Roadside Safety Pooled Fund

Texas A&M Transportation Institute

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Test Report Date: November 2012

TRANSITION DESIGN FOR PINNED-DOWN ANCHORED TEMPORARY BARRIER TO RIGID CONCRETE BARRIER

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16. Abstract

The objective of this research was to develop and crash test a transition barrier design that can be used to transition from the pinned-down F-shape temporary concrete barrier placed on concrete to a permanent concrete barrier. The transition was developed to meet American Association of State Highway and Transportation Officials *Manual for Assessment of Safety Hardware* (*MASH*) test level 3 criteria, using an existing 32-inch tall pinned-down anchored F-shape temporary concrete barrier design connected to a 42-inch tall single slope rigid concrete barrier.

In the *MASH* test level 3 crash test, the transition for the anchored temporary concrete barrier placed on concrete, to the rigid single slope concrete barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic and static deflections of the transition were 5.7 inches and 2.5 inches, respectively. No detached elements, fragments, or other debris from the test article were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 3.625 inches in the floorpan on the driver's side. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 13 degrees and 8 degrees, respectively. Occupant risk factors were within the limits specified in *MASH*. The 2270P vehicle exited the barrier within the exit box. The transition for anchored temporary barrier to rigid concrete barrier performed acceptably according to the *MASH* criteria required for test 3-21 for transitions.

17. Key Words	18. Distribution Statement
Anchored barrier, anchored to free-standing, bridge deck, F-Shape, FEA, finite element analysis, limited deflection, LS-DYNA, MASH, pin and loop connection, portable concrete barrier, temporary barrier, temporary concrete barrier, Test Level 3, transition barrier, work zone barrier, pinned down	Copyrighted. Not to be copied or reprinted without consent from the Roadside Safety Research Program Pooled Fund Study.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square 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)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		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)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		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.
(Revised March 2003)

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TABLE OF CONTENTS

Section | Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

1. INTRODUCTION

1.1 PROBLEM

In 2008, Texas A&M Transportation Institute (TTI) 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. The design was developed for use on concrete pavements or bridge decks as thin as seven inches. When this pinned-down barrier is used on a road or bridge project, it is sometimes desired to install it adjacent to a permanent concrete barrier. A transition design from the pinned-down anchored precast concrete barrier to a permanent concrete barrier is needed to allow smooth redirection of impacting vehicle in this region.

1.2 BACKGROUND

In 2008, TTI developed a restrained F-shape temporary concrete barrier design that was easy to install and minimized damage to bridge decks or concrete pavements (*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 Highway 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. The design has now been adopted by some of the participating pooled-fund states and there is a desire to develop a transition for using the pinned-down barrier with a rigid concrete barrier.

Among other anchored concrete barrier designs, Midwest Roadside Safety Facility (MwRSF) has developed a design for the F-shape temporary concrete barrier along with various transition details. In 2003, MwRSF developed a concrete bridge deck tie-down system for 12.5 ft long, F-shape Kansas temporary barriers (*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. Later on 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 steel pins that were driven down vertically through holes cast in each barrier segment. The pins were 3-ft long and pinned the barrier to the underlying asphalt ground. The maximum static and dynamic deflections in the test were 11.1 inches and 21.8 inches, respectively.

In the same study, MwRSF 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 comprised of four 12.5-ft long barrier segments in which steel pins were driven in 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 this 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.

And more recently in 2009, MwRSF developed a transition design for attaching free-standing F-shape barrier to the rigid concrete barrier (*5*). This design employs the anchored barrier section developed by MwRSF earlier in 2005 and an intermediate section to transition from the free-standing to the rigid barriers. At one end the anchored barrier segments connect to the free-standing barrier, and at other end they connect to a rigid concrete barrier. A 42-inch tall single slope barrier was used as the rigid barrier system. The number of pins in the anchored barrier segments was varied to gradually increase the lateral restraint of the barrier over four 12.5-ft long segments. The anchored barrier segments were placed on a 3-inch thick asphalt pad. To reduce snagging of the vehicle while transitioning from the anchored barrier to the rigid barrier, a nested 12-guage thrie beam section was used. The rail segment was attached to the traffic and field side faces of the rigid and anchored barrier segments.

In 1999, California Department of Transportation (Caltrans) developed a pinning/staking configuration for its 20-ft long, NJ profile concrete barriers connected with a pin-and-loop type connection (*6*). The configuration met *NCHRP Report 350* 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/SCOPE OF RESEARCH

The objective of this research was to develop and crash test a transition barrier design that can be used to transition from the pinned-down F-shape temporary concrete barrier placed on concrete to a permanent concrete barrier. The transition was to be developed for American Association of State Highway and Transportation Officials *Manual for Assessment of Safety Hardware* (*MASH*) test level 3 criteria, using the existing pinned-down F-shape temporary concrete barrier design to the extent possible (*7*).

At the start of this research, the researchers evaluated rigid concrete barrier systems used by the participating pooled-fund states to select a rigid barrier design that is most critical with respect to the potential for vehicle snagging and instability during redirection in the transition region. The researchers then developed a conceptual design of the transition from the pinned-down F-shape concrete barrier to the selected rigid concrete barrier. The researchers then developed a full-scale finite element model of the transition concept and performed vehicle impact simulations according to *MASH* test level 3 impact conditions. The results of the simulation analysis were used to make necessary changes to the transition design and arrive at the final design. The researchers then built a prototype of the transition system and performed a full-scale crash test to demonstrate the acceptable performance of the transition design under *MASH* test level 3 conditions.

Details of the conceptual design and finite element analysis are presented in chapter 2. Relevant crash testing criteria, details of the test installation, details of crash test performed, and crash test results and evaluation using *MASH* test level 3 criteria are presented in chapter 3 and onwards.

2. DESIGN AND ANALYSIS[1]

2.1 RIGID BARRIER SELECTION

With many states participating in this pooled fund-project, and each state having various rigid concrete barrier designs, the researchers started the project by evaluating rigid barrier designs of all participating states. The evaluation was conducted to select a rigid barrier design that was deemed most critical with respect to the potential for vehicle snagging and instability during redirection in the transition region. The transition design was to be developed for the selected worse case rigid barrier system. A transition design that performs successfully with the selected rigid barrier can then be used for other rigid barrier designs with minor modifications in most cases.

In reviewing the existing rigid barrier designs of the participating states, the researchers compared the profiles of the rigid barriers with the F-shape pinned-down temporary concrete barrier. Each barrier profile was aligned with the F-shape profile in a way that minimized the snagging potential between the two profiles (i.e. the barriers were aligned as they would be placed in the field). Once aligned, the researchers calculated and compared the points of maximum discrepancies in the barrier profiles, which have the potential to cause vehicle snagging during redirection after vehicle impact. The researchers determined that the 42-inch tall single slope concrete barrier presents the greatest potential for snagging if used in the transition design (see figure 2.1). The use of the 42-inch single slope rigid concrete barrier was approved in the annual meeting of the pool fund states. The complete list of profiles considered in the evaluation and their comparisons with the F-shape profile are presented in appendix A.

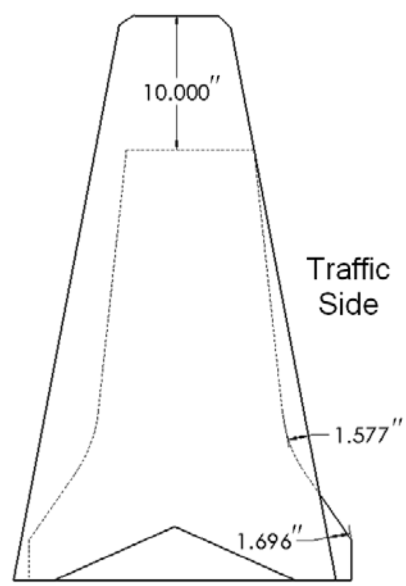


Figure 2.1. Comparison of the 42-inch tall single slope barrier profile with the 32-inch tall F-shape profile.

[1] TTI Proving Ground's A2LA scope of accreditation does not include permanent barrier selection and transition design using simulation analysis.

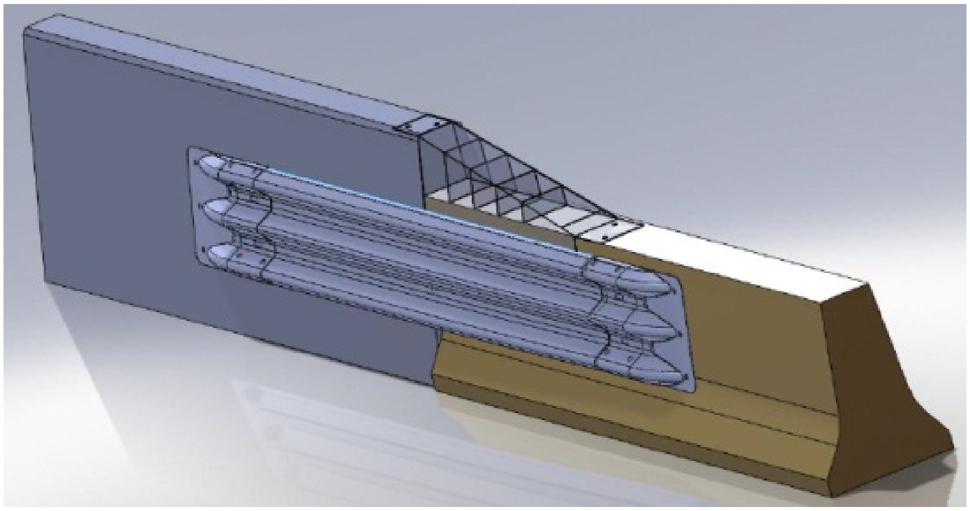
Having selected the rigid barrier system, the researchers developed a transition concept for transitioning from the pinned-down F-shape temporary concrete barrier placed on concrete to the 42-inch tall rigid single slope barrier. Two variations of the transition concept are shown in figure 2.1. In both variations, the F-shape temporary concrete barrier was to be anchored to concrete using steel pins dropped into inclined holes in the toe of the barrier. These pins continue a short distance into the underlying concrete pavement, and thus lock the barrier in place. The transition section was comprised of the same 12.5-ft long F-shape barrier segment with two 1-1/2-inch diameter steel pins as the existing pinned-down barrier system. To accommodate the 10-inch difference in barrier height while transitioning from the 32-inch tall F-shape barrier to the 42-inch tall single slope barrier, a cap with a tapered profile was bolted to the top of the F-shape and the single slope barriers, as shown in figure 2.

In the first variation of the concept, a nested thrie beam cover was bolted to the F-shape concrete barrier segment and the rigid single slope barrier using the standard thrie beam end shoes. This cover was intended to provide a smoother transitioning surface during the change in the barrier profiles from F-shape to single slope. It was also used to establish a connection between the rigid and the pinned-down barriers.

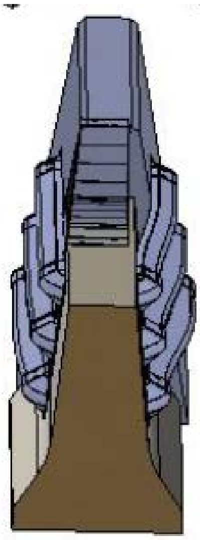
The researchers were to perform full scale vehicle impact simulation with this first variation of the transition concept. If the results of the simulation analysis showed that the nested thrie beam cover on the traffic side is not enough to provide a smooth lateral stiffness variation over the length of the transition, an additional thrie beam cover was to be added to the field side of the barriers, as shown in the second variation of the transition concepts (see figure 2.2b).

The transition concept developed is very similar to the design previously developed and crash tested by Midwest Roadside Safety Facility (MwRSF) *(4)*. The MwRSF's transition was developed to transition from free standing F-shape barrier to a 42-inch tall rigid single slope barrier. The transition barrier segments in this design were pinned over asphalt, which makes the design problem very similar to this research problem. However, the MwRSF design was developed for a median application, whereas in this project, the transition is being developed for use in roadside or bridge rail applications. Furthermore, the temporary barrier in MwRSF's case was placed on asphalt whereas it is placed on concrete in this project.

Having developed the transition concepts, the researchers developed a detailed finite element model of the first transition concept. The model was developed with the nested thrie beam cover on the traffic side only. The researchers performed *MASH* test level 3 impact simulation using a 2270P pickup truck vehicle model. The simulation evaluated impact conditions of test 3-21 of *MASH*, which is an impact of a 5000-lb pickup truck at a speed of 62.2 mi/h and an angle of 25 degrees. The impact point in the simulation was 4.3 ft upstream of the joint between the anchored and the rigid barrier systems. This impact point was selected based on guidance provided in Table 2.6 of *MASH*. This is the recommended distance for testing upstream of the joint in a rigid barrier system that has the highest potential for vehicle snagging. Since the greatest variation in the stiffness of the barrier exists at the joint between the anchored and the rigid barrier, along with the change in barrier profiles, it is believed that the recommended 4.3 ft upstream of this joint is the appropriate critical impact point (CIP) for this design. The finite element model and the results of the impact simulation are shown in figure 2.3.



(a) First variation (thrie beam on traffic face only).



(b) Second variation (thrie beam on traffic and field sides)

Figure 2.2. Transition design concepts.

Simulation results indicated that the vehicle is successfully contained and redirected after the impact. Based on the results of the simulation, it was anticipated that the transition concept with nested thrie beams attached only to the traffic side of the barrier is sufficient for redirecting the vehicle. Also based on the simulation results, the researchers added a steel strap on the field side of the barrier to provide additional resistance to lateral roll and sliding of the pinned F-shape barrier segment adjacent to the rigid single slope barrier. This strap is expected to provide a smoother transition to the impacting vehicle and the design details are presented in the next chapter under Test Article Design and Construction.

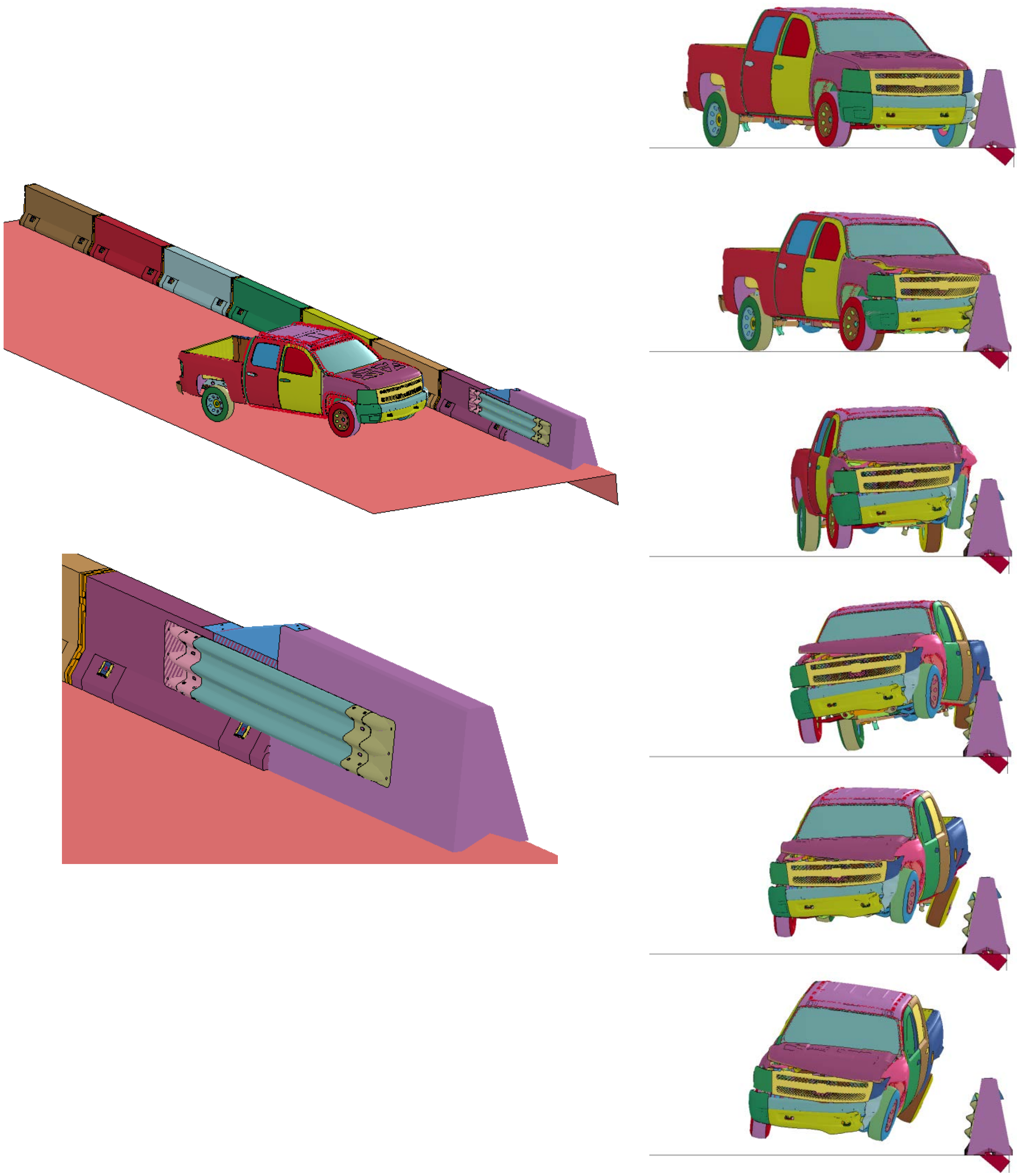


Figure 2.3. Finite element model and results of the *MASH* test 3-21 impact simulation.

3. SYSTEM DETAILS

3.1 TEST ARTICLE DESIGN AND CONSTRUCTION

The overall length of the test installation was 104 ft-6 inches. The installation was comprised of seven 12 ft-6 inch long precast concrete barrier segments that were 32 inches tall and had the standard "F" profile. The precast segments were anchored to the underlying concrete pavement using two 1-1/2-inch diameter steel pins per barrier segment. The downstream end of the precast concrete barrier installation was connected to a 16 ft long and 42 inches tall permanent single slope concrete barrier with an 11-degree slope of the barrier's traffic-side face.

The precast concrete barrier segments were 32 inches tall, 24 inches wide at the base, and 9-1/2 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 17-7/8 inches and 7-7/8 inches, respectively.

Adjacent precast barrier segments were connected using a pin-and-loop type connection. The loops were made of 0.75-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 1/4 inch. 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 1-7/8-inch wide and 4-inch long slotted holes, inclined 40 degrees from the ground, were cast into the toe of each precast 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 end of the barrier segment and were used for anchoring the barrier to the underlying concrete pavement. The third slotted hole was positioned in the middle of the barrier segment, but was not used for anchoring.

Once the precast barrier segments were positioned in place, the slotted holes near each end of the portable concrete barrier segment were used as a guide to drill a hole in the underlying concrete pavement. These holes were drilled using a 1-3/4-inch diameter drill bit. After the holes were drilled, a 1-1/2-inch diameter, 21-3/8-inch long anchoring pin was passed through each of the slotted holes in the barrier (except the middle slots) and into the concrete pavement. Thus, each barrier segment was anchored to the ground with two pins. The top of each anchoring pin had a ½-inch thick, 4-inch × 4-inch ASTM A36 steel 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. The concrete pavement underneath the pavement was unreinforced and was nominally eight inches thick.

Inside the F-shape 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 connection loops on the downstream end of the F-shape barrier segment placed adjacent to the permanent single slope barrier were cut off. This allowed placing the pinned-down F-shape barrier segment flush to the rigid single slope barrier. The connection between the F-shape barrier and the single slope barrier was established using nested 12-gauge thrie beam guardrails. At one end, the nested thrie beam guardrails were connected to the traffic-side face of the F-shape barrier segment, and at the other end, the guardrails were connected to the traffic-side face of the single slope barrier. The connection to the barrier was made using a 10 gauge thrie beam end-shoe and five 7/8-inch diameter, ASTM A325 bolts that passed through the cross-section of the barrier and were fastened using heavy hex nuts on the field side of the barriers. One of the through-bolts for the end-shoe attached to the single slope barrier could not be fastened with a nut in the test installation. Absence of this hex nut did not have any effect on the performance of the transition.

On the field side of the barriers, a 1/4-inch thick and 16.33 ft long ASTM A36 steel plate was fastened to barriers using the top two through-bolts used to connect the thrie beam end-shoes. An 8-inch × 8-inch × 2-1/2-inch wood block spacer was attached to the 1/4-inch steel plate near the end of the pinned-down F-shape segment placed adjacent to the single slope barrier. The wood block spacer was attached to the steel plate using a 5/8-inch diameter carriage bolt that was bolted with a hex nut on the field side of the steel plate. The 1/4-inch steel plate and the wood spacer were used to reduce slack near the top of the F-shape and the single slope barrier profiles, thus providing additional resistance to the lateral roll of the pinned-down F-shape barrier during vehicle redirection.

A transition cap made of 1/8 inch thick ASTM A36 steel was attached to the top of the F-shape and single slope barriers. The transition cap ramped 10 inches over a length of 48 inches to transition from the 32-inch tall F-shape barrier to the 42-inch tall single slope barrier. The transition cap was reinforced using five stiffener plates that were also 1/8 inch thick. At each end, the cap was bolted to the top of the F-shape and the single slope barriers using two 1/2-inch diameter Hilti HAS adhesive anchors. The adhesive anchors were installed using Hilti HIT500 epoxy and had a 4-1/2-inch embedment.

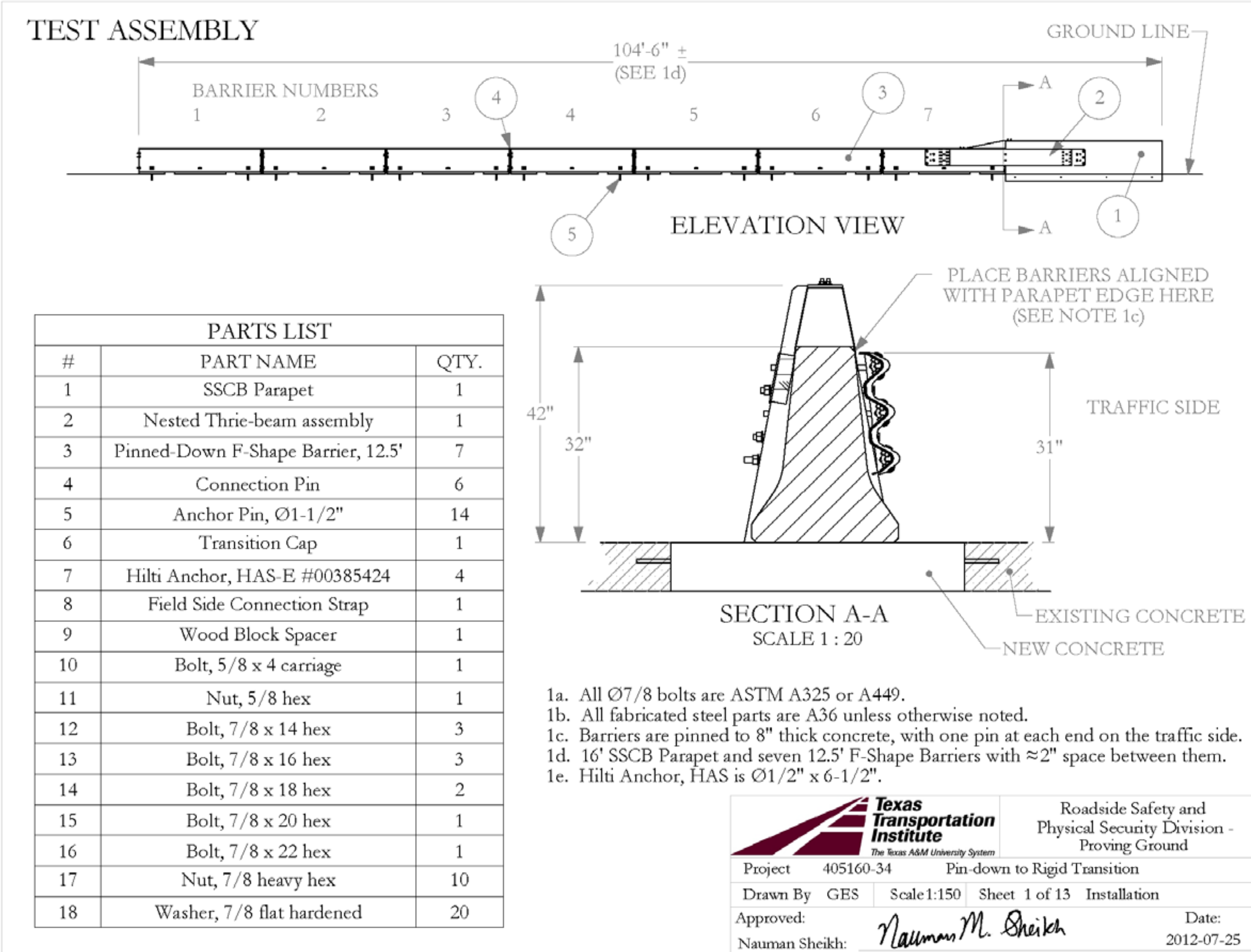
The 42-inch tall permanent single slope barrier was 16 ft long, 24 inches wide at the base, and 8 inches wide at the top. The barrier had an 11-degree slope of the traffic and field sides. The barrier was reinforced using 16 #4 lateral stirrup bars that were bent to conform to the profile of the barrier and provide a 2-inch concrete cover. The lateral stirrups were spaced 12 inches apart along the length of the single slope barrier. The longitudinal reinforcement of the single slope barrier was comprised of ten #5 bars that were placed inside the lateral stirrup and spaced vertically along the height of the barrier. The barrier was cast over a reinforced concrete foundation that was 48 inches wide and 8 inches deep. At the location of each lateral stirrup in the single slope barrier, an L-shaped #6 bar was placed inside the concrete foundation with the longer leg raised upwards into the single slope barrier. The shorter leg of L-shaped bar was placed 2 inches above the bottom of the concrete foundation. At the location of each L-shaped bar, a 44-inch long #4 bar was placed laterally. The 44-inch bars were placed 2 inches above the bottom of the concrete foundation. The longitudinal reinforcement of the concrete foundation was comprised of four #4 bars that were 15 ft-9 inches long and were spaced 12 inches apart. The concrete foundation was connected to the surrounding unreinforced concrete apron using eight #5 bars that were 12 inches long. The #5 bars were installed in the surrounding concrete with a minimum 5-5/8-inch embedment using Hilti HIT 150 epoxy. These bars were placed at a height of 5 inches from the bottom of the concrete foundation.

The F-shape temporary concrete barrier segments used in the test installation were donated by WASKEY. The drawing and photos of the test installation are shown in figures 3.1 and 3.2, respectively. Detailed drawings of the test installation are presented in appendix B.

3.2 MATERIAL SPECIFICATIONS

The specified compressive strength of the concrete for the single slope barrier and the concrete foundation was 3000 psi. The compressive strength on the day of testing was 3602 psi for the deck at 10 days of age and 4024 psi for the parapet at 8 days of age. Results of the tests performed to determine the compressive strength are shown in appendix C.

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. Certifications for different materials used are included in appendix D.



PARTS LIST

#	PART NAME	QTY.
1	SSCB Parapet	1
2	Nested Thrie-beam assembly	1
3	Pinned-Down F-Shape Barrier, 12.5'	7
4	Connection Pin	6
5	Anchor Pin, Ø1-1/2"	14
6	Transition Cap	1
7	Hilti Anchor, HAS-E #00385424	4
8	Field Side Connection Strap	1
9	Wood Block Spacer	1
10	Bolt, 5/8 x 4 carriage	1
11	Nut, 5/8 hex	1
12	Bolt, 7/8 x 14 hex	3
13	Bolt, 7/8 x 16 hex	3
14	Bolt, 7/8 x 18 hex	2
15	Bolt, 7/8 x 20 hex	1
16	Bolt, 7/8 x 22 hex	1
17	Nut, 7/8 heavy hex	10
18	Washer, 7/8 flat hardened	20

Figure 3.1. Layout of the transition design for anchored temporary barrier to rigid concrete barrier.

Figure 3.2. Transition design for anchored temporary barrier to rigid concrete barrier prior to testing.

4. TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1 CRASH TEST MATRIX

According to *MASH*, two tests are recommended to evaluate transitions to test level three (TL-3).

> ***MASH* Test Designation 3-20:** A 2425-lb vehicle impacting the critical impact point (CIP) of the transition 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 3-21:** A 5000-lb pickup truck impacting the CIP of the transition 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.

Test reported herein corresponds to *MASH* test 3-21. This test was deemed sufficient to evaluate the impact performance of the transition. It was argued that the test with the smaller 2425-lb was not needed. Due to higher impact energy and a higher vehicle CG, the test with the 5000-lb pickup truck will result in greater potential for snagging and vehicular instability. The transition design is not expected to cause any underside when impacted by the small passenger car. Similarly, the lighter passenger car is not expected to cause any significant movement of the pinned-down barriers that can increase the potential for vehicle snagging or pocketing. Thus, only test 3-21 was conducted.

The target CIP for test 3-21 was determined to be 51.6 inches upstream of the joint between the pinned-down F-shape barrier and the permanent single slope barrier. This impact point was selected based on guidance provided in Table 2.6 of *MASH*. This is the recommended distance for testing upstream of the joint in a rigid barrier system that has the highest potential for vehicle snagging. Since the greatest variation in the stiffness of the barrier exists at the joint between the pinned-down F-shape and the permanent single slope barrier, along with the change in barrier profiles and heights, it is believed that the recommended 51.6 in. upstream of this joint is the appropriate critical impact point (CIP) for this design.

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 transition design for anchored temporary barrier to rigid concrete barrier 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 transition design for anchored temporary barrier to rigid concrete 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 A&M 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 safety evaluation of roadside safety hardware. The site selected for the installation of the transition design for the pinned-down temporary barrier to the rigid concrete barrier is along the surface 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 inches deep. The apron is over 60 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, 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 produced 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 acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra small size, solid state units designs 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 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 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 are 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 factor 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 the tests with the 2270P vehicle.

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 405160-34-1 (*MASH* TEST NO. 3-21)

6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH test 3-21 involves a 2270P vehicle weighing 5000 lb ±110 lb and impacting the transition 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 51.6 inches upstream of the joint between the pinned-down F-shape barrier and the permanent single slope barrier. The 2007 Dodge Ram 1500 pickup used in the test weighed 5026 lb and the actual impact speed and angle were 62.8 mi/h and 25.7 degrees, respectively. The actual impact point was 50.7 inches upstream of the joint. Target impact severity (IS) was calculated to be 115.1 kips, and the actual IS was calculated at 124.6 kips.

6.2 TEST VEHICLE

The 2007 Dodge Ram 1500, shown in figures 6.1 and 6.2, was used for the crash test. Test inertia weight of the vehicle was 5026 lb, and its gross static weight was 5026 lb. The height to the lower edge of the vehicle front bumper was 13.75 inches, and the height to the upper edge of the front bumper was 25.38 inches. The height to the center of gravity was 28.5 inches. Additional dimensions and information of the vehicle are given in appendix E, tables E1 and E2. 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 August 10, 2012. Weather conditions at the time of testing were: Wind speed: 7 mi/h; wind direction: 240 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 92ºF; relative humidity: 61 percent.

6.4 TEST DESCRIPTION

The 2007 Dodge Ram 1500, traveling at an impact speed of 62.8 mi/h, impacted the transition 50.7 inches upstream of joint between the pinned-down F-shape and the permanent single slope barrier at an impact angle of 25.7 degrees. At approximately 0.037 s, the transition began to deflect towards the field side, and at 0.040 s, the vehicle began to redirect. The transition reached maximum deflection of 20.2 inches at 0.079 s, and the rear of the vehicle contacted the transition at 0.190 s. At 0.363 s, the vehicle lost contact with the transition and was traveling at an exit speed and angle of 48.9 mi/h and 8.6 degrees. Brakes on the vehicle were applied at 0.95 s, and the vehicle subsequently came to rest 196 ft downstream of impact and 18 ft toward traffic lanes from the traffic face of the transition. Sequential photographs of the test period are shown in appendix E, figure E1.

Figure 6.1. Vehicle and installation geometrics for test 405160-34-1.

Figure 6.2. Vehicle before test 405160-34-1.

6.5 TEST ARTICLE AND COMPONENT DAMAGE

Damage to the transition for anchored temporary barrier to rigid concrete barrier is shown in figures 6.3 and 6.4. The thrie beam guardrail element was deformed in the area of impact. Movement at the joint between temporary barriers 6 and 7 was 0.75 inch toward the field side, and the end of barrier 7 adjacent to the rigid concrete barrier moved 2.5 inches toward the field side. The pin at the downstream end of barrier 7 adjacent to the rigid barrier was pulled up 2.5 inches. Vehicle penetration (formerly working width) was 8.9 inches. Maximum dynamic deflection during the test was 5.7 inches.

6.6 TEST VEHICLE DAMAGE

Figure 6.5 shows damage to the 2270P vehicle. The left frame rail, left front upper and lower A-arms, and left rear U-bolts were deformed. The drive shaft was pulled out of the housing, and the rear axle was pushed rearward. Also damaged were the front bumper, hood, grill, left front fender, left front tire and wheel rim, left front and rear doors, left exterior bed, left rear tire and wheel rim, rear bumper, and the tail gate. The windshield sustained stress cracks at the right lower corner. Maximum exterior crush to the vehicle was 17.0 inches in the side plane at the left front corner at bumper height. Maximum occupant compartment deformation was 3.625 inches in the floor pan on the driver's side. Photographs of the interior of the vehicle are shown in figure 6.6. Exterior vehicle crush and occupant compartment measurements are shown in appendix E, tables E3 and E4.

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 22.6 ft/s at 0.098 s, the highest 0.010-s occupant ridedown acceleration was 3.6 Gs from 0.204 to 0.214 s, and the maximum 0.050-s average acceleration was -11.3 Gs between 0.035 and 0.085 s. In the lateral direction, the occupant impact velocity was 28.2 ft/s at 0.098 s, the highest 0.010-s occupant ridedown acceleration was 10.4 Gs from 0.230 to 0.240 s, and the maximum 0.050-s average was 14.2 Gs between 0.045 and 0.095 s. Theoretical Head Impact Velocity (THIV) was 39.8 km/h or 11.0 m/s at 0.096 s; Post-Impact Head Decelerations (PHD) was 10.7 Gs between 0.230 and 0.240 s; and Acceleration Severity Index (ASI) was 1.83 between 0.035 and 0.085 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 E, figures E2 through E8.

Figure 6.3. Vehicle and installation positions after test 405160-34-1.

Figure 6.4. Installation after test 405160-34-1.

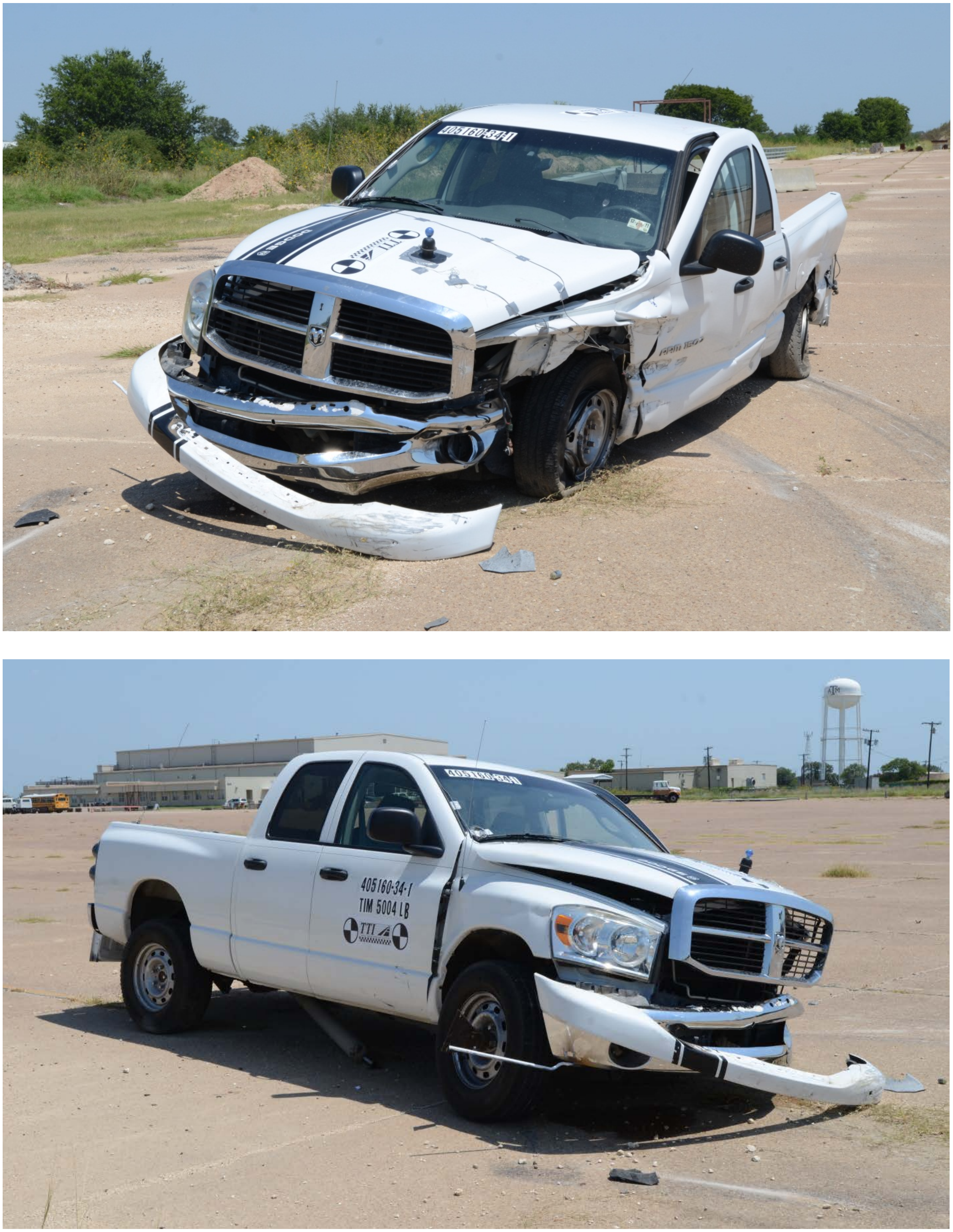
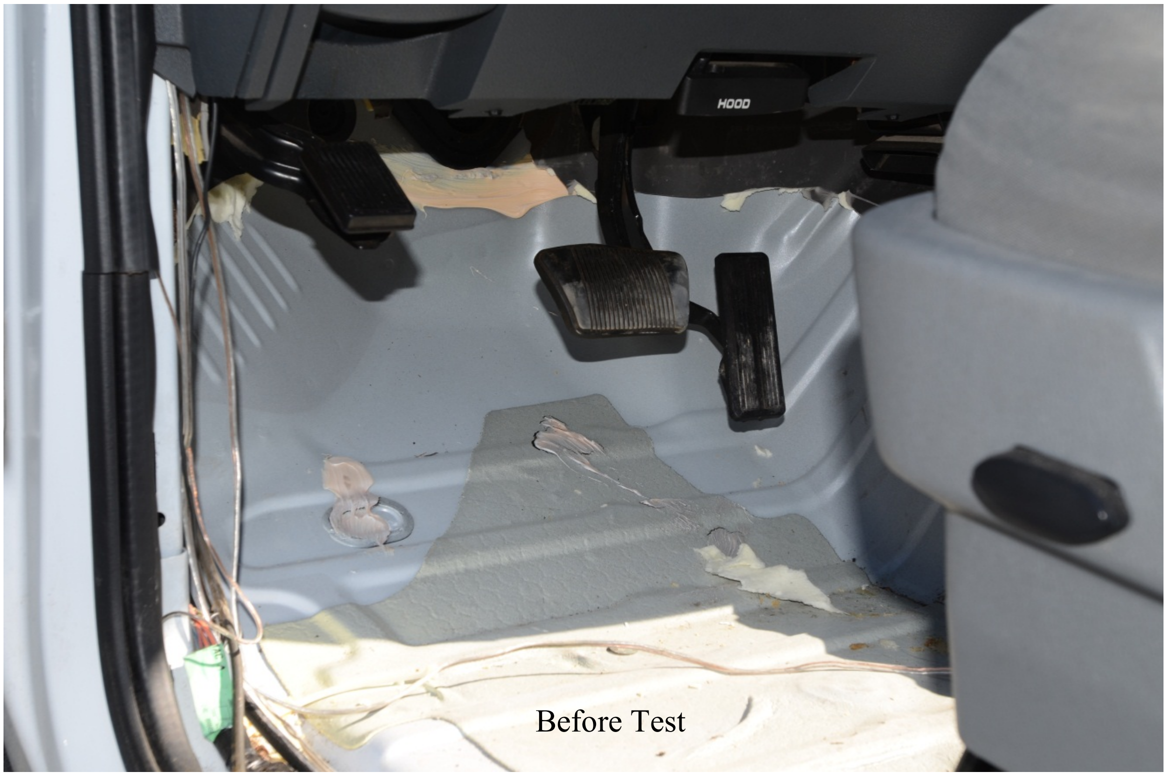


Figure 6.5. Vehicle after test 405160-34-1.



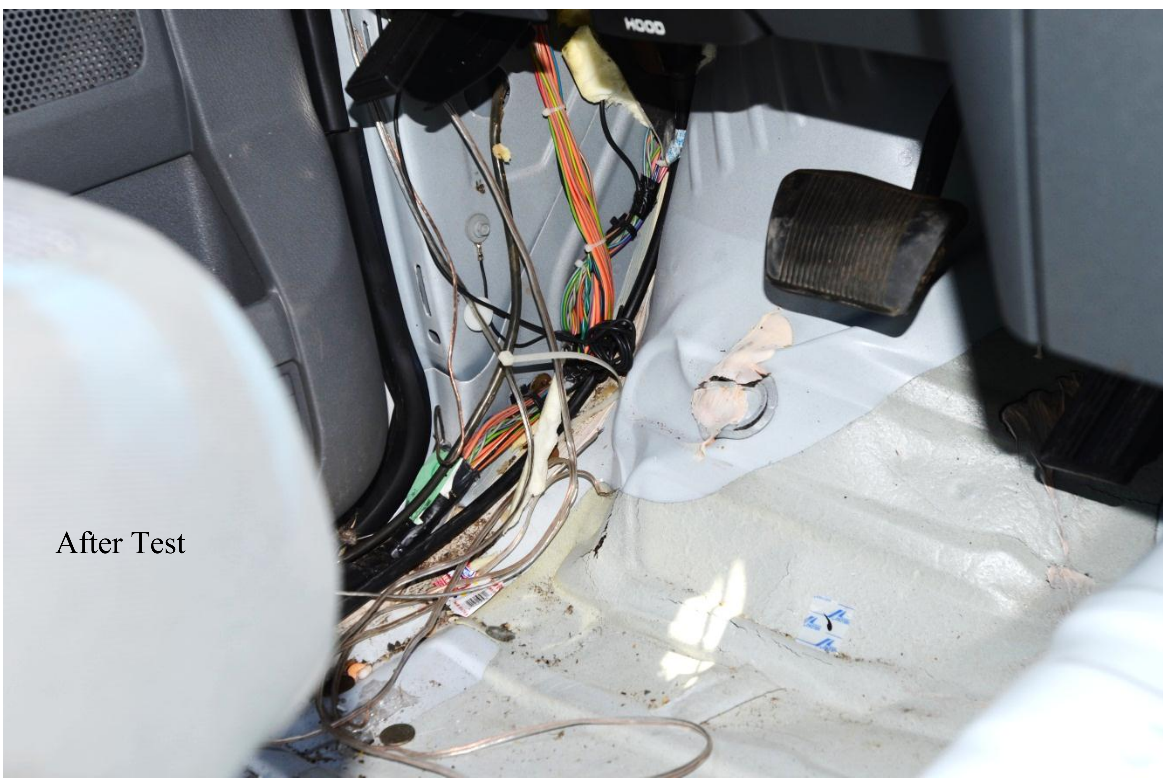
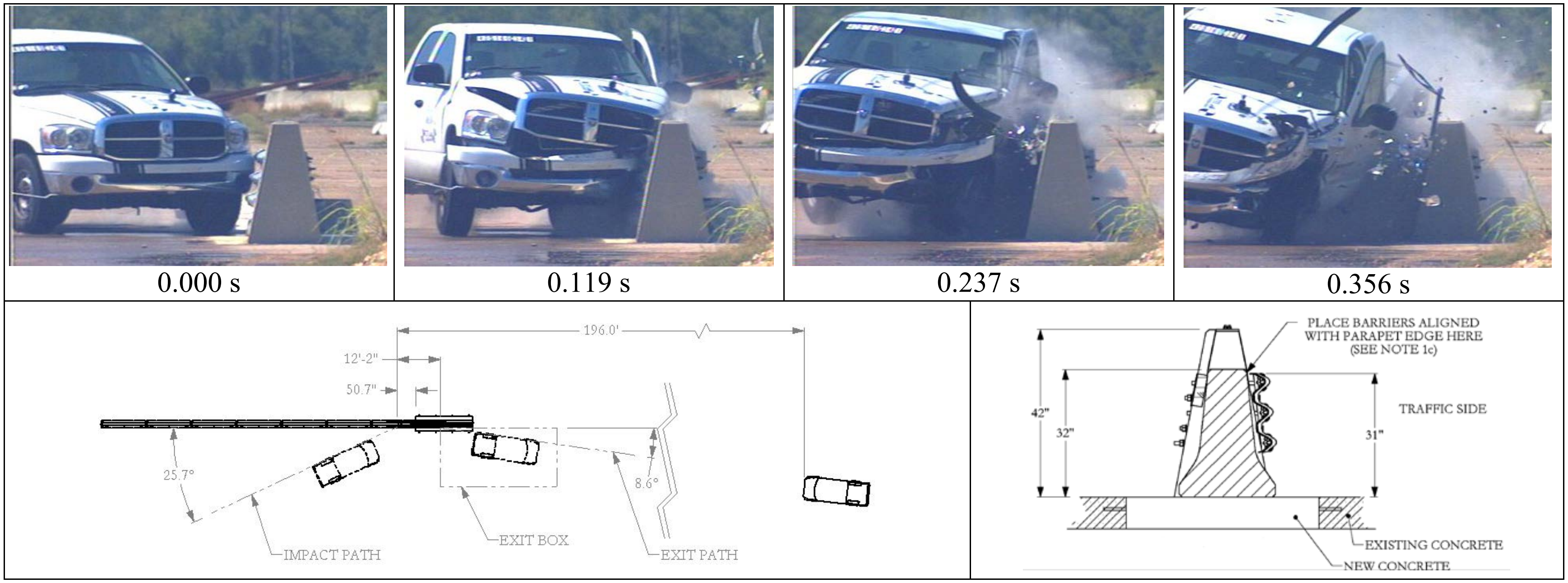


Figure 6.6. Interior of vehicle for test 405160-34-1.



General Information
Test Agency .... Texas A&M Transportation Institute (TTI)
Test Standard Test No. .... MASH Test 3-21
TTI Test No. 405160-34-1
Date 2012-08-10

Test Article
Type....................................... Transition
Name .... Transition for anchored temporary barrier to rigid concrete barrier
Installation Length .... 104.5 ft
Material or Key Elements .... 12.5 ft long 32-inch tall F-shaped precast concrete barriers anchored to concrete pavement using two 1.5 inch diameter steel pins each segment and connected to 42-inch tall permanent single slope concrete barrier

Soil Type and Condition........... Concrete Surface, Dry

Test Vehicle
Type/Designation 2270P
Make and Model...................... 2007 Dodge Ram 1500 Pickup
Curb .... 4910 lb
Test Inertial .... 5026 lb
Dummy.................................... No dummy
Gross Static............................ 5026 lb

Impact Conditions
Speed.................................62.8 mi/h
Angle..................................25.7 degrees
Location/Orientation ....50.7 upstrm of parapet

Impact Severity......................124.6 kips

Exit Conditions
Speed.................................48.9 mi/h
Angle..................................8.6 degrees

Occupant Risk Values
Impact Velocity
Longitudinal......................22.6 ft/s
Lateral..............................28.2 ft/s
Ridedown Accelerations
Longitudinal......................3.6 G
Lateral..............................10.4 G
THIV..................................39.8 km/h
PHD ....10.7 G
ASI 1.83
Max. 0.050-s Average
Longitudinal......................-11.3 G
Lateral..............................14.2 G
Vertical.............................-3.8 G

Post-Impact Trajectory
Stopping Distance .... 196 ft dwnstrm
16.8 ft twd traffic

Vehicle Stability
Maximum Yaw Angle................. 37 degrees
Maximum Pitch Angle................ 8 degrees
Maximum Roll Angle.................. 13 degrees
Vehicle Snagging....................... No
Vehicle Pocketing...................... No

Test Article Deflections
Dynamic .... 5.7 inches
Permanent.................................. 2.5 inches
Working Width .... 5.7 inches
Vehicle Penetration .... 8.9 inches

Vehicle Damage
VDS... 11LFQ5
CDC 11FLEW4
Max. Exterior Deformation .... 17.0 inches
OCDI LF0100000
Max. Occupant Compartment Deformation......................... 3.625 inches

Figure 6.7. Summary of results for *MASH* test 3-21 on the transition for anchored temporary barrier to rigid concrete barrier.

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 transition for pinned-down temporary concrete barrier to rigid concrete barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 5.7 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).

Results: No detached elements, fragments, or other debris from the test article were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. (PASS)
Maximum occupant compartment deformation was 3.625 inches in the floorpan on the driver's side. (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 13 degrees and 8 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 22.6 ft/s, and lateral occupant impact velocity was 28.2 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 occupant ridedown acceleration was 3.6 G, and lateral occupant ridedown acceleration was 11.0 G. (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 exited the barrier within the exit box. (PASS)

7. SUMMARY AND CONCLUSIONS

7.1 SUMMARY OF RESULTS

The transition for F-shape pinned-down temporary concrete barrier to rigid concrete barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 5.7 inches. No detached elements, fragments, or other debris from the test article were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 3.625 inches in the floor pan on the driver's side. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 13 degrees and 8 degrees, respectively. Occupant risk factors were within the limits specified in *MASH*. The 2270P vehicle exited the barrier within the exit box.

7.2 CONCLUSIONS

According to the *MASH* criteria required for test 3-21 for transitions shown in Table 7.1, the transition for anchored F-shape pinned-down temporary concrete barrier to rigid concrete barrier performed acceptably.

7.3 IMPLEMENTATION[2]

The transition in the crash test performed used a 42-inch tall single slope barrier as the rigid concrete barrier. However, this transition design can also be used with other common rigid concrete barrier profiles, such as the New Jersey profile, F-shape profile, vertical wall, etc. When using a different rigid concrete barrier profile, the pinned-down F-shape barrier should be placed adjacent to the rigid barrier in a position that minimizes the potential for vehicle snagging, as shown in appendix A. The nested thrie beam should then be used to provide a smooth transition surface over the pinned-down and rigid barrier interface, as tested herein with the single slope rigid concrete barrier. The steel transition cap used in this crash test for transitioning over the 10-inch difference in the barrier heights (i.e. from 32-inch F-shape to 42-inch single slope) can be modified to accommodate variations in heights of other rigid barrier types. So for instance, no transition cap will be required in transitioning from the 32-inch tall pinned-down F-shape to 32-inch tall rigid New Jersey or F-shape barriers. If however a 36-inch tall rigid barrier is used, the slope of the transition cap should be adjusted accordingly to accommodate the 4-inch height difference. In making modifications to the transition cap, the length of the transition cap should not be reduced.

In the crash test performed, a ¼-inch thick, 8-inch wide, and 16.33-ft long steel plate was bolted on the field side of the barrier using two of the bolts of the nested thrie beam end shoes. If desired, this steel plate may be replaced with a thrie beam or a W-beam section. Doing so does

[2] TTI Proving Ground's A2LA scope of accreditation does not include the Implementation section of this report.

not reduce the strength or lateral stiffness of the transition connection. The W-beam or the thrie beam section replacing the field side plate can be attached using existing bolts, or additional epoxy anchor bolts. As in the crash tested design, the attachment at each end of the W-beam or the thrie beam section should be made with at least two bolts.

The crash test performed in this project used pinned-down F-shape barrier segments that were 12.5-ft long. However, the transition design can also be used with longer lengths of the pinned-down barrier segments (such as 15-ft and 20-ft long segments). When using longer segment lengths, the position of the anchoring pin adjacent to the rigid barrier should not be changed as it can alter the lateral stiffness of the transition design.

The crash tested transition design was developed for use with pinned-down barriers placed on concrete pavement or deck. It should not be used with pinned-down barriers placed on asphalt without further evaluation using finite element analysis and/or crash testing. Similarly, the crash tested design was developed for transitioning to rigid concrete barriers and should not be used with other deformable barrier types (such as metal rails) without further evaluation.

Table 7.1. Performance evaluation summary for *MASH* test 3-21 on the transition for anchored temporary barrier to rigid concrete barrier.

Test Agency: Texas A&M Transportation Institute | Test No.: 405160-34-1 | Test Date: 2012-08-10

MASH Test 3-21 Evaluation Criteria	Test Results	Assessment
Structural Adequacy A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable*	The transition for anchored temporary barrier to rigid concrete barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 5.7 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 from the test article were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 3.625 inches in the floor pan on the driver's side.	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 13 degrees and 8 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 22.6 ft/s, and lateral occupant impact velocity was 28.2 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 occupant ridedown acceleration was 3.6 G, and lateral occupant ridedown acceleration was 11.0 G.	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 exited the barrier within the exit box.	Pass

REFERENCES

1. Sheikh, N.M., Bligh, R.P., and Menges, W.L. (2008). “Crash Testing and Evaluation of the 12 ft Pinned F-shape Temporary Barrier.” Texas Transportation Institute, College Station, Texas.
2. Ross, H. E., D. L. Sicking, Zimmer, R. A., and Michi, J. D. *Recommended Procedures for the Safety Performance Evaluation*. National Cooperative Highway Research Program Report 350. National Academy Press, Washington, D.C, 1993.
3. Polivka, K.A., Faller, R.K., Rohde, J.R., Holloway, J.C., Bielenberg, B.W., and Sicking, D.L. (2003). “Development and Evaluation of a Tie-Down System for the Redesigned F-Shape Concrete Temporary Barrier.” Midwest Roadside Safety Facility, Nebraska.
4. Bielenberg, B.W., Reid, J.D., Faller, R.K., Rohde, J.R., and Sicking, D.L. (2006). “Tie-downs and Transitions for Temporary Concrete Barriers.” Transportation Research Record, TRR 1984.
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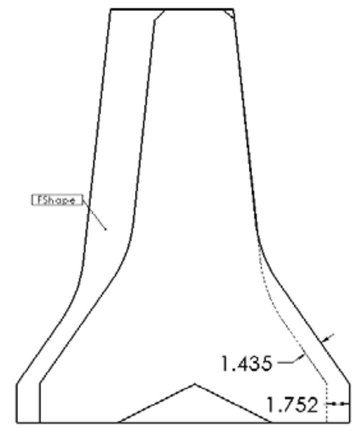
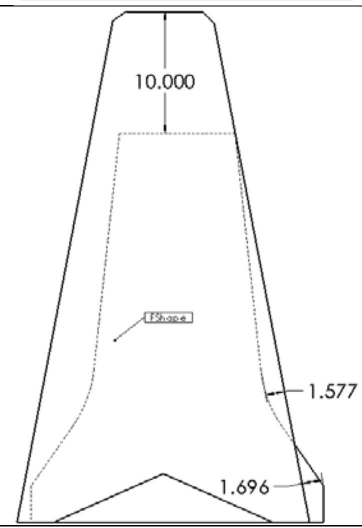
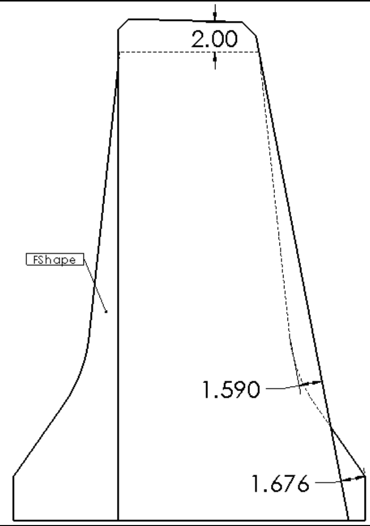
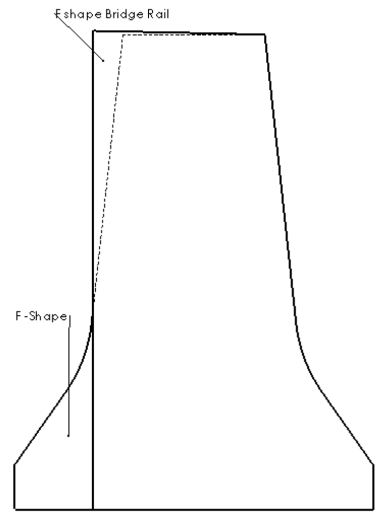
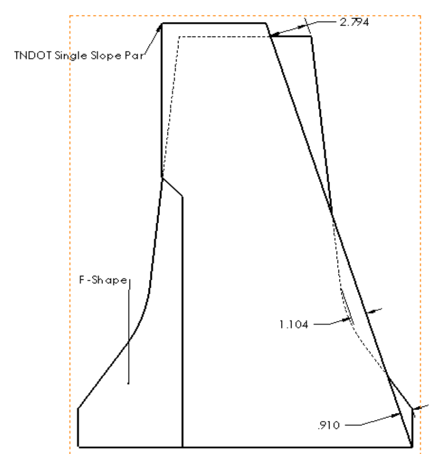
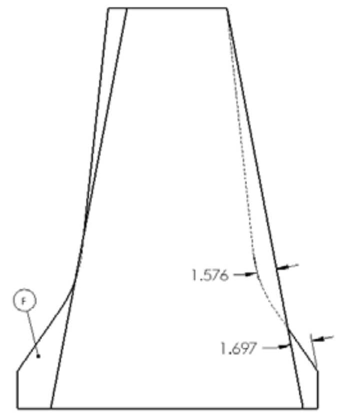
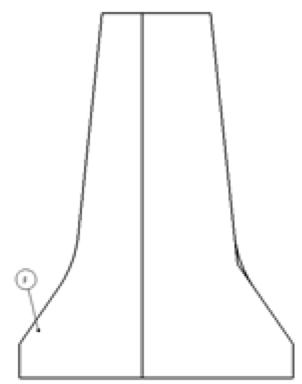
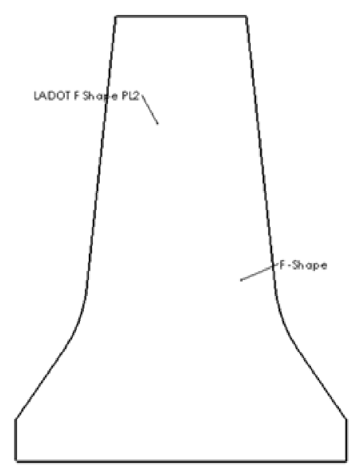
6. Jewel, J., Weldon, G., and Peter, R. (1999). “Compliance Crash Testing of K-Rail Used in Semi-Permanent Installations.” *Report No. 59-680838*, Division of Materials Engineering and Testing Services, CALTRANS, Sacramento, CA.
7. AASHTO. *Manual for Assessing Safety Hardware*. American Association of State Highway and Transportation Officials, Washington, DC, 2009.

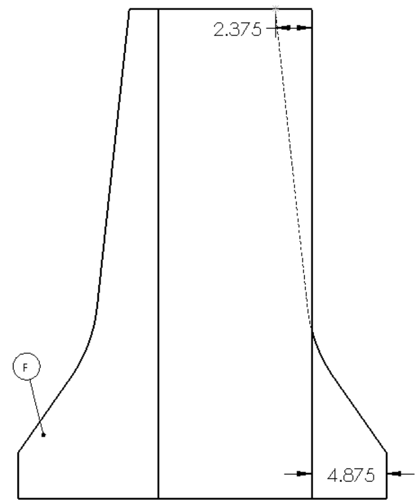
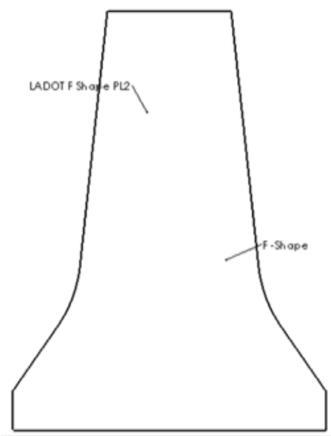
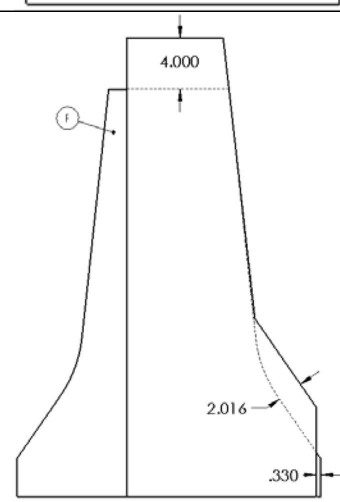
APPENDIX A. COMPARISON OF RIGID BARRIER DESIGNS

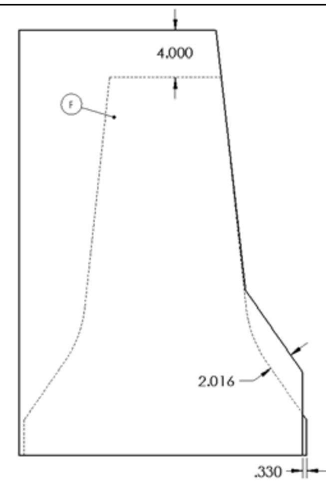
Comparisons of the profile of a standard 32-inch F-shape temporary concrete barrier with the different rigid concrete barrier designs used by the participating pooled-fund states are presented below. The profiles are overlaid to show the discrepancies and to help identify the most critical design for developing the transition.

State, Barrier Name, Design Description	Profile Comparison (Traffic Side on Right)
Washington, WSDOT C-8, 32-inch tall NJ Barrier	
Washington, WSDOT C-13, 42-inch tall single slope barrier	

Washington, WSDOT SSB Rail, 34-inch barrier height and single slope face.	
Washington, WSDOT F-shape Bridge Rail, 32-inch F-shape rail with vertical profile on back.	
Tennessee, TNDOT Single Slope Concrete Parapet, single slope face on traffic side.	

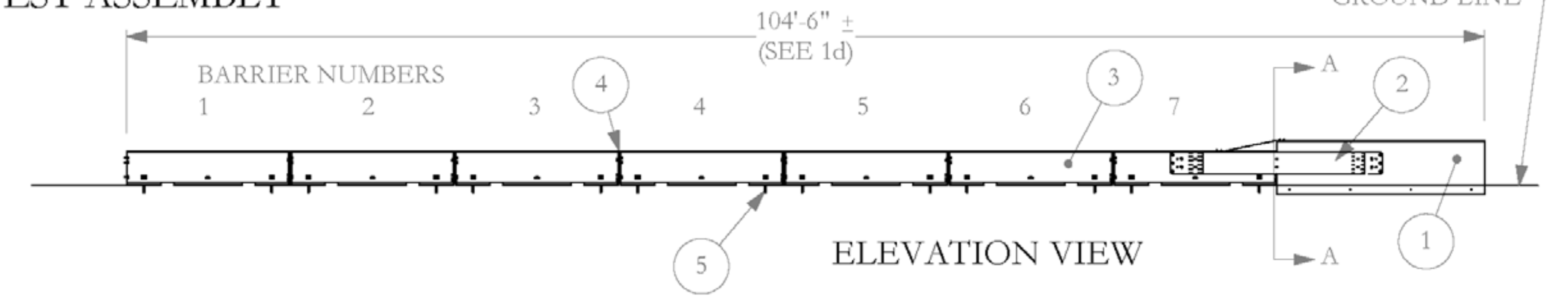
Tennessee, TNDOT Standard Single Slope Median, 32-inch height.	
Louisiana, LADOTD F-shape PL-2, vertical profile at back.	
Louisiana, LADOTD Median Barrier (bridge) F-Shape PL2, same as pinned F-shape.	

Louisiana, LADOTD Vertical Wall PL-2, 32-inch vertical wall.	
Louisiana, LADOTD F-shape, same as pinned F-shape barrier.	
Alaska, AKDOT Concrete Barrier, 36-inch tall barrier with vertical profile at back.	

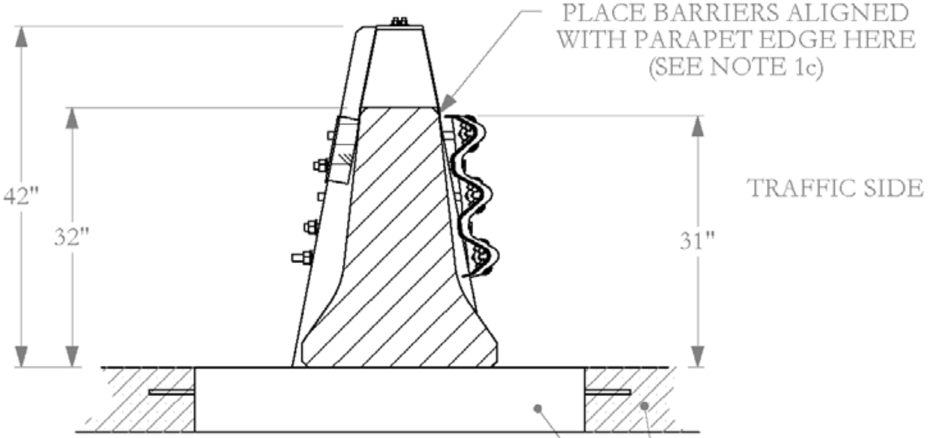
Washington, WSDOT C8-F, 36-inch barrier height.	

APPENDIX B. DETAILS OF TEST ARTICLE

TEST ASSEMBLY



ELEVATION VIEW



SECTION A-A
SCALE 1 : 20

PARTS LIST		
#	PART NAME	QTY.
1	SSCB Parapet	1
2	Nested Thrie-beam assembly	1
3	Pinned-Down F-Shape Barrier, 12.5'	7
4	Connection Pin	6
5	Anchor Pin, Ø1-1/2"	14
6	Transition Cap	1
7	Hilti Anchor, HAS-E #00385424	4
8	Field Side Connection Strap	1
9	Wood Block Spacer	1
10	Bolt, 5/8 x 4 carriage	1
11	Nut, 5/8 hex	1
12	Bolt, 7/8 x 14 hex	3
13	Bolt, 7/8 x 16 hex	3
14	Bolt, 7/8 x 18 hex	2
15	Bolt, 7/8 x 20 hex	1
16	Bolt, 7/8 x 22 hex	1
17	Nut, 7/8 heavy hex	10
18	Washer, 7/8 flat hardened	20

1a. All Ø7/8 bolts are ASTM A325 or A449.
1b. All fabricated steel parts are A36 unless otherwise noted.
1c. Barriers are pinned to 8" thick concrete, with one pin at each end on the traffic side.
1d. 16' SSCB Parapet and seven 12.5' F-Shape Barriers with ≈2" space between them.
1e. Hilti Anchor, HAS is Ø1/2" x 6-1/2".

Texas Transportation Institute — The Texas A&M University System	Roadside Safety and Physical Security Division - Proving Ground
Project 405160-34	Pin-down to Rigid Transition
Drawn By GES · Scale 1:150	Sheet 1 of 13 Installation
Approved: Nauman Sheikh: [signature]	Date: 2012-07-25

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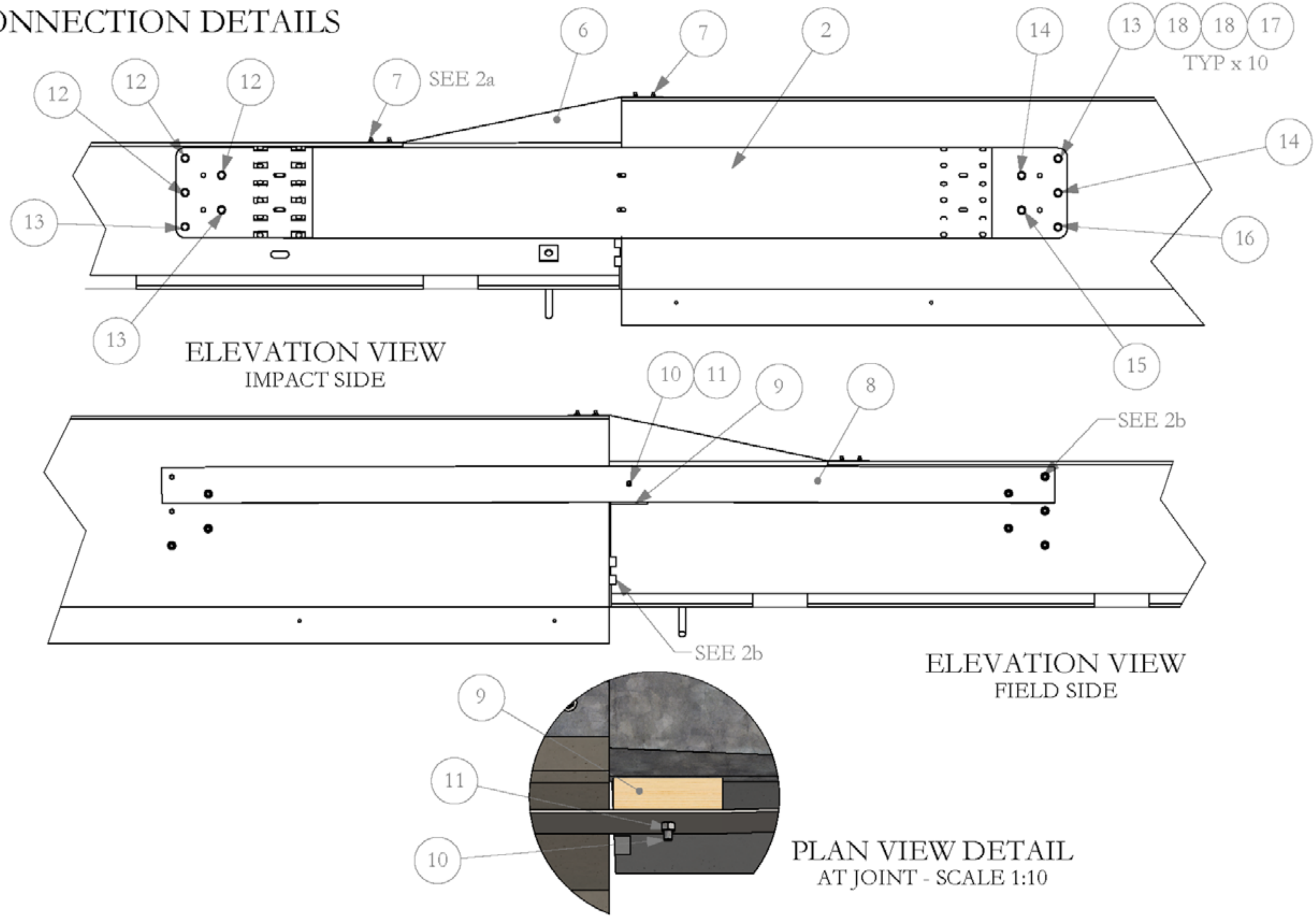
CONNECTION DETAILS



2a. Install Hilti Anchors with Hilti HIT 150 epoxy according to manufacturer's instructions, with 4-1/2" minimum embedment..

2b. Cut off end loops on one end of barrier #7 and place it tight against SSCB Parapet. Core Ø1" holes for 7/8" bolts. Do not percussion drill.

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Project 405160-34	Pin-down to Rigid Transition	2012-07-25
Drawn By GES	Scale 1:30	Sheet 2 of 13 Transition Details

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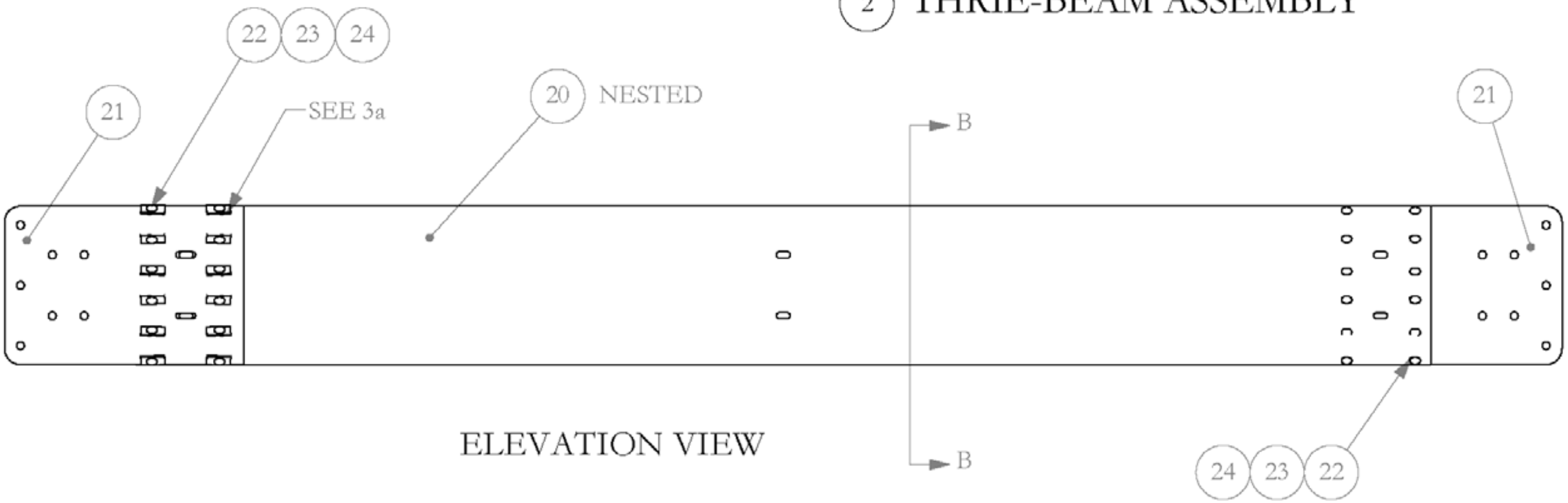
(2) THRIE-BEAM ASSEMBLY



ELEVATION VIEW

SECTION B-B
SCALE 1 : 10

THRIE-BEAM ASSEMBLY PARTS			
#	PART NAME	TF-13 #	QTY.
20	Thrie-Beam, 2 space 12 gauge	RTM02a	2
21	End Shoe, Thrie-beam 10 ga.	RTE01b	2
22	Bolt, Guardrail 2"	FBB02	24
23	Washer, rectangular guardrail	FWR03	24
24	Nut, 5/8 Guardrail	FBB	24

3a. Rectangular washers go under bolt head on upstream end, and under nut on downstream end.

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Roadside Safety and Physical Security Division - Proving Ground

Project 405160-34	Pin-down to Rigid Transition		2012-07-25
Drawn By GES	Scale 1:20	Sheet 3 of 13	Thrie-beam Assembly

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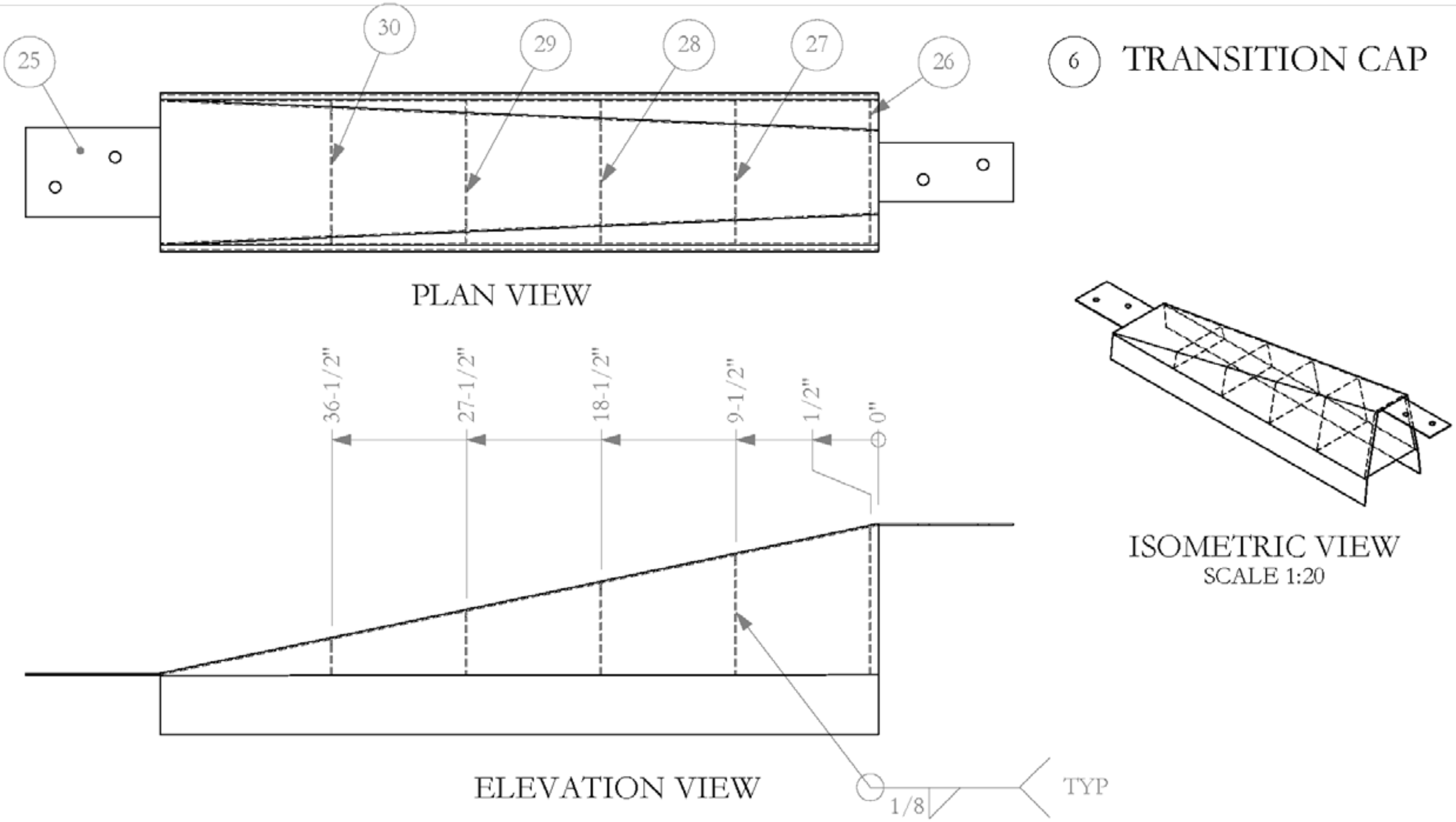

TRANSITION CAP CUT-LIST		
#	PART NAME	QTY.
25	Box	1
26	Rib 1	1
27	Rib 2	1
28	Rib 3	1
29	Rib 4	1
30	Rib 5	1

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Project 405160-34	Pin-down to Rigid Transition		2012-07-25
Drawn By GES	Scale 1:10	Sheet 4 of 13	Transition Cap

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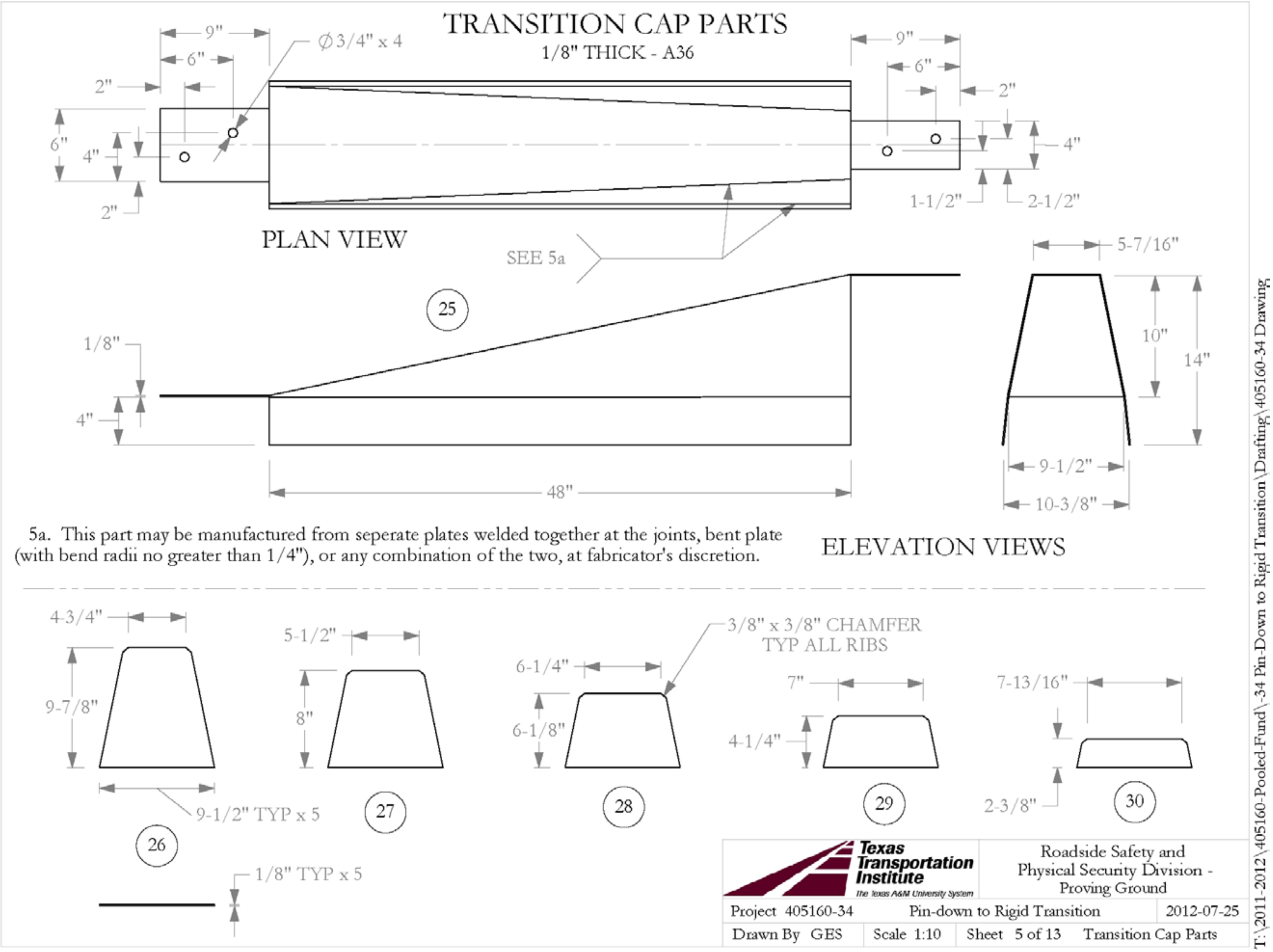
TRANSITION CAP PARTS
1/8" THICK - A36
9"
6"
2"
Ø3/4" x 4
6"
4"
2"
9"
6"
2"
4"
1-1/2"
2-1/2"
PLAN VIEW
SEE 5a
25
1/8"
4"
48"
5-7/16"
10"
14"
9-1/2"
10-3/8"
5a. This part may be manufactured from seperate plates welded together at the joints, bent plate (with bend radii no greater than 1/4"), or any combination of the two, at fabricator's discretion.
ELEVATION VIEWS
4-3/4"
9-7/8"
9-1/2" TYP x 5
26
1/8" TYP x 5
5-1/2"
8"
27
6-1/4"
6-1/8"
28
3/8" x 3/8" CHAMFER
TYP ALL RIBS
7"
4-1/4"
29
7-13/16"
2-3/8"
30
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Roadside Safety and Physical Security Division - Proving Ground
Project 405160-34
Pin-down to Rigid Transition
2012-07-25
Drawn By GES
Scale 1:10
Sheet 5 of 13
Transition Cap Parts
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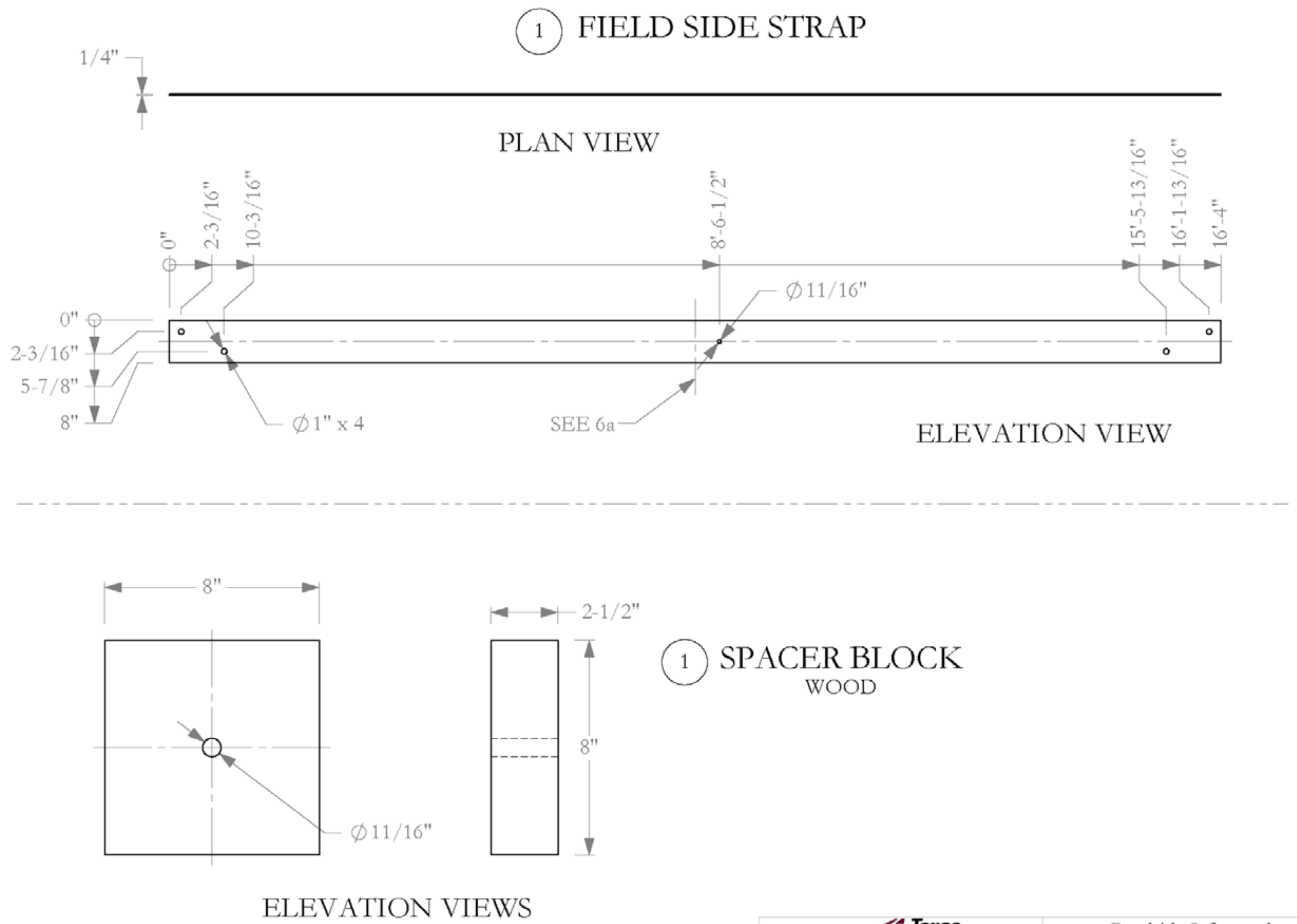

6a. Plate is symmetrical about ℄, except for ∅11/16" hole.

Texas Transportation Institute, The Texas A&M University System	Roadside Safety and Physical Security Division - Proving Ground		
Project 405160-34	Pin-down to Rigid Transition		2012-07-25
Drawn By GES	Scale 1:25	Sheet 6 of 13	Field Side Strap

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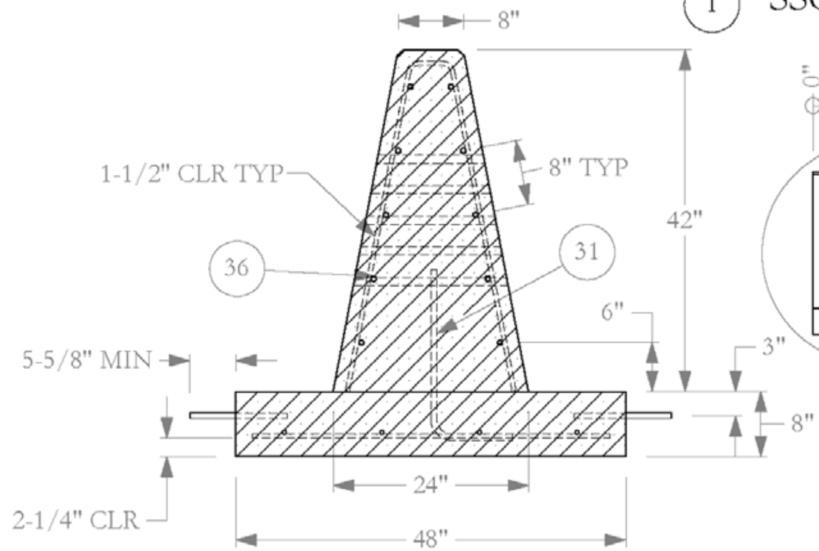
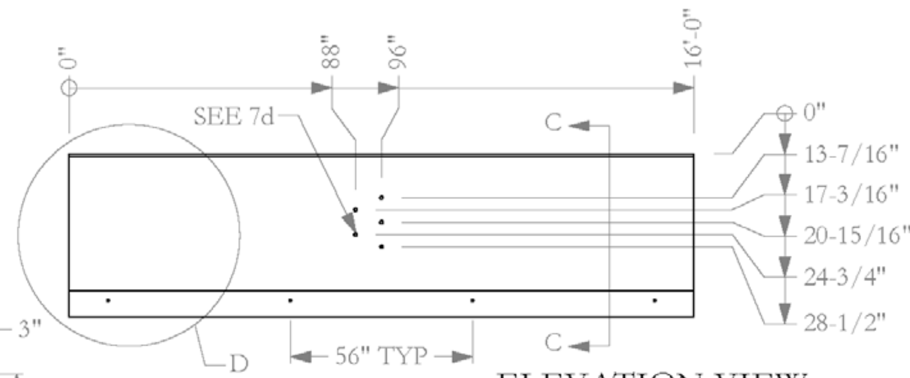
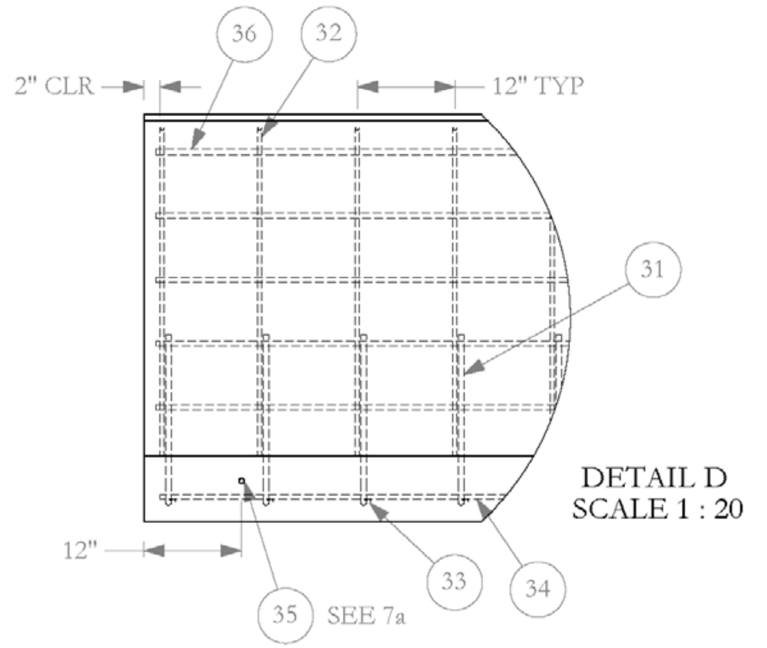
① SSCB PARAPET DETAILS



SECTION C-C
SCALE 1 : 20



ELEVATION VIEW



DETAIL D
SCALE 1 : 20

#	PART NAME	QTY.
31	L-bar for SSCB	16
32	Stirrup, V1	16
33	Rebar, #4 x 44"	16
34	Rebar, #4 x 15'9"	4
35	Rebar, #5 x 12"	8
36	Rebar, #5 x 15'9"	10

7a. Install (35) bars in existing concrete with Hilti HIT 150 epoxy according to manufacturer's instructions.
7b. All rebar is grade 60.
7c. Minimum concrete strength is 3600 psi.
7d. Form or core Ø1" holes (x 5). Do not percussion drill.

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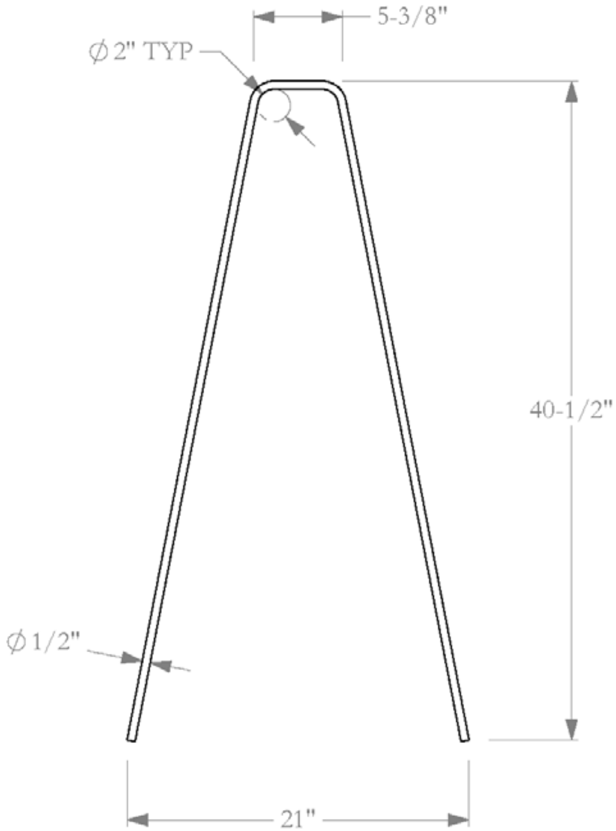
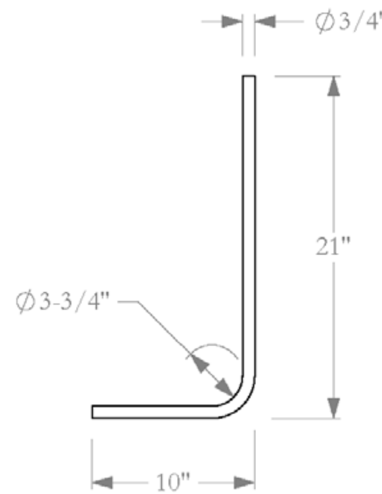
Project 405160-34	Pin-down to Rigid Transition	2012-07-25
Drawn By GES	Scale 1:50	Sheet 7 of 13 SSCB Parapet



32 V1 STIRRUP



31 L-BAR

Texas Transportation Institute, The Texas A&M University System	Roadside Safety and Physical Security Division - Proving Ground		
Project 405160-34	Pin-down to Rigid Transition		2012-07-25
Drawn By GES	Scale 1:10	Sheet 8 of 13	SSCB Stirrups

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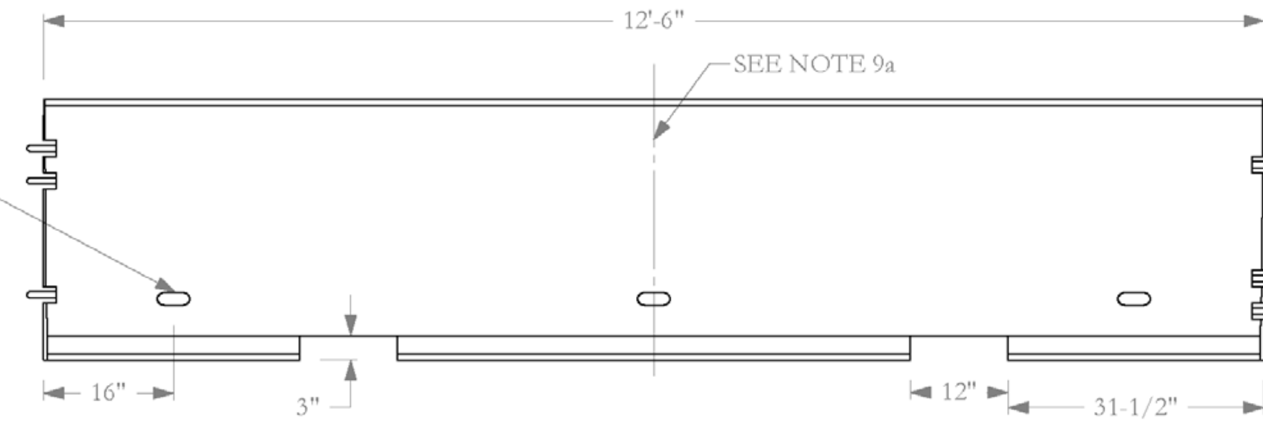
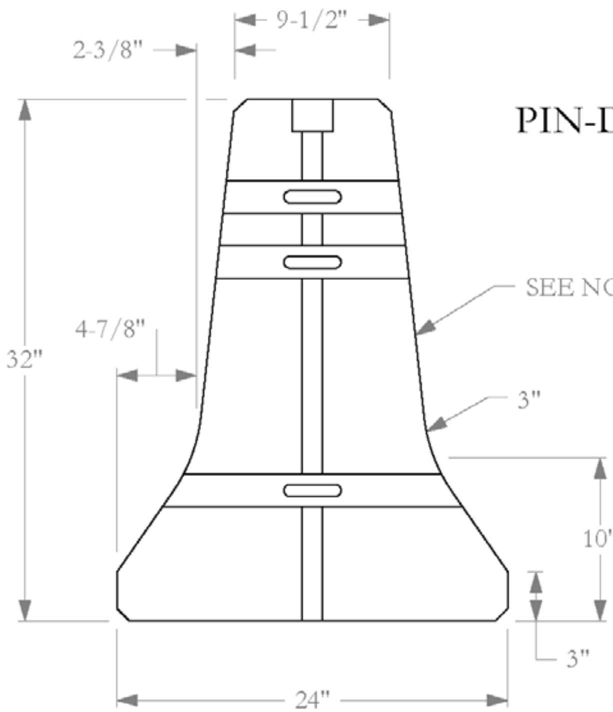
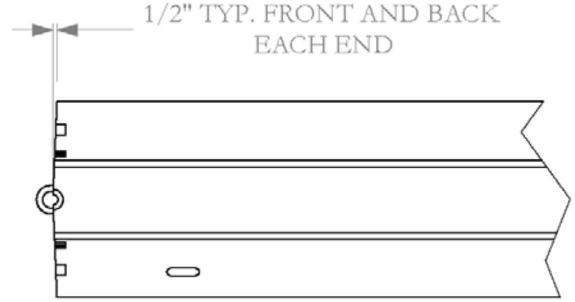


ELEVATION VIEW

PIN-DOWN BARRIER



END VIEW
SCALE 1:10



PLAN VIEW

9a. Barriers are symmetrical about ℄ 's, except for end loops. See next sheet for end loop and cut-out details.
9b. All rebar is grade 60.
9c. Concrete shall be 5000 psi.
9d. Chamfer top, bottom, and ends 3/4". End chamfers not shown for clarity.

Texas Transportation Institute — The Texas A&M University System	Roadside Safety and Physical Security Division - Proving Ground	
Project 405160-34	Pin-down to Rigid Transition	2012-07-25
Drawn By GES	Scale 1:20	Sheet 9 of 13 Barrier Details a

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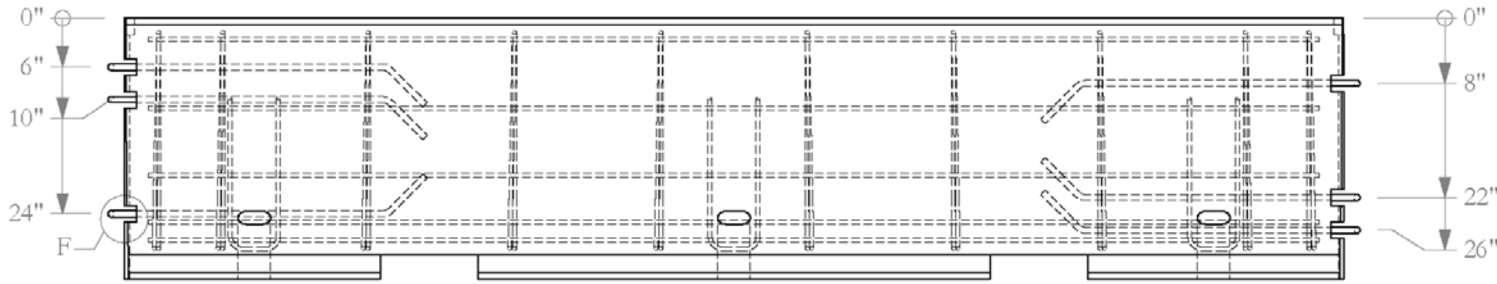
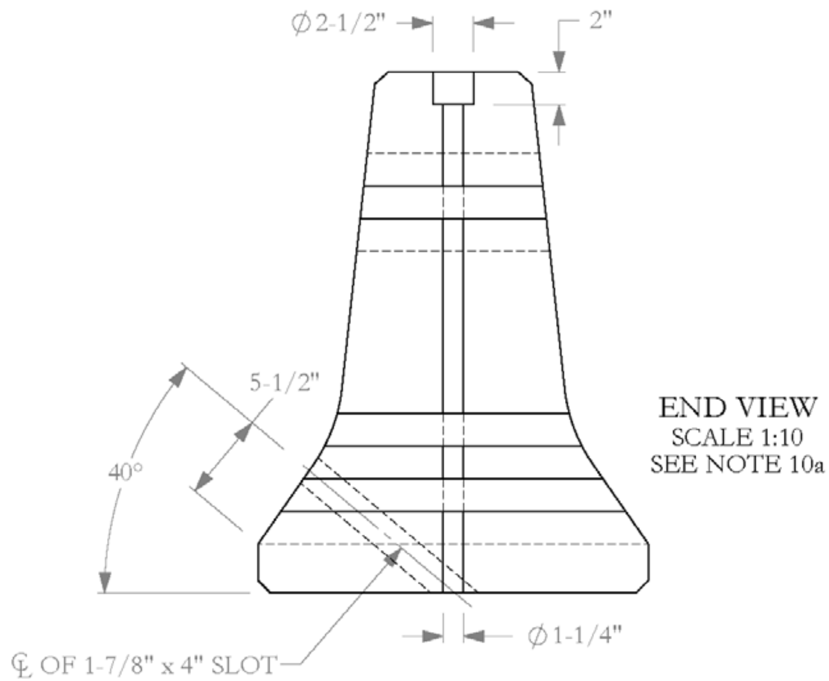
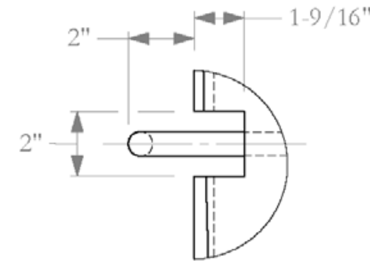


END LOOP DETAILS



END VIEW
SCALE 1:10
SEE NOTE 10a



DETAIL F
SCALE 1 : 5
TYP x 6

10a. Rebar and End Loops not shown in End View for clarity.

Texas Transportation Institute — The Texas A&M University System	Roadside Safety and Physical Security Division - Proving Ground	
Project 405160-34	Pin-down to Rigid Transition	2012-07-25
Drawn By GES	Scale 1:20	Sheet 10 of 13 Barrier Details b

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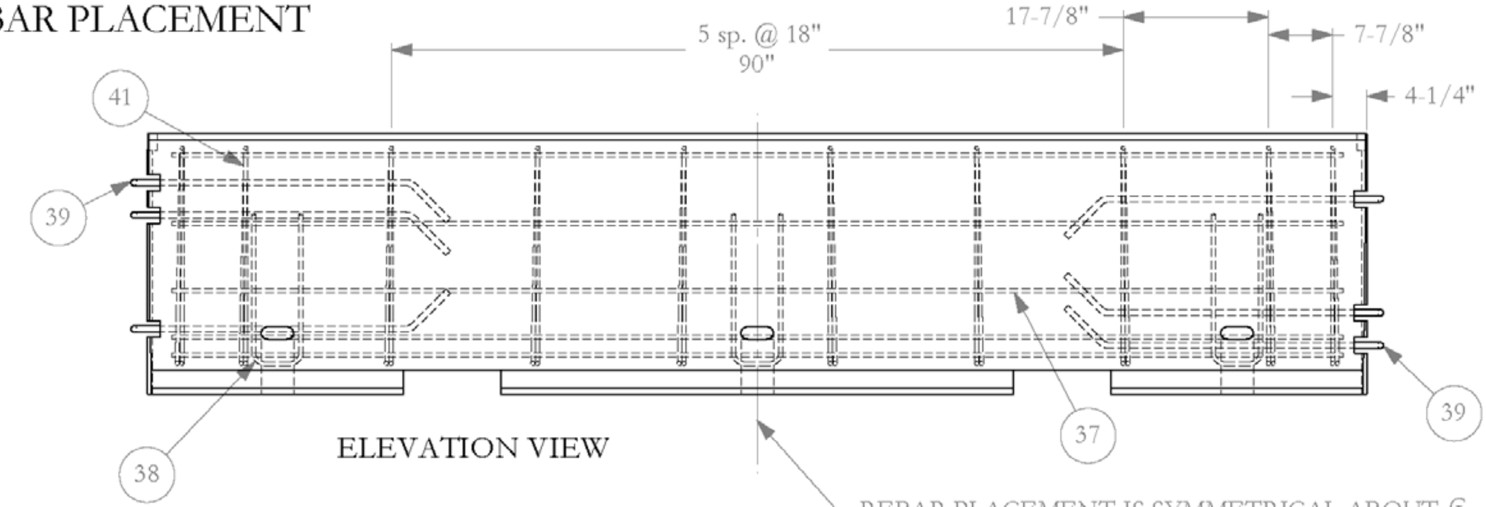
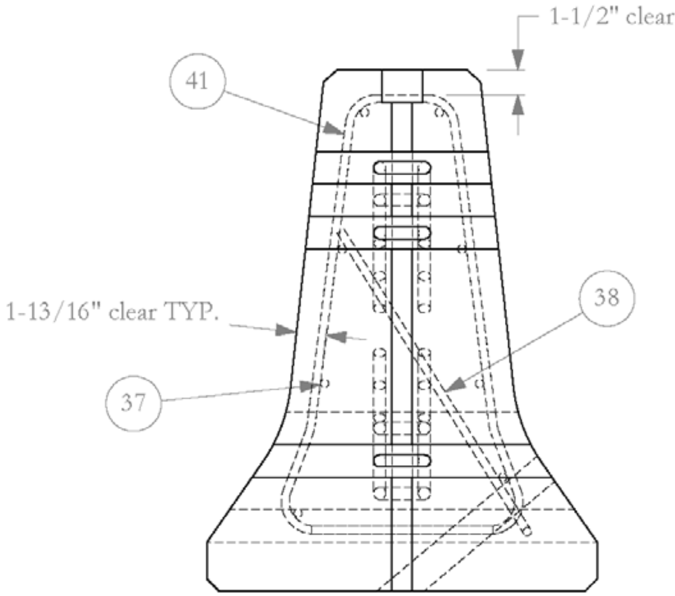
REBAR PLACEMENT



ELEVATION VIEW



END VIEW
SCALE 1:10

#	PART NAME	QTY.
37	Rebar, #4 x 144"	8
38	403 Bar	3
39	End Loops	6
41	Stirrup	10

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Roadside Safety and Physical Security Division - Proving Ground

Project 405160-34	Pin-down to Rigid Transition	2012-07-25
Drawn By GES	Scale 1:20	Sheet 11 of 13 Barrier Details c

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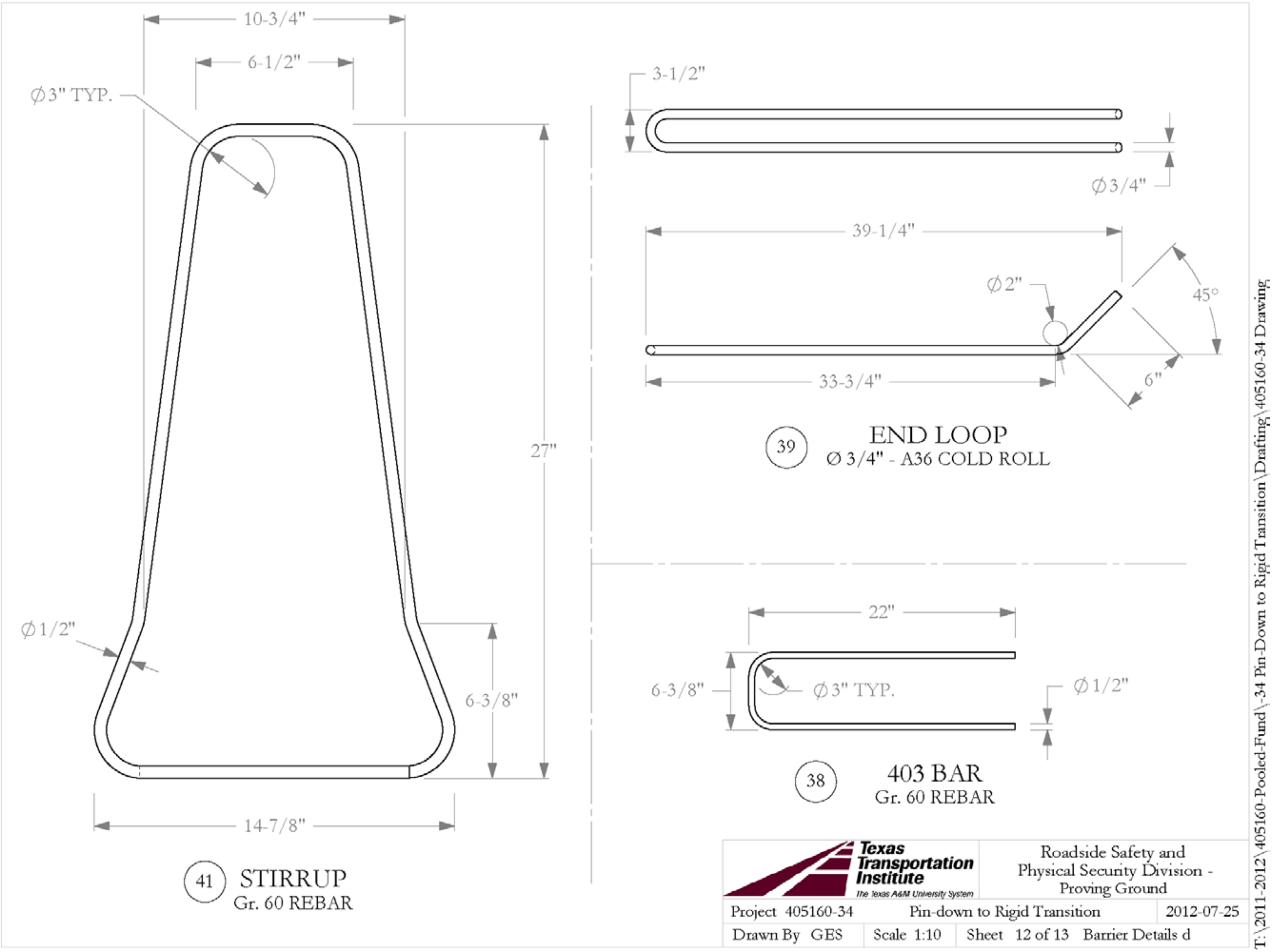
10-3/4"
6-1/2"
∅3" TYP.
27"
∅1/2"
6-3/8"
14-7/8"
41 STIRRUP
Gr. 60 REBAR
3-1/2"
∅3/4"
39-1/4"
∅2"
45°
33-3/4"
6"
39 END LOOP
Ø 3/4" - A36 COLD ROLL
22"
6-3/8"
∅3" TYP.
∅1/2"
38 403 BAR
Gr. 60 REBAR
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Roadside Safety and Physical Security Division - Proving Ground
Project 405160-34
Pin-down to Rigid Transition
2012-07-25
Drawn By GES
Scale 1:10
Sheet 12 of 13
Barrier Details d
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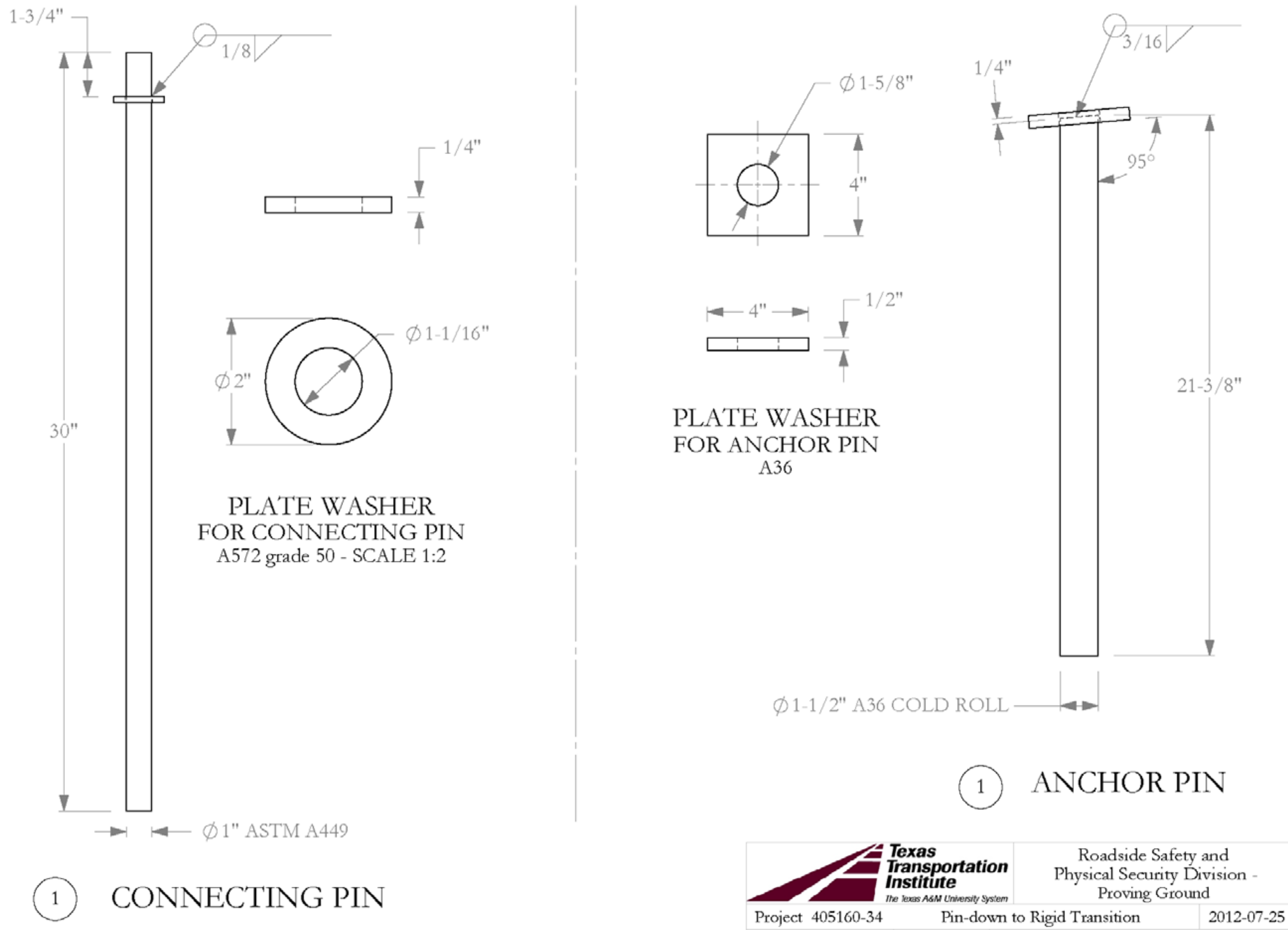

Texas Transportation Institute, The Texas A&M University System	Roadside Safety and Physical Security Division - Proving Ground	
Project 405160-34	Pin-down to Rigid Transition	2012-07-25
Drawn By GES	Scale 1:5	Sheet 13 of 13 Pin Details

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Texas Transportation Institute Proving Ground, 3100 SH 47, Bldg 7091, Bryan, TX 77807 Texas A&M University, College Station, TX 77843, Phone 979-845-6375	5.7.2 Concrete Break	Doc. No. *5_7_2_Concrete _Break.doc*	Revision Date: 2010-02-12
Subject: **Quality Policy Form**	Revised by: W. L. Menges Approved by: C. E. Buth	Revision: 4	Page: 1 of 1

Project No.: 405160-34 **Casting Date:** 2012-07-31

Placement: DECK **Mix Design P.S.I.:** 4000

Truck No.	Batch Ticket	Yards

Printed name of Technician taking sample: Edwin Hafe

Signature of Technician taking sample: [signature]

Printed name of Technician breaking sample: Glenn Schroeder

Signature of Technician breaking sample: [signature]

Break Date	Cylinder Age	Truck No.	Total Load (Pounds)	PSI Break	Average
2012-08-10	10 DAYS		105,000	3714	
			102,500	3608	3602
			98,500	3484	

Texas Transportation Institute Proving Ground 3100 SH 47, Bldg 7091 Bryan, TX 77807 Texas A&M University College Station, TX 77843 Phone 979-845-6375	5.7.2 **Concrete Break**	Doc. No. *5_7_2_Concrete _Break.doc*	Revision Date: 2010-02-12
Subject: **Quality Policy Form**	Revised by: W. L. Menges Approved by: C. E. Buth	Revision: 4	Page: 1 of 1

Project No.: 405160-34

Casting Date: 2012-08-02

Placement: PARAPET

Mix Design P.S.I.: 4000

Truck No.	Batch Ticket	Yards

Printed name of Technician taking sample: EDWIN HAUG

Signature of Technician taking sample: [signature]

Printed name of Technician breaking sample: GLENN SCHROEDER

Signature of Technician breaking sample: [signature]

Break Date	Cylinder Age	Truck No.	Total Load (Pounds)	PSI Break	Average
2012-08-10	8 DAYS		118,250	4183	
			114,500	4050	4024
			108,500	3838	

APPENDIX D. SUPPORTING CERTIFICATION DOCMENTS

MATERIAL USED

TEST NUMBER 405160-34

TEST NAME Pin-down to Rigid Transition

DATE 2012-08-10

DATE RECEIVED	ITEM NUMBER	DESCRIPTION	SUPPLIER	HEAT #	NOTE
2011-07-11	End Shoe-01	thrie-beam end shoe	Trinity Industries	none provided	a
2012-02-08	End Shoe-02	thrie-beam end shoe	Trinity Industries	125745	b
2009-08-03	Thrie-beam 1	12 gauge- 12' 6" -4 space	Trinity Industries	70978	
2012-07-30	Rebar 05-16	5/8" x 20' grd 60	CMC-Sheplers	JW12103635	
2012-07-30	Rebar 04-27	1/2" x 20' gr 60	CMC-Sheplers	11-07831	
2011-11-04	Barriers-01	12'6" CMB's	Waskey	none	
2012-08-07	Bolt 0.8750-02	7/8 x 14 hex gr. 5	Mack Bolt & Steel	SW03229	
2012-08-07	Bolt 0.8750-03	7/8 x 16 hex gr. 5	Mack Bolt & Steel	313229	
2012-08-07	Bolt 0.8750-04	7/8 x 18 hex gr. 5	Mack Bolt & Steel	313232	
2012-08-07	Bolt 0.8750-05	7/8 x 22 hex gr. 8	Mack Bolt & Steel	U693219	
2012-08-07	Nut 0.8750-01	7/8 Heavy Hex	Mack Bolt & Steel	*	
2012-08-07	Washer 0.8750-01	7/8 Flat Hardened	Mack Bolt & Steel	*	

a. End shoe at upstream end.
b. End shoe at downstream end.

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

Shipper's No. 16-40479

S/O No. 1164772

RECEIVED, subject to the classifications and tariffs in effect on the date of receipt by the carrier of the property described in the Original Bill of Lading,
at Ft Worth, TX 2/7/ 20 12 from Trinity Highway Products,LLC Carrier 9

Consigned to: SAMPLES,TESTING,TRAINING MTRLS Cust. P.O. TTI-ET 2000 Load No 96-1
Destination: TTI - ATTN: GARY GERKE 3100 STATE HWY 47
SAFETY & STRUCT. SYST. DIV. BLDG. 7090
Total Weight: 896.97

City: BRYAN State: TX Zip: 77807
Ship: 2/7/12
Arrive: 2/8/12 8:00:00AM

Contact: Gary Gerke Phone: 936-825-4661 323168

Delivering Carrier: FEDEX FX FE Vehicle or Car Initial: No.

Subject to Section 7 of Conditions of applicable Bill of Lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.
TRINITY HIGHWAY PRODUCTS, LLC
Trinity Highway Products,LLC
(Signature of Consignor)

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

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

Agent or Cashier
Per
(The signature here acknowledges only the amount prepaid.)
Charges advanced:

Collect On Delivery: $ and remit to:
C.O.D. charge to be paid by Shipper ☐ Consignee ☐
Street City State

Upon delivery, all materials subject to Trinity Highway Products,LLC Storage Stain Policy No. LG-002.

Project Info: SAMPLES & TESTING TTI ET-2000 GILCHRIST/SHRB COURTYARD

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
	2	32G 12/12'6/6'3/S ET2000 ANC			
	2	704A CABLE ANCHOR BRKT			
	2	3000G CBL 3/4X6'6/DBL			
	22	3340G 5/8" GR HEX NUT			
	18	3360G 5/8"X1.25" GR BOLT			
	4	3500G 5/8"X10" GR BOLT A307			
	4	3701G 3/4" ROUND WASHER F436			
	4	3704G 3/4" HVY HEX NUT A563 DH			
	4	3717G 3/4"X2.5" HEX BOLT A325			
	4	3900G 1" ROUND WASHER F844			
	4	3910G 1" HEX NUT A563			
	4	4076B WD BLK RTD 6X8X14			
	8	4254G 3/8" ROUND WASHER F436			
	4	4255G 3/8" FENDER WASHER F844			
	4	4258G 3/8" LOCK WASHER			
	4	4261G 3/8"X1.5" HEX BOLT GR-5			
	4	4389G 7/16" WASHER F844			
	4	4390G 7/16"X1.5" HEX BOLT GRD 5			
	4	4393G 7/16" LOCK WASHER			
	4	4396G 7/16" HEX NUT A563 DH			
	4	4699G 3/4" LOCK WASHER			
	4	6321G 3/8"X2" HEX BOLT GR-5 HDG			
	8	6405G 3/8" HVY HEX NUT			
	2	10967G 12/9'4.5/3'1.5/S			
	6	15000G 6'0 SYT PST/8.5/31" GR HT			
	2	19258A HBA-BRG PL/WELDED TABS			
	4	19948G .135(10Ga)X1.75X1.75 WSHR			

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
	2	33795G SYT-3"AN STRT 3-HL 6'6			

1 - CRATE
1 - BUNDLE
2 - PALLETES

GUARDRAIL HWY STEEL
NMFC ITEM 105460
CLASS 50

SPECIAL INSTRUCTIONS: 16-40479

SHIPPER LOAD - CONSIGNEE UNLOAD

Total Weight 896 3

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

ORIGIN — SHIPPER OR AGENT: I hereby authorize this shipment and make the declaration of values (if any) and agree to the contract terms and conditions hereof. SIGN HERE [signature] DATE 2/7/12
AGENT OR DRIVER: This shipment received subject to exceptions as noted and according to the terms and conditions hereof. (SIGN HERE) DATE

DESTINATION — CONSIGNEE OR AGENT: Received the above described property in good condition except as noted on the back hereof and agree to the foregoing contract terms and conditions. SIGN HERE DATE / / TIME A.M. P.M.
DRIVER NO

Permanent post-office address of shipper.
TRI 609-RF (R 10/93)

(This Bill of Lading is to be signed by the shipper and agent of the carrier issuing same.)

CONSIGNEE/CUSTOMER COPY

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

Carrier: Trinity Highway Products,LLC 3

Shipper's No. 16-40480

S/O No. 1164715

RECEIVED, subject to the classifications and tariffs in effect on the date of receipt by the carrier of the property described in the Original Bill of Lading, at Ft Worth, TX 2/7/ 20, 12 from Trinity Highway Products,LLC

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

Consigned to: SAMPLES,TESTING,TRAINING MTRLS — Cust. P.O. Samples — Load No.: 96-2

Destination: TTI - ATTN: GARY GERKE, 3100 STATE HWY 47, SAFETY & STRUCT. SYST. DIV., BLDG. 7090 — Total Weight: 3,971.83

City: Bryan State: TX Zip: 77807 — Ship: 2/7/12

Arrive: 2/8/12 8:00:00AM

Contact: Gary Gerke Phone: 936-825-4661 — 323269

Delivering Carrier: Fedex FX FE Vehicle or Car Initial: No.

Subject to Section 7 of Conditions of applicable Bill of Lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.
TRINITY HIGHWAY PRODUCTS, LLC
Per Trinity Highway Products,LLC
(Signature of Consignor)

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

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

Agent or Cashier

Per (The signature here acknowledges only the amount prepaid.)

Charges advanced:

Collect On Delivery: $ and remit to:

Street City State

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

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
		Upon delivery, all material subject to Trinity Highway Products,LLC Storage Policy No. LG-002.			
		Project Info: SAMPLES & TESTING TRAINING MTRLS			
	6	11G 12/12'6/3'1.5/S			
	14	533G 6'0 POST/8.5/DDR			
	2	980G T10/END SHOE/SLANT 1"HO.			
	42	3300G 5/8" RD WASHER 1 3/4 OD			
	24	3320G 3/16"X1.75"X3" WASHER			
	154	3340G 5/8" GR HEX NUT			
	64	3360G 5/8"X1.25" GR BOLT			
	48	3400G 5/8"X2" GR BOLT			
	42	3500G 5/8"X10" GR BOLT A307			
	10	3725G 7/8" WASHER F844 TYPE A/N			
	10	3735G 7/8" HEX NUT A-563			
	14	4076B WD BLK RTD 6X8X14			
	16	6149B WD BLK RTD 6X8X18			
	10	6900G 7/8"X15.5" HXBLT A449 5"T			
	4	12227G T12/12'6/3'1.5:6@16.75/S			
	12	14784G 7'0 POST/8.5#/3HI TX			
	2	14785G 6'0 POST/8.5#/3HI TX			
	2	14786G 6'0 POST/8.5#/TRANS TX			
	2	32218G T10/TRAN/TB:WB/ASYM/RT			
	2	35247A CONN PL 40"X20" RT MO			

1 CRATE

GUARDRAIL HWY STEEL
NMFC ITEM 105460
CLASS 50

16-40480

SPECIAL INSTRUCTIONS:

SHIPPER LOAD - CONSIGNEE UNLOAD

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

4

Total Weight 3,971 — 3

ORIGIN — SHIPPER OR AGENT: I hereby authorize this shipment and make the declaration of values (if any) and agree to the contract terms and conditions hereof. SIGN HERE [signature] DATE 2/7/12

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

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

DRIVER NO.

Permanent post-office address of shipper.

TRI 609-RF (R 10/93)

(This Bill of Lading is to be signed by the shipper and agent of the carrier issuing same.)

CONSIGNEE/CUSTOMER COPY

TR No. 405160-34-1 62 2012-11-27

SOLD TO: ADELPHIA METALS I LLC
411 MAIN ST E
NEW PRAGUE, MN 56071-

NUCOR
NUCOR CORPORATION
NUCOR STEEL TEXAS

CERTIFIED MILL TEST REPORT

Ship from:

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

SHIP TO: ADELPHIA METALS-CUST PU
N/A
JEWETT, TX 75846-

Date: 24-May-2012
B.L. Number: 606068
Load Number: 212939

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

NBMG-08 January 1, 2012

LOT # / HEAT #	DESCRIPTION	PHYSICAL TESTS: YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	CHEMICAL TESTS: C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	803585												
JW1210363501	Nucor Steel - Texas	64,200	101,400	12.0%			.41	1.04	.010	.042	.15	.28	.61
JW12103635	16/#5 Rebar	443MPa	699MPa				.14	.10	.042	.004	.002		
	40' A615M GR 420 (Gr60)												
	ASTM A615/A615M-12 GR 60[420]												
	AASHTO M31-07												
PO# =>	803585												
JW1210363601	Nucor Steel - Texas	66,200	103,700	12.0%			.43	1.04	.011	.053	.15	.31	.63
JW12103636	16/#5 Rebar	456MPa	715MPa				.14	.12	.042	.004	.001		
	40' A615M GR 420 (Gr60)												
	ASTM A615/A615M-12 GR 60[420]												
	AASHTO M31-07												

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.
1.) Weld repair was not performed on this material.
2.) Melted and Manufactured in the United States.
3.) Mercury, Radium, or Alpha source materials in any form

QUALITY ASSURANCE: Nathan Stewart

TR No. 405160-34-1 63 2012-11-27

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

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

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

Daniel J. Schacht
Quality Assurance Manager

HEAT NO.:11-07831 SECTION: REBAR 13MM 1/2"(#4) 20'0"GR60 420/60 IMP GRADE: ASTM A615-12 Gr 420/60 ROLL DATE: MELT DATE:	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900

Delivery#: 80765904
BOL#: 70270578
CUST PO#: 564924
CUST P/N:
DLVRY LBS / HEAT: 46092.000 LB
DLVRY PCS / HEAT: 3450 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.47%				
Mn	0.66%				
P	0.015%				
S	0.021%				
Si	0.11%				
Cu	0.35%				
Cr	0.07%				
Ni	0.11%				
Mo	0.018%				
V	0.022%				
Cb	0.000%				
Sn	0.000%				
Al	0.000%				
Yield Strength test 1	65.6ksi				
Tensile Strength test 1	98.9ksi				
Elongation test 1	12%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	1.750IN				
Bend Test 1	Passed				

THIS MATERIAL IS FULLY KILLED, 100% MELTED AND MANUFACTURED IN THE USA, WITH NO WELD REPAIR OR MERCURY CONTAMINATION IN THE PROCESS.

REMARKS :

06/05/2012 20:12:51

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111

Customer:	SAMPLES,TESTING,TRAINING MTRLS	Sales Order:	1164772	Print Date:	2/7/12
	2525 STEMMONS FRWY	Customer PO:	TTI-ET 2000	Project:	SAMPLES & TESTING TTI ET-2000 GILCHRIST/SHI
		BOL #	40479	Shipped To:	TX
		Document #	1	Use State:	TX
	DALLAS, TX 75207				

Trinity Highway Products, LLC

Certificate Of Compliance For Trinity Industries, Inc. ** E.T. PLUS EXTRUDER TERMINAL **

NCHRP Report 350 Compliant

Pieces	Description	Part No
2	12/12'6/6'3/S ET2000 ANC	000032G
2	CABLE ANCHOR BRKT ET-2000	000704A
2	CBL 3/4X6'6/DBL SWG/NOHWD	003000G
22	5/8" GR HEX NUT	003340G
18	5/8"X1.25" GR BOLT	003360G
4	5/8"X10" GR BOLT A307	003500G
4	3/4" ROUND WASHER F436	003701G
4	3/4" HVY HEX NUT A563 DH	003704G
4	3/4"X2.5" HEX BOLT A325	003717G
4	1" ROUND WASHER F844	003900G
4	1" HEX NUT A563	003910G
4	WD BLK RTD 6X8X14	004076B
8	3/8" ROUND WASHER F436	004254G
4	3/8" FENDER WASHER F844	004255G
4	3/8" LOCK WASHER	004258G
4	3/8"X1.5" HEX BOLT GR-5	004261G
4	7/16" WASHER F844	004389G
4	7/16"X1.5" HEX BOLT GRD 5	004390G
4	7/16" LOCK WASHER	004393G
4	7/16" HEX NUT A563 DH	004396G
4	3/4" LOCK WASHER	004699G
4	3/8"X2" HEX BOLT GR-5 HDG	006321G
8	3/8" HVY HEX NUT A563GRDH	006405G
2	12/9'4.5/3'1.5/S	010967G
6	6'0 SYT PST/8.5/31" GR HT	015000G
2	HBA-BRG PL/WELDED TABS	019258A
4	.135(10Ga)X1.75X1.75 WSHR	019948G
2	SYT-3"AN STRT 3-HL 6'6	033795G

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111

Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207

Sales Order: 1164772
Customer PO: TTI-ET 2000
BOL # 40479
Document # 1

Print Date: 2/7/12
Project: SAMPLES & TESTING TTI ET-2000 GILCHRIST/SHI
Shipped To: TX
Use State: TX

Trinity Highway Products, LLC

Certificate Of Compliance For Trinity Industries, Inc. ** E.T. PLUS EXTRUDER TERMINAL **

NCHRP Report 350 Compliant

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

TL -3 or TL-4 COMPLIANT when installed according to manufactures specifications

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Texas, County of Tarrant. Sworn and Subscribed before me this 7th day of February, 2012

Notary Public:
Commission Expires:

JOMARY LUGINSLAND
MY COMMISSION EXPIRES
May 24, 2015

Trinity Highway Products, LLC
Certified By:
Quality Assurance

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111

Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207

Project: SAMPLES & TESTING TRAINING MTRLS

Order Number: 1164715
Customer PO: Samples
BOL Number: 40480
Document #: 1
Shipped To: TX
Use State: TX

As of: 2/7/12

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
6	11G	12/12'6/3'1.5/S	A-500		2	202248	53,600	75,500	29.0	0.190	0.780	0.011	0.020	0.120	0.120	0.00	0.050	0.002	4
			M-180	A	2	101800	50,000	73,300	30.0	0.190	0.750	0.012	0.002	0.020	0.120	0.000	0.070	0.002	4
			M-180	A	2	101802	51,800	74,700	29.0	0.190	0.770	0.009	0.002	0.020	0.120	0.000	0.050	0.002	4
			M-180	A	2	101804	54,500	75,800	28.0	0.190	0.800	0.011	0.002	0.020	0.120	0.000	0.050	0.002	4
			M-180	A	2	102475	58,700	79,800	25.0	0.200	0.820	0.010	0.010	0.007	0.130	0.000	0.050	0.000	4
			M-180	A	2	102476	58,100	77,900	26.0	0.190	0.750	0.009	0.001	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	202249	51,800	74,500	30.0	0.190	0.790	0.010	0.002	0.020	0.120	0.000	0.050	0.002	4
			M-180	A	2	202250	54,100	76,100	27.0	0.200	0.820	0.012	0.002	0.020	0.120	0.000	0.050	0.003	4
			M-180	A	2	202938	57,600	80,400	25.0	0.190	0.830	0.009	0.001	0.020	0.130	0.000	0.050	0.003	4
			M-180	A	2	202939	56,800	78,400	25.0	0.190	0.770	0.009	0.004	0.020	0.130	0.000	0.050	0.003	4
14	533G	6'0 POST/8.5/DDR	A-36			1017017	53,642	71,899	26.8	0.110	0.960	0.008	0.038	0.180	0.260	0.00	0.090	0.004	4
	533G		A-36			1017007	53,613	72,244	25.7	0.120	0.930	0.012	0.040	0.180	0.360	0.00	0.140	0.003	4
	533G		A-36			1016666	56,666	73,288	29.7	0.110	0.940	0.013	0.037	0.190	0.320	0.00	0.150	0.004	4
	533G		A-36			1017003	55,742	71,204	24.3	0.100	0.950	0.014	0.046	0.180	0.300	0.00	0.160	0.004	4
2	980G	T10/END SHOE/SLANT	A-36			125745	58,100	66,100	31.9	0.050	0.570	0.012	0.003	0.030	0.100	0.01	0.050	0.000	4
4	12227G	T12/12'6/3'1.5:6@1'6.75/S	M-180	A	2	150054	61,580	80,600	25.0	0.190	0.720	0.010	0.003	0.010	0.130	0.00	0.060	0.001	4
12	14784G	7'0 POST/8.5#/3HI TX	A-36			1014849	50,787	69,032	25.6	0.100	0.960	0.015	0.037	0.180	0.310	0.00	0.180	0.003	4
	14784G		A-36			1014844	53,141	69,983	28.3	0.110	0.960	0.010	0.037	0.180	0.330	0.00	0.110	0.003	4
	14784G		A-36			1014840	57,069	73,001	30.4	0.110	0.960	0.010	0.035	0.170	0.320	0.00	0.150	0.004	4

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111
Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207
Project: SAMPLES & TESTING TRAINING MTRLS

Order Number: 1164715
Customer PO: Samples
BOL Number: 40480
Document #: 1
Shipped To: TX
Use State: TX

As of: 2/7/12

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
	14784G		A-36			1014843	55,191	72,737	29.7	0.110	0.950	0.010	0.035	0.180	0.310	0.00	0.120	0.003	4
2	14785G	6'0 POST/8.5#/3HI TX	A-36			1013730	50,597	70,003	26.7	0.110	0.970	0.012	0.032	0.180	0.270	0.00	0.140	0.004	4
2	14786G	6'0 POST/8.5#/TRANS TX	A-36			1014843	55,191	72,737	29.7	0.110	0.950	0.010	0.035	0.180	0.310	0.00	0.120	0.003	4
2	32218G	T10/TRAN/TB:WB/ASYM/R	M-180	B	2	24240	66,000	77,100	33.1	0.060	1.250	0.011	0.004	0.021	0.030	0.04	0.030	0.004	4
2	35247A	CONN PL 40"X20" RT MO	A-36			B056774	59,800	70,100	31.9	0.200	0.410	0.010	0.007	0.060	0.290	0.00	0.080	0.001	4

TL -3 or TL-4 COMPLIANT when installed according to manufactures specifications

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

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

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.

BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111
Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207

Project: SAMPLES & TESTING TRAINING MTRLS

Order Number: 1164715
Customer PO: Samples
BOL Number: 40480
Document #: 1
Shipped To: TX
Use State: TX

As of: 2/7/12

State of Texas, County of Tarrant. Sworn and subscribed before me this 7th day of February, 2012

Notary Public:
Commission Expires: /

JOMARY LUGINSLAND
MY COMMISSION EXPIRES
May 24, 2015

Trinity Highway Products, LLC
Certified By:
Quality Assurance

Certified Test Report

NORTH STAR BLUESCOPE STEEL LLC
6767 County Road 9
Delta, Ohio 43515
Telephone: (888) 822-2112

Customer:
Trinity Industries
1170 N. State St.
Girard, OH 44420
Customer P.O.: 117696
Cust. Ref/Part # guardrail - spot

Order Number 113524
Line Item Number 1
Heat Number 70978
Coil Number 597652

Ordered Width (mm/in) 1511.300 / 59.500
Ordered Gauge (mm/in) 2.438 / 0.096
Material Description ASTM A568, 1021 CQ Modified
Production Date/Time Aug 1 2005 7:13PM

Heat Chemical Analysis (wt%)

Type	C	Mn	P	S	Si	Al	Cu	Cr	Ni	Mo	Sn	N	B	V	Nb	Ti	Ca
Heat	0.20	0.74	0.012	0.002	0.02	0.02	0.09	0.04	0.03	0.01	0.00	0.006		0.000	0.001	0.001	0.001

Mechanical Test Report

All mechanical tests are performed on a sample from the tail of a coil.

Yield Strength	Tensile Strength	% Elongation in 2 Inches
60,770 psi	78,960 psi	28.0%

This material has been produced and tested in accordance with each of the following applicable standards: ASTM E 1806-96, ASTM E 415-99a, ASTM A 751-01, ASTM A 370-03a, JIS Z2201:1998, JIS Z 2241:1998. This report certifies that the above test results are representative of those contained in the records of North Star BlueScope Steel LLC for the material identified in this test report and is intended to comply with the requirements of the material description. North Star BlueScope Steel LLC is not responsible for the inability of this material to meet specific applications. Any modifications to this certification as provided negates the validity of this test report. All reproductions must have the written approval of North Star BlueScope Steel. This product was manufactured, melted, cast, and hot-rolled (min. 3:1 reduction ratio), entirely within the U.S.A at North Star BlueScope Steel LLC, Delta, Ohio. This material was not exposed to Mercury or any alloy which is liquid at ambient temperature during processing or while in North Star BlueScope Steel LLC possession. Test equipment calibration certificates are available upon request. NIST traceability is established through test equipment calibration certificates which are available upon request. Uncertainty calculations are calculated in accordance with NIST standards and are maintained at a 4:1 ratio in accordance with NIST standards. Uncertainty data is available upon request.

Tim Mitchell — Manager Quality Assurance and Technology

Date Issued: Aug 17, 2005 14:36:14
Revision#: 01

DARLING BOLT COMPANY
2941 E. 10 MILE ROAD
WARREN, MI 48091-1300
(586) 757-4100
FAX (586) 757-1555

MATERIAL CERTIFICATION

CUSTOMER: MACK BOLT STEEL & MACHINE

CUSTOMER ORDER NO: 23447

DARLING BOLT ORDER NO: 1169443

DATE SHIPPED: 8/6/12

CUSTOMER PART NO:

QUANTITY SHIPPED: 1 PC

DESCRIPTION: 7/8-9X22 HEX HD CAP CUT FROM 7/8-9X24 GR8 PLAIN

LOT NO: 6000512/F2J0226100

CUSTOMER SPECIFICATION: SAE J429

COUNTRY OF ORIGIN: KOREA

STEEL TYPE: 4140

STEEL HEAT NO: U693219

STEEL CHEMISTRY

C	MN	P	S	SI	NI	CR	MO	CU	AL
.40	.77	.016	.012	.21	.09	1.03	.17	.12	.013

PHYSICAL PROPERTIES

TENSILE STRENGTH		YIELD STRENGTH		RED. OF	SURFACE HDN		CORE HDN	
PSI REQ	TEST RESULTS	PSI	ELONG %	AREA%	R30N	RC	BHN	RC
120,000	169,425	157,275	16	55	56.5			36

"I certify that the material or product described in this report has been inspected and/or tested, and that such specimens or samples as have been inspected or tested were taken from the lot of quantity described herein and the material meets the blueprint specification or other requirements specifically stated on the purchase order."

DARLING BOLT COMPANY

Marina Meriggi

Marina Meriggi
Quality Assurance
Marina@darlingbolt.com

DARLING BOLT COMPANY
2941 E. 10 MILE ROAD
WARREN, MI 48091-1300
(586) 757-4100
FAX (586) 757-1555

MATERIAL CERTIFICATION

CUSTOMER: MACK BOLT STEEL & MACHINE | CUSTOMER ORDER NO: 23447

DARLING BOLT ORDER NO: 1169443 | DATE SHIPPED: 8/6/12

CUSTOMER PART NO: | QUANTITY SHIPPED: 4 PC

DESCRIPTION: 7/8-9X18 HEX HD CAP GR5 PLAIN | LOT NO: 6000928/F2J2531400

CUSTOMER SPECIFICATION: SAE J429 ASTM A449 | COUNTRY OF ORIGIN: KOREA

STEEL TYPE: S45C | STEEL HEAT NO: 313232

STEEL CHEMISTRY

C	MN	P	S	SI	NI	CR	MO	CU	AL
.44	.71	.012	.014	.21	.07	.16	.03	.17	

PHYSICAL PROPERTIES

TENSILE STRENGTH PSI REQ	TENSILE STRENGTH TEST RESULTS	YIELD STRENGTH PSI	ELONG %	RED. OF AREA%	SURFACE HDN R30N	SURFACE HDN RC	CORE HDN BHN	CORE HDN RC
120,000	137,825	109,575	19	51	51			29

"I certify that the material or product described in this report has been inspected and/or tested, and that such specimens or samples as have been inspected or tested were taken from the lot of quantity described herein and the material meets the blueprint specification or other requirements specifically stated on the purchase order."

DARLING BOLT COMPANY
Marina Meriggi (signature)
Marina Meriggi
Quality Assurance
Marina@darlingbolt.com

DARLING BOLT COMPANY
2941 E. 10 MILE ROAD
WARREN, MI 48091-1300
(586) 757-4100
FAX (586) 757-1555

MATERIAL CERTIFICATION

CUSTOMER: MACK BOLT STEEL & MACHINE

CUSTOMER ORDER NO: 23447

DARLING BOLT ORDER NO: 1169443

DATE SHIPPED: 8/6/12

CUSTOMER PART NO:

QUANTITY SHIPPED: 4 PC

DESCRIPTION: 7/8-9X16 HEX HD CAP GR5 PLAIN

LOT NO: 6001486/F2K1942000

CUSTOMER SPECIFICATION: SAE J429 ASTM A449

COUNTRY OF ORIGIN: KOREA

STEEL TYPE: S45C

STEEL HEAT NO: 313229

STEEL CHEMISTRY

C	MN	P	S	SI	NI	CR	MO	CU	AL
.44	.69	.009	.013	.21	.05	.11	.02	.14	

PHYSICAL PROPERTIES

TENSILE STRENGTH		YIELD STRENGTH		RED. OF	SURFACE HDN		CORE HDN	
PSI REQ	TEST RESULTS	PSI	ELONG %	AREA%	R30N	RC	BHN	RC
120,000	135,375	105,675	20	50	52			27

"I certify that the material or product described in this report has been inspected and/or tested, and that such specimens or samples as have been inspected or tested were taken from the lot of quantity described herein and the material meets the blueprint specification or other requirements specifically stated on the purchase order."

DARLING BOLT COMPANY

Marina Meriggi

Marina Meriggi
Quality Assurance
Marina@darlingbolt.com

DARLING BOLT COMPANY
2941 E. 10 MILE ROAD
WARREN, MI 48091-1300
(586) 757-4100
FAX (586) 757-1555

MATERIAL CERTIFICATION

CUSTOMER: MACK BOLT STEEL & MACHINE

CUSTOMER ORDER NO: 23447

DARLING BOLT ORDER NO: 1169443

DATE SHIPPED: 8/6/12

CUSTOMER PART NO:

QUANTITY SHIPPED: 3 PC

DESCRIPTION: 7/8-9X14 HEX HD CAP GR5 PLAIN

LOT NO: 6000898/F2J2280000

CUSTOMER SPECIFICATION: SAE J429 ASTM A449

COUNTRY OF ORIGIN: KOREA

STEEL TYPE: S45C

STEEL HEAT NO: SW03229

STEEL CHEMISTRY

C	MN	P	S	SI	NI	CR	MO	CU	AL
.44	.69	.015	.007	.21					

PHYSICAL PROPERTIES

TENSILE STRENGTH PSI REQ	TEST RESULTS	YIELD STRENGTH PSI	ELONG %	RED. OF AREA%	SURFACE HDN R30N	SURFACE HDN RC	CORE HDN BHN	CORE HDN RC
120,000	138,025	121,900	20	52	51			30

"I certify that the material or product described in this report has been inspected and/or tested, and that such specimens or samples as have been inspected or tested were taken from the lot of quantity described herein and the material meets the blueprint specification or other requirements specifically stated on the purchase order."

DARLING BOLT COMPANY

Marina Meriggi
Quality Assurance
Marina@darlingbolt.com

APPENDIX E. CRASH TEST NO. 405160-34-1

E1. VEHICLE PROPERTIES AND INFORMATION

Table E1. Vehicle properties for test 405160-34-1.

Date: 2012-08-10 Test No.: 405160-34-1 VIN No.: 1D7HA18X7J531594

Year: 2007 Make: Dodge Model: Ram 1500

Tire Size: 265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 129681

Note any damage to the vehicle prior to test: ______

● Denotes accelerometer location.

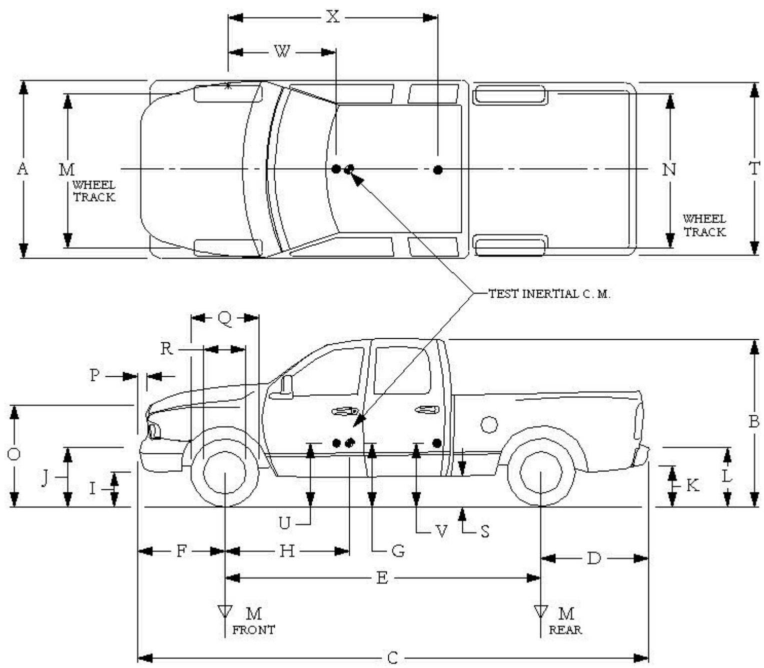
NOTES: ______

Engine Type: V-8
Engine CID: 4.7 liter

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

Optional Equipment: ______

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



Geometry: inches

A	78.25	F	36.00	K	20.50	P	2.88	U	28.50
B	75.00	G	28.50	L	29.12	Q	31.25	V	29.50
C	223.75	H	62.12	M	68.50	R	18.38	W	60.50
D	47.25	I	13.75	N	68.00	S	12.00	X	78.00
E	140.50	J	25.38	O	44.50	T	77.50		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	5.00	Bottom Frame Height - Front	17.125
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	10.25	Bottom Frame Height - Rear	24.75

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2853	2804	
Back	3900	M_{rear}	2057	2222	
Total	6700	M_{Total}	4910	5026	

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

Mass Distribution:
lb LF: 1410 RF: 1394 LR: 1115 RR: 1107

Table E2. Measurements of vehicle vertical CG for test 405160-34-1.

Date: 2012-08-10 Test No.: 405160-34-1 VIN: 1D7HA18X7J531594

Year: 2007 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Pickup Mileage: 129681

Engine: V-8 4.7 liter Transmission: Automatic

Fuel Level: Empty Ballast: 19 lb weight at front of bed (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70R17

Measured Vehicle Weights: (lb)						
LF:	1410	RF:	1394	Front Axle:	2804	
LR:	1115	RR:	1107	Rear Axle:	2222	
Left:	2525	Right:	2501	Total:	5026	
				5000 ±110 lb allowed		
Wheel Base:	140.5 inches	Track: F:	68.5 inches	R:	68	inches
	148 ±12 inches allowed		Track = (F+R)/2 = 67 ±1.5 inches allowed			
Center of Gravity, SAE J874 Suspension Method						
X:	62.12 in	Rear of Front Axle	(63 ±4 inches allowed)			
Y:	-0.16 in	Left - Right +	of Vehicle Centerline			
Z:	28.5 in	Above Ground	(minumum 28.0 inches allowed)			

Hood Height: 44.50 inches Front Bumper Height: 25.3785 inches

43 ±4 inches allowed

Front Overhang: 36.00 inches Rear Bumper Height: 29.125 inches

39 ±3 inches allowed

Overall Length: 223.75 inches

237 ±13 inches allowed

Table E3. Exterior crush measurements for test 405160-34-1.

Date: 2012-08-10 Test No.: 405160-34-1 VIN No.: 1D7HA18X7J531594

Year: 2007 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	23	13	24	13	9	7	3.5	1.5	0	-12
2	Side plane at bumper ht	23	17	40	0	3.5	8	11	15	17	+67
	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.

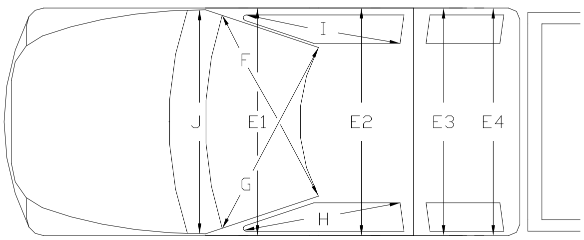
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

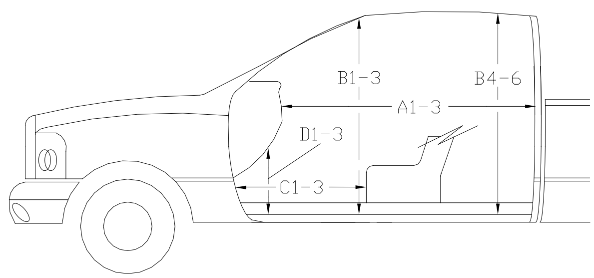
***Measure and document on the vehicle diagram the location of the maximum crush.

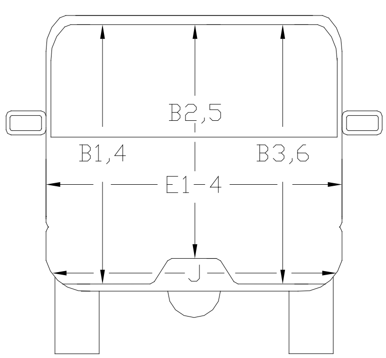
Note: Use as many lines/columns as necessary to describe each damage profile.

Table E4. Occupant compartment measurements for test 405160-34-1.

Date:	2012-08-10	Test No.:	405160-34-1	VIN No.:	1D7HA18X7J531594
Year:	2007	Make:	Dodge	Model:	Ram 1500







OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	**After** (inches)
A1	64.50	64.00
A2	64.50	64.25
A3	65.00	65.00
B1	42.12	41.50
B2	39.00	39.00
B3	45.12	45.50
B4	42.12	42.12
B5	44.75	44.75
B6	42.12	42.12
C1	29.25	24.25
C2	----	----
C3	26.00	26.00
D1	12.75	14.50
D2	----	----
D3	11.50	11.50
E1	62.50	61.75
E2	64.25	65.50
E3	63.75	63.50
E4	64.00	64.00
F	60.00	60.00
G	60.00	60.00
H	39.00	39.00
I	39.00	39.00
J*	62.00	59.12

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

E2. SEQUENTIAL PHOTOGRAPHS

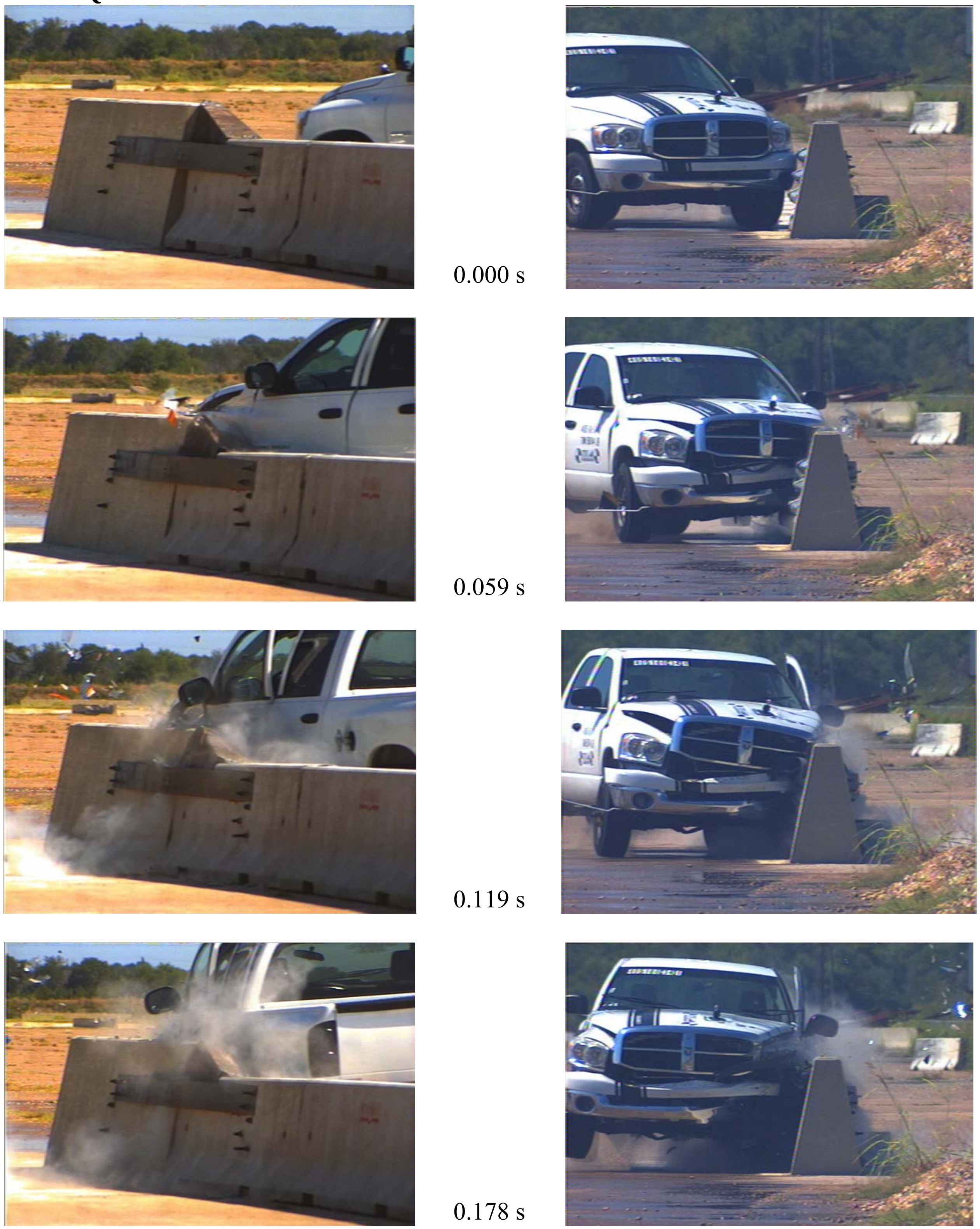


Figure E1. Sequential photographs for test 405160-34-1
(field side and frontal views).

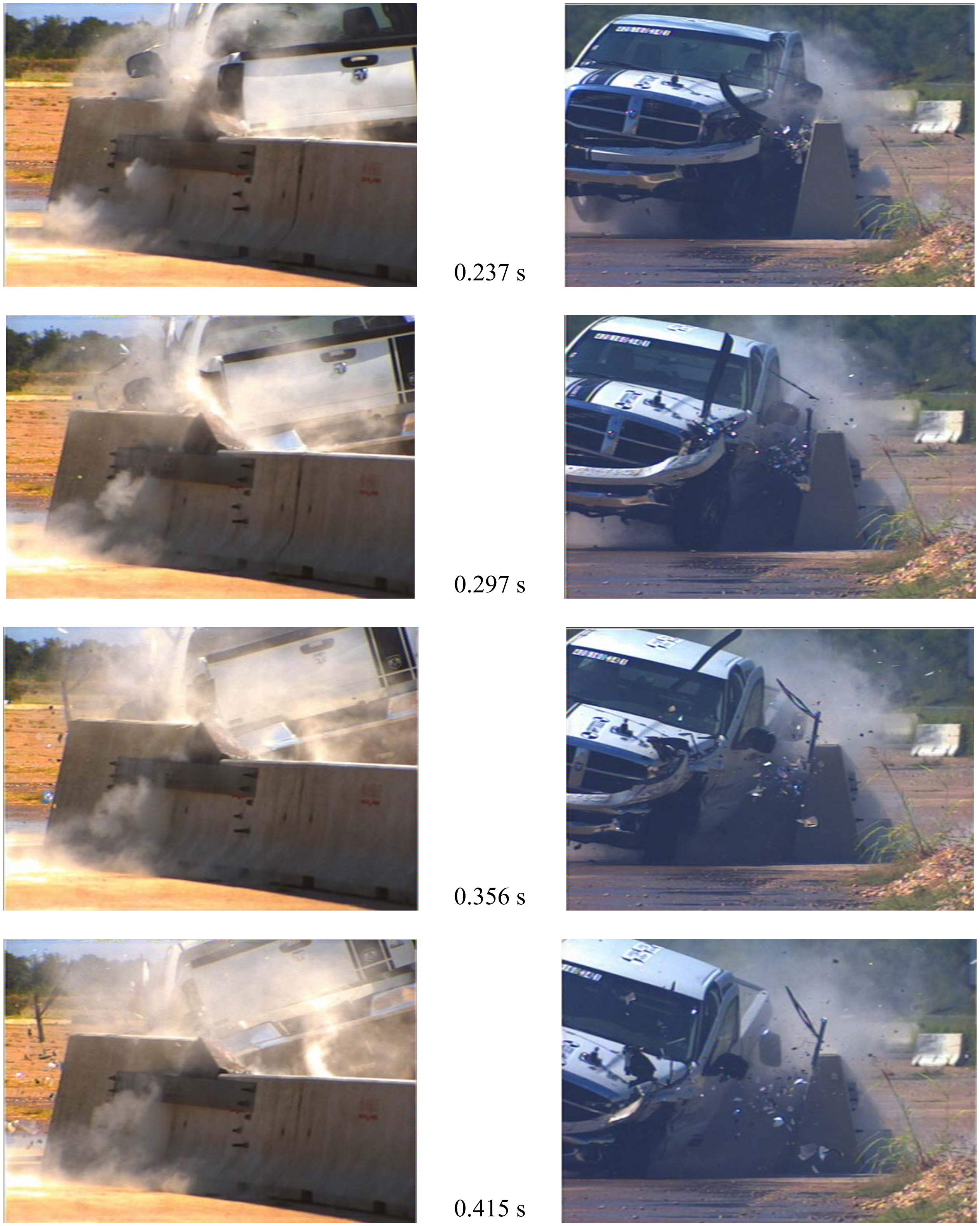


Figure E1. Sequential photographs for test 405160-34-1
(field side and frontal views) (continued).

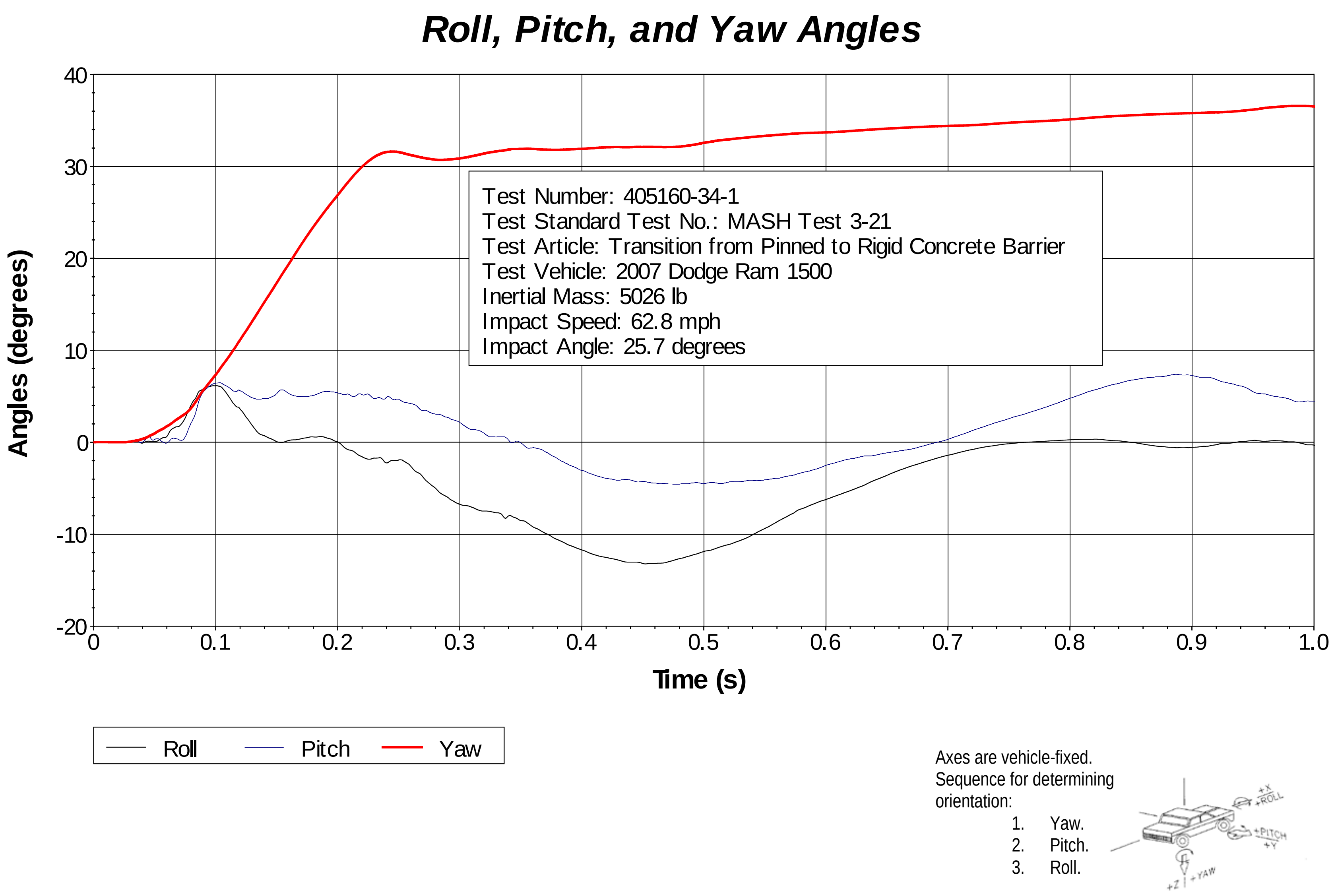


Figure E2. Vehicle angular displacements for test 405160-34-1.

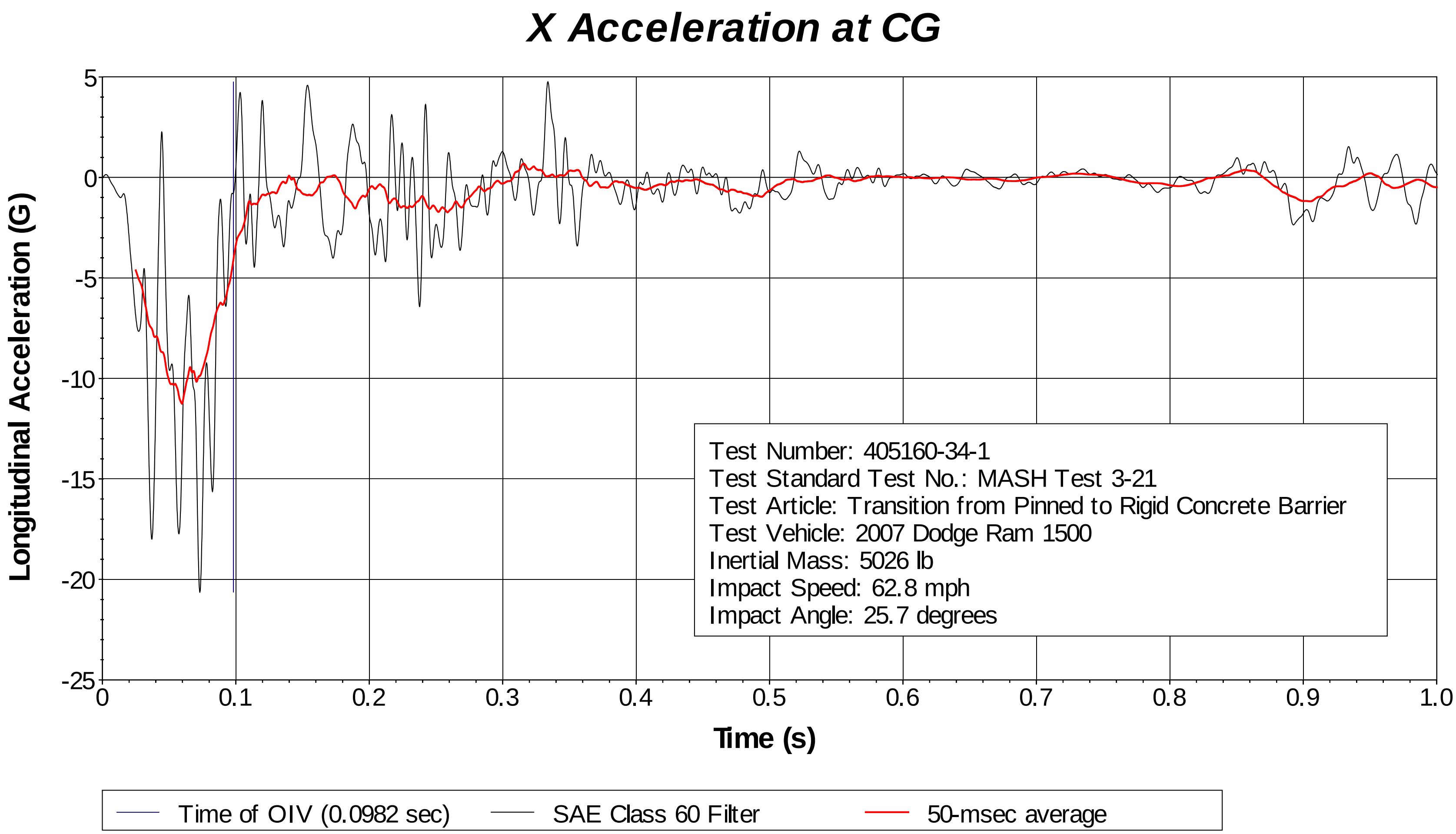


Figure E3. Vehicle longitudinal accelerometer trace for test 405160-34-1 (accelerometer located at center of gravity).

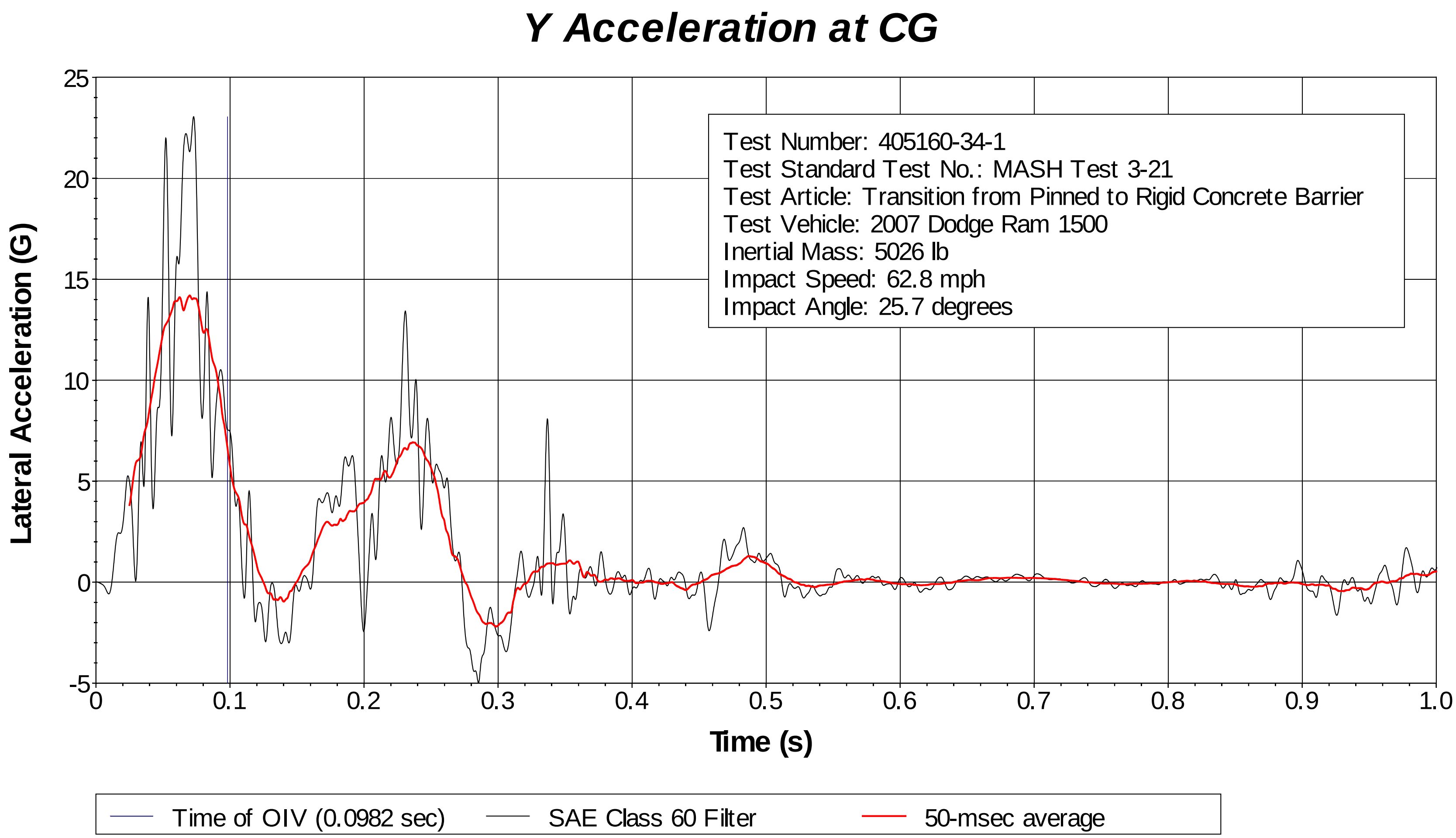


Figure E4. Vehicle lateral accelerometer trace for test 405160-34-1
(accelerometer located at center of gravity).

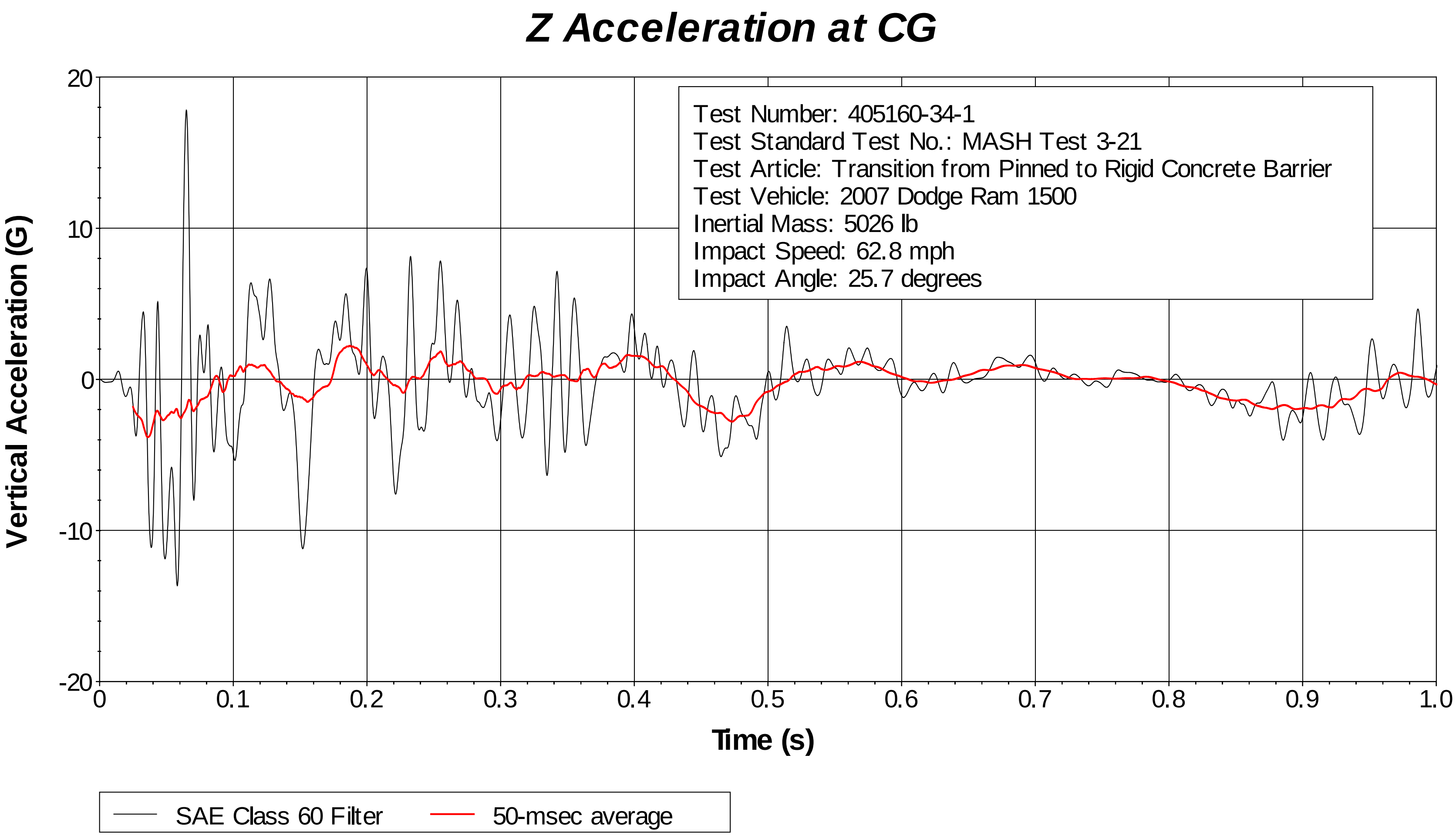


Figure E5. Vehicle vertical accelerometer trace for test 405160-34-1
(accelerometer located at center of gravity).

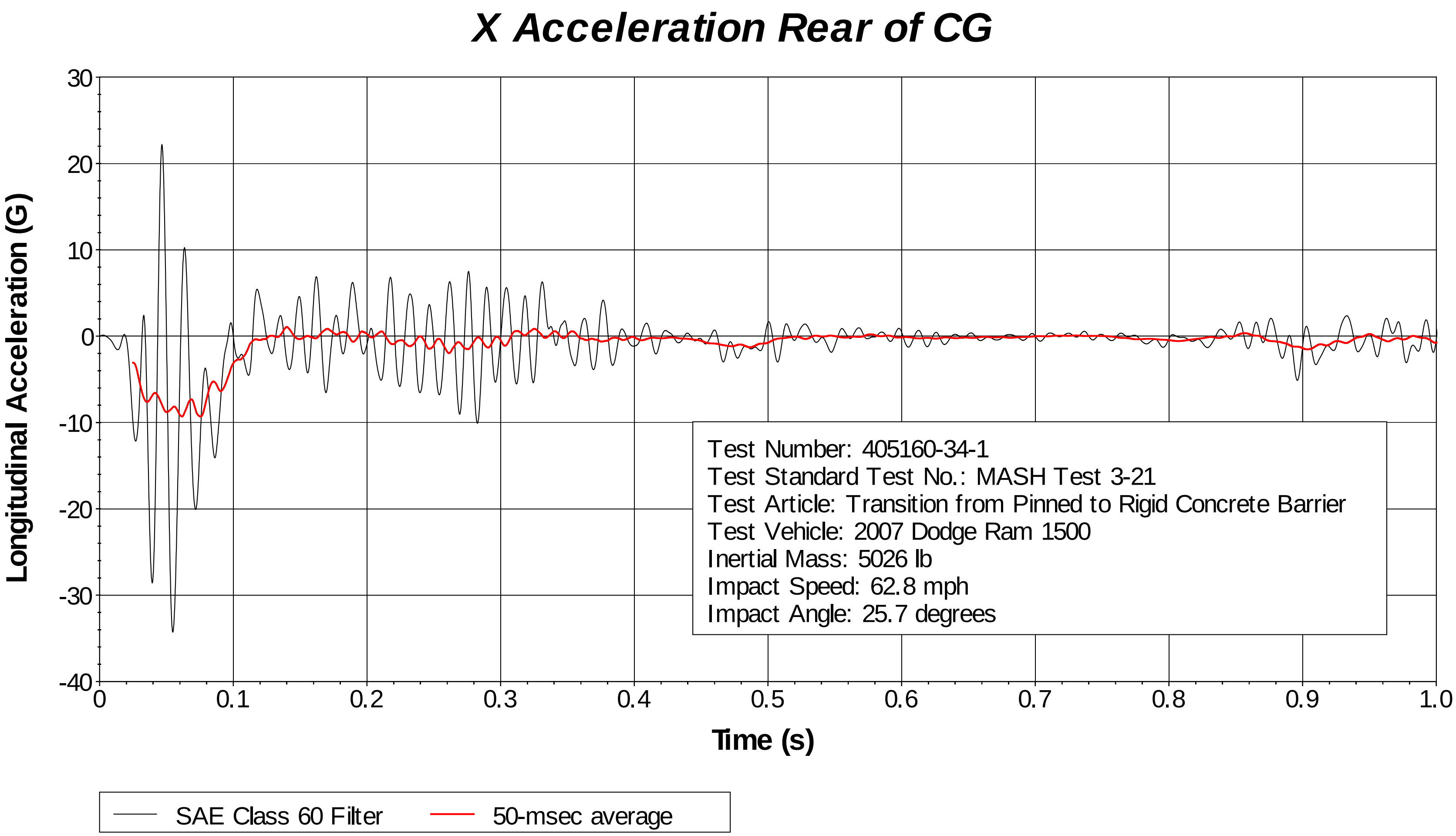


Figure E6. Vehicle longitudinal accelerometer trace for test 405160-34-1
(accelerometer located rear of center of gravity).

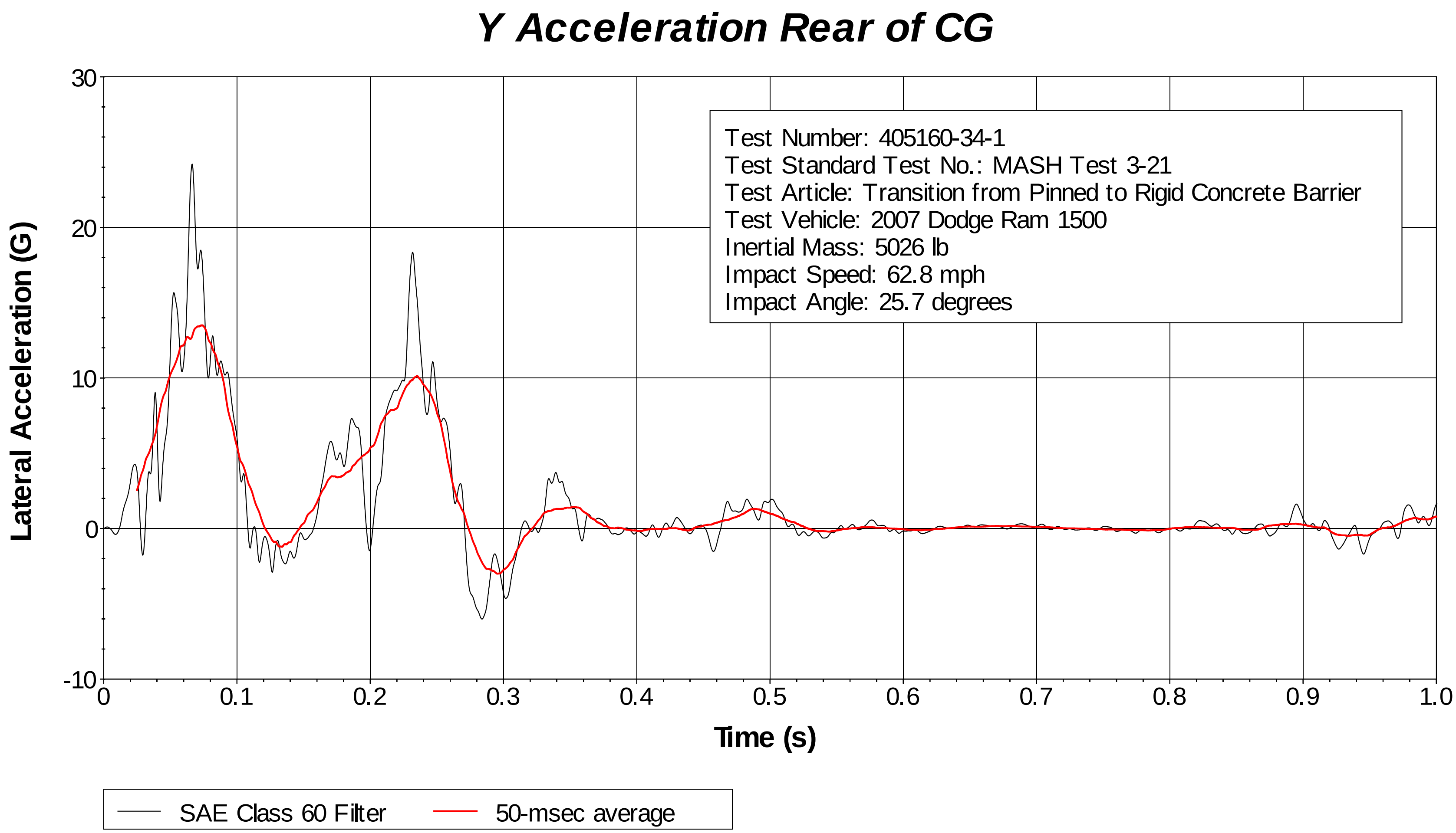


Figure E7. Vehicle lateral accelerometer trace for test 405160-34-1
(accelerometer located rear of center of gravity).

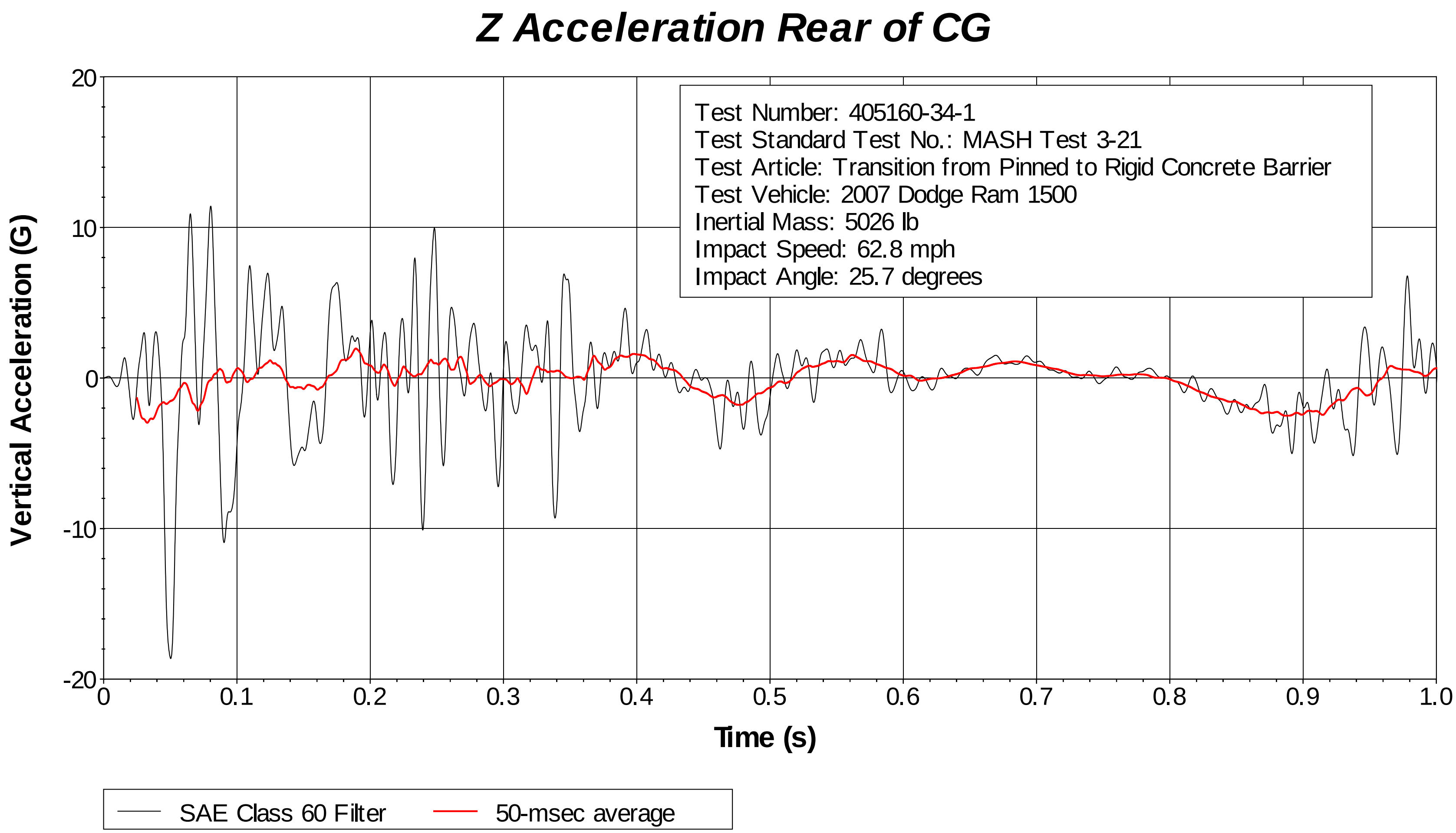


Figure E8. Vehicle vertical accelerometer trace for test 405160-34-1
(accelerometer located rear of center of gravity).