lab Test Data		Project Requirements	
Mat. No.	**Proctor Ref. No.**	**Classification and Description**	**Laboratory Test Method**	**Optimum Water Content (%)**	**Max. Lab Dry Unit Weight (pcf)**	**Water Content (%)**	**Minimum Compaction (%)**
1	A1111007.0015	Crushed stone	ASTM D698	8.3	132.6	8.3 - 12.3	95%

Field Test Data

Test No.	**Test Location**	**Lift / Elev.**	**Mat. No.**	**Probe Depth (in)**	**Wet Density (pcf)**	**Water Content (pcf)**	**Water Content (%)**	**Dry Unit Weight (pcf)**	**Percent Compaction (%)**
	West Side of Runway								
1	Northwest end		1	10	144.4	9.6	7.1	134.8	100+
2	Centerline of runway		1	10	144.2	11.3	8.5	132.9	100+
3	Southwest end		1	10	144.5	11.8	8.9	132.7	100+

Datum: **Gauge ID:** 3430 **Std. Cnt. M:**618 **Std. Cnt. D:** 2210

Comments:

Services: Perform in-place density and moisture content tests with a Troxler type gauge to determine degree of compaction and material moisture condition.

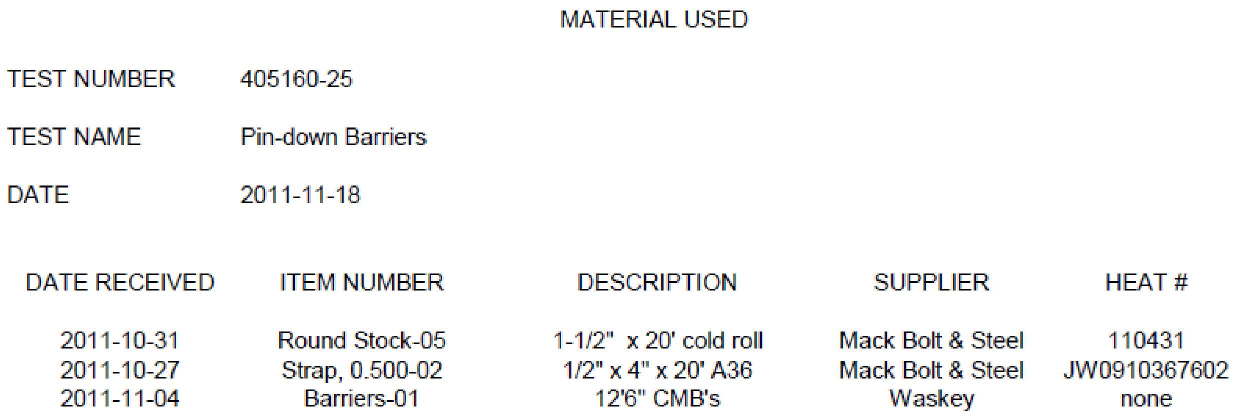
Terracon Rep.: Matcek, James
Reported To:
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Emailed

Started: 0830
Finished: 0930

Reviewed By:
Mark E.Dornak, E.I.T.
Project Manager

Test Methods: ASTM D6938-07 Method A

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS



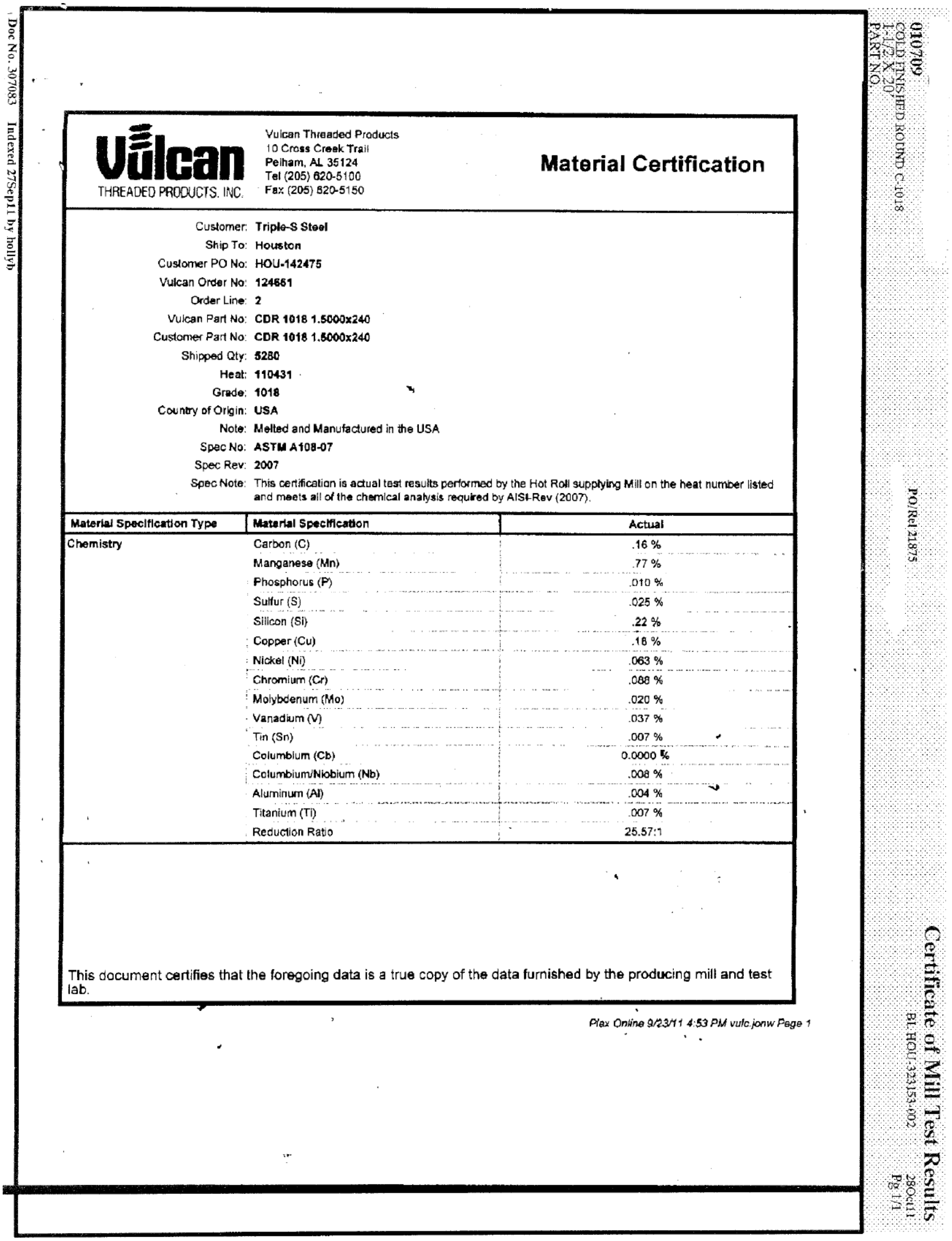
MATERIAL USED

TEST NUMBER 405160-25

TEST NAME Pin-down Barriers

DATE 2011-11-18

DATE RECEIVED	ITEM NUMBER	DESCRIPTION	SUPPLIER	HEAT #
2011-10-31	Round Stock-05	1-1/2" x 20' cold roll	Mack Bolt & Steel	110431
2011-10-27	Strap, 0.500-02	1/2" x 4" x 20' A36	Mack Bolt & Steel	JW0910367602
2011-11-04	Barriers-01	12'6" CMB's	Waskey	none



Doc No. 307083 Indexed 27Sep11 by hollyb

010709
COLD FINISHED ROUND C-1018
1-1/2 X 20'
PART NO.

PO/Rel 21875

Certificate of Mill Test Results
BL HOU-323153-002
28Oct11
Pg 1/1

Vulcan
THREADED PRODUCTS, INC.

Vulcan Threaded Products
10 Cross Creek Trail
Pelham, AL 35124
Tel (205) 620-5100
Fax (205) 620-5150

Material Certification

Customer: **Triple-S Steel**
Ship To: **Houston**
Customer PO No: **HOU-142475**
Vulcan Order No: **124651**
Order Line: **2**
Vulcan Part No: **CDR 1018 1.5000x240**
Customer Part No: **CDR 1018 1.5000x240**
Shipped Qty: **5280**
Heat: **110431**
Grade: **1018**
Country of Origin: **USA**
Note: **Melted and Manufactured in the USA**
Spec No: **ASTM A108-07**
Spec Rev: **2007**
Spec Note: **This certification is actual test results performed by the Hot Roll supplying Mill on the heat number listed and meets all of the chemical analysis required by AISI-Rev (2007).**

Material Specification Type	Material Specification	Actual
Chemistry	Carbon (C)	.16 %
	Manganese (Mn)	.77 %
	Phosphorus (P)	.010 %
	Sulfur (S)	.025 %
	Silicon (Si)	.22 %
	Copper (Cu)	.18 %
	Nickel (Ni)	.063 %
	Chromium (Cr)	.088 %
	Molybdenum (Mo)	.020 %
	Vanadium (V)	.037 %
	Tin (Sn)	.007 %
	Columbium (Cb)	0.0000 %
	Columbium/Niobium (Nb)	.008 %
	Aluminum (Al)	.004 %
	Titanium (Ti)	.007 %
	Reduction Ratio	25.57:1

This document certifies that the foregoing data is a true copy of the data furnished by the producing mill and test lab.

Plex Online 9/23/11 4:53 PM vulc.jonw Page 1

SOLD TO:
NAMASCO CORP
500 COLONIAL CENTER PKWY
STE 500
ROSWELL, GA 30076-

SHIP TO:
NAMASCO
SOUTH LOOP 4
BUDA, TX 78610-

NUCOR

BAR MILL GROUP
JEWETT DIVISION

CERTIFIED MILL TEST REPORT

Page: 1

Ship from:
Nucor Steel - Texas
8812 Hwy 79 W
JEWETT, TX 75846
800-527-6445

Date: 2-Nov-2009
B.L. Number: 527300
Load Number: 144986

Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative.

NBMG-08 March 24 2009

HEAT NUM. *	DESCRIPTION	PHYSICAL TESTS					CHEMICAL TESTS						
		YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	6231588												
JW0910367602	Nucor Steel - Texas	45,800	65,700	22.0%			.11	.69	.017	.040	.22	.31	.31
	1/2x4" FL 20'	316MPa	453MPa				.20	.21	.048	.002	.001		
	A36	45,200	65,600	22.0%									
	ASTM A36/A36M-08, A709/A709M-07	312MPa	452MPa										
	GR36, ASME SA36-07												
	ASME SA36-2007 EDITION												
PO# =>	6230835												
JW0910481001	Nucor Steel - Texas	48,700	70,400	24.0%			.16	.71	.016	.010	.23	.32	.37
	1/2x8" FL 20'	336MPa	485MPa				.23	.22	.061	.002	.001		
	A36	45,400	68,900	24.0%									
	ASTM A36/A36M-08, A709/A709M-07	313MPa	475MPa										
	GR36, ASME SA36-07												
	ASME SA36-2007 EDITION												
PO# =>	6231588												
JW0910481201	Nucor Steel - Texas	44,100	64,000	25.0%			.10	.76	.010	.020	.19	.30	.30
	3/8x8" FL 20'	304MPa	441MPa				.14	.17	.045	.003	.001		
	A36	44,000	62,500	24.0%									
	ASTM A36/A36M-08, A709/A709M-07	303MPa	431MPa										
	GR36, ASME SA36-07												
	ASTM A709/A709M-08 GR 36 [250]												
	ASME SA36 2007 EDITION												
PO# =>	6230835												
JW0910550901	Nucor Steel - Texas	47,000	65,300	27.0%			.09	.66	.008	.030	.17	.31	.27
	1/4x5" FL 20'	324MPa	450MPa				.16	.13	.039	.002	.001		
	A36	48,200	65,200	27.0%									
	ASTM A36/A36M-08, A709/A709M-07	332MPa	450MPa										
	GR36, ASME SA36-07												
	ASME SA36-2007 EDITION												

I HEREBY CERTIFY THAT THE ABOVE FIGURES ARE CORRECT AS CONTAINED IN THE RECORDS OF THE CORPORATION

ALL MANUFACTURING PROCESSES OF THE STEEL MATERIALS IN THIS PRODUCT, INCLUDING MELTING, HAVE OCCURRED WITHIN THE UNITED STATES. ALL PRODUCTS PRODUCED ARE WELD FREE. MERCURY, IN ANY FORM, HAS NOT BEEN USED IN THE PRODUCTION OR TESTING OF THIS MATERIAL.

QUALITY ASSURANCE: Ben Cave

Ben R Cave

APPENDIX C. CRASH TEST NO. 405160-25-1

C1. VEHICLE PROPERTIES AND INFORMATION

Table C1. Vehicle properties for test 405160-25-1.

Date: 2011-11-18 Test No.: 405160-25-1 VIN No.: 1D7HA18N95J593340

Year: 2005 Make: Dodge Model: Ram 1500

Tire Size: 245/75R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 196773

Note any damage to the vehicle prior to test: ______

● Denotes accelerometer location.

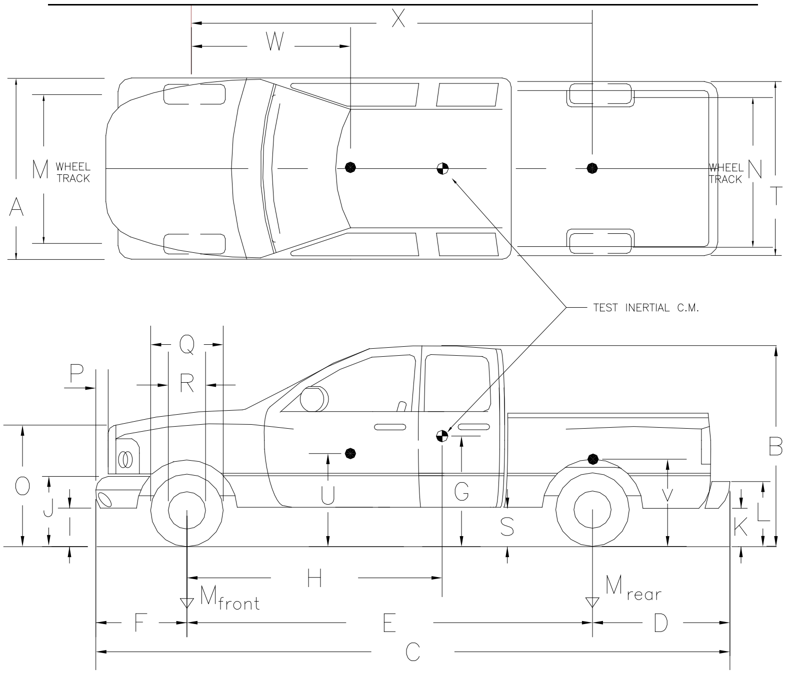
NOTES: ______

Engine Type: ______
Engine CID: ______

Transmission Type:
x Auto or ____ Manual
____ FWD x RWD ____ 4WD

Optional Equipment: ______

Dummy Data:
Type: No dummy
Mass: ______
Seat Position: ______



Geometry: inches

A	77.00	F	39.00	K	220.30	P	3.00	U	27.50
B	73.25	G	29.50	L	28.75	Q	29.50	V	30.00
C	227.00	H	63.94	M	68.25	R	18.50	W	63.00
D	47.50	I	13.50	N	67.25	S	14.25	X	99.00
E	140.50	J	26.00	O	44.75	T	75.50		

Wheel Center Height Front	14.125	Wheel Well Clearance (Front)	6.125	Bottom Frame Height - Front	16.625
Wheel Center Height Rear	14.25	Wheel Well Clearance (Rear)	11.25	Bottom Frame Height - Rear	24.25

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front		M_{front}	2848	2755	
Back		M_{rear}	1986	2301	
Total		M_{Total}	4843	5056	

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

Mass Distribution:
lb LF: 1381 RF: 1374 LR: 1133 RR: 1168

Table C2. Measurements of vehicle vertical CG for test 405160-25-1.

Date: 2011-11-18 Test No.: 405160-25-1 VIN: 1D7HA18N95J593340

Year: 2005 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 196773

Engine: 4.7 liter Transmission: Automatic

Fuel Level: Empty Ballast: 240 + 100 in front of bed (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 245/75R17

Measured Vehicle Weights: (lb)

LF: 1389	RF: 1414	Front Axle: 2803
LR: 1133	RR: 1147	Rear Axle: 2280
Left: 2522	Right: 2561	Total: 5083 5000 ±110 lb allowed

Wheel Base: 140.5 inches Track: F: 68.25 inches R: 67.25 inches

148 ±12 inches allowed Track = (F+R)/2 = 67 ±1.5 inches allowed

Center of Gravity, SAE J874 Suspension Method

X: 63.02 in Rear of Front Axle (63 ±4 inches allowed)

Y: 0.26 in Left - Right + of Vehicle Centerline

Z: 29.5 in Above Ground (minumum 28.0 inches allowed)

Hood Height: 44.75 inches Front Bumper Height: 26.00 inches

43 ±4 inches allowed

Front Overhang: 39.00 inches Rear Bumper Height: 28.75 inches

39 ±3 inches allowed

Overall Length: 227.00 inches

237 ±13 inches allowed

Table C3. Exterior crush measurements for test 405160-25-1.

Date: 2011-11-18 Test No.: 405160-25-1 VIN No.: 1D7HA18N95J593340

Year: 2005 Make: Dodge Model: Ram 1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	17	11	24	11	10	5	3.5	1.5	1	-18
2	Side plane at bumper ht	17	18	54	1.5	2.5	---	---	16	18	+73
	Measurements recorded										
	in inches										

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

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

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

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

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

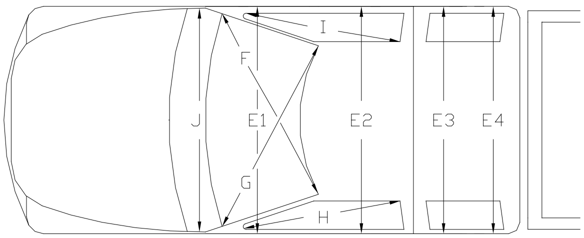
Note: Use as many lines/columns as necessary to describe each damage profile.

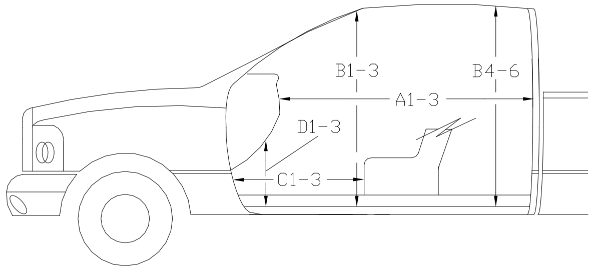
Table C4. Occupant compartment measurements for test 405160-25-1.

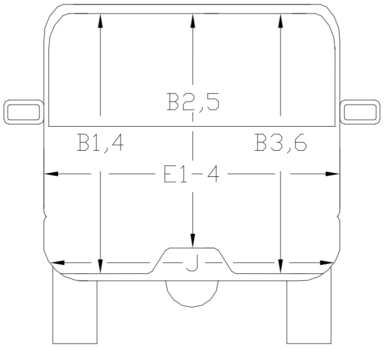
Date: 2011-11-18 Test No.: 405160-25-1 VIN No.: 1D7HA18N95J593340

Year: 2005 Make: Dodge Model: Ram 1500

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT



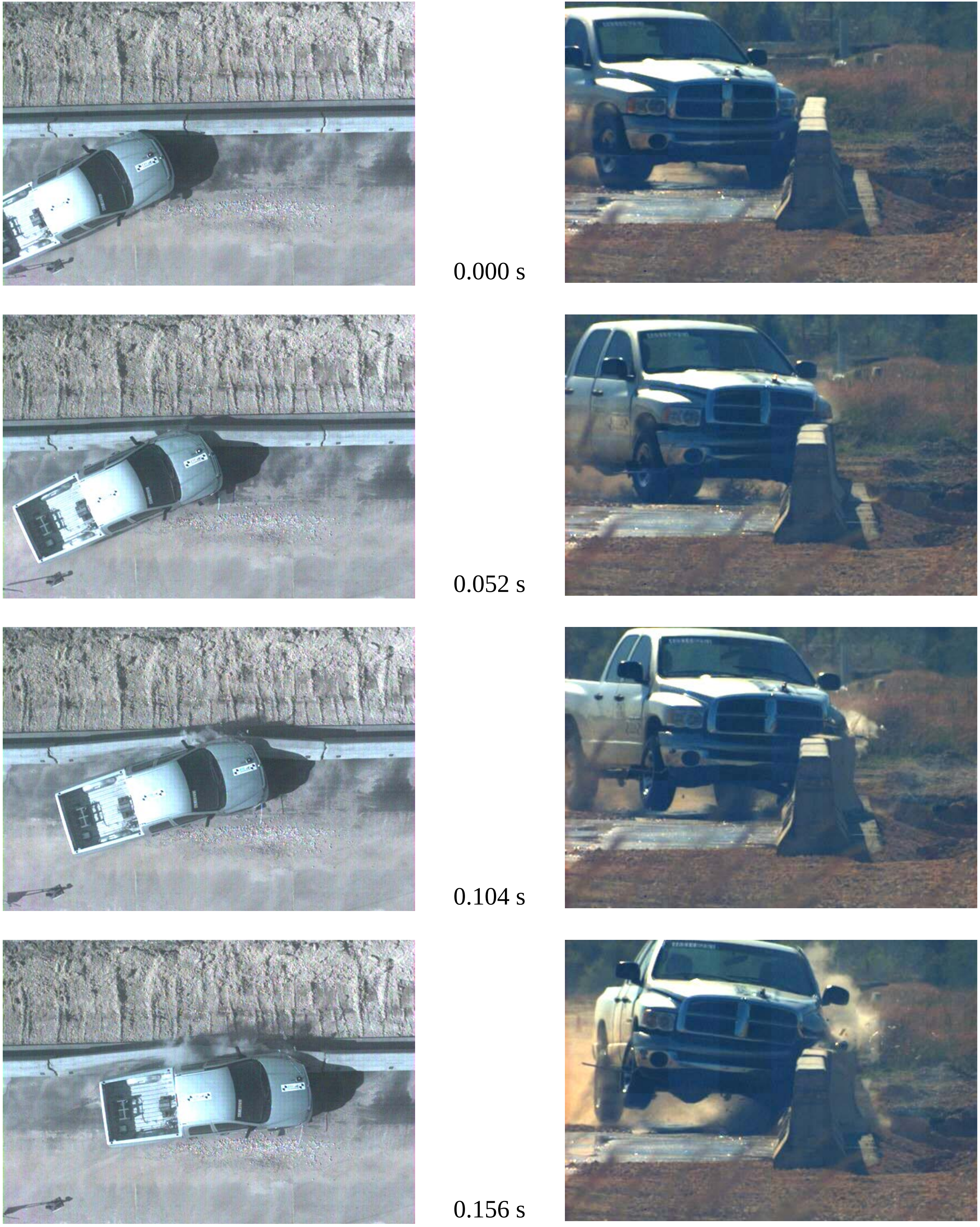




	Before (inches)	**After** (inches)
A1	64.50	64.50
A2	64.75	64.75
A3	65.50	65.50
B1	45.50	45.50
B2	39.25	39.25
B3	45.50	45.50
B4	42.25	42.25
B5	42.50	42.50
B6	42.25	42.25
C1	29.25	29.25
C2	---	---
C3	27.25	27.25
D1	13.12	13.12
D2	10.25	10.25
D3	11.50	11.50
E1	62.50	62.00
E2	64.50	63.75
E3	64.00	63.50
E4	64.00	64.00
F	60.00	60.00
G	60.00	60.00
H	39.50	39.50
I	39.50	39.50
J*	62.25	62.12

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

C2. SEQUENTIAL PHOTOGRAPHS



0.000 s

0.052 s

0.104 s

0.156 s

Figure C1. Sequential photographs for test 405160-25-1
(overhead and frontal views).

0.208 s

0.260 s

0.400 s

Out of view

0.600 s

Figure C1. Sequential photographs for test 405160-25-1
(overhead and frontal views) (continued).

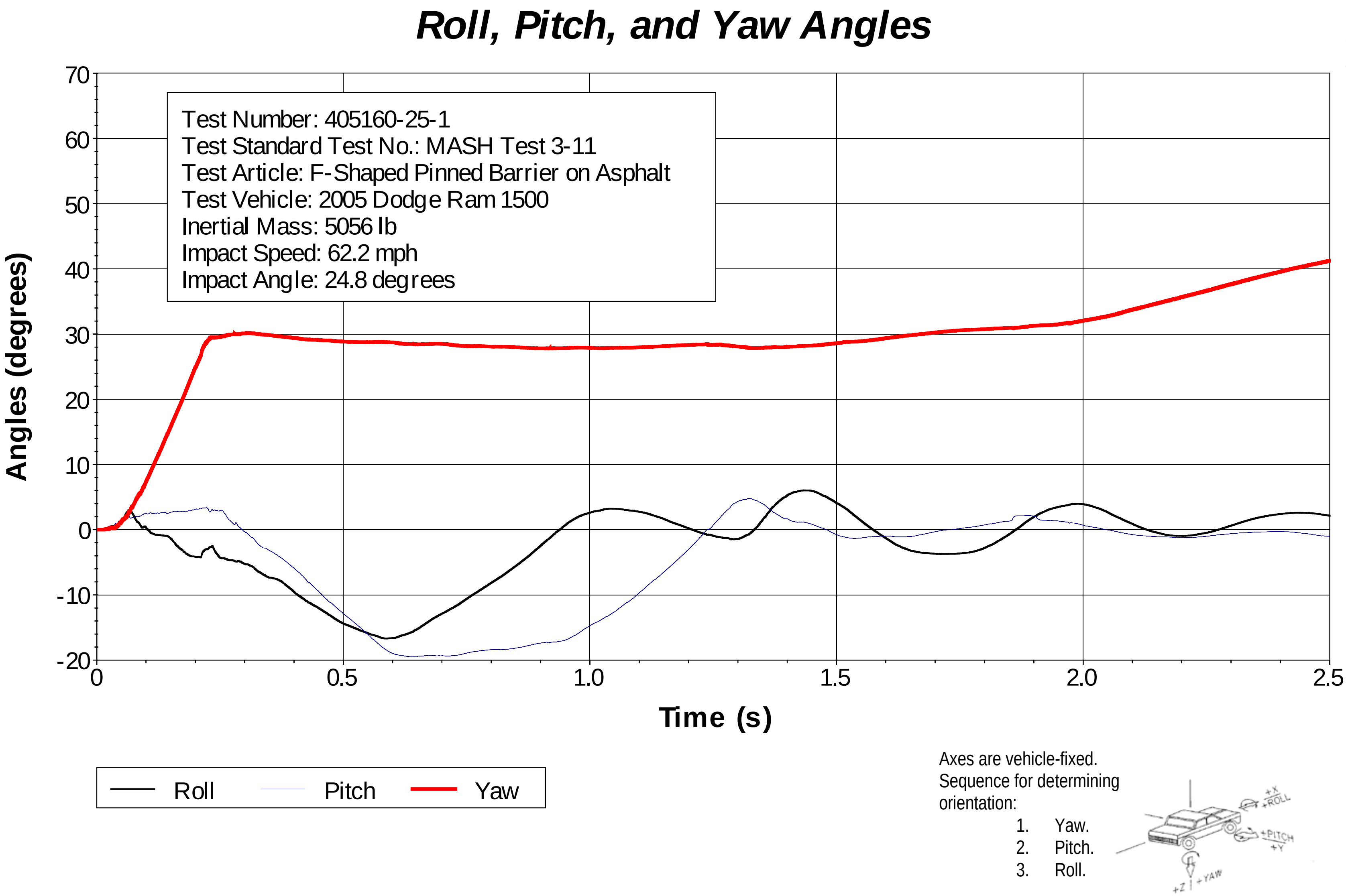


Figure C2. Vehicle angular displacements for test 405160-25-1.

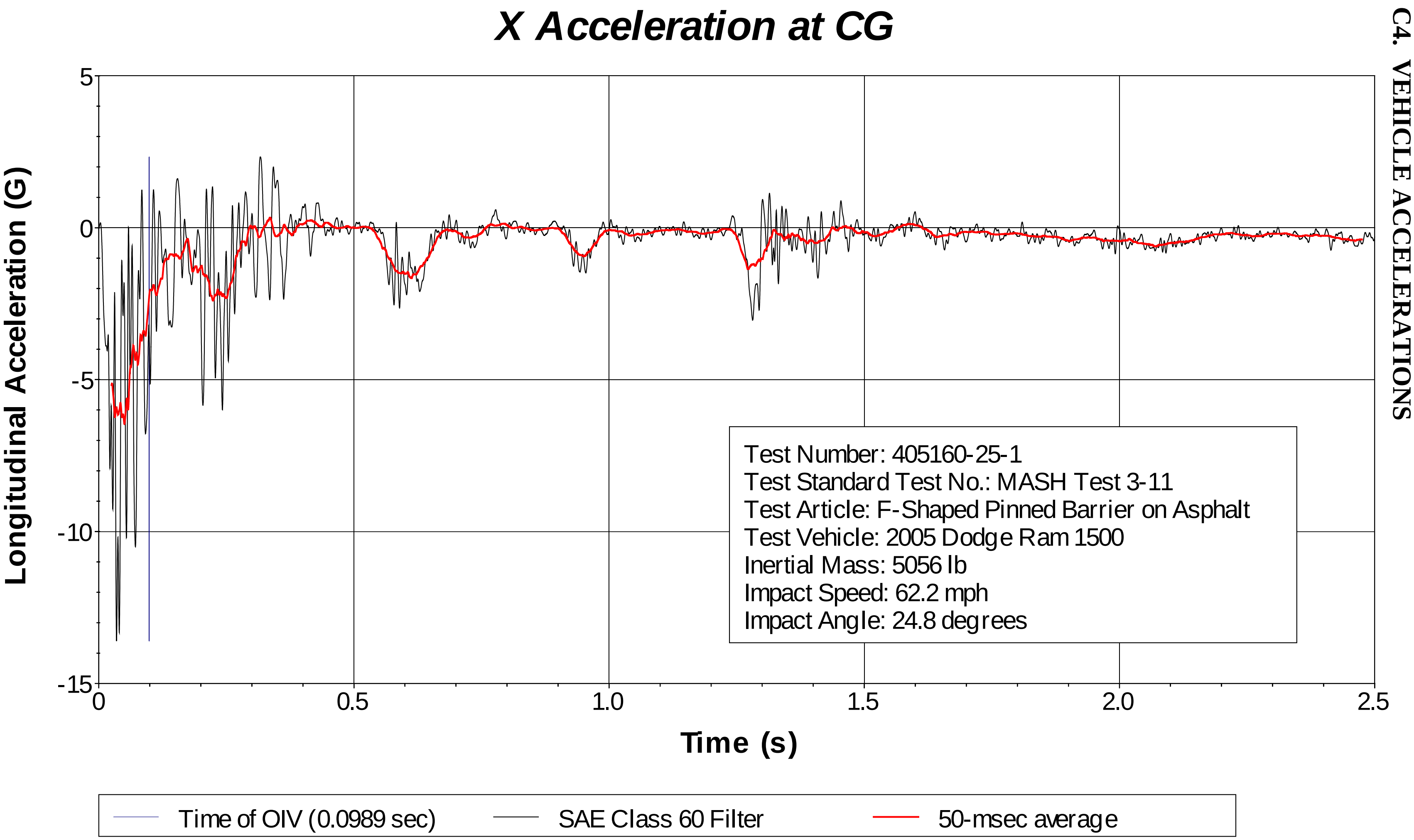


Figure C3. Vehicle longitudinal accelerometer trace for test 405160-25-1
(accelerometer located at center of gravity).

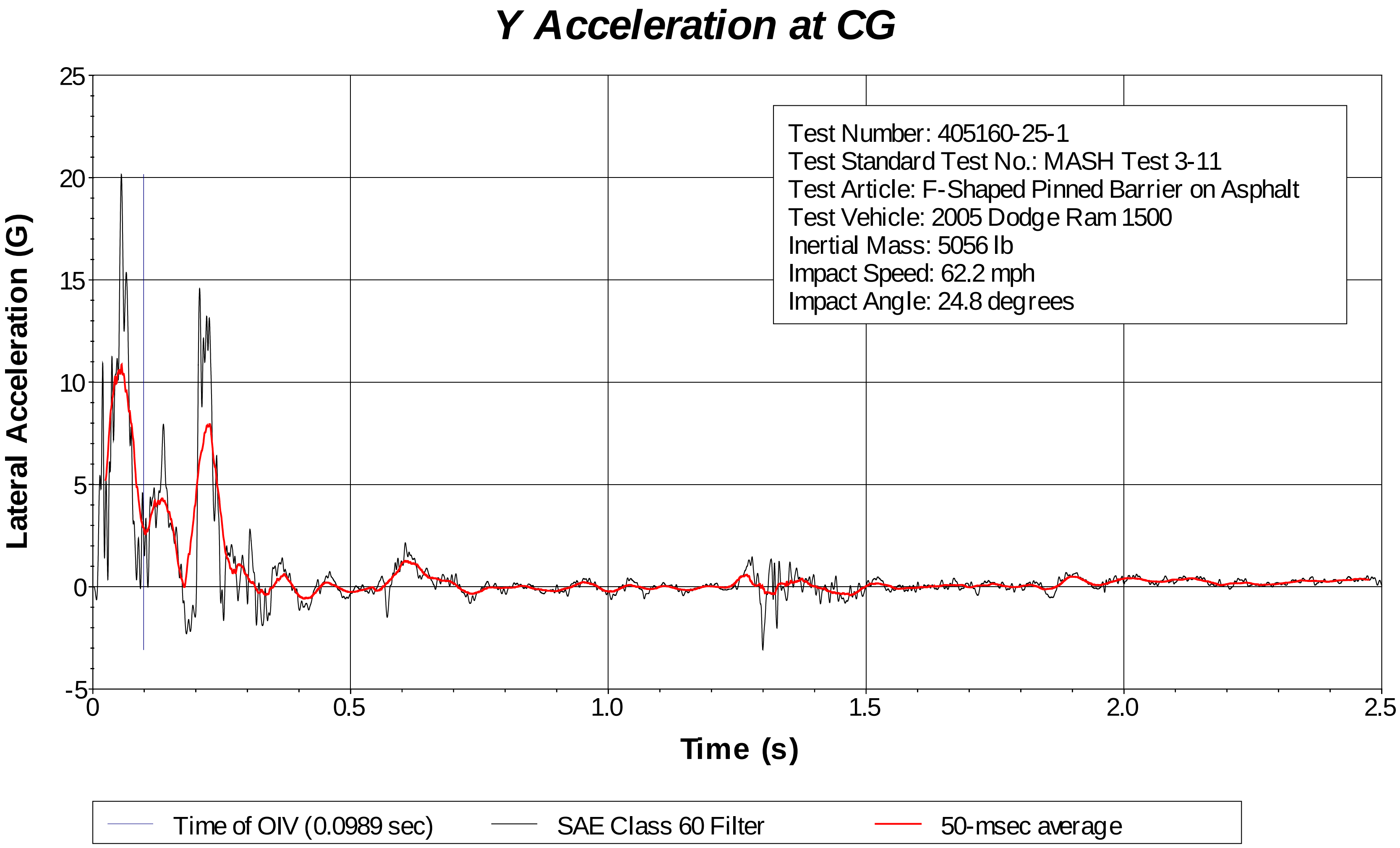


Figure C4. Vehicle lateral accelerometer trace for test 405160-25-1
(accelerometer located at center of gravity).

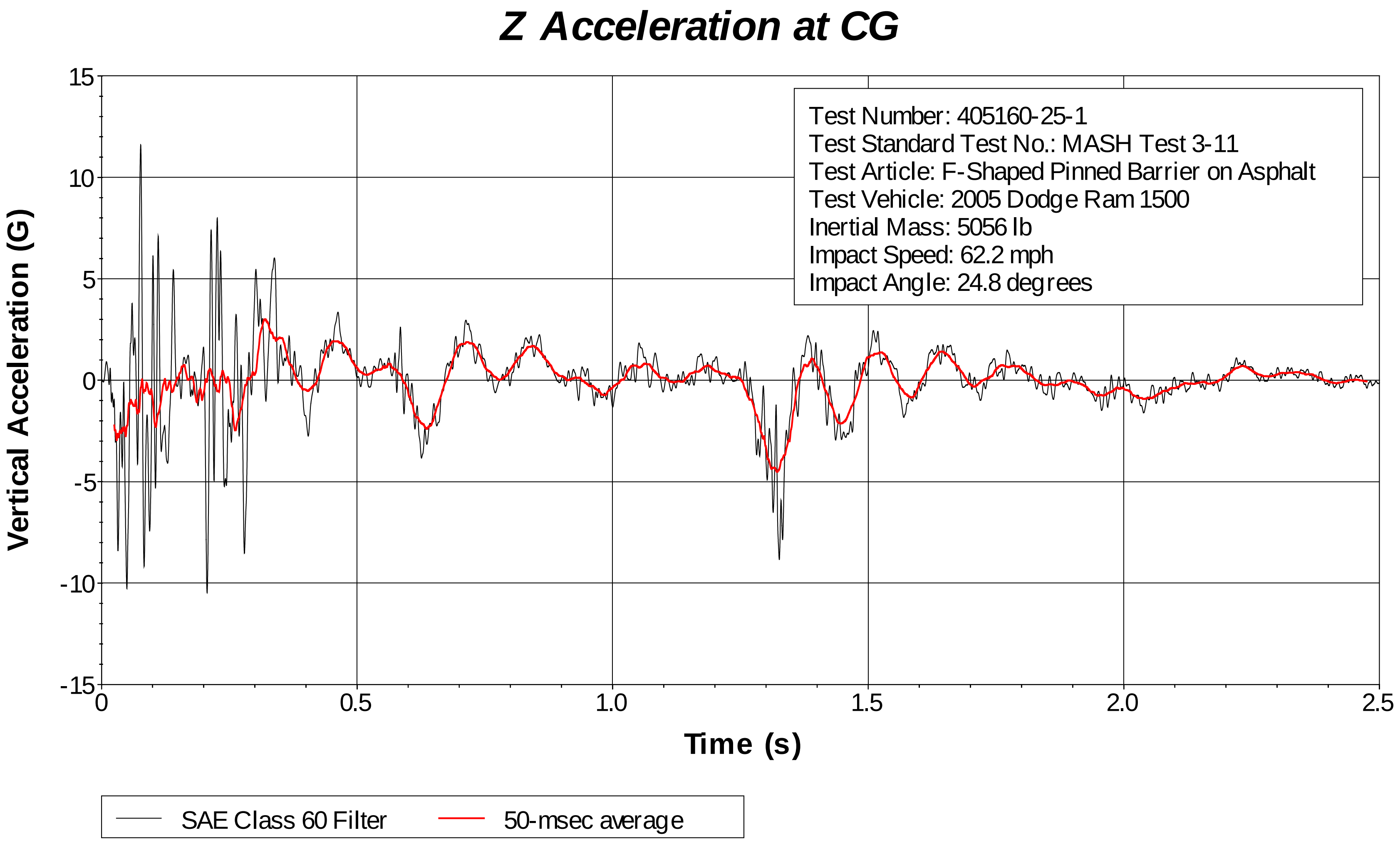


Figure C5. Vehicle vertical accelerometer trace for test 405160-25-1 (accelerometer located at center of gravity).

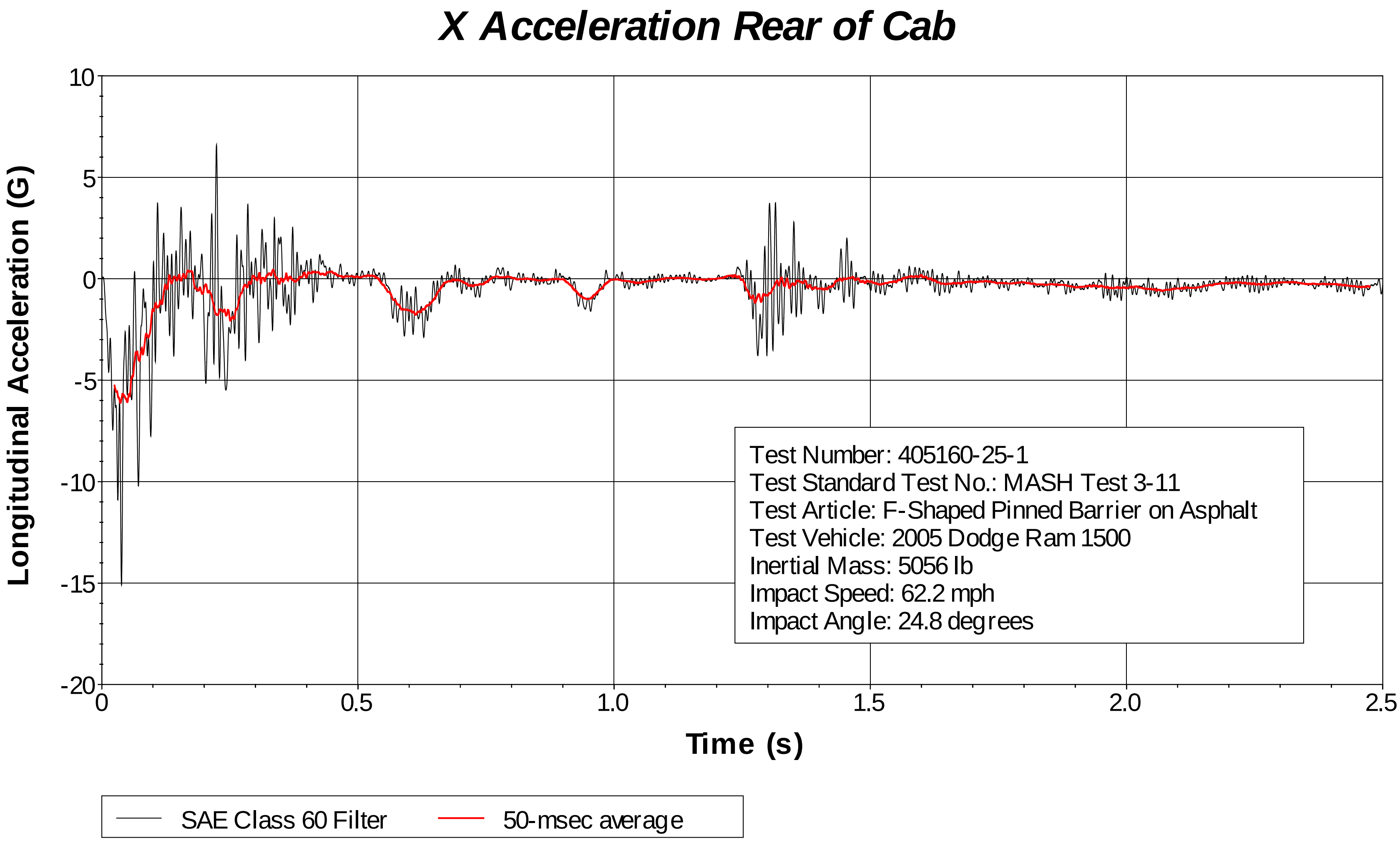


Figure C6. Vehicle longitudinal accelerometer trace for test 405160-25-1
(accelerometer located rear of cab).

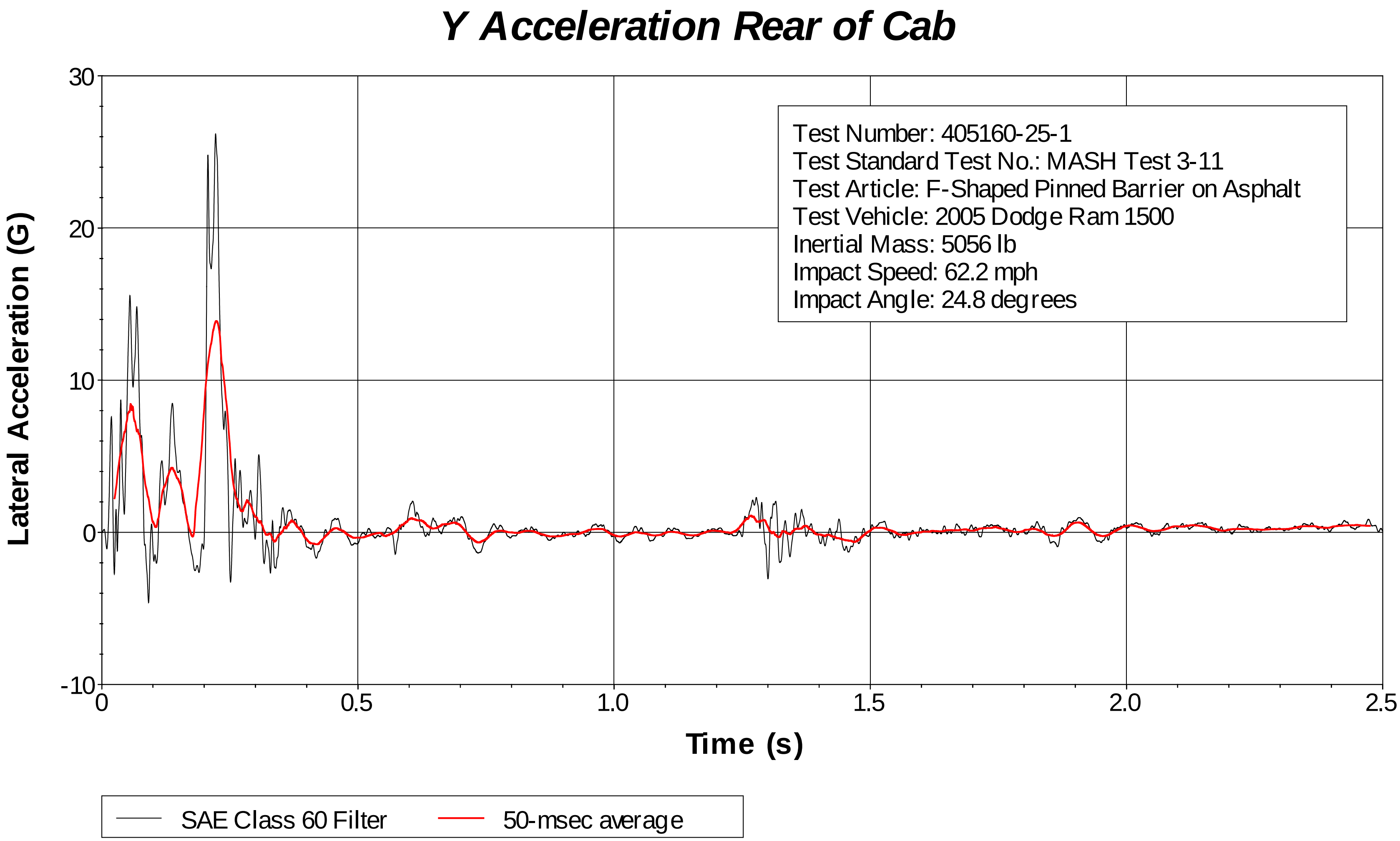


Figure C7. Vehicle lateral accelerometer trace for test 405160-25-1
(accelerometer located rear of cab).

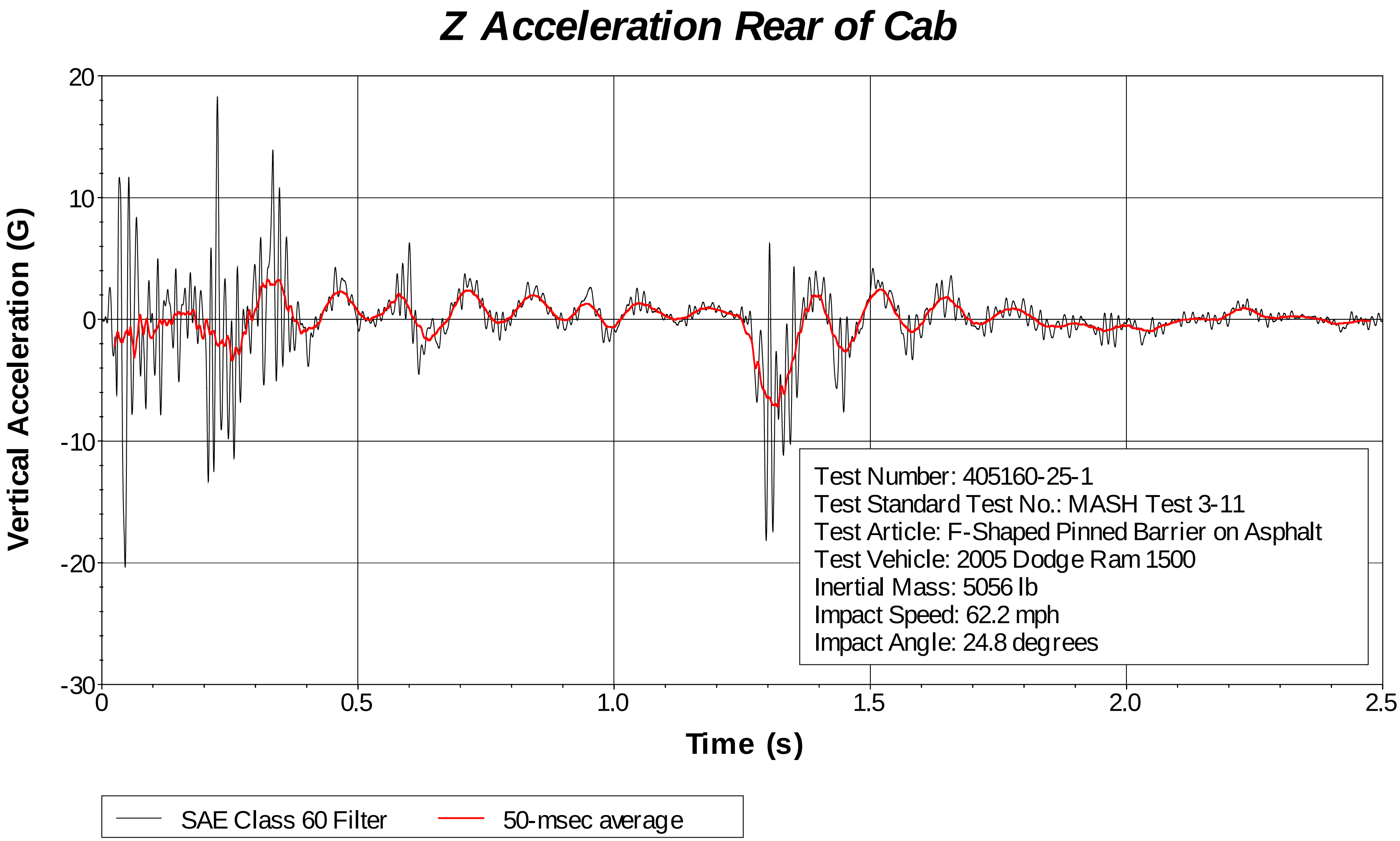


Figure C8. Vehicle vertical accelerometer trace for test 405160-25-1
(accelerometer located rear of cab).