Roadside Safety Pooled Fund

Texas A&M Transportation Institute Proving Ground

Test Report No.: 405160-26
Test Report Date: March 2013

DEVELOPMENT AND TESTING OF A TRANSITION FROM FREE-STANDING TO PINNED TEMPORARY CONCRETE BARRIER

by

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16. Abstract

In 2008, Texas A&M Transportation Institute 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. The objective of this research was to develop a transition design that can be used to transition from a free-standing F-shape temporary concrete barrier system to the pinned down F-shape barrier placed on concrete pavement or bridge deck.

The transition was developed in accordance with American Association of State Highway and Transportation Officials' (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) test level 3 criteria, using the existing F-shape pinned concrete barrier design to the extent possible. The researchers developed a transition design concept and used full-scale finite element vehicular impact analysis to determine the critical impact point (CIP) of the transition design. The design was subsequently crash tested in accordance with *MASH* test 3-21 criteria (5000-lb vehicle, 62 mi/h, 25 degrees) at the critical impact point.

Results of the crash test were evaluated to determine that the transition from the free-standing to anchored F-shape barrier placed on concrete performed acceptably for *MASH* test level 3.

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

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Unclassified	Unclassified	100	

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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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1. INTRODUCTION

1.1 PROBLEM

TTI recently developed a pinned down F-shaped temporary concrete barrier system that provides limited lateral deflection (less than 6 inches) and can be used for bridge or roadway applications *(1)*. The design was developed for use on concrete pavements or bridge decks as thin as seven inches. If this application is used on a roadway and bridge project, it is possible that a non-anchored free-standing barrier section will be used with the anchored section. A transition detail from the anchored to free-standing barrier is needed to prevent increased occupant risk or vehicle instability due to abrupt changes in barrier's lateral stiffness.

1.2 BACKGROUND

In 2008, TTI developed a restrained F-shaped temporary concrete barrier design that was easy to install and minimized damage to the bridge deck or concrete 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 short distance into the underlying concrete pavement, thus locking the barrier in place. The pinned 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 the free-standing barrier.

In 2003, Midwest Roadside Safety Facility (MwRSF) developed a concrete bridge deck tie-down system for 12.5 ft long, F-shaped 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 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 pavement. The maximum static and dynamic deflections in the test were 11.1 inches and 21.8 inches, respectively.

In this same study, MwRSF also developed a transition from the free-standing 12.5-ft long temporary concrete barrier to the anchored temporary concrete barrier design developed earlier in 2003. The transition section 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 segment 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.

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 (*5*). 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 a transition design that can be used to transition from a free-standing F-shape barrier (placed on concrete or asphalt pavement) to the pinned F-shape barrier placed on concrete. If it were determined during initial evaluation that a single transition design could not be achieved for placement on concrete and asphalt, the transition was to be developed for use with the free-standing and pinned barriers placed on concrete only.

The transition was developed in accordance with American Association of State Highway and Transportation Officials' (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) test level 3 criteria (*6*), using the existing pinned concrete barrier design to the extent possible.

The researchers developed the transition design using finite element simulation analysis. The analysis was used to determine the critical impact point for the *MASH* test 3-21. In the first phase of the project, a transition design was developed and crash tested, but it failed to meet the *MASH* requirements. Results of the failed crash test have been included in appendix A for the purpose of documenting work performed under this project. Subsequent to the failed test, the researchers redesigned the transition and determined its critical impact point using finite element (FE) analysis. Details of the FE analysis are presented in chapter 2. The researchers then performed *MASH* test 3-21 (5000-lb vehicle, 62 mi/h, 25 degrees) with the transition design. Included in the main body of this report are the details of the installation used in the crash testing, details of the full-scale crash testing, and evaluation of the crash testing.

2. DESIGN AND SIMULATION ANALYSIS*

2.1 INTRODUCTION

In a separate research project, the researchers developed and crash tested an anchored F-shape temporary concrete barrier design for placement on asphalt (*7*). Component level testing performed under this project showed that three pins were needed to anchor the 12.5-ft long concrete barrier segment to asphalt. The existing design for anchoring the barrier on concrete however, requires two pins per 12.5-ft barrier segment. Due to the differences in the number of pins required to anchor the barriers on concrete and asphalt, it was determined that a single transition design could not be developed for placement on both concrete and asphalt. Thus in this project, the researchers focused on developing the transition design for placement on concrete pavement or deck only. The design developed in this project may be extended to use on asphalt after further evaluation through simulation and crash testing. However, within the budgetary constraints of the project, only placement on concrete could be evaluated.

A transition design was developed in the earlier phase of the project. However, this initial design failed to meet the crash test performance requirements of *MASH*. The vehicle in the test was redirected, but a high roll was induced during redirection, which resulted in the vehicle stopping on one of its side. Details of this failed test are included in appendix A. Subsequent to this test, the researchers redesigned the transition and conducted finite element analysis to find the critical impact point. This final design was crash tested and was successful in meeting the *MASH* test 3-21 criteria for transitions.

Described in this chapter are the details of the final transition's conceptual design and the full-scale impact analysis performed to determine the critical impact point (CIP) for crash testing.

2.2 TRANSITION DESIGN CONCEPT

One of desired objectives was to keep the transition design relatively simply by not attaching external members to the barrier segments (such as bolting thrie beam rail elements to the face of the barriers, attaching other brackets or straps, etc.). The transition concept was thus simple with one standard F-shape barrier segment in the transition region that connected the free-standing and the anchored barrier segment (see figure 2.1). The design of the transition segment was kept exactly the same as the anchored segments. However, only one pin was used in the transition segment to pin it to the underlying concrete, near the anchored barrier end of the installation. The drop-pin used in the transition segment was the same 1½-inch diameter pin used to anchor the existing pinned-down barrier.

* TTI Proving Ground's A2LA scope of accreditation does not include simulation analysis.

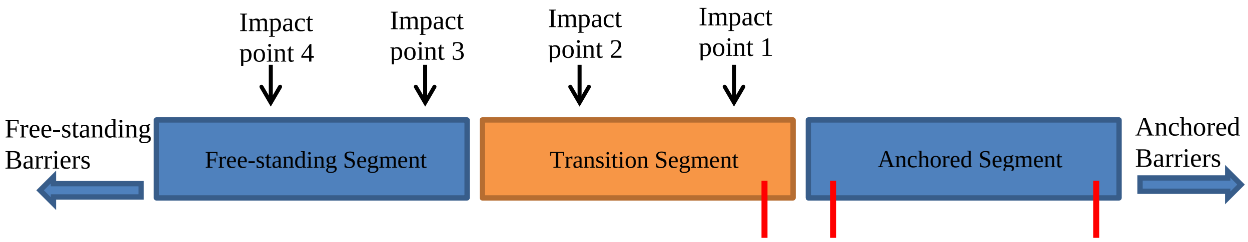
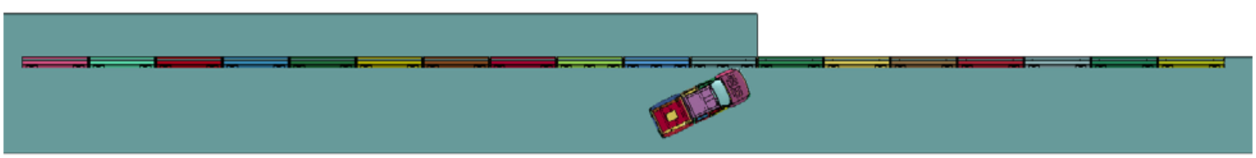


Figure 2.1. Transition design concept and impact location.

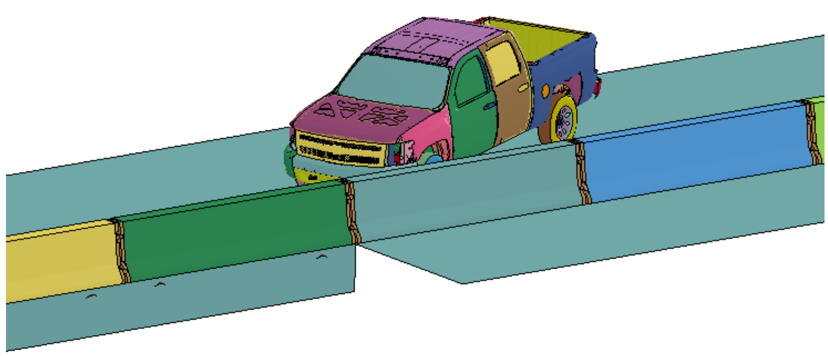
2.3 CRITICAL IMPACT POINT

MASH recommends using FE analysis to determine the CIP for a transition design. The researchers developed a full-scale FE model of the barrier system to perform *MASH* Test 3-21 impact simulations. The barrier system was comprised of the 12.5-ft long F-shape free-standing barrier segments, one transition segment with one drop-pin, and the standard anchored barrier system with two drop-pins per segment (see figure 2.2). The pinned-down anchored barrier segments were placed adjacent to the ground's edge, simulating a bridge deck drop-off. The free-standing segments and the transition segment were placed on the ground with no drop-off on the field side.

The barrier segments were modeled using mostly rigid material representation. However, regions around the drop-pin holes where pins were passed to anchor the barrier were modeled using concrete material model with material failure capabilities. Holes in the underlying concrete pavement that host the steel drop-pin were also modeled using concrete material properties with material failure capabilities. The connections between adjacent barrier segments were modeled with elastic-plastic material properties. The vehicle model used in the simulations was developed by National Crash Analysis Center (NCAC) and incorporated various modifications made by TTI to improve its performance and robustness.



Top View



Iso View

Figure 2.2. Finite element model of the barrier system for determining CIP.

Vehicle impact simulations were performed at the four impact locations shown in figure 2.1 to determine the most critical impact point for use in crash testing. The first impact point was selected just upstream of the anchoring pin in the transition segment. The second, third and fourth impact points were spaced 6.25 ft apart. Each of the simulations was performed using test 3-21 impact conditions of *MASH* (i.e., 5000-lb pickup truck vehicle, impacting the installation at 62.2 mi/h and 25 degrees). The objective of these simulations was to determine the critical impact point, at which the vehicle would have the greatest instability due to pocketing of the barrier system. Results of the impact analyses are shown in figures 2.3 and 2.4.

In addition to the four simulation cases described above, a simulation was performed with the vehicle impacting the existing pinned-down anchored concrete barrier system. Results of this simulation were used to compare the performance of the transition impact simulations.

Simulation results for impacts closer to the standard anchored barrier (impact point 1 and 2) indicated that the barriers do not deflect significantly (see simulation results for impact points 1 and 2 in figure 2.3). The behavior of the barrier for impact points 1 and 2 was very similar to impact with standard anchored barrier installation (also shown in figure 2.3). Vehicle impacts closer to the standard anchored barrier do not allow enough interaction with the vehicle for the barrier segments in the free standing and the transition region to deflect laterally. Thus, vehicle pocketing cannot be evaluated with these impact points. For this reason, it was concluded that impact points 1 and 2 are not the critical impact points.

Simulation results for impact points 3 and 4, which are farther upstream from the start of the standard anchored barrier segments, showed greater lateral barrier deflection than impact points 1 and 2. For impact point 3, the vehicle had significant chance of pocketing due to the lateral deflection of the barriers. Even though the lateral deflection increased for impact point 4, the performance at this point resembled that of a free standing barrier, as opposed to a transition. For this reason, it can be seen in figure 2.4 that the vehicle is more stable for impact point 4 compared to impact point 3.

Since impact point 3 offers greatest chance of vehicle instability and pocketing, it was selected as the CIP for the transition design. This impact point was 14.67 ft upstream from the joint between the transition barrier segment and the anchored barrier segment. A crash test was subsequently performed at this impact point, and the details are presented in the following chapters.

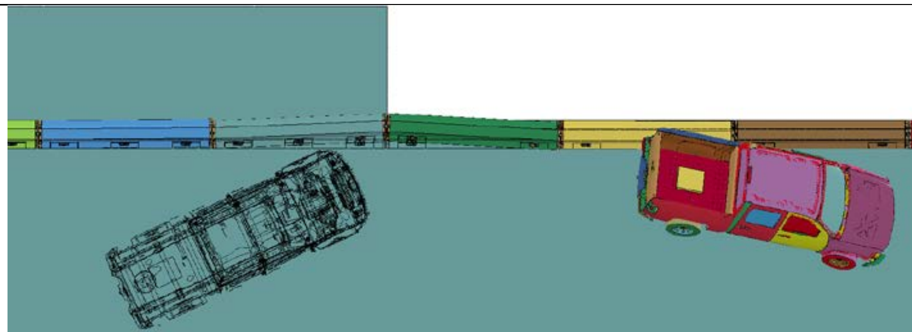
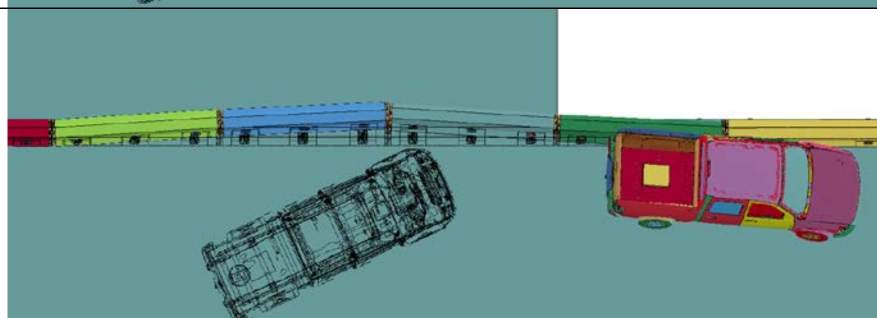
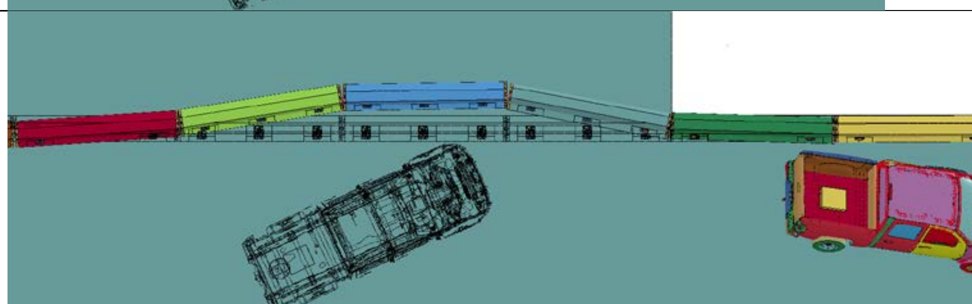
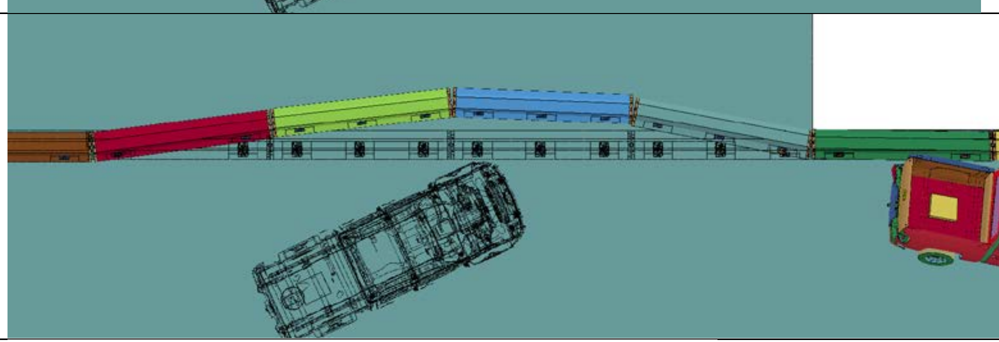
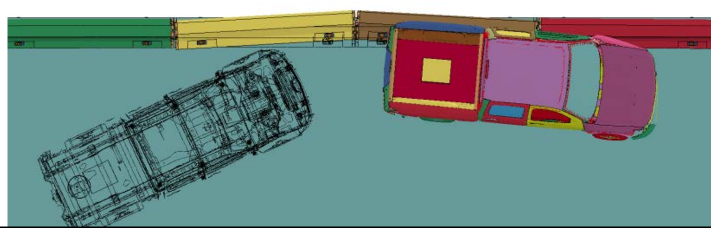
IMPACT POINT 1	
IMPACT POINT 2	
IMPACT POINT 3	
IMPACT POINT 4	
IMPACT WITH STD. ANCHORED BARRIER (NO TRANSITION)	

Figure 2.3. Simulation results (top view showing initial state and maximum barrier deflection).

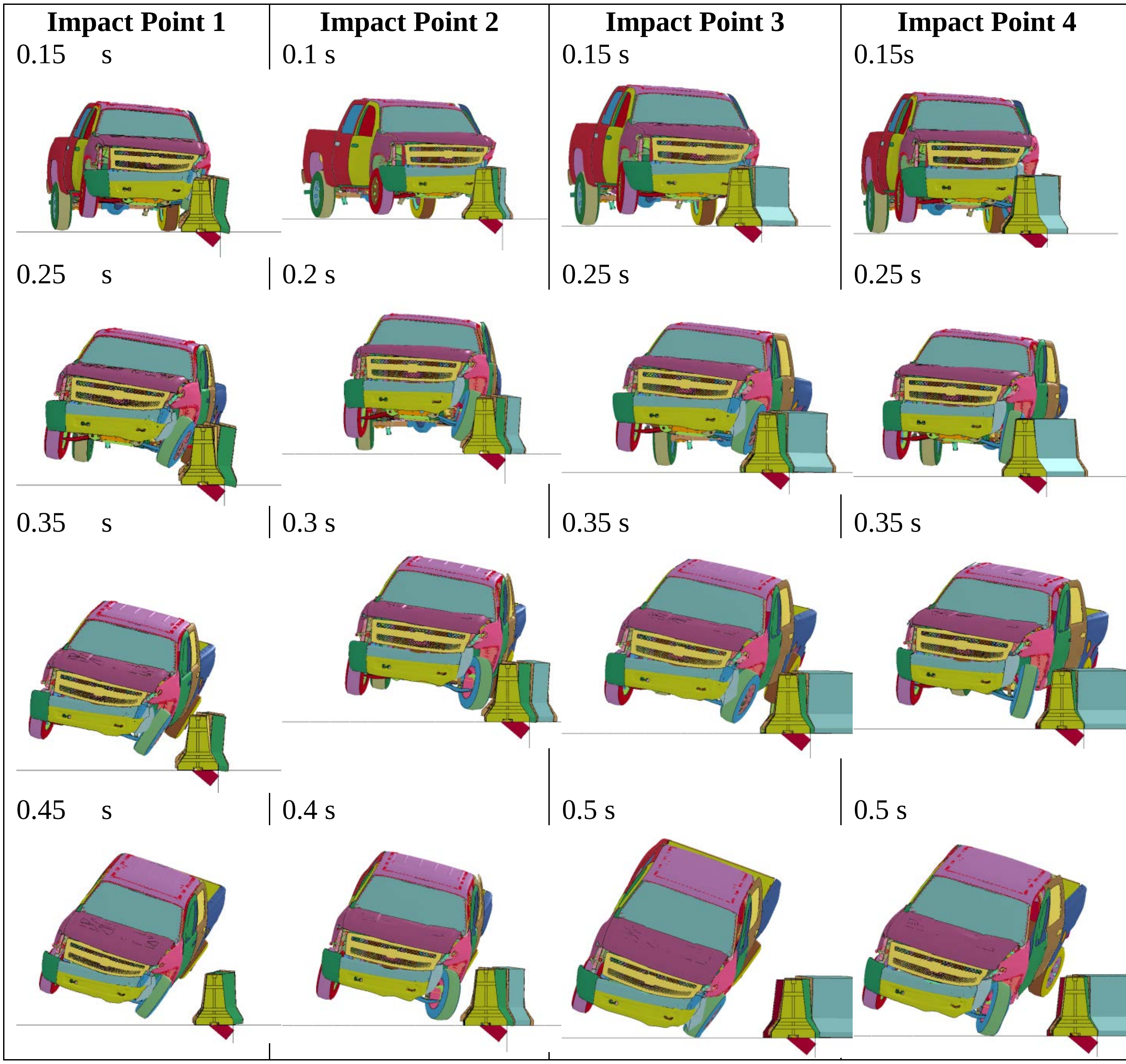


Figure 2.4. Simulation results (vehicle stability and barrier performance for different impact locations).

3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 CRASH TEST MATRIX

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

> ***MASH* Test Designation 3-20:** A 2425 lb vehicle impacting the critical impact point (CIP) in the transition at a speed of 62 mi/h and an angle of 20 degrees.
>
> ***MASH* Test Designation 3-21:** A 5000 lb pickup truck impacting the CIP in the transition at a speed of 62 mi/h and an angle of 25 degrees.

Test 3-21 of *MASH* (5000-lb pickup, 62 mi/h, 25 degrees) was performed to evaluate the performance of the transition design. It is argued that test 3-20 with the lighter 2425-lb vehicle is not needed. Due to higher impact energy, the test with the 5000-lb pickup truck will result in greater lateral barrier deflection and vehicle pocketing and help evaluate the transition of the anchoring pins and connection. An impact resulting from the lighter, 2425-lb passenger car under same impact speed and angle will not result in any increased barrier deflection or vehicle pocketing, nor will it impart a higher force on the barrier to evaluate transition of the anchoring scheme and barrier connection. Thus, the test was conducted with the 5000-lb pickup only.

Target CIP for the *MASH* test 3-21 on the transition was determined to be 14.67 ft upstream of the joint between the transition segment and the standard anchored pinned-down barrier segment.

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

3.2 EVALUATION CRITERIA

The crash test was evaluated in accordance with the criteria presented in *MASH*. The performance of the transition 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 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.

4. TEST CONDITIONS

4.1 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 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 6-8 inches deep. The apron is over 60 years old and the joints have some displacement, but are otherwise flat and level.

4.2 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.

4.3 DATA ACQUISITION SYSTEMS

4.3.1 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 fracture of 95% (k=2).

TRAP uses the data from the TDAS Pro to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-millisecond (ms) average ridedown acceleration. TRAP calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

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

4.3.2 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.

4.3.3 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.

5. TRANSITION FROM FREE-STANDING BARRIER TO PINNED BARRIER - CRASH TEST 405160-26-2 (*MASH* TEST NO. 3-21)

5.1 TEST ARTICLE DESIGN AND CONSTRUCTION

The overall length of the test installation was 201 ft-3 inches. The installation was comprised of 16 12 ft-6 inch long precast concrete barrier segments that were 32 inches tall and had the standard "F" profile. The first eight barrier segments (1 to 8) were free-standing and were not anchored to the underlying concrete pavement. Barrier segment 9 was pinned to the underlying concrete pavement using a single 1-1/2 inch diameter steel pin that passed through the inclined slotted hole near the downstream end of the segment. Segments 12 through 16 were pinned using two 1-1/2-inch diameter steel pins per barrier segment. These pins were passed through the inclined slotted holes near each end of the segments.

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 any of the barrier segments.

Once the precast barrier segments were positioned in place, the slotted holes in the barrier toes were used as a guide to drill holes in the underlying concrete pavement for each of the pinning location. 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 at a pinning location. 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 barrier was unreinforced and was nominally six 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 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 5.1 and 5.2, respectively. Detailed drawings of the test installation are presented in appendix B.1.

5.2 MATERIAL SPECIFICATIONS

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 B.2.

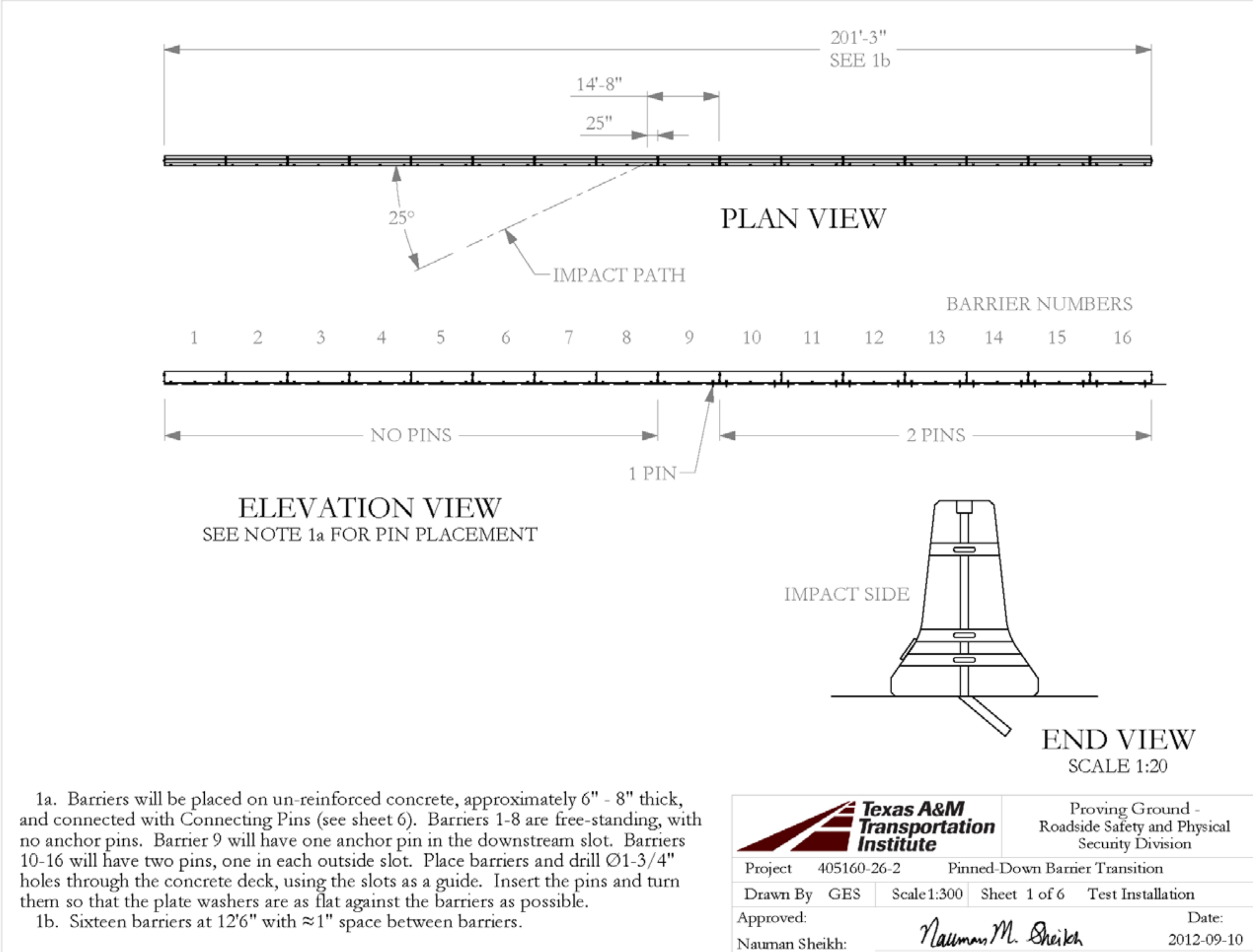


Figure 5.1. Layout of the transition from free-standing F-shape barrier to pinned F-shape barrier for test 405160-26-2.

Figure 5.2. Transition from free-standing F-shape barrier to pinned F shape barrier prior to test 405160-26-2.

5.3 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

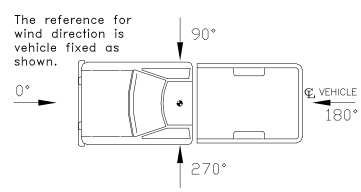
MASH test 3-21 involves a 2270P vehicle weighing 5000 lb ±100 lb and impacting the transition at an impact speed of 62.2 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target CIP was 14.67 ft upstream of the joint 9-10 of the barrier installation. CIP was determined using finite element analysis and the details are presented in chapter 2. The 2007 Dodge Ram 1500 used in the test weighed 4999 lb and the actual impact speed and angle were 61.1 mi/h and 25.4 degrees, respectively. The actual impact point was 15.0 ft upstream of the joint between the 9th and 10th barrier segment. Target impact severity (IS) was 115.2 kip-ft, and the actual IS was 114.8 kip-ft. IS not less than 8 percent of the target value is acceptable under *MASH*.

5.4 TEST VEHICLE

A 2007 Dodge Ram 1500 pickup truck, shown in figures 5.3 and 5.4, was used for the crash test. Test inertia weight of the vehicle was 4999 lb, and its gross static weight was 4999 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 28.12 inches. Additional dimensions and information on the vehicle are given in appendix B.3, tables B.1 and B.2. 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.

5.5 WEATHER CONDITIONS

The crash test was performed the morning of September 24, 2012. Weather conditions at the time of testing were: Wind speed: 6 mi/h; wind direction: 330 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 64ºF; relative humidity: 97 percent.



5.6 TEST DESCRIPTION

The 2007 Dodge Ram pickup, traveling at an impact speed of 61.1 mi/h, impacted the transition 15.0 ft upstream of joint 9-10 of the barrier system at an impact angle of 25.4 degrees. At approximately 0.027 s, segments 8 and 9 began to deflect towards the field side, and at 0.041 s, the vehicle began to redirect. Segment 7 began to move downstream at 0.064 s, and segment 10 began to deflect towards the field side at 0.117 s. The vehicle began to travel parallel with the barrier at 0.188 s, and the rear of the vehicle contacted the barrier at 0.261 s. At 0.379 s, the vehicle lost contact with the barrier traveling at an exit speed and angle of 49.8 mi/h and 14.1 degrees, respectively. Brakes on the vehicle were applied at 2.4 s after impact, and the vehicle subsequently came to rest 157 ft downstream of impact and 7 ft towards traffic lanes. Sequential photographs of the test period are shown in appendix B.4, figures B.1 and B.2.

Figure 5.3. Vehicle/installation geometrics for test 405160-26-2.

Figure 5.4. Vehicle before test 405160-26-2.

5.7 TEST ARTICLE AND COMPONENT DAMAGE

Damage to the transition installation is shown in figures 5.5 and 5.6. The downstream ends of segments 1 through 4 deflected downstream 1.0 inch, 1.5 inches, 2.0 inches and 2.25 inches, respectively. Segment 5 moved downstream 3.0 inches and toward the traffic side 5.0 inches. Segment 6 moved downstream 6.0 inches and 8.0 inches toward the field side. Segment 7 moved downstream 3.0 inches and 30.0 inches toward the field side. Segment 8 moved 44.0 inches toward the field side. Segment 9 deflected toward the field side 9.0 inches and upstream 3.0 inches. Segment 10 deflected toward the field side 1.0 inch and upstream 1.0 inch. Segment 11 moved upstream 0.5 inch. Moderate concrete damage occurred at the adjacent ends of segments 8 and 9, and significant damage to the adjacent ends of segments 9 and 10. The pins on the adjacent ends of segments 9 and 10 pulled upward 5.0 inches and were deformed. The downstream pin on segment 10 pulled upward 0.75 inch. Working width was 5.8 ft, vehicle penetration was 4.7 ft, maximum dynamic deflection during the test was 3.9 ft, and maximum permanent deformation was 3.7 ft.

5.8 TEST VEHICLE DAMAGE

Damage to the 2270P vehicle is shown in figure 5.7. The upper and the lower ball joints on the left side broke and left frame rail was deformed. Also damaged were the front bumper, grill, left front fender, left front door, left rear door, left front and left rear tires and wheel rims, left exterior bed, rear bumper and tailgate. Maximum exterior crush to the vehicle was 15.0 inches in the side plane at the left front corner at bumper height. Maximum occupant compartment deformation was 1.5 inches in the lateral area across the cab at hip height. Photographs of the interior of the vehicle are shown in figure 5.8 Exterior vehicle crush and occupant compartment measurements are shown in appendix B.3, tables B.3 and B.4.

5.9 OCCUPANT RISK VALUES

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 13.4 ft/s at 0.106 s, the highest 0.010-s occupant ridedown acceleration was 5.7 Gs from 0.261 to 0.271 s, and the maximum 0.050-s average acceleration was -7.1 Gs between 0.011 and 0.061 s. In the lateral direction, the occupant impact velocity was 19.4 ft/s at 0.106 s, the highest 0.010-s occupant ridedown acceleration was 13.3 Gs from 0.261 to 0.271 s, and the maximum 0.050-s average was 9.1 Gs between 0.240 and 0.290 s. Theoretical Head Impact Velocity (THIV) was 25.9 km/h or 7.2 m/s at 0.103 s; Post-Impact Head Decelerations (PHD) was 14.5 Gs between 0.262 and 0.272 s; and Acceleration Severity Index (ASI) was 1.14 between 0.011 and 0.061 s. These data and other pertinent information from the test are summarized in figure 5.9. Vehicle angular displacements and accelerations versus time traces are presented in appendix B.5, figure B.3 and Appendix B.6, figures B.3 through B.9, respectively.

Figure 5.5. Vehicle/installation positions after test 405160-26-2.

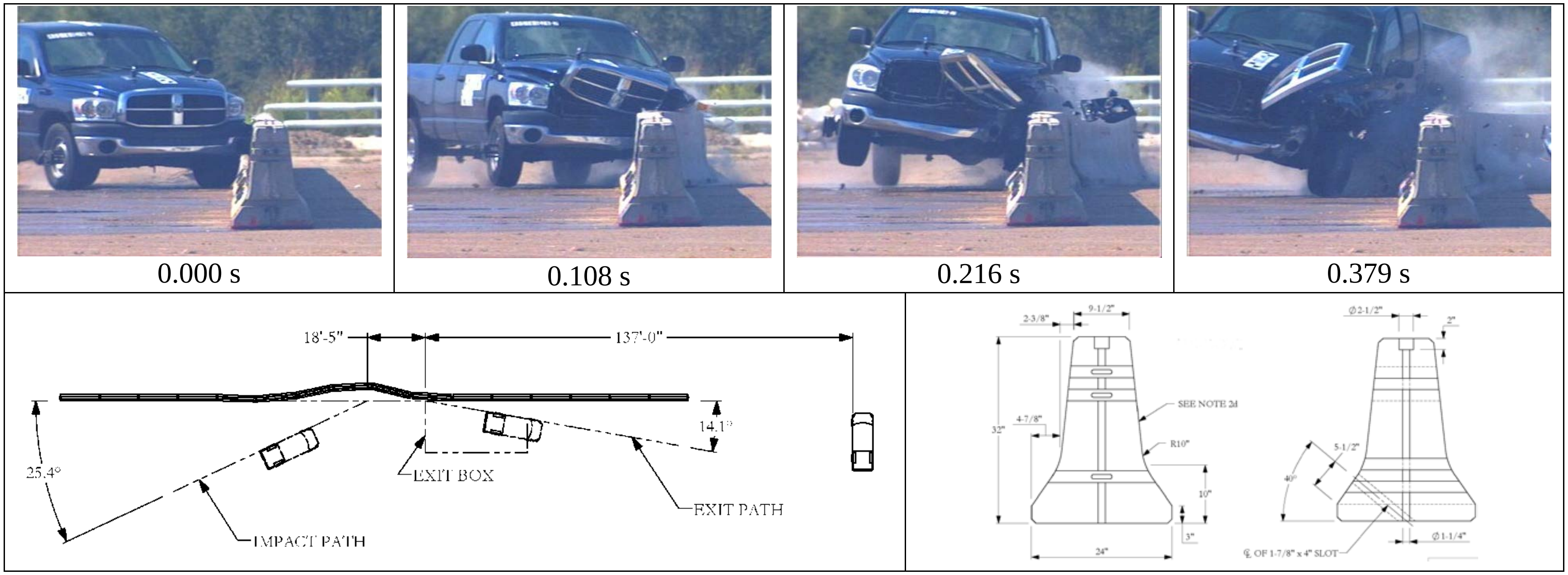
Figure 5.6. Installation after test 405160-26-2.

Figure 5.7. Vehicle after test 405160-26-2.

Before Test

After Test

Figure 5.8. Interior of vehicle for test 405160-26-2.



General Information
Test Agency .... Texas A&M Transportation Institute (TTI)
Test Standard Test No. .... MASH Test 3-21
TTI Test No. 405160-26-2
Date .... September 24, 2012

Test Article
Type .... Transition
Name .... Transition from free-standing F-shape barrier to pinned F-shape barrier
Installation Length .... 201.25 ft
Material or Key Elements ....

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

Test Vehicle
Type/Designation 2270P
Make and Model .... 2007 Dodge Ram 1500 Pickup
Curb .... 4797 lb
Test Inertial .... 4999 lb
Dummy .... No dummy
Gross Static .... 4999 lb

Impact Conditions
Speed .... 61.1 mi/h
Angle .... 25.4 degrees
Location/Orientation .... 15.0 ft upstrm joint 9-10

Impact Severity ....

Exit Conditions
Speed .... 49.8 mi/h
Angle .... 14.1 degrees

Occupant Risk Values
Impact Velocity
Longitudinal .... 13.4 ft/s
Lateral .... 19.4 ft/s
Ridedown Accelerations
Longitudinal .... 5.7 G
Lateral .... 13.3 G
THIV .... 25.9 km/h
PHD .... 14.5 G
ASI 1.14
Max. 0.050-s Average
Longitudinal .... -7.1 G
Lateral .... 9.1 G
Vertical .... -3.3 G

Post-Impact Trajectory
Stopping Distance .... 157 ft dwnstrm 7 ft twd traffic

Vehicle Stability
Maximum Yaw Angle .... 39 degrees
Maximum Pitch Angle .... 17 degrees
Maximum Roll Angle .... 20 degrees
Vehicle Snagging .... No
Vehicle Pocketing .... No

Test Article Deflections
Dynamic .... 3.9 ft
Permanent .... 3.7 ft
Working Width .... 5.8 ft
Vehicle Intrusion .... 4.7 ft

Vehicle Damage
VDS 11LFQ5
CDC 11FLEW4
Max. Exterior Deformation .... 15.0 inches
OCDI LF0020000
Max. Occupant Compartment Deformation .... 1.5 inches

Figure 5.9. Summary of results for *MASH* test 3-21 on transition from the free-standing F-shape barrier to pinned F-shape barrier.

5.10 ASSESSMENT OF TEST RESULTS

An assessment of the test was made based on the following applicable *MASH* safety evaluation criteria.

5.10.1 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 from the free-standing F-shape barrier to pinned F-shape barrier placed on concrete contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the barrier during the test was 3.7 ft. (PASS)

5.10.2 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, fragment, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area. (PASS)
Maximum occupant compartment deformation was 1.5 inches in the lateral area across the cab at hip height. (PASS)

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

Results: The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 20 degrees and 17 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 13.4 ft/s, and lateral occupant impact velocity was 19.4 ft/s. (PASS)

I. *Occupant ridedown accelerations should satisfy the following:*

Longitudinal and Lateral Occupant Ridedown Accelerations	
Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Longitudinal ridedown acceleration was 5.7 G, and lateral ridedown acceleration was 13.3 G. (PASS)

5.10.3 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 within the exit box. (PASS)

6. SUMMARY AND CONCLUSIONS

6.1 SUMMARY OF RESULTS

The transition from the free-standing F-shape barrier to pinned F-shape barrier placed on concrete contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the barrier during the test was 3.7 ft. No detached elements, fragment, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 1.5 inches in the lateral area across the cab at hip height. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 20 degrees and 17 degrees, respectively. Occupant risk factors were within limits specified in *MASH*. The 2270P vehicle exited within the exit box.

6.2 CONCLUSIONS

According to the *MASH* criteria required for test 3-21 for transitions shown in table 6.1, the transition from the free-standing to anchored F-shape barrier placed on concrete performed acceptably.

6.3 IMPLEMENTATION*

The transition design developed and crash tested in this research was developed for use on concrete pavement or bridge decks. This design should not be used on asphalt pavement without further evaluation through crash testing and/or detailed finite element analysis.

The length of the barrier segments used in the test installation was 12.5 feet. The layout of the transition is shown in figure 5.1. A single transition segment was placed between the free-standing barrier (with no anchoring pins), and the fully anchored pinned down barrier (with two anchoring pins). The design of the transition segment was kept the same as the pinned down anchored barrier system for simplicity and to minimize inventory requirements for user agencies. The only difference in the transition segment was that it was pinned using a single pin instead of two pins per segment used in the standard pinned-down anchored barrier system.

While the crash tested design used a 12.5 ft long transition segment, the user agencies may use longer transition segments to retain simplicity of the design and reduced inventory requirements. Due to higher mass, the longer barrier segment is not expected to result in greater barrier deflection and vehicle pocketing. Thus using transition segment lengths greater than 12.5 ft to match the segment length of the free standing and anchored barrier systems should be acceptable, and is not expected to deteriorate the performance of the transition. In using longer segment lengths, it should however be ensured that the anchoring pin in the transition segment is

* TTI Proving Ground's A2LA scope of accreditation covers accreditation for crash testing and does not include implementation recommendations. Recommendations for implementation were developed by the research engineer.

placed at the same distance from the adjacent joint as tested herein. Altering pin distance from the joint can change the performance of the anchoring scheme, and therefore should not be done without further evaluation.

Table 6.1. Performance evaluation summary for *MASH* test 3-21 on the transition from free-standing F-shape barrier to pinned F-shape barrier in test 405160-26-2.

Test Agency: Texas A&M Transportation Institute	Test No.: 405160-26-2	Test Date: 2012-09-24
***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 from the free-standing F-shape barrier placed on concrete to pinned F-shape barrier placed on pavement contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the barrier during the test was 3.7 ft.	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, fragment, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 1.5 inches in the lateral area across the cab at hip height.	Pass
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 20 degrees and 17 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 13.4 ft/s, and lateral occupant impact velocity was 19.4 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.*	Longitudinal ridedown acceleration was 5.7 G, and lateral ridedown acceleration was 13.3 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 within the exit box.	Pass

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APPENDIX A. TRANSITION FROM FREE-STANDING BARRIER TO PINNED BARRIER - CRASH TEST 405160-26-1 (*MASH* TEST NO. 3-21)

A.1 TEST ARTICLE DESIGN AND CONSTRUCTION

The overall length of the test installation was 226 ft-5 inches. The installation was comprised of 18 12 ft-6 inch long precast concrete barrier segments that were 32 inches tall and had the standard “F” profile. The first eight barrier segments (1 to 8) were free-standing and were not anchored to the underlying concrete pavement. Barrier segments 9 and 10 were pinned using a single ¾ inch diameter steel pin that passed through the center inclined slotted hole in the toe of these segments. Barrier segment 11 was pinned with two ¾ inch diameter steel pins passing through inclined slotted holes near the ends of the barrier segment. Segments 12 through 18 were pinned to the underlying concrete pavement using two 1-1/2-inch diameter steel pins per barrier segment. These pins also used the inclined slotted holes near each end of the segments.

The precast concrete barrier segments had the F-shape profile and 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 surface, 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. Other than segments 9 and 10 in the transition, the middle slotted holes were not used for anchoring.

Once the precast barrier segments were positioned in place, the slotted holes in the barrier toes were used as a guide to drill holes in the underlying concrete pavement for each of the pinning location. 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 at a pinning location. The diameter of the anchoring pin was reduced to 3/4 inches in the transition segments 9 through 11. 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 barrier was unreinforced and was nominally six 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.

Drawings of the test installation are shown in figure A.1, and photographs are shown in Figure A.2.

A.2 MATERIAL SPECIFICATIONS

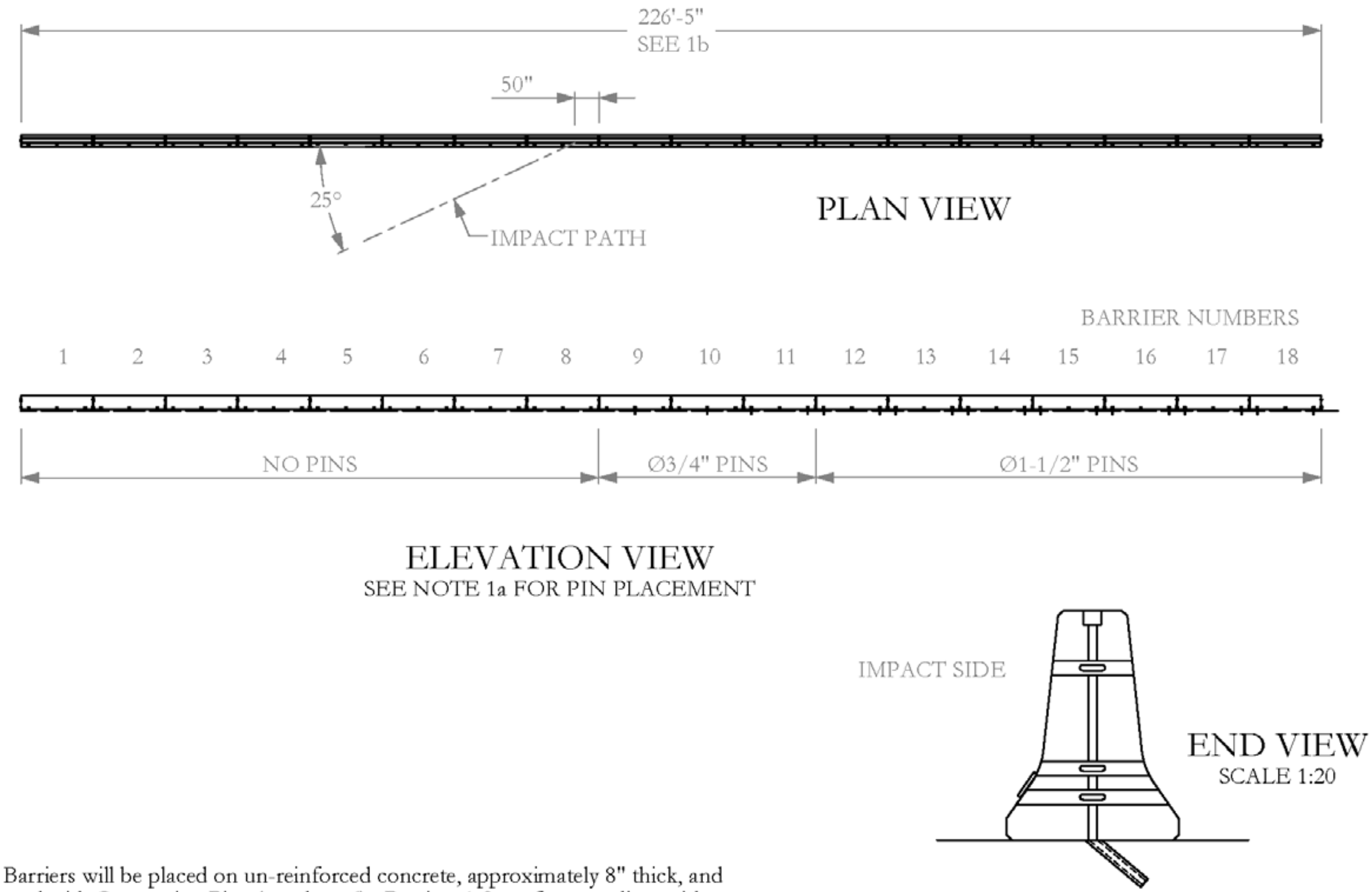
The F-shape temporary concrete barrier segments used in the test installation were donated by WASKEY. All rebar reinforcement was grade 60 steel material. The loops for the connecting pin, the anchoring pins, and the washers welded on top of the anchoring pins were A36 steel. The connecting pin between adjacent barrier segments was A572 grade 50 steel. Certifications for different materials used are on file at the TTI Proving Ground.

A.3 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH test 3-21 involves a 2270P vehicle weighing 5000 lb ±100 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 CIP was 4.17 ft upstream of the joint between the free-standing barrier and transition to the pinned down barrier. The 2005 Dodge Ram 1500 used in the test weighed 5017 lb and the actual impact speed and angle were 61.7 mi/h and 26.1 degrees, respectively. The actual impact point was 3.7 ft upstream of the joint between the free-standing barrier and transition to the pinned down barrier. Target impact severity (IS) was 115.2 kip-ft, and actual IS was 123.6 kip-ft, where not less than 8 percent is acceptable.

A.4 TEST VEHICLE

A 2005 Dodge Ram 1500 pickup truck, shown in figures A.3 and A.4, was used for the crash test. Test inertia weight of the vehicle was 5017 lb, and its gross static weight was 5017 lb. The height to the lower edge of the vehicle front bumper was 13.5 inches, and the height to the upper edge of the front bumper was 26.00 inches. The height to the center of gravity was 28.9 inches. Additional dimensions and information on the vehicle are given in tables A.1 and A.2. 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.



1a. Barriers will be placed on un-reinforced concrete, approximately 8" thick, and connected with Connecting Pins (see sheet 6). Barriers 1-8 are free-standing, with no anchor pins. Barriers 9-10 will have one Ø3/4" anchor pin in the center slot. Barrier 11 will have two Ø3/4" pins, one in each outside slot. Barriers 12-18 will have two Ø1-1/2" pins, one in each outside slot. Place barriers and drill holes through the concrete deck, Ø1-3/4" for both pin sizes, using the slots as a guide. Insert the pins and turn them so that the plate washers are as flat against the barriers as possible.

1b. Eighteen barriers at 12'6" with ≈1" space between barriers.

Texas Transportation Institute		The Texas A&M University System College Station, Texas 77843	
Project 405160-26		Pinned-Down Barrier Transition	
Drawn By GES	Scale 1:300	Sheet 1 of 6	Test Installation
Approved: Nauman Sheikh:	Signature: Nauman M. Sheikh		Date: 2011-11-09

Figure A.1. Details of the F-shape barrier used in test 405160-26-1.

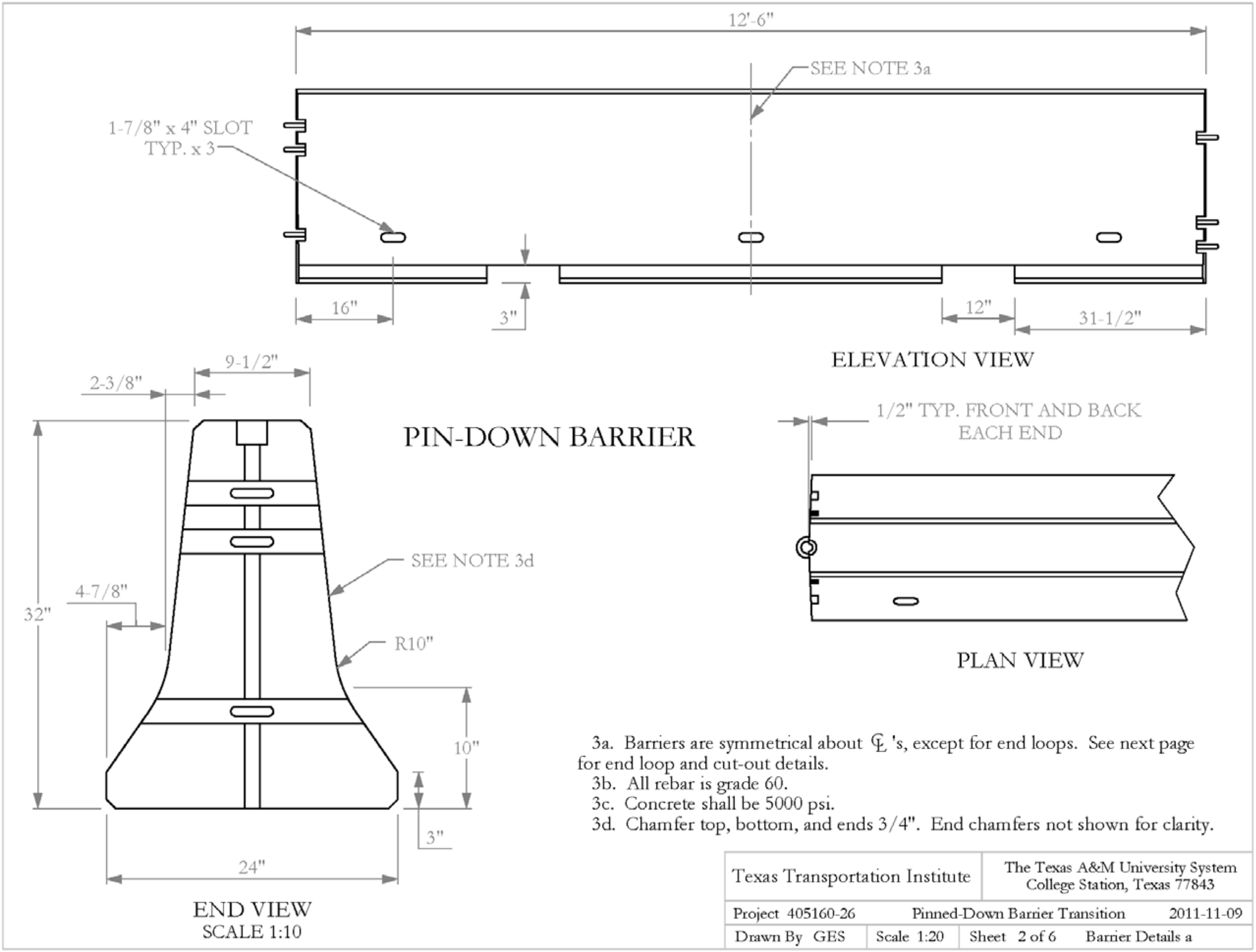


Figure A.1. Details of the F-shape barrier used in test 405160-26-1 (continued).

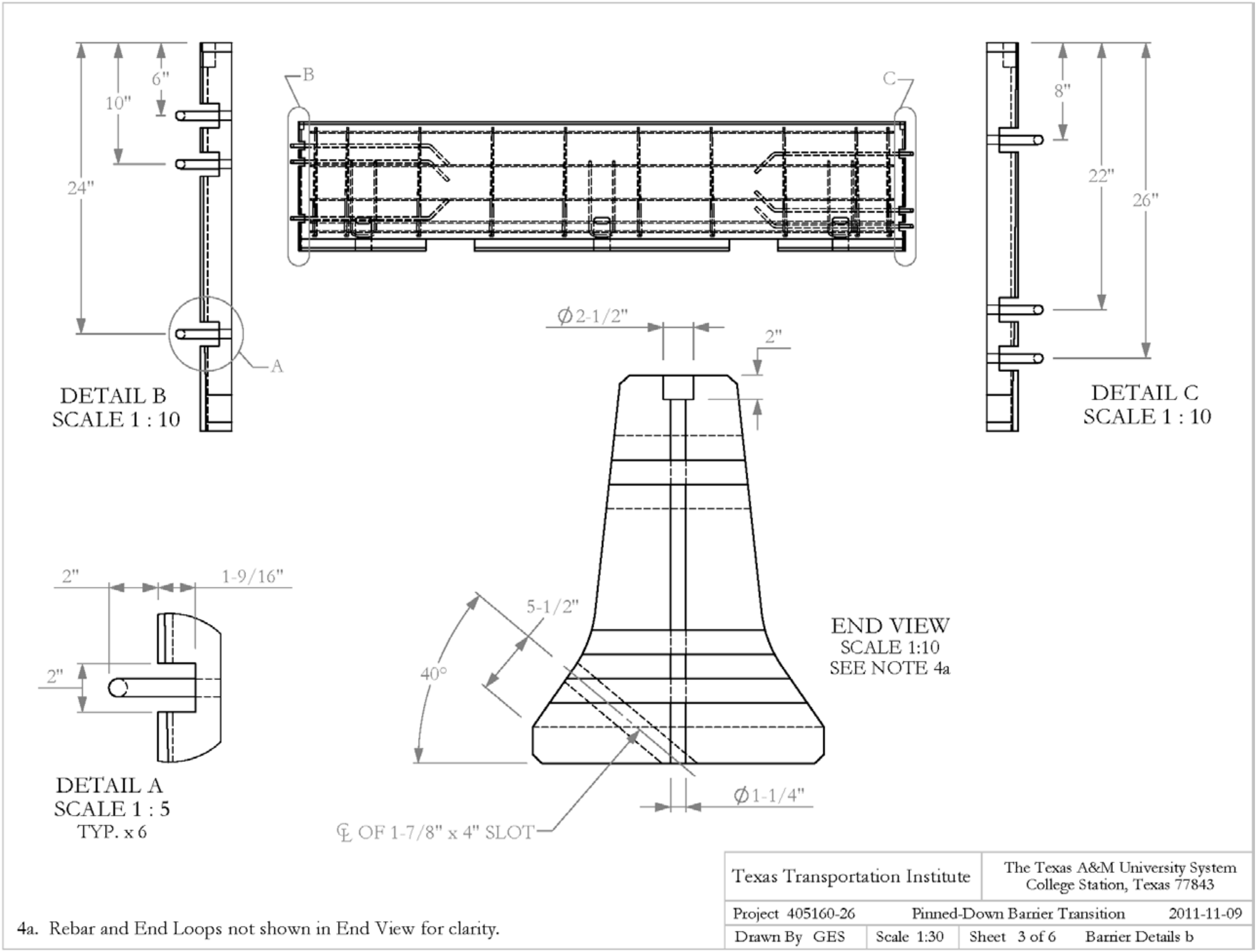
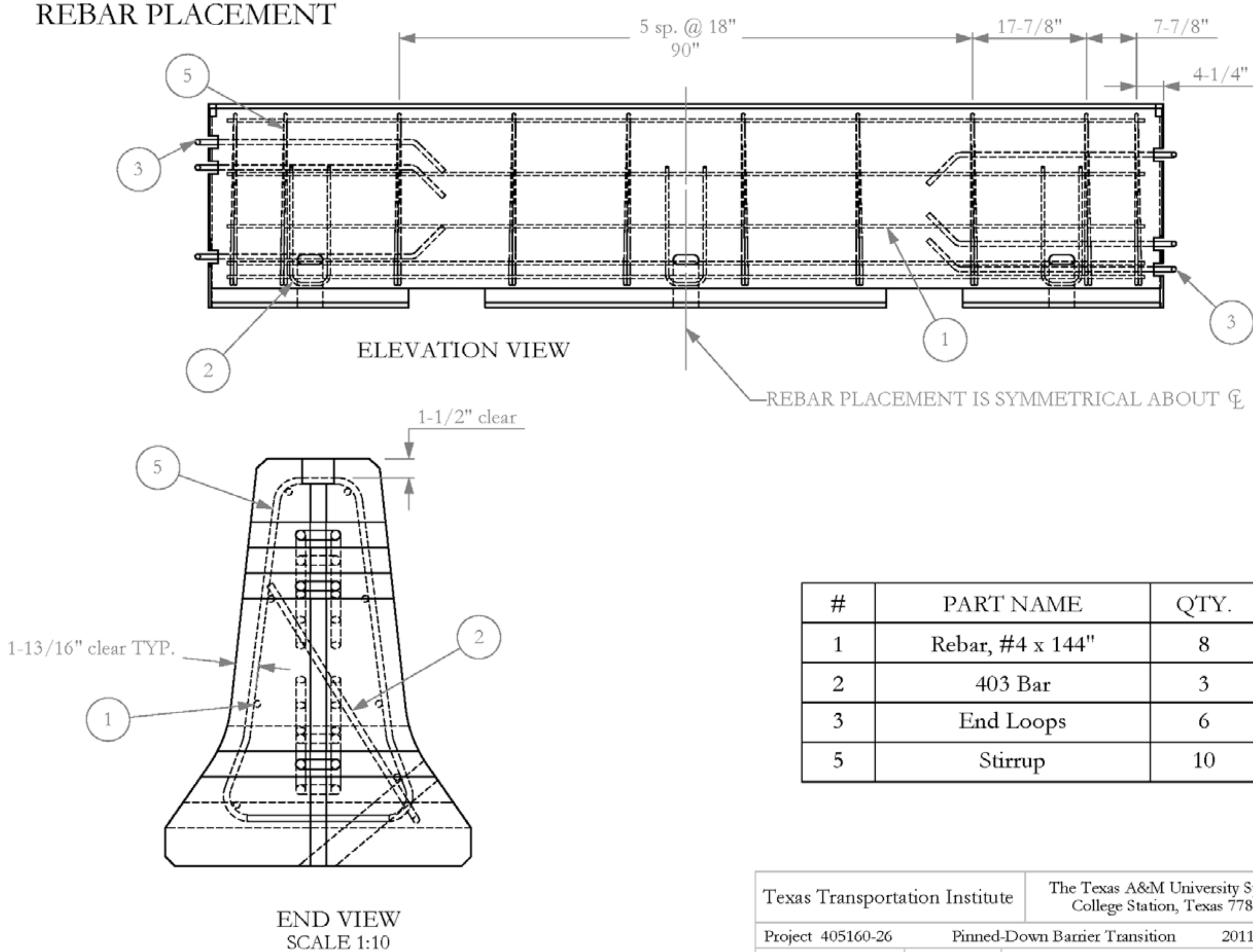


Figure A.1. Details of the F-shape barrier used in test 405160-26-1 (continued).



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

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Drawn By GES	Scale 1:20	Sheet 4 of 6	Rebar Placement

Figure A.1. Details of the F-shape barrier used in test 405160-26-1 (continued).

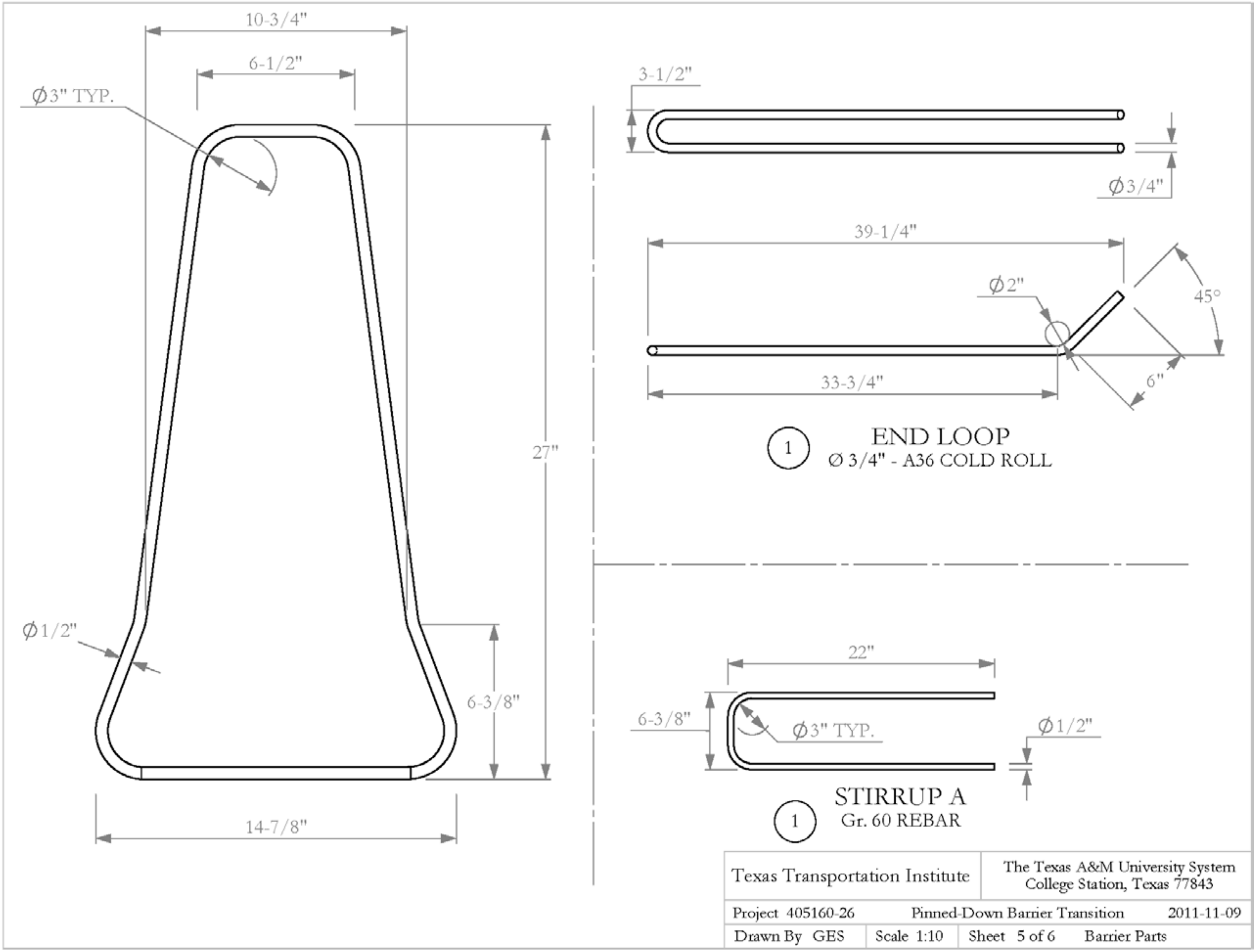


Figure A.1. Details of the F-shape barrier used in test 405160-26-1 (continued).

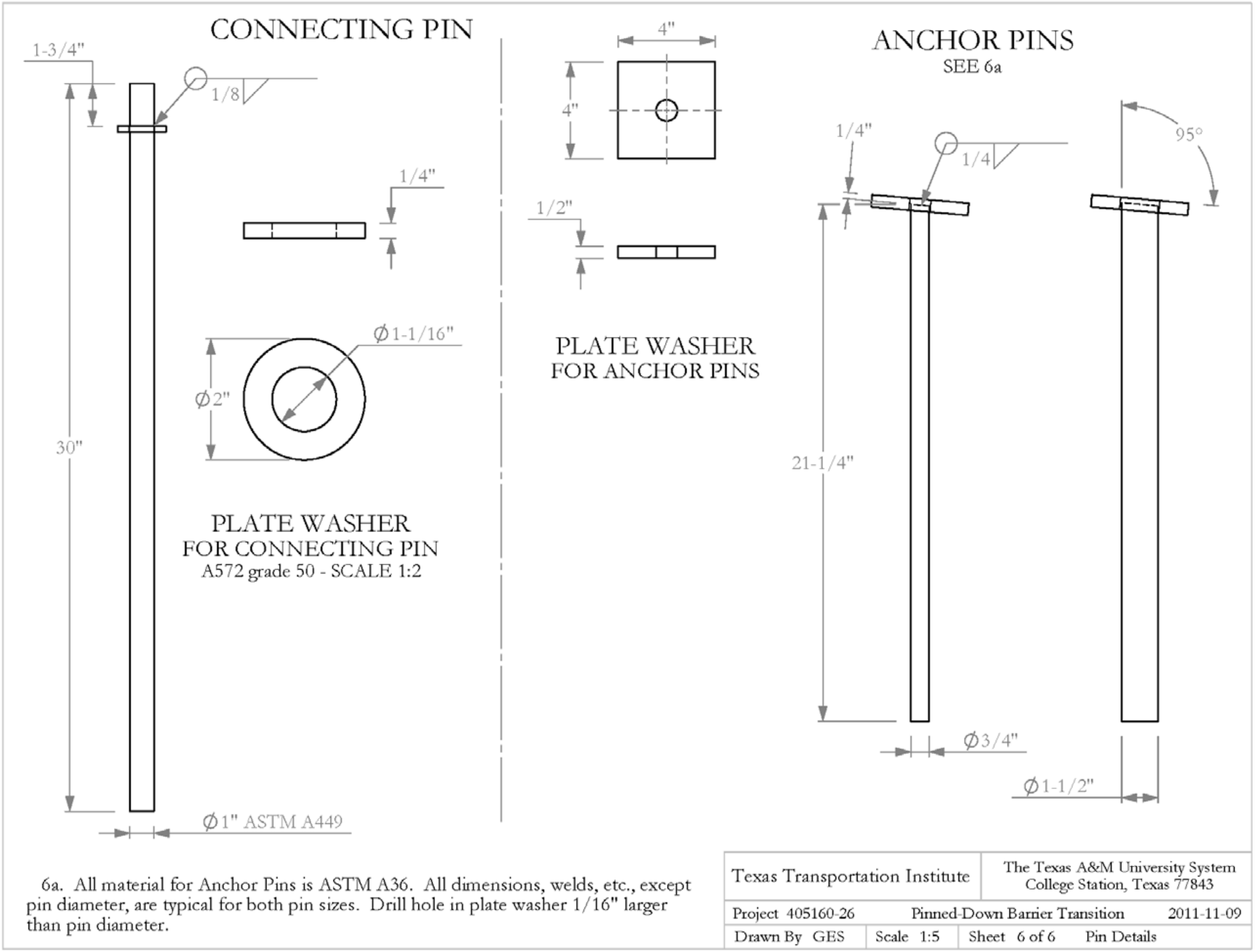


Figure A.1. Details of the F-shape barrier used in test 405160-26-1 (continued).

Figure A.2. Transition from free-standing F-shape barrier to pinned F shape barrier prior to test 405160-26-1.

Figure A.3. Vehicle/installation geometrics for test 405160-26-1.

Table A.1. Vehicle properties for test 405160-26-1.

Date: 2011-11-16 Test No.: 405160-26-1 VIN No.: 1D7HA18N85J573385

Year: 2005 Make: Dodge Model: Ram 1500

Tire Size: P245/75R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 155391

Note any damage to the vehicle prior to test: ______

● Denotes accelerometer location.

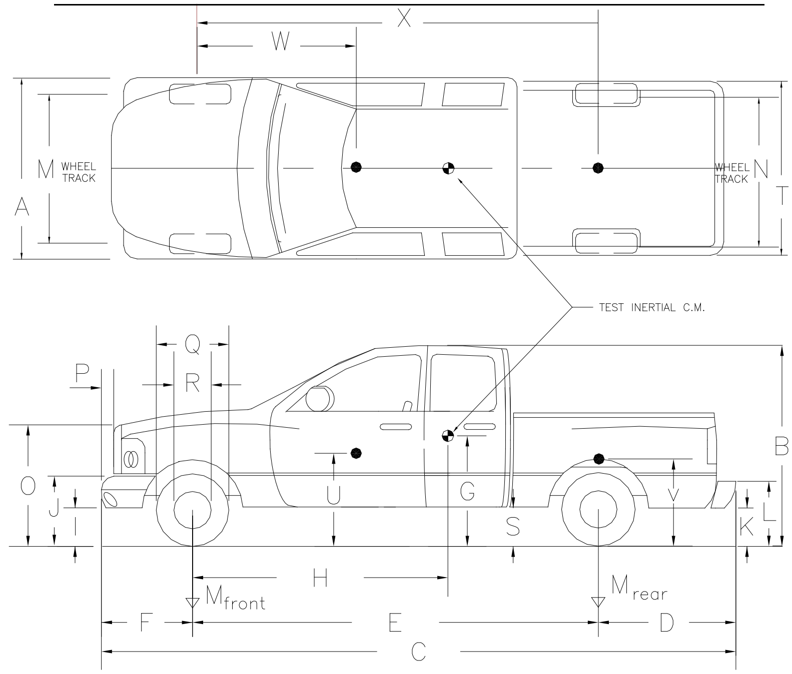
NOTES: ______

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	77.00	F	39.00	K	20.30	P	3.00	U	27.50
B	73.25	G	28.88	L	28.75	Q	29.50	V	30.00
C	227.00	H	63.51	M	68.25	R	18.50	W	63.00
D	47.50	I	13.50	N	67.25	S	14.25	X	99.00
E	140.50	J	26.00	O	44.75	T	75.50		

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3650	M_{front}	2800	2749	
Back	3900	M_{rear}	2051	2268	
Total	6650	M_{Total}	4851	5017	

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

Mass Distribution:
lb LF: 1372 RF: 1377 LR: 1153 RR: 1115

Table A.2. Measurements of vehicle vertical CG for test 405160-26-1.

Date: 2011-11-16 Test No.: 405160-26-1 VIN: 1D7HA18N85J573385

Year: 2005 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 155391

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 235 lb at front of bed (440 lb max)

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

Measured Vehicle Weights: (lb)

LF:	1382	RF:	1402	Front Axle:	2784
LR:	1135	RR:	1104	Rear Axle:	2239
Left:	2517	Right:	2506	Total:	5023
					5000 ±110 lb allowed

Wheel Base: 140.5 inches Track: F: 68.25 inches R: 62.25 inches

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

Center of Gravity, SAE J874 Suspension Method

X: 62.63 in Rear of Front Axle (63 ±4 inches allowed)

Y: -0.07 in Left - Right + of Vehicle Centerline

Z: 28.875 in Above Ground (minumum 28.0 inches allowed)

Hood Height: 44.75 inches Front Bumper Height: 26.00 inches

43 ±4 inches allowed

Front Overhang: 39.00 inches Rear Bumper Height: 28.75 inches

39 ±3 inches allowed

Overall Length: 227.00 inches

237 ±13 inches allowed

A.5 WEATHER CONDITIONS

The crash test was performed the morning of November 16, 2011. Weather conditions at the time of testing were: Wind speed: 6 mi/h; wind direction: 330 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 64ºF; relative humidity: 97 percent.

A.6 TEST DESCRIPTION

The 2005 Dodge Ram pickup, traveling at an impact speed of 61.7 mi/h, impacted the transition 3.7 ft upstream of the joint between the free-standing barrier and transition to the pinned down barrier at an impact angle of 26.1 degrees. At approximately 0.014 s after impact, the vehicle began to redirect, and at 0.020 s, the left front tire blew out. The right front and right rear wheels became airborne at 0.097 s and 0.112 s, respectively. At 0.197 s, the vehicle was traveling parallel with the transition at a speed of 53.5 mi/h. At 0.277 s, the vehicle lost contact with the barriers and was traveling at an exit speed and angle of 50.6 mi/h and 13.1 degrees, respectively. The barriers reached maximum deflection of 39.3 inches at 0.295 s. Brakes on the vehicle were not applied, and the vehicle rolled onto its left side and came to rest 196.6 ft downstream of impact and 43.0 ft toward traffic lanes from the traffic face of the barriers. Sequential photographs of the test period are shown in figure A.4.

A.7 TEST ARTICLE AND COMPONENT DAMAGE

Damage to the transition installation is shown in figures A.5 and A.6. The upstream end of segment 2 deflected upstream 0.5 inch, and the upstream ends of segment 3 and 4 deflected upstream 1.5 inches each. Segment 5 moved upstream 2.0 inches and toward the field side 0.75 inch. Segment 6 moved upstream 6.0 inches and 1.0 inch toward the field side on the upstream end and 2.0 inches toward traffic lanes on the downstream end. Segment 7 moved upstream 2.5 inches and 1.5 inches toward traffic lanes on the upstream end and 22.0 inches toward the field side on the downstream end. Segment 8 moved 3.5 inches upstream and 22.75 inches toward the field side on the upstream end and 44.5 inches toward the field side on the downstream end. Segment 9 deflected toward the field 44.0 inches on the upstream end and 37.5 inches on the downstream end. Segment 10 deflected toward the field side 37.5 inches on the upstream end and 4.5 inches on the downstream end. Segment 11 moved downstream 2.5 inches and 4.5 inches toward the field side. Segment 12 moved 1.5 inches downstream, and segments 13 and 14 moved 1.0 inch downstream. Working width was 5.1 ft, maximum dynamic deflection during the test was 3.7 ft, and maximum permanent deformation was 3.7 ft.

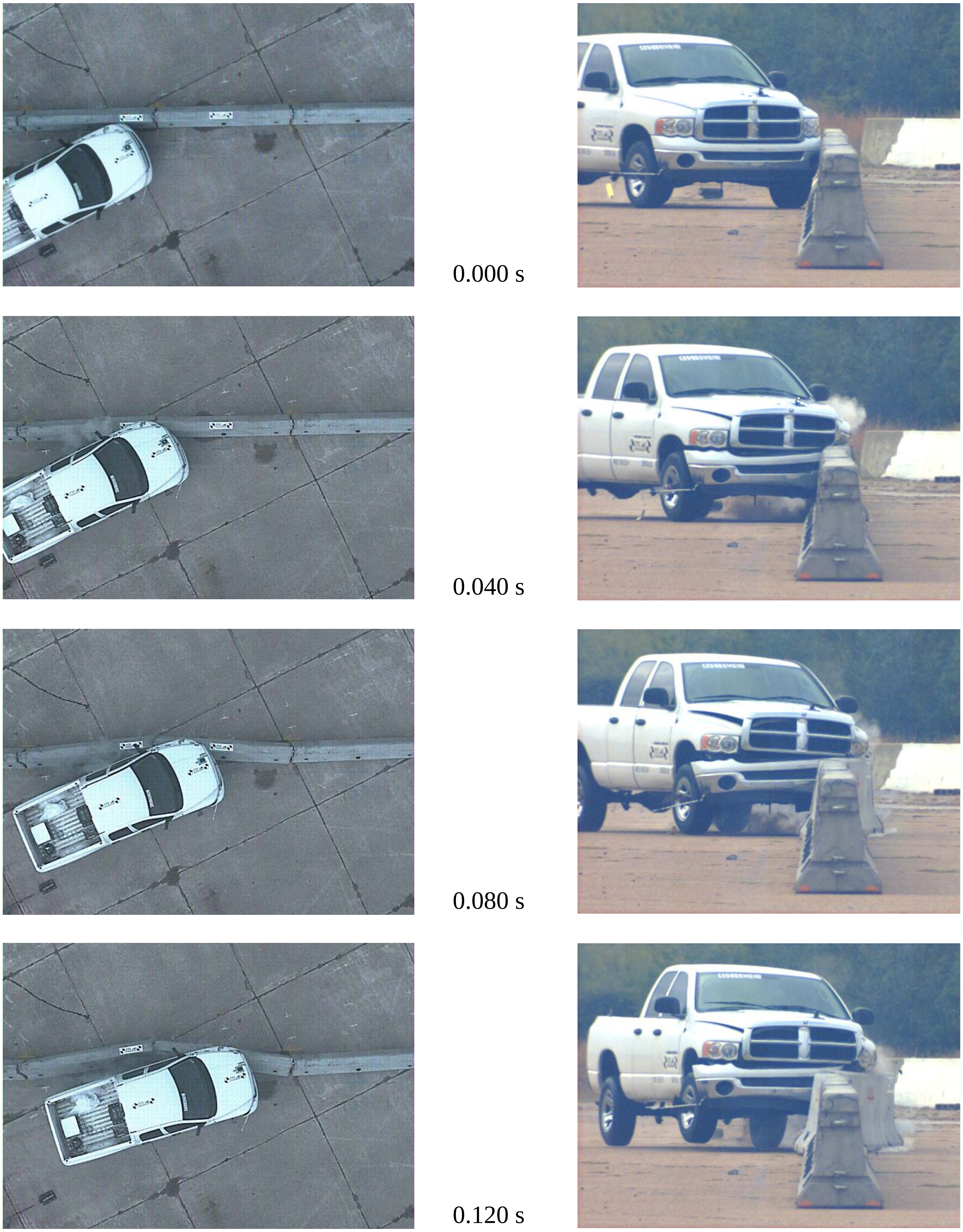
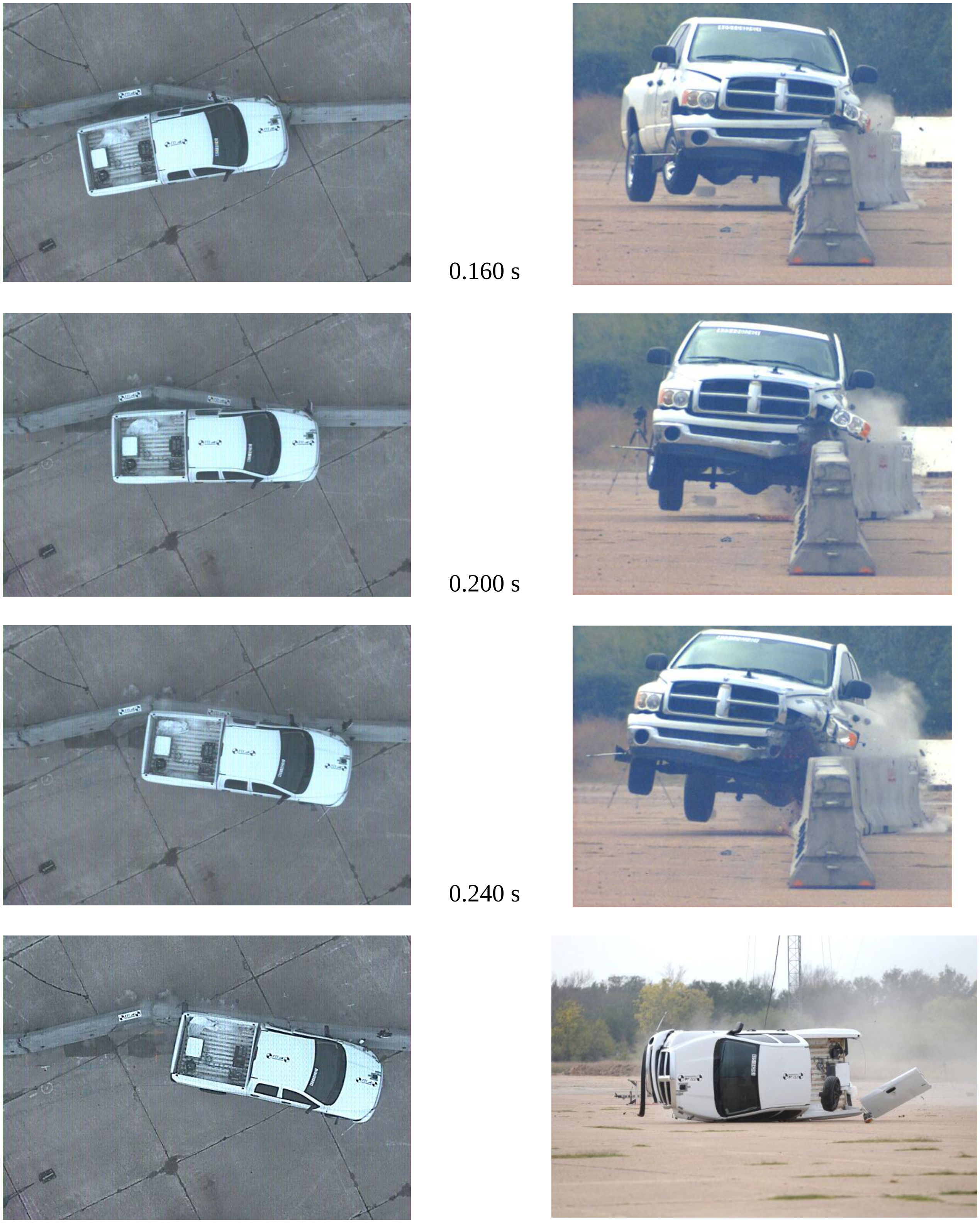


Figure A.4. Sequential photographs for test 405160-26-1
(overhead and frontal views).



0.160 s

0.200 s

0.240 s

0.280 s

After Test

Figure A.4. Sequential photographs for test 405160-26-1 (overhead and frontal views) (continued).

Figure A.5. Vehicle/installation positions after test 405160-26-1.

Figure A.6. Installation after test 405160-26-1.

A.8 TEST VEHICLE DAMAGE

Damage to the 2270P vehicle is shown in figure A.7. The upper ball joints on the left side pulled out of the socket and the lower ball joint on the left side broke. The tie rod end broke, the left upper and lower A-arms, sway bar, and left frame rail were deformed. Also damaged were the front bumper, grill, left front fender, left front door, left rear door, left front and left rear tires and wheel rims, left exterior bed, and rear bumper. Maximum exterior crush to the vehicle was 20 inches in the side plane at the left front corner at bumper height. Maximum occupant compartment deformation was 5.0 inches in the left side floor pan. The seam opened in the left front corner of the floor pan forming a 6-inch × 8-inch hole. Exterior vehicle crush and occupant compartment measurements are shown in tables A.3 and A.4.

Figure A.7. Vehicle after test 405160-26-1.

A.9 OCCUPANT RISK VALUES

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 13.8 ft/s at 0.105 s, the highest 0.010-s occupant ridedown acceleration was 6.1 Gs from 0.122 to 0.132 s, and the maximum 0.050-s average acceleration was -7.6 Gs between 0.018 and 0.068 s. In the lateral direction, the occupant impact velocity was 17.1 ft/s at 0.105 s, the highest 0.010-s occupant ridedown acceleration was 11.2 Gs from 0.139 to 0.149 s, and the maximum 0.050-s average was 9.6 Gs between 0.018 and 0.068 s. Theoretical Head Impact Velocity (THIV) was 25.2 km/h or 7.0 m/s at 0.101 s; Post-Impact Head Decelerations (PHD) was 11.5 Gs between 0.139 and 0.149 s; and Acceleration Severity Index (ASI) was 1.26 between 0.018 and 0.068 s. These data and other pertinent information from the test are summarized in figure A.8. Vehicle angular displacements and accelerations versus time traces are presented in figure A.9, and figures A.10 through A.15, respectively.

Table A.3. Exterior crush measurements for test 405160-26-1.

Date: 2011-11-16 Test No.: 405160-26-1 VIN No.: 1D7HA18N85J573385

Year: 2005 Make: Dodge Model: Ram 1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	16	12	30	12	10	9	2	1	0	-11
2	Side plane at bumper ht	16	20	58	0	4	---	---	18	20	+75
	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.

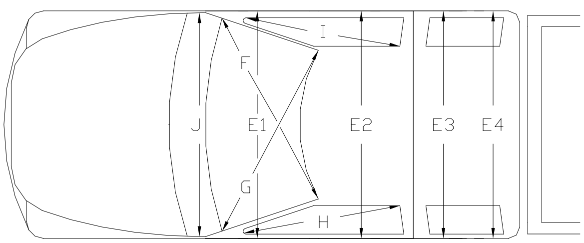
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

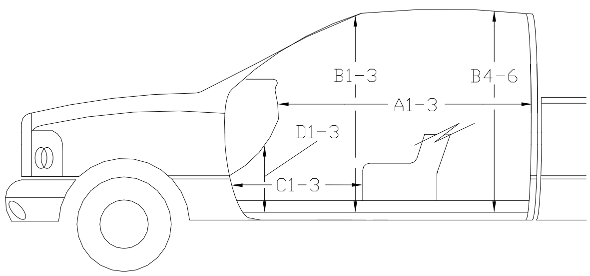
***Measure and document on the vehicle diagram the location of the maximum crush.

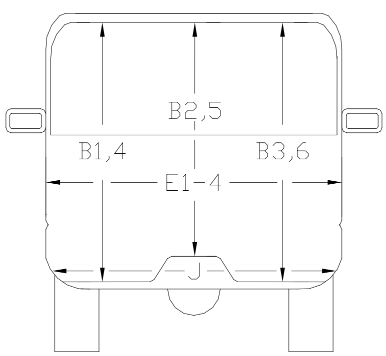
Note: Use as many lines/columns as necessary to describe each damage profile.

Table A.4. Occupant compartment measurements for test 405160-26-1.

Date:	2011-11-16	Test No.:	405160-26-1	VIN No.:	1D7HA18N85J573385
Year:	2005	Make:	Dodge	Model:	Ram 1500



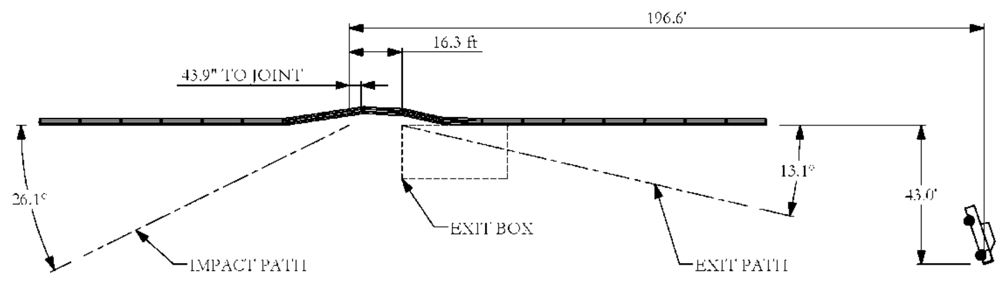


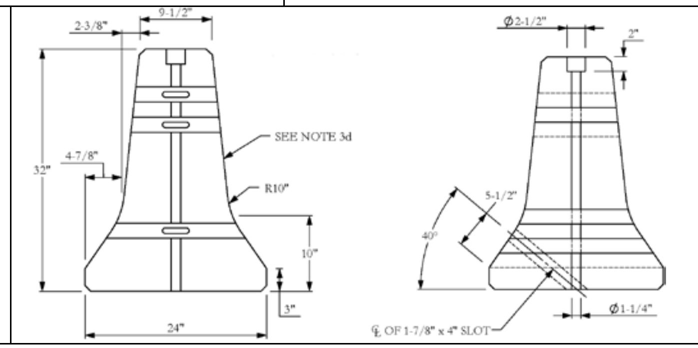


OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	**After** (inches)
A1	64.25	64.25
A2	64.75	64.75
A3	65.50	65.50
B1	45.25	45.25
B2	39.00	39.00
B3	45.25	45.25
B4	42.00	42.00
B5	42.75	42.75
B6	42.00	42.00
C1	29.50	24.50
C2	----	----
C3	27.25	27.25
D1	12.50	11.25
D2	10.00	10.00
D3	11.50	11.50
E1	62.50	61.50
E2	64.50	64.75
E3	64.00	63.75
E4	64.00	64.25
F	60.00	60.00
G	60.00	60.00
H	38.50	38.50
I	39.50	39.50
J*	62.25	61.75

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





General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-21
TTI Test No.	405160-26-1
Date	November 16, 2011
Test Article	
Type	Transition
Name	Transition from free-standing F-shape barrier to pinned F-shape barrier
Installation Length	226.4 ft
Material or Key Elements	
Soil Type and Condition	Concrete Surface, Dry
Test Vehicle	
Type/Designation	2270P
Make and Model	2005 Dodge Ram 1500 Pickup
Curb	4851 lb
Test Inertial	5017 lb
Dummy	No dummy
Gross Static	5017 lb

Impact Conditions	
Speed	61.7 mi/h
Angle	26.1 degrees
Location/Orientation	3.7 ft upstrm of joint
Impact Severity	
Exit Conditions	
Speed	50.6 mi/h
Angle	13.1 degrees
Occupant Risk Values	
Impact Velocity	
Longitudinal	13.8 ft/s
Lateral	17.1 ft/s
Ridedown Accelerations	
Longitudinal	6.1 G
Lateral	11.2 G
THIV	25.2 km/h
PHD	11.5 G
ASI	1.26
Max. 0.050-s Average	
Longitudinal	-7.6 G
Lateral	9.6 G
Vertical	-2.4 G

Post-Impact Trajectory	
Stopping Distance	196.5 ft dwnstrm 43 ft twd traffic
Vehicle Stability	
Maximum Yaw Angle	70 degrees
Maximum Pitch Angle	13 degrees
Maximum Roll Angle	90 degrees
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	3.7 ft
Permanent	3.7 ft
Working Width	5.4 ft
Vehicle Penetration	5.1 ft
Vehicle Damage	
VDS	11LFQ4
CDC	11FLEW4
Max. Exterior Deformation	20.0 inches
OCDI	LF0020000
Max. Occupant Compartment Deformation	5.0 inches

Figure A.8. Summary of results for *MASH* test 3-21 on transition from free-standing F-shape barrier to pinned F-shape barrier.

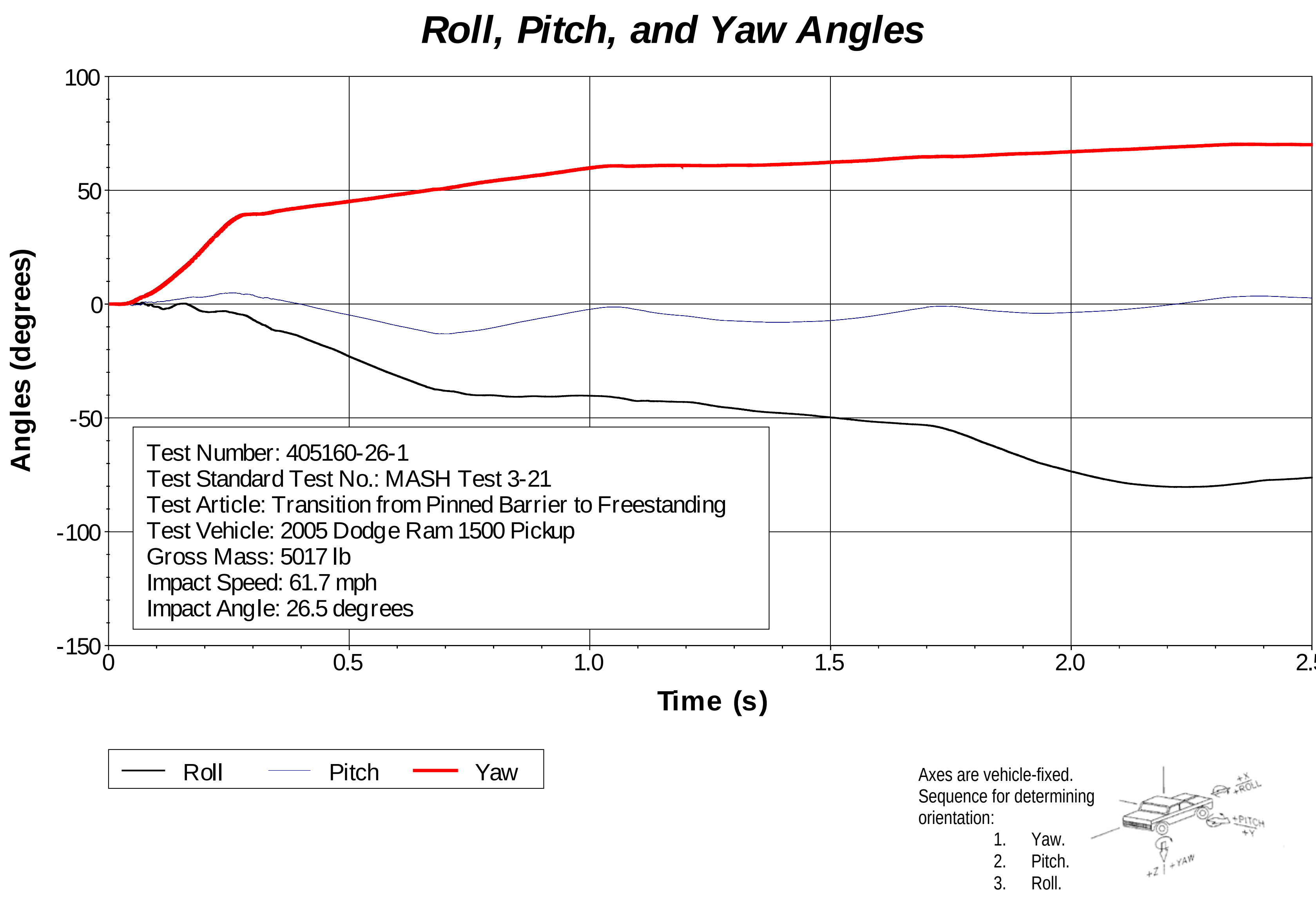


Figure A.9. Vehicle angular displacements for test 405160-26-1.

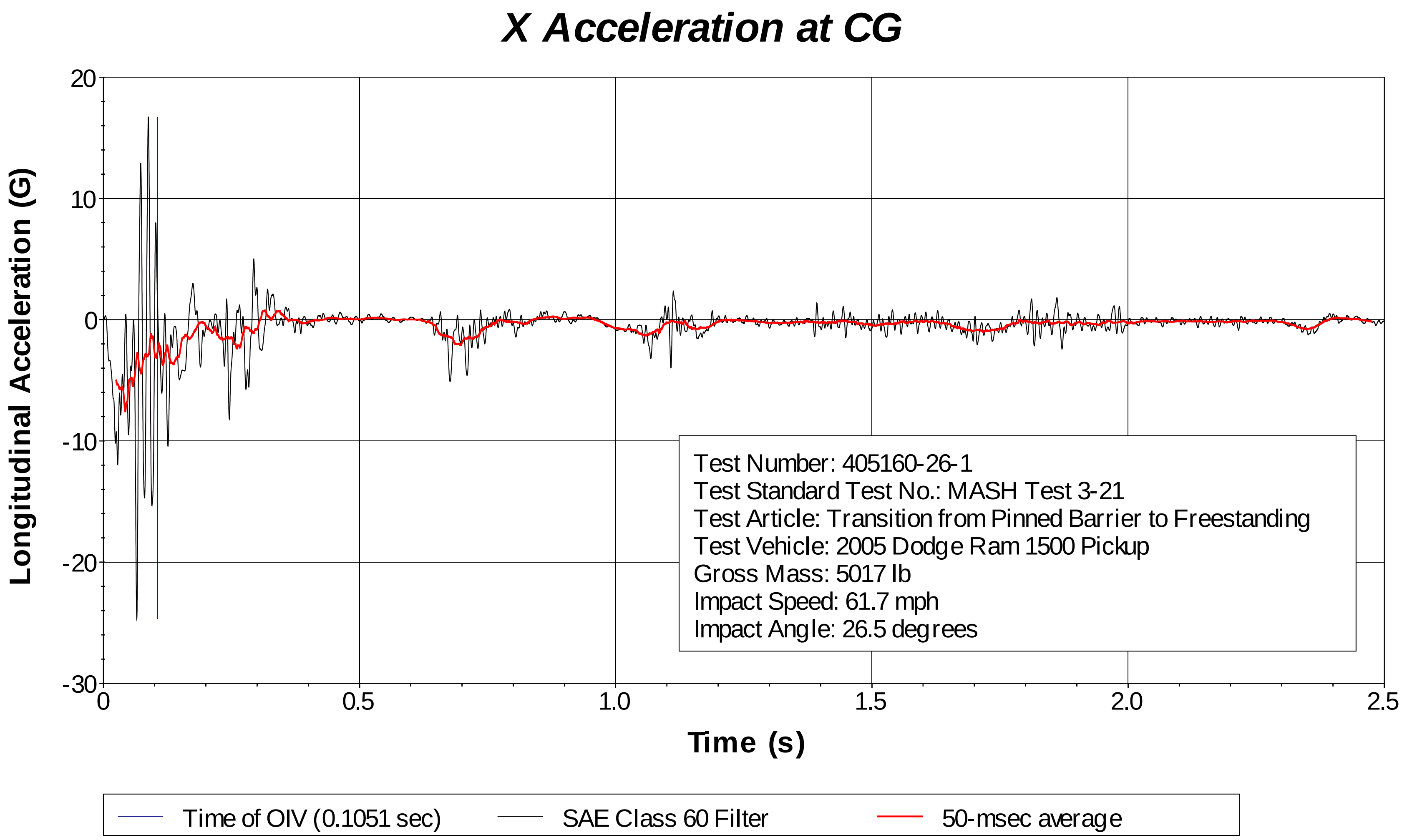


Figure A.10. Vehicle longitudinal accelerometer trace for test 405160-26-1 (accelerometer located at center of gravity).

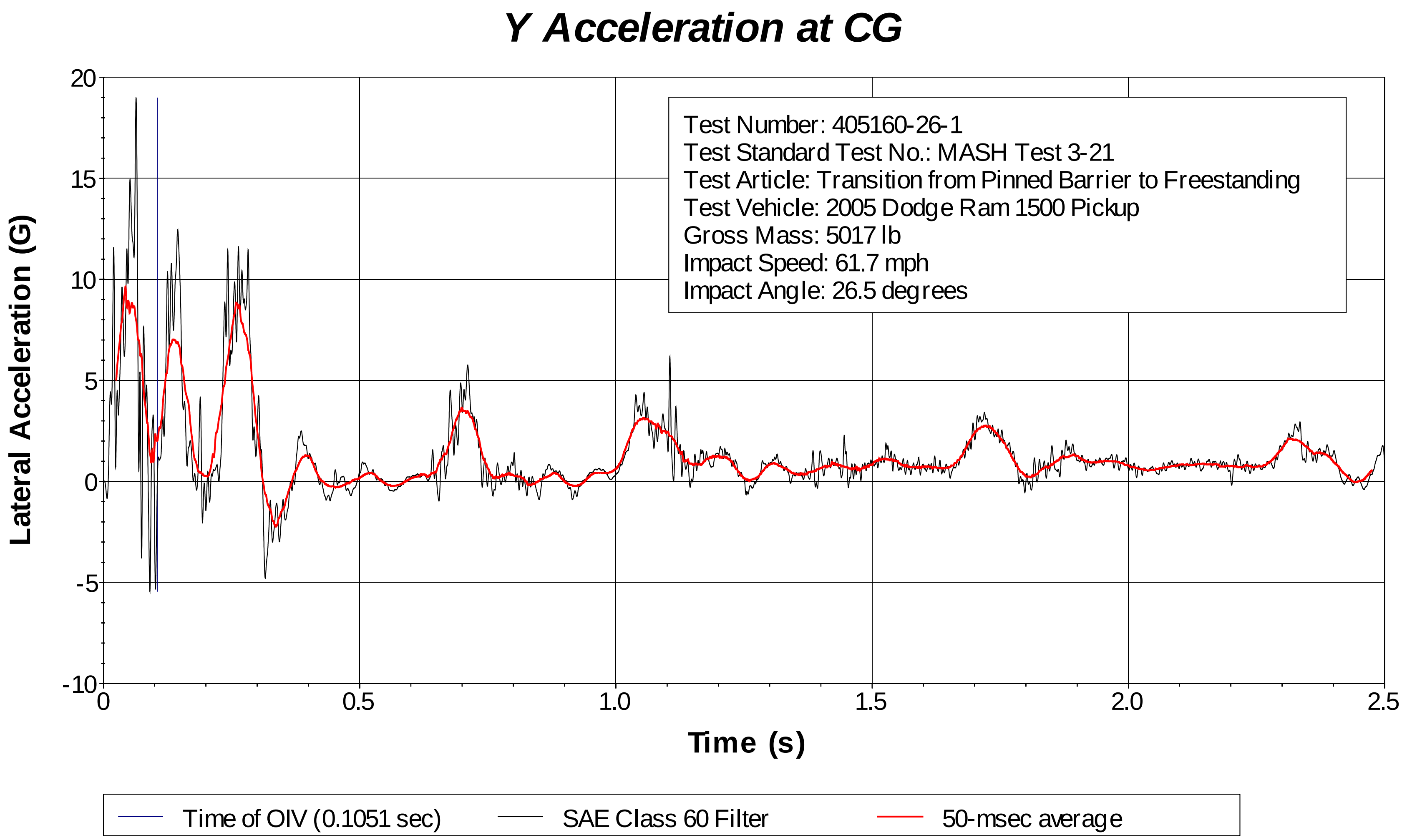


Figure A.11. Vehicle lateral accelerometer trace for test 405160-26-1
(accelerometer located at center of gravity).

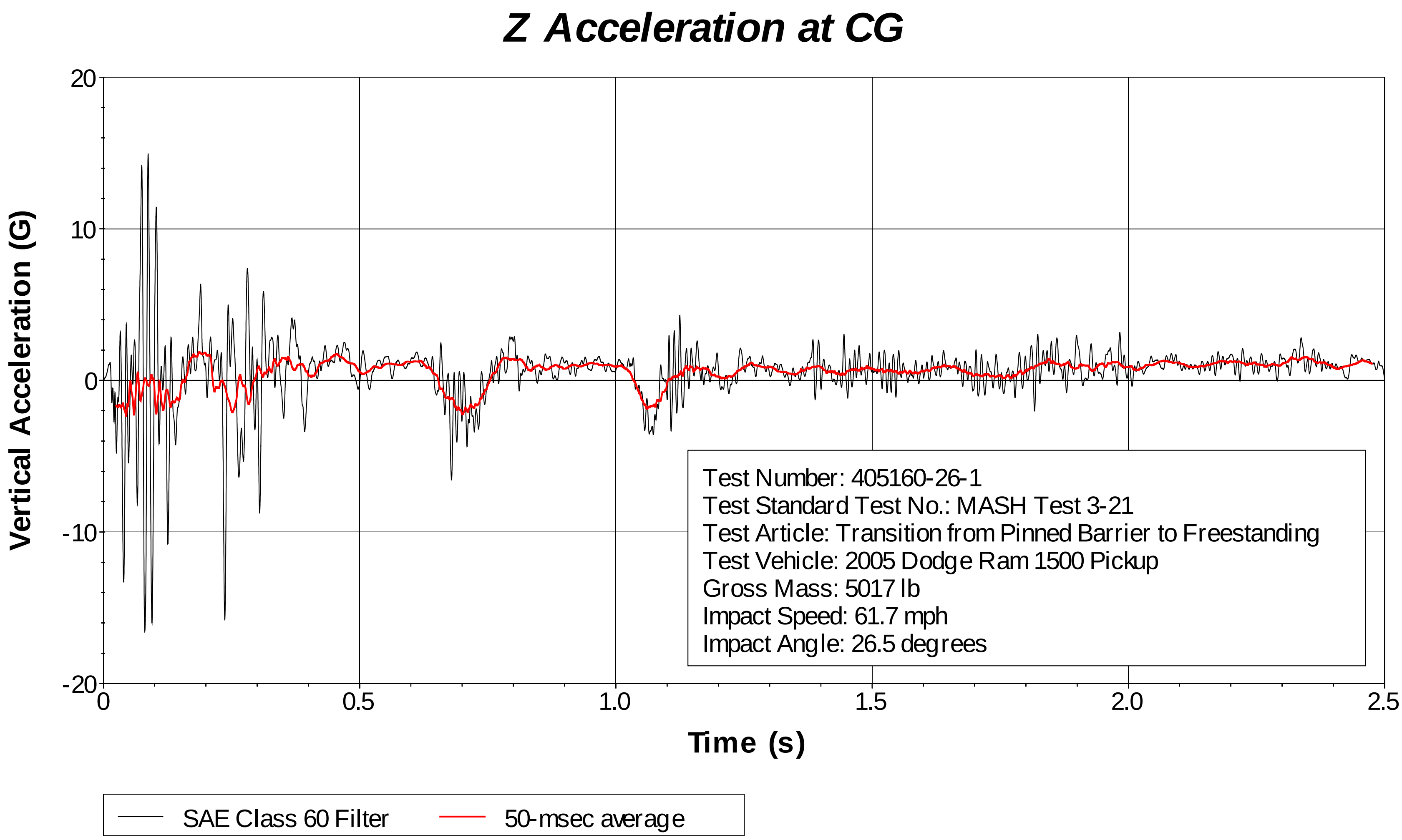


Figure A.12. Vehicle vertical accelerometer trace for test 405160-26-1 (accelerometer located at center of gravity).

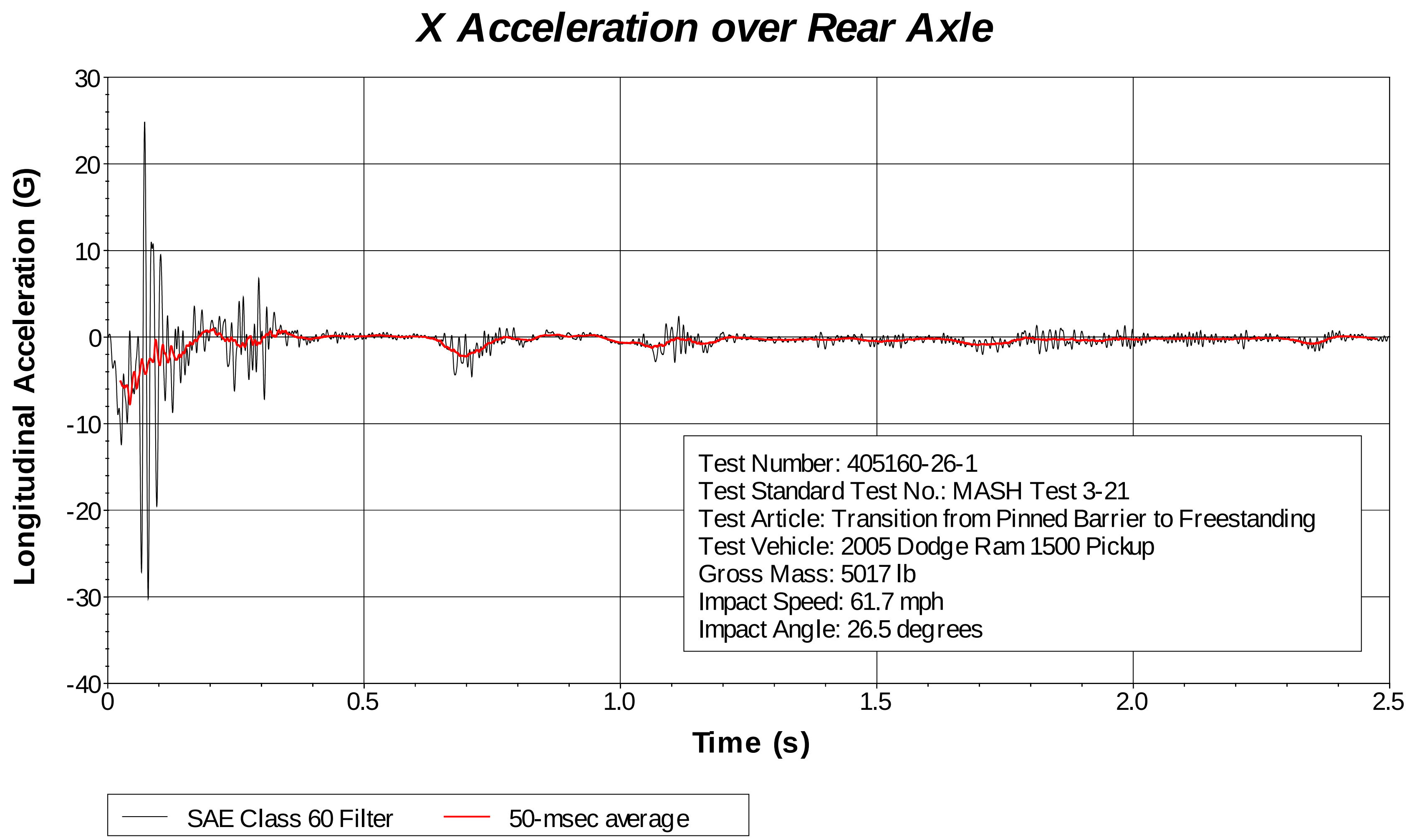


Figure A.13. Vehicle longitudinal accelerometer trace for test 405160-26-1 (accelerometer located over rear axle).

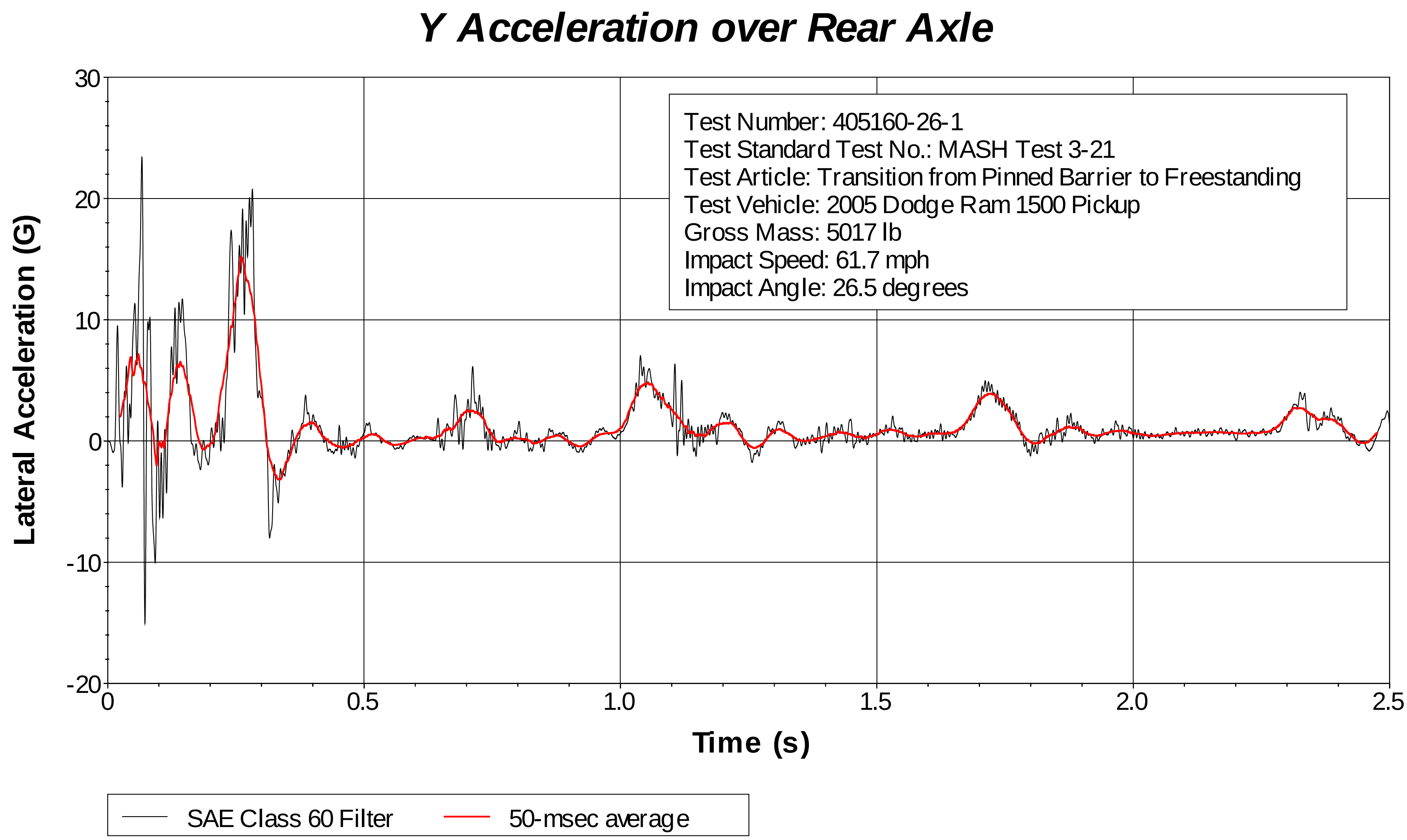


Figure A.14. Vehicle lateral accelerometer trace for test 405160-26-1 (accelerometer located over rear axle).

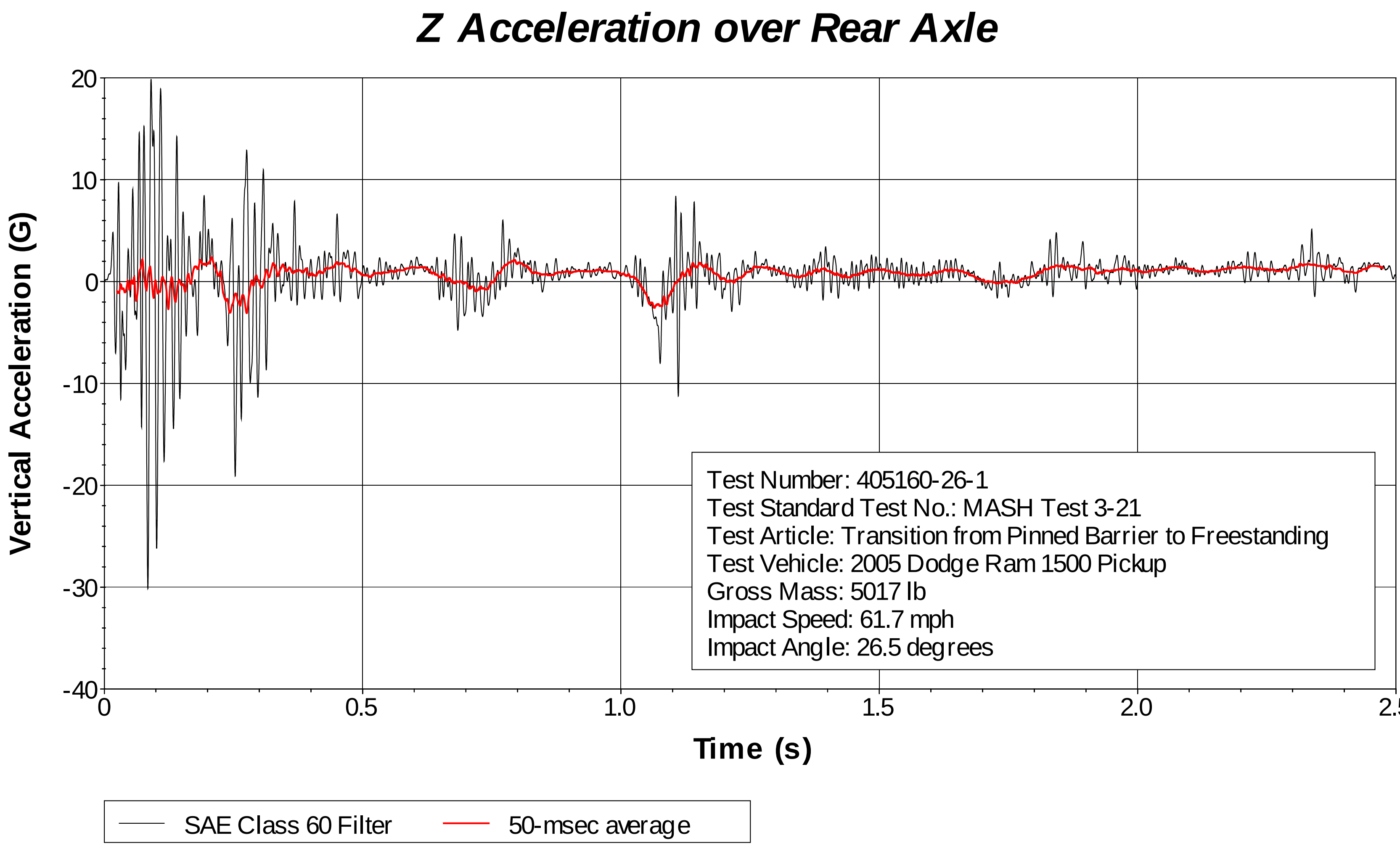


Figure A.15. Vehicle vertical accelerometer trace for test 405160-26-1
(accelerometer located over rear axle).

A.10 ASSESSMENT OF TEST RESULTS

An assessment of the test was made based on the following applicable *MASH* safety evaluation criteria.

A.10.1 Structural Adequacy

B. 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 from the free-standing F-shape barrier to pinned F-shape barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the barrier during the test was 3.7 ft. (PASS)

A.10.2 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: There were no detached elements, fragment, or other debris present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area. (PASS)
Maximum occupant compartment deformation was 5.0 inches in the left front corner of the floor pan. (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 the collision event. However, after loss of contact, the vehicle rolled 90 degrees. (FAIL)

I. 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 13.8 ft/s, and lateral occupant impact velocity was 17.1 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Longitudinal ridedown acceleration was 6.1 G, and lateral ridedown acceleration was 11.2 G. (PASS)

A.10.3 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 within the exit box. (PASS)

A.11 SUMMARY AND CONCLUSIONS – CRASH TEST 405160-26-1

The transition from the free-standing F-shape barrier to pinned F-shape barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the barrier during the test was 3.7 ft. There were no detached elements, fragment, or other debris present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 5.0 inches in the left front corner of the floor pan. The 2270P vehicle remained upright during the collision event. However, after loss of contact, the vehicle rolled 90 degrees. Occupant risk factors were within the limits specified in *MASH*. The 2270P vehicle exited within the exit box.

Due to rollover of the vehicle, the transition from the free-standing F-shape barrier to pinned F-shape barrier did not perform acceptably according to *MASH* specifications for *MASH* test 3-21, as shown in table A.5.

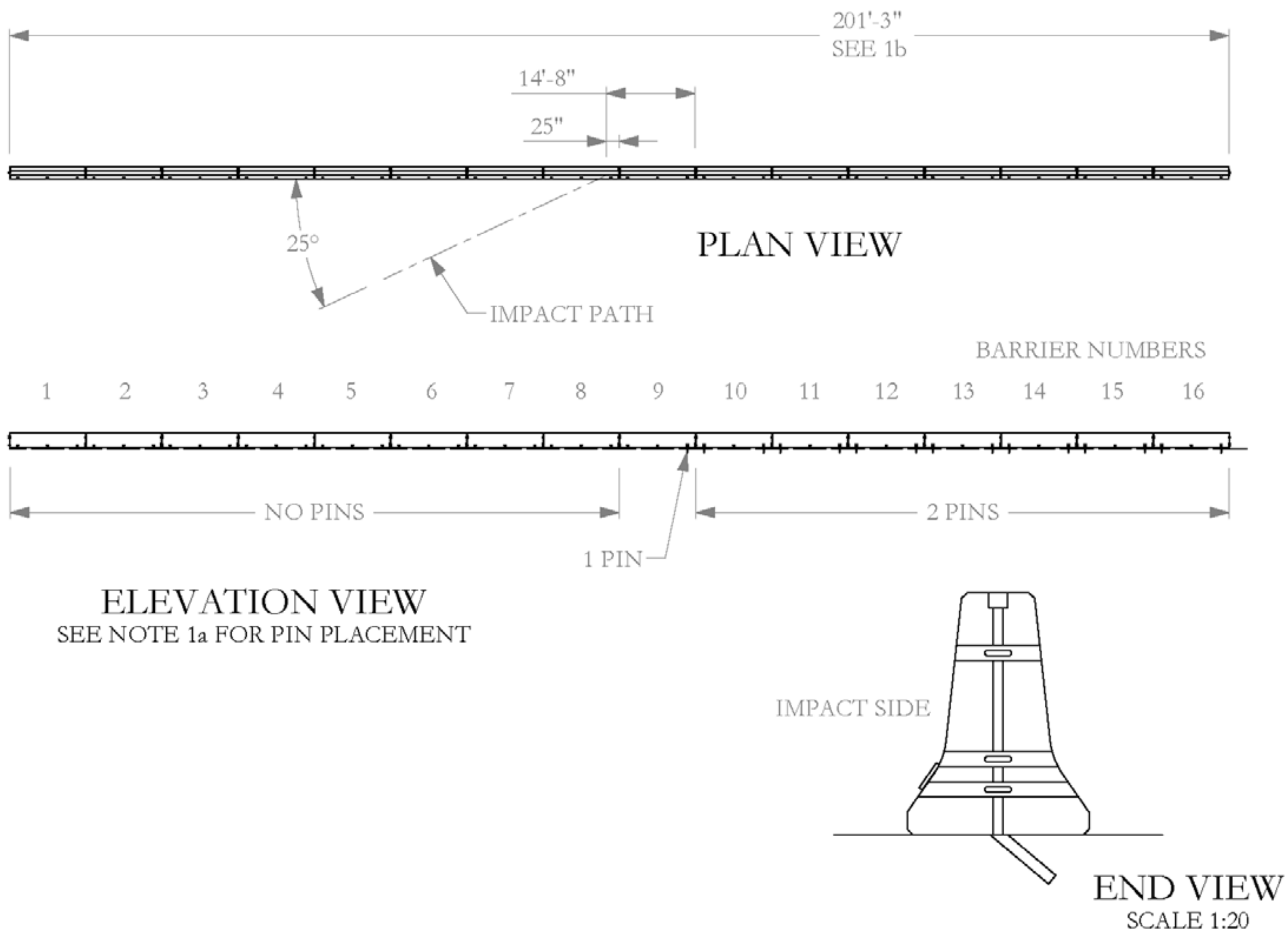
Table A.5. Performance evaluation summary for *MASH* test 3-21 on the transition from free-standing F-shape barrier to pinned F-shape barrier in test 405160-26-1.

Test Agency: Texas A&M Transportation Institute | Test No.: 405160-26-1 | Test Date: 2011-11-16

MASH **Test 3-21 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable*	The transition from the pinned F-shape barrier placed on concrete to free-standing F-shape barrier placed on pavement contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the barrier during the test was 3.7 ft.	Pass
<u>Occupant Risk</u> D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	There were no detached elements, fragment, or other debris present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 5.0 inches in the left front corner of the floor pan.	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 the collision event. However, after loss of contact, the vehicle rolled 90 degrees.	Fail
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 13.8 ft/s, and lateral occupant impact velocity was 17.1 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.*	Longitudinal ridedown acceleration was 6.1 G, and lateral ridedown acceleration was 11.2 G.	Pass
<u>Vehicle Trajectory</u> *For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).*	The vehicle exited within the exit box.	Pass

APPENDIX B. CRASH TEST 405160-26-2

B.1. DETAILS OF PINNED BARRIER FOR TEST 405160-26-2



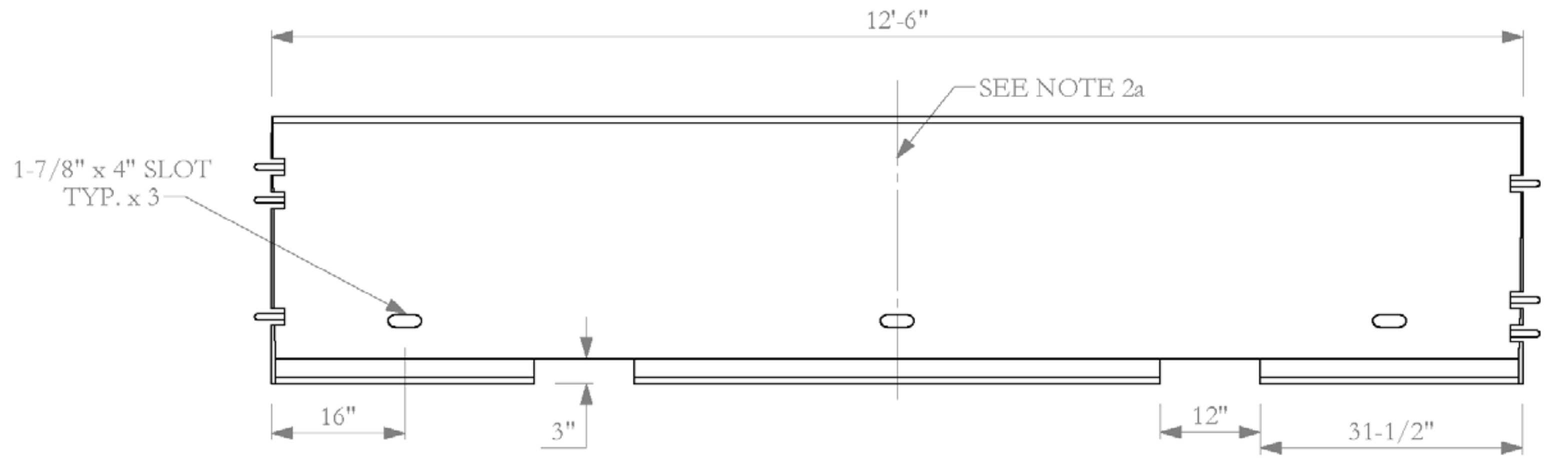
1a. Barriers will be placed on un-reinforced concrete, approximately 6" - 8" thick, and connected with Connecting Pins (see sheet 6). Barriers 1-8 are free-standing, with no anchor pins. Barrier 9 will have one anchor pin in the downstream slot. Barriers 10-16 will have two pins, one in each outside slot. Place barriers and drill Ø1-3/4" holes through the concrete deck, using the slots as a guide. Insert the pins and turn them so that the plate washers are as flat against the barriers as possible.

1b. Sixteen barriers at 12'6" with ≈1" space between barriers.

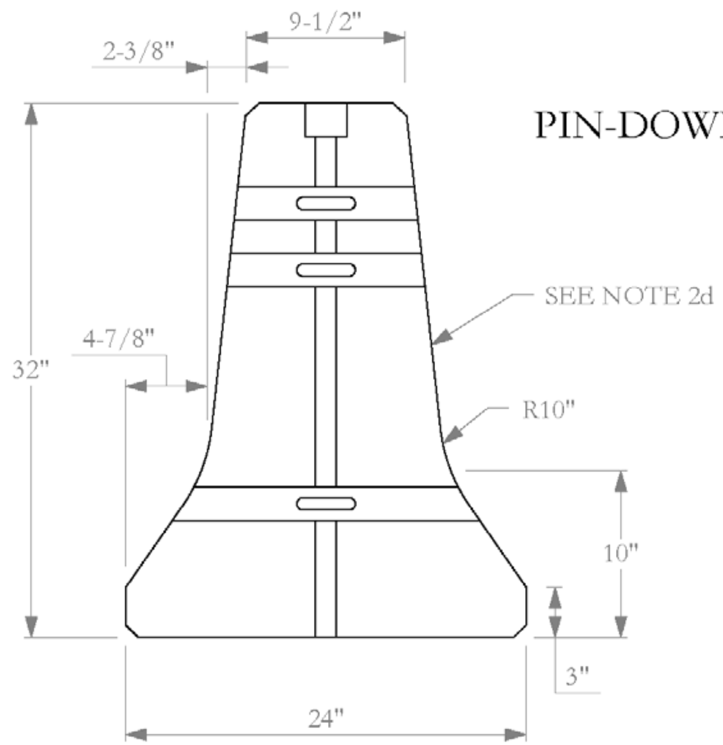
Texas A&M Transportation Institute — Proving Ground - Roadside Safety and Physical Security Division

Project 405160-26-2	Pinned-Down Barrier Transition		
Drawn By GES	Scale 1:300	Sheet 1 of 6	Test Installation
Approved: Nauman Sheikh:	Nauman M. Sheikh	Date: 2012-09-10	

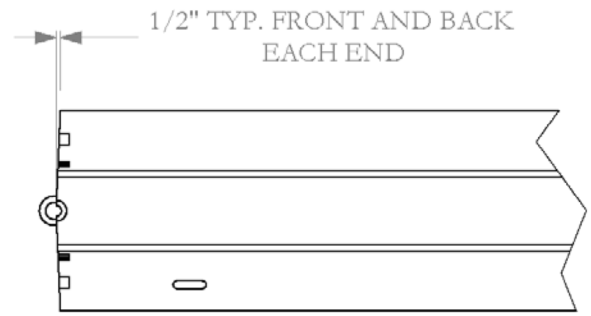
PIN-DOWN BARRIER



ELEVATION VIEW



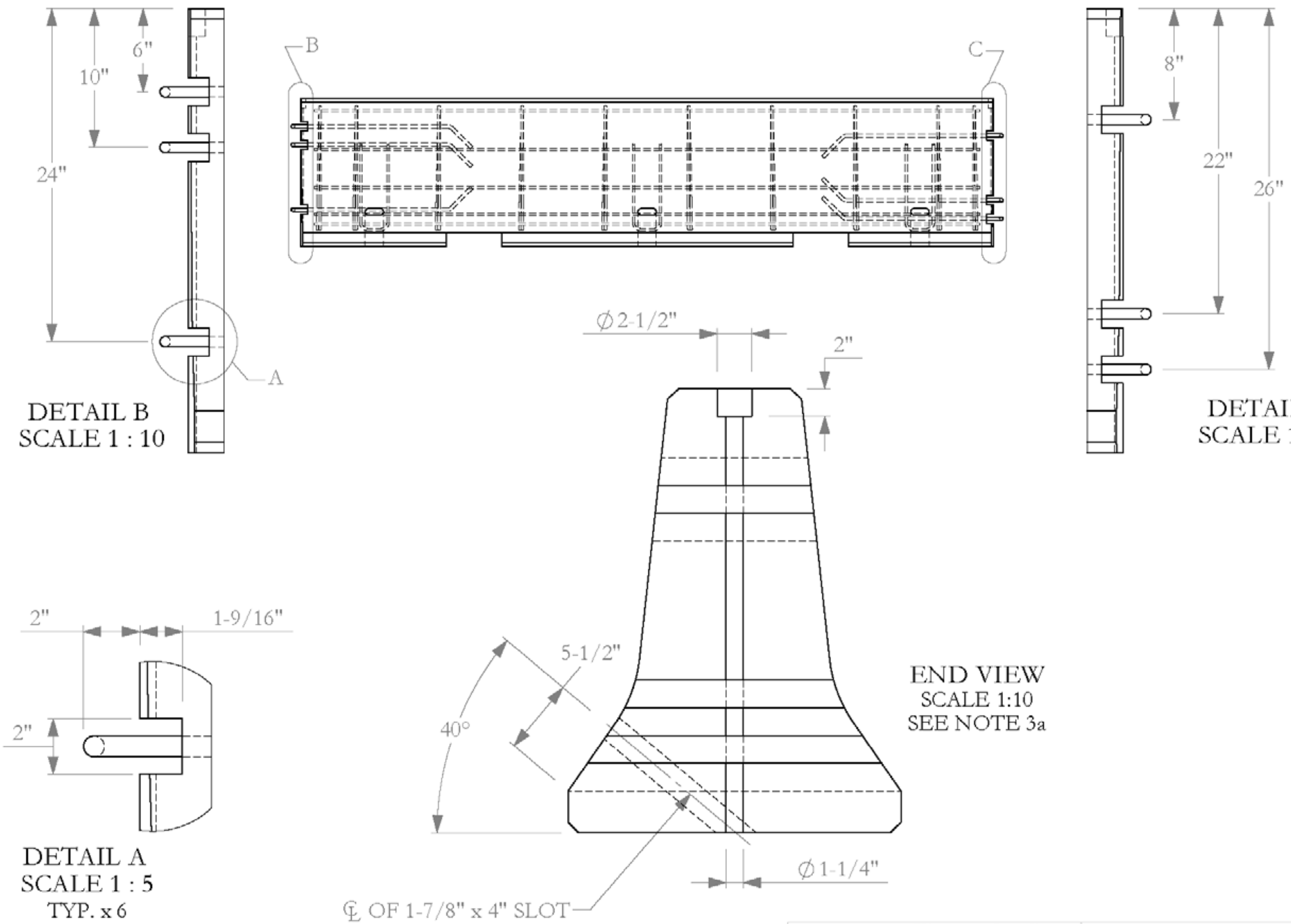
END VIEW
SCALE 1:10



PLAN VIEW

2a. Barriers are symmetrical about ℄'s, except for end loops. See next page for end loop and cut-out details.
2b. All rebar is grade 60.
2c. Concrete shall be 5000 psi.
2d. Chamfer top, bottom, and ends 3/4". End chamfers not shown for clarity.

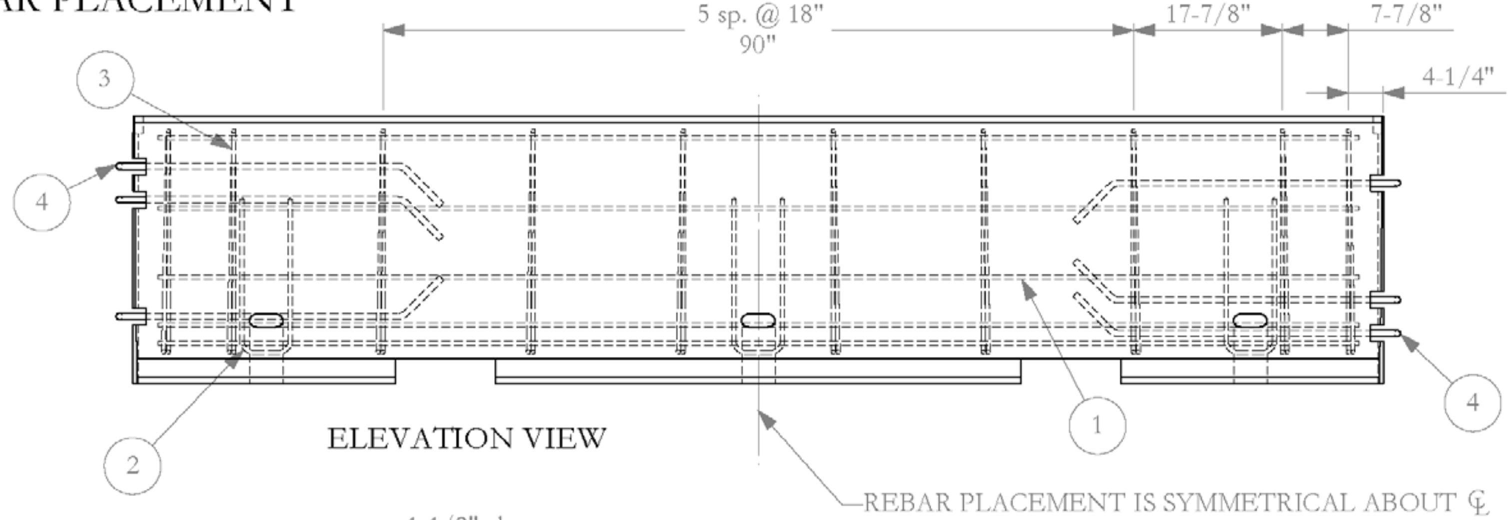
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project 405160-26-2		Pinned-Down Barrier Transition	2012-09-10
Drawn By GES	Scale 1:20	Sheet 2 of 6	Barrier Details a



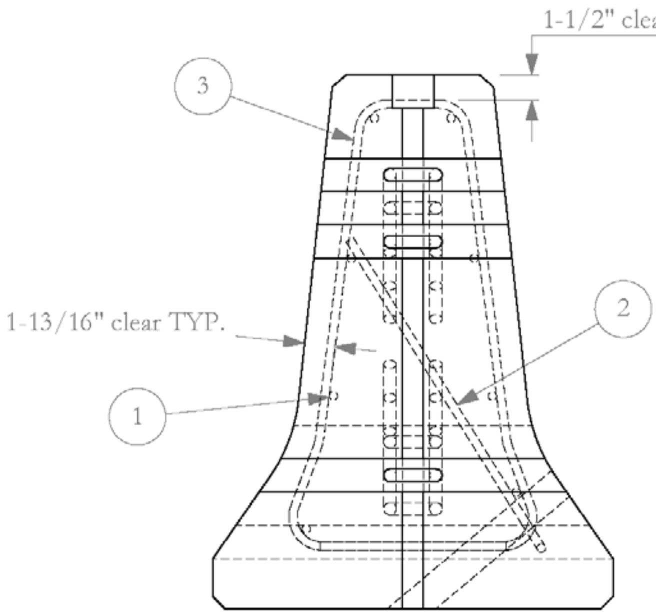
3a. Rebar and End Loops not shown in End View for clarity.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
Project 405160-26-2	Pinned-Down Barrier Transition		2012-09-10
Drawn By GES	Scale 1:30	Sheet 3 of 6	Barrier Details b

REBAR PLACEMENT



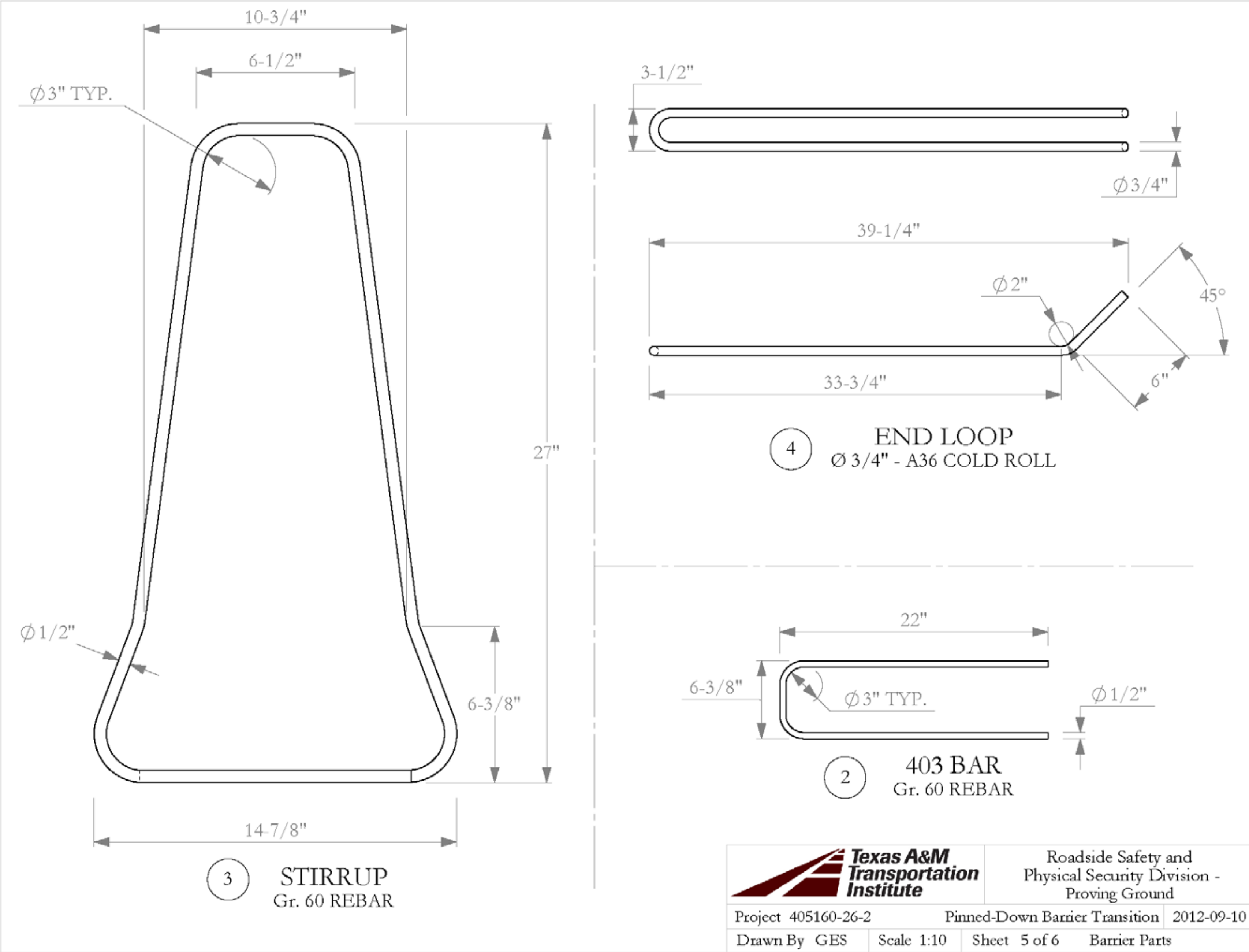
ELEVATION VIEW

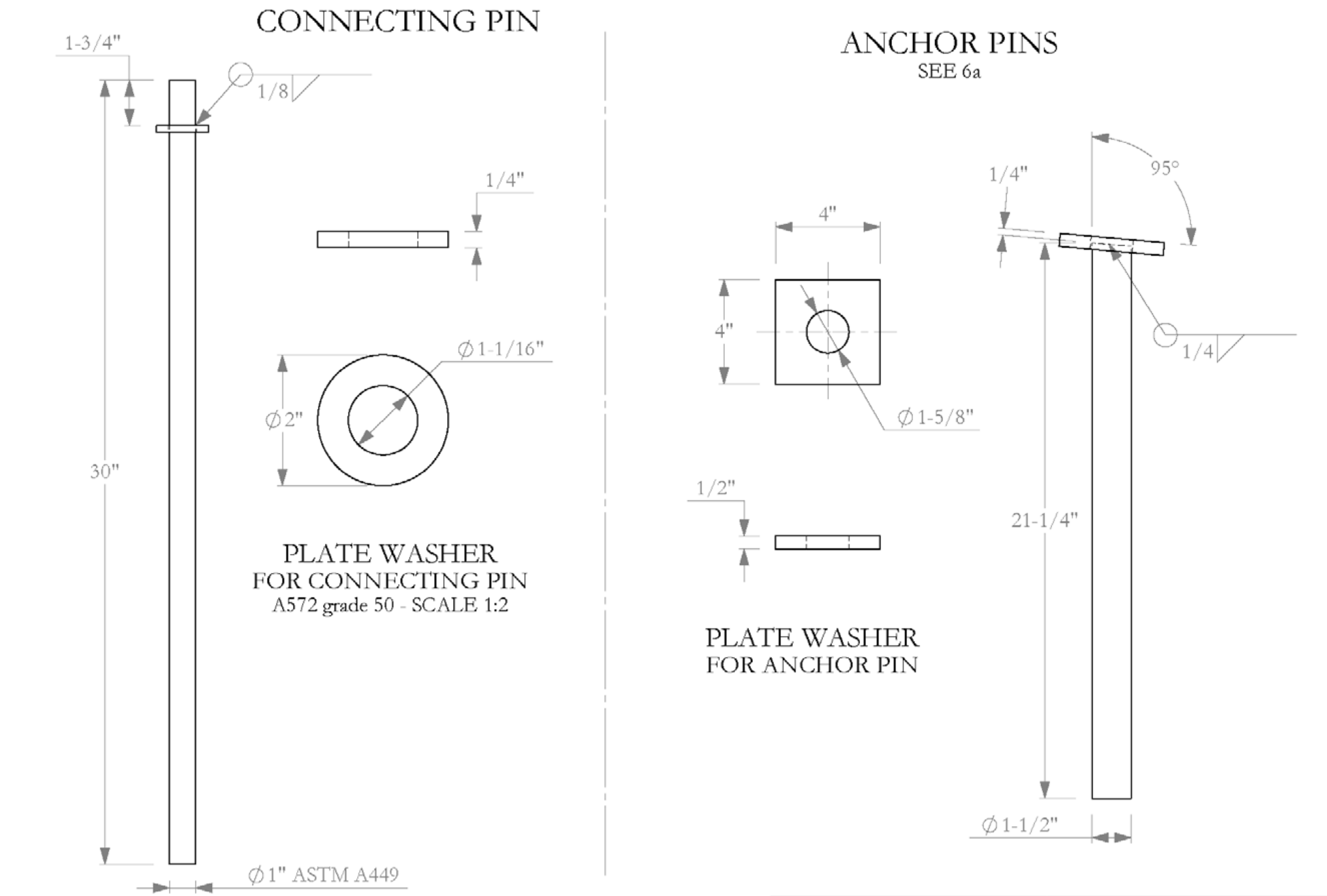


END VIEW
SCALE 1:10

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

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
Project 405160-26-2	Pinned-Down Barrier Transition		2012-09-10
Drawn By GES	Scale 1:20	Sheet 4 of 6	Rebar Placement


10-3/4"
6-1/2"
∅3" TYP.
27"
∅1/2"
6-3/8"
14-7/8"
3
STIRRUP
Gr. 60 REBAR
3-1/2"
∅3/4"
39-1/4"
∅2"
45°
33-3/4"
6"
4
END LOOP
Ø 3/4" - A36 COLD ROLL
22"
6-3/8"
∅3" TYP.
∅1/2"
2
403 BAR
Gr. 60 REBAR
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project 405160-26-2
Pinned-Down Barrier Transition
2012-09-10
Drawn By GES
Scale 1:10
Sheet 5 of 6
Barrier Parts



6a. All material for Anchor Pins is ASTM A36.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground
Project 405160-26-2	Pinned-Down Barrier Transition 2012-09-10
Drawn By GES · Scale 1:5 · Sheet 6 of 6	Pin Details

B.2. SUPPORTING CERTIFICATION DOCUMENTS FOR INSTALLATION USED IN TEST 405160-26-1

MATERIAL USED

TEST NUMBER 405160-26-1

TEST NAME Pinned-down CMB Transition

DATE 2011-11-16

DATE RECEIVED	ITEM NUMBER	DESCRIPTION	SUPPLIER	HEAT #
2011-11-11	Round Stock-06	3/4" x 20' Cold Roll	Mack Bolt & Steel	DL1110245701
2011-11-11	Round Stock-07	1-1/2" x 20' Cold Roll	Mack Bolt & Steel	A091282
2011-11-04	Barriers-01	12'6" CMB's	Waskey	none

The round stock above was used for the anchor pins. No paperwork was provided with the barriers or connection pins.

Vulcan THREADED PRODUCTS, INC.

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

Material Certification

Customer: **Namasco Southeast**
Ship To: **AUSTIN**
Customer PO No: **6223248**
Vulcan Order No: **47318**
Order Line: **4**
Vulcan Part No: **CDR 1018 1.5000x240**
Customer Part No: **CDR 1018 1.5000x240**
Shipped Qty: **8225**
Heat: **A091282**
Grade: **1018**
Note:
Spec No: **ASTM A108-07**
Spec Rev: **2007**
Spec Note: **This certification is actual test results performed by the Hot Roll supplying Mill on the heat number listed and meets all of the chemical analysis required by AISI C1018-Rev (2007).**

Material Specification Type	Material Specification	Actual
Chemistry	Carbon (C)	0.1600 %
	Manganese (Mn)	0.6300 %
	Phosphorus (P)	0.0060 %
	Sulfur (S)	0.0190 %
	Silicon (Si)	0.2400 %
	Chromium (Cr)	0.1500 %
	Molybdenum (Mo)	0.0400 %
	Nickel (Ni)	0.1100 %
	Vanadium (V)	0.0020 %
	Copper (Cu)	0.2000 %
	Aluminum (Al)	0.0230 %
	Tin (Sn)	0.0110 %
	Titanium (Ti)	0.0010 %
	Columbium/Niobium (Nb)	0.0020 %
	Range Ni+Cr+Mo	0.0000 %
	Reduction Ratio	0

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

Pfax Online 9/9/09 11:47 AM vulc.thud Page 1

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

Material Certification

Customer PO No: 6390280
Vulcan Order No: 126923
Order Line: 3
Vulcan Part No: CDR 1018 .750x240
Customer Part No: CDR 1018 .750x240
Shipped Qty: 1408
Heat: DL1110245701
Grade: 1018
Country of Origin: USA
Note: Melted and Manufactured in USA
Spec No: ASTM A108-07
Spec Rev: 2007
Spec Note: This certification is actual test results performed by the Hot Roll supplying Mill on the heat number listed and meets all of the chemical analysis required by AISI-Rev (2007).

Material Specification Type	Material Specification	Actual
Chemistry	Carbon (C)	.16 %
	Manganese (Mn)	.81 %
	Phosphorus (P)	.007 %
	Sulfur (S)	.019 %
	Silicon (Si)	.25 %
	Copper (Cu)	.17 %
	Nickel (Ni)	.07 %
	Chromium (Cr)	.11 %
	Molybdenum (Mo)	.010 %
	Vanadium (V)	.005 %
	Tin (Sn)	0.0000 %
	Columbium (Cb)	0 %
	Columbium/Niobium (Nb)	.003 %
	Aluminum (Al)	0.0000 %
	Titanium (Ti)	0.0000 %
	Reduction Ratio	94:1

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

B.3. VEHICLE PROPERTIES AND INFORMATION

Table B.1. Vehicle properties for test 405160-26-2.

Date: 2012-09-24 Test No.: 405160-26-2 VIN No.: 1DTHA18P075162075

Year: 2007 Make: Dodge Model: Ram 1500

Tire Size: P265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 121029

Note any damage to the vehicle prior to test: ____________________

● Denotes accelerometer location.

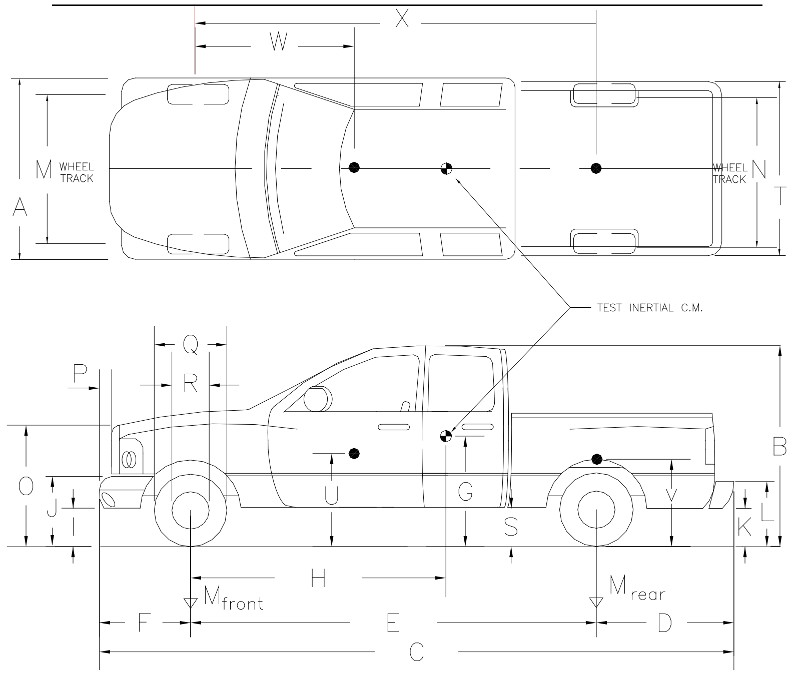
NOTES: ____________________

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	753.00	G	28.12	L	29.12	Q	31.25	V	29.50
C	223.75	H	62.68	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)	5.0	Bottom Frame Height - Front	17.125
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	10.25	Bottom Frame Height - Rear	24.75

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2797	2769	
Back	3900	M_{rear}	1999	2230	
Total	6700	M_{Total}	4796	4999	

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

Mass Distribution:
lb LF: 1392 RF: 1377 LR: 1110 RR: 1120

Table B.2. Measurements of vehicle vertical CG for test 405160-26-2.

Date: 2012-09-24 Test No.: 405160-26-2 VIN: 1DTHA18P075162075

Year: 2007 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 121029

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 236 lb at front of bed (440 lb max)

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

Measured Vehicle Weights: (lb)								
LF:	1392		RF:	1377		Front Axle:	2769	
LR:	1110		RR:	1120		Rear Axle:	2230	
Left:	2502		Right:	2497		Total:	5023	
						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:	62.38	in	Rear of Front Axle	(63 ±4 inches allowed)				
Y:	-0.20	in	Left - Right +	of Vehicle Centerline				
Z:	28.125	in	Above Ground	(minumum 28.0 inches allowed)				

Hood Height: 44.5 inches
43 ±4 inches allowed

Front Bumper Height: 25.375 inches

Front Overhang: 36.00 inches
39 ±3 inches allowed

Rear Bumper Height: 29.125 inches

Overall Length: 223.75 inches
237 ±13 inches allowed

Table B.3. Exterior crush measurements for test 405160-26-2.

Date: 2012-09-24 Test No.: 405160-26-2 VIN No.: 1DTHA18P075162075

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 Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bumper ht	19	14	24	14	12.5	8.5	4	3	1	-12
2	Side plane at bumper ht	19	15	60	1	2	--	--	12	14	+72
	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).

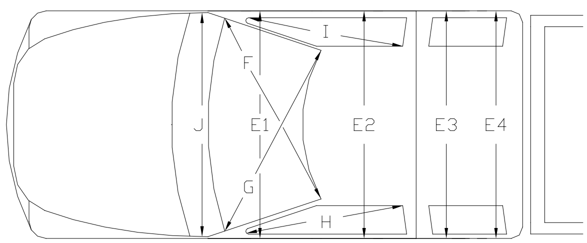
***Measure and document on the vehicle diagram the location of the maximum crush.

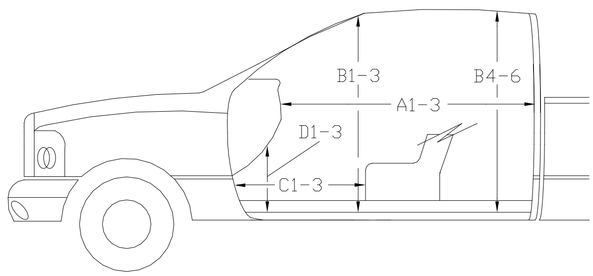
Note: Use as many lines/columns as necessary to describe each damage profile.

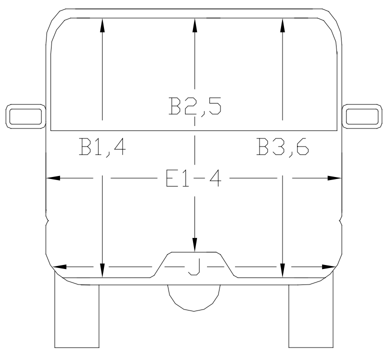
Table B.4. Occupant compartment measurements for test 405160-26-2.

Date: 2012-09-24 Test No.: 405160-26-2 VIN No.: 1DTHA18P075162075

Year: 2007 Make: Dodge Model: Ram 1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	**After** (inches)
A1	64.75	64.25
A2	64.50	64.50
A3	64.75	64.75
B1	45.00	45.00
B2	39.25	39.25
B3	45.00	45.00
B4	42.25	42.25
B5	44.75	44.75
B6	42.25	42.25
C1	30.00	30.00
C2	----	----
C3	26.50	26.50
D1	12.50	12.50
D2	----	----
D3	11.50	11.50
E1	62.75	62.00
E2	64.50	63.00
E3	64.00	63.75
E4	64.25	63.00
F	60.00	60.00
G	60.00	60.00
H	39.00	39.00
I	39.00	39.00
J*	62.00	61.75

B.4. SEQUENTIAL PHOTOGRAPHS

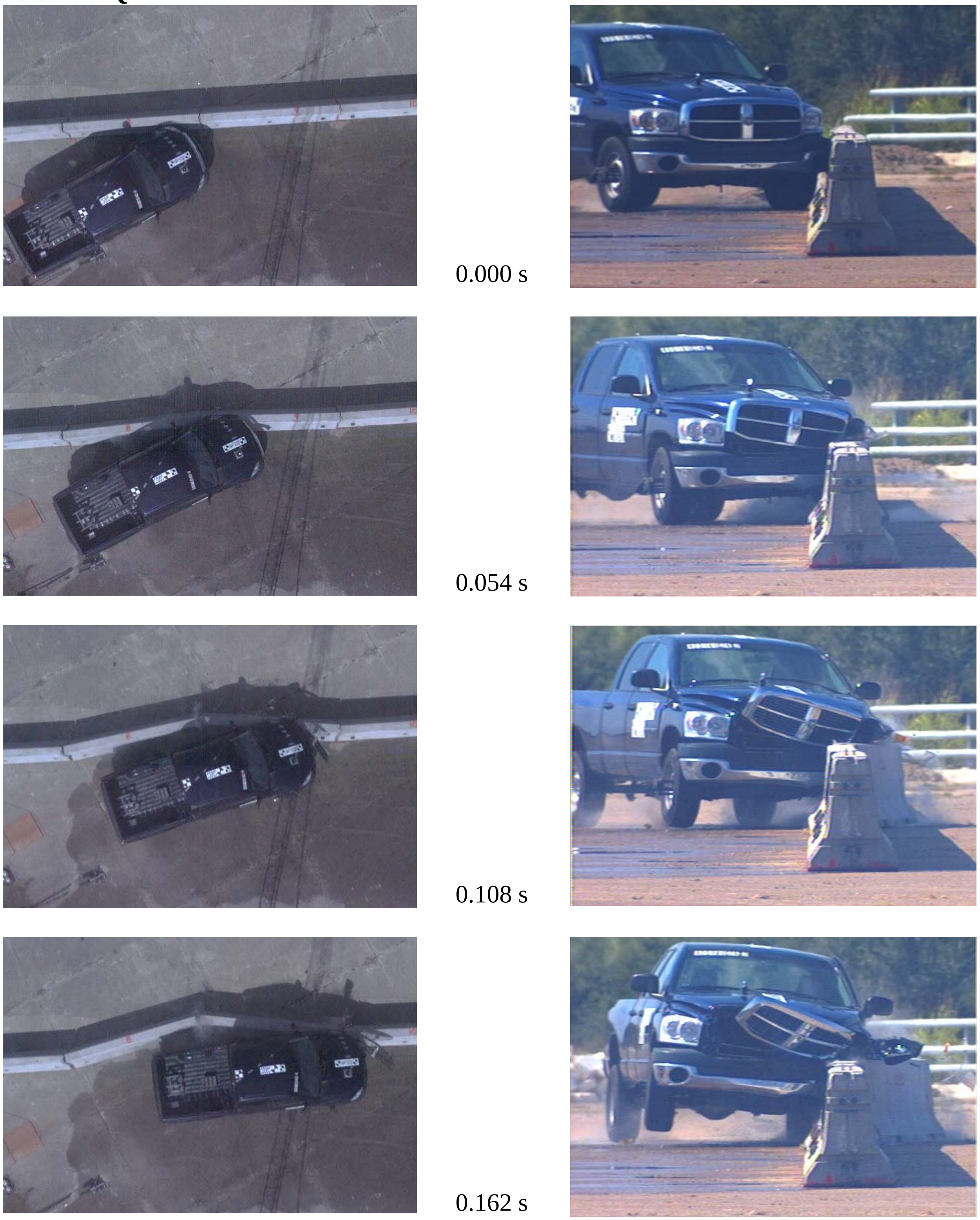


Figure B.1. Sequential photographs for test 405160-26-2
(overhead and frontal views).


0.216 s



0.270 s



0.324 s



0.379 s


Figure B.1. Sequential photographs for test 405160-26-2 (overhead and frontal views) (continued).

0.000 s

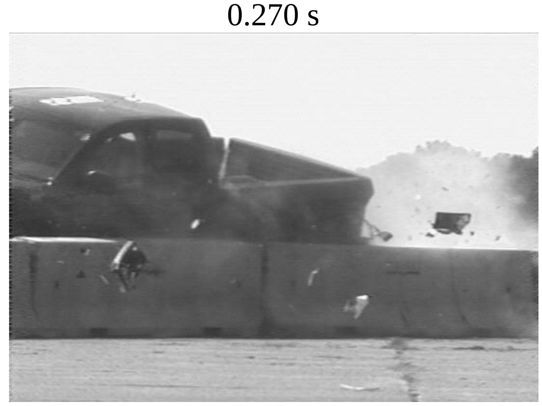
0.054 s

0.108 s

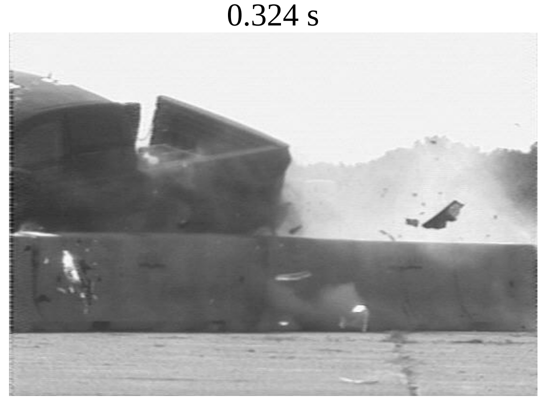
0.162 s

0.216 s

0.270 s



0.324 s



0.379 s

Figure B.2. Sequential photographs for test 405160-26-2
(rear view).

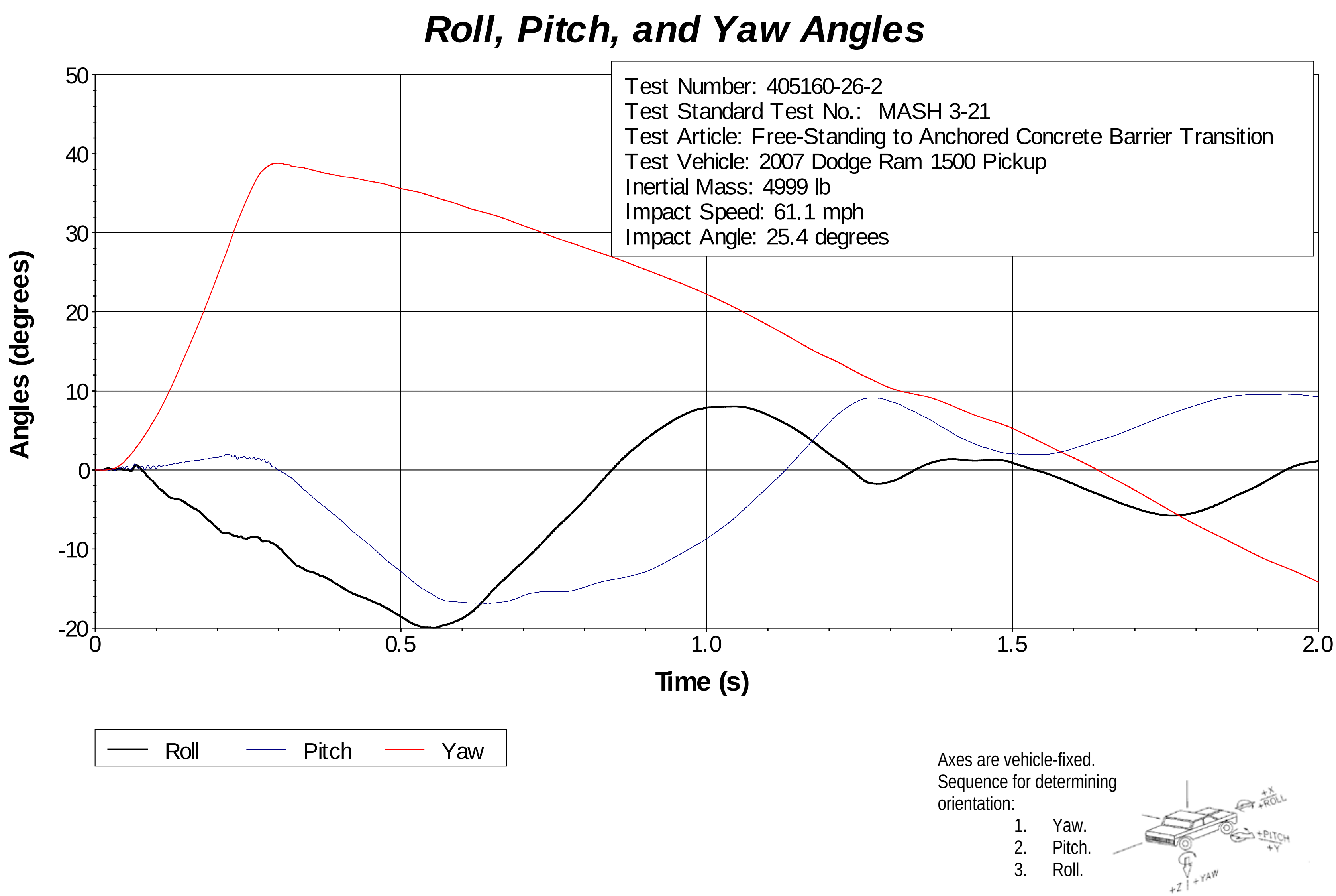


Figure B.3. Vehicle angular displacements for test 405160-26-2.

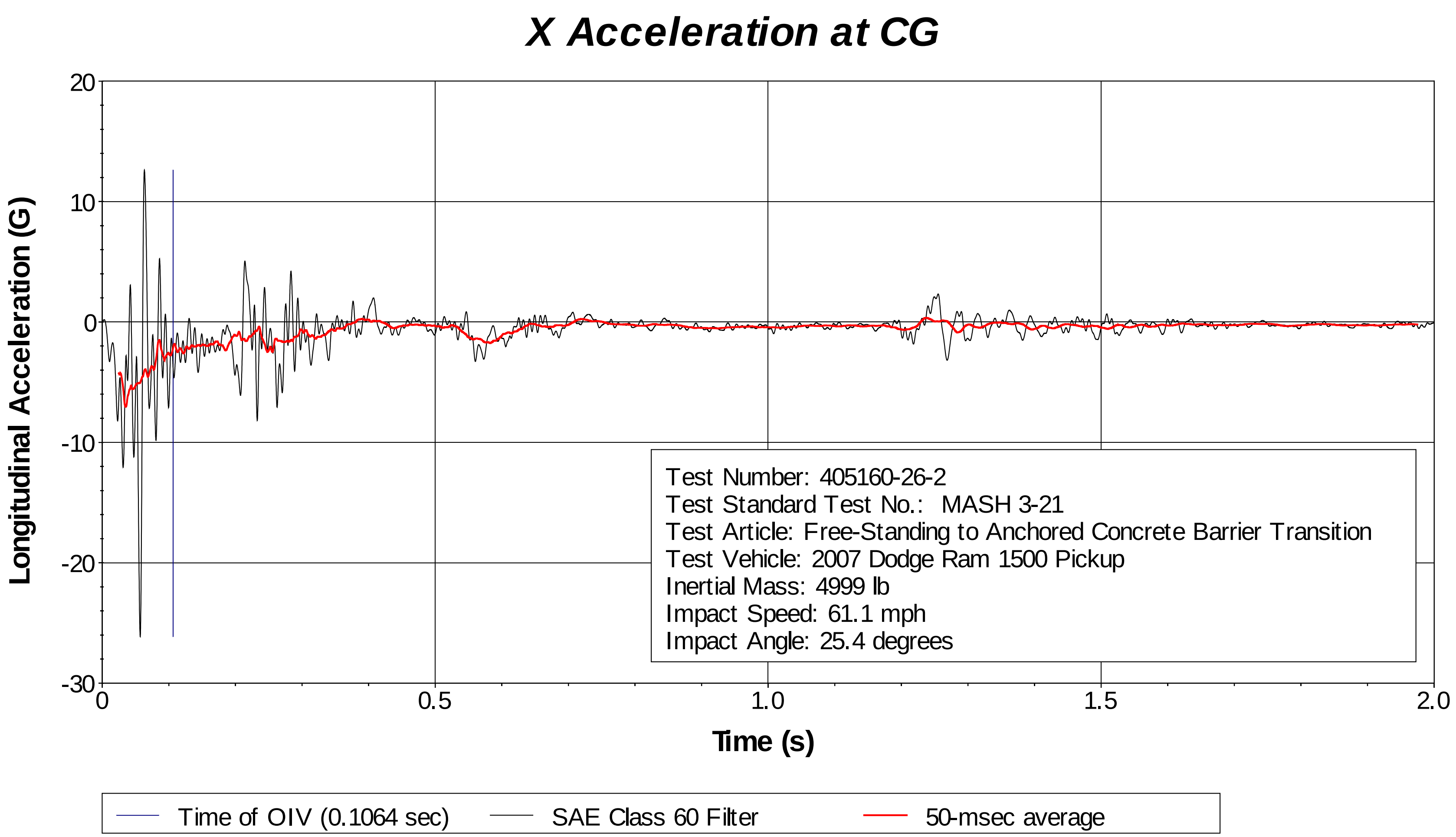


Figure B.4. Vehicle longitudinal accelerometer trace for test 405160-26-2 (accelerometer located at center of gravity).

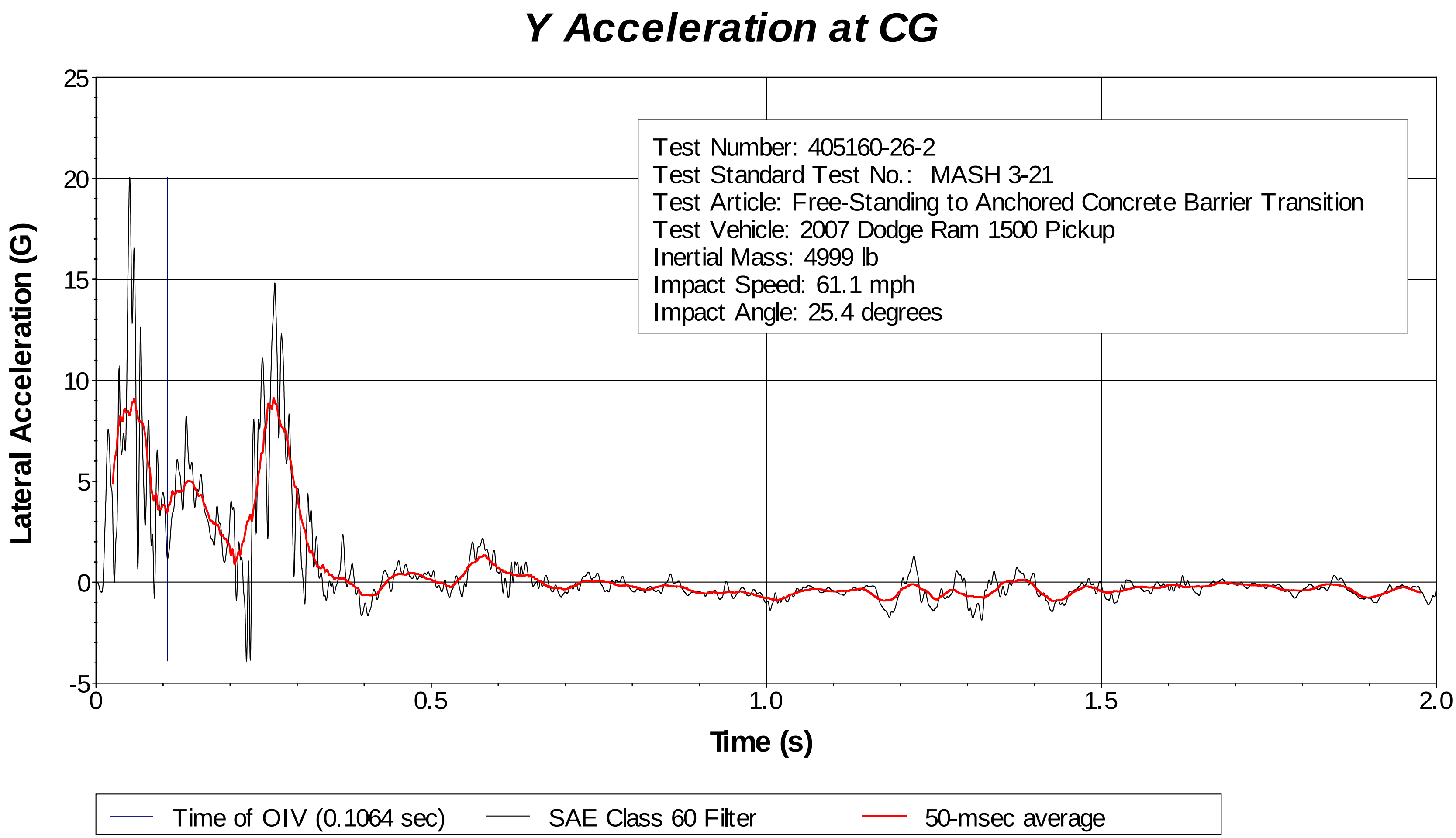


Figure B.5. Vehicle lateral accelerometer trace for test 405160-26-2
(accelerometer located at center of gravity).

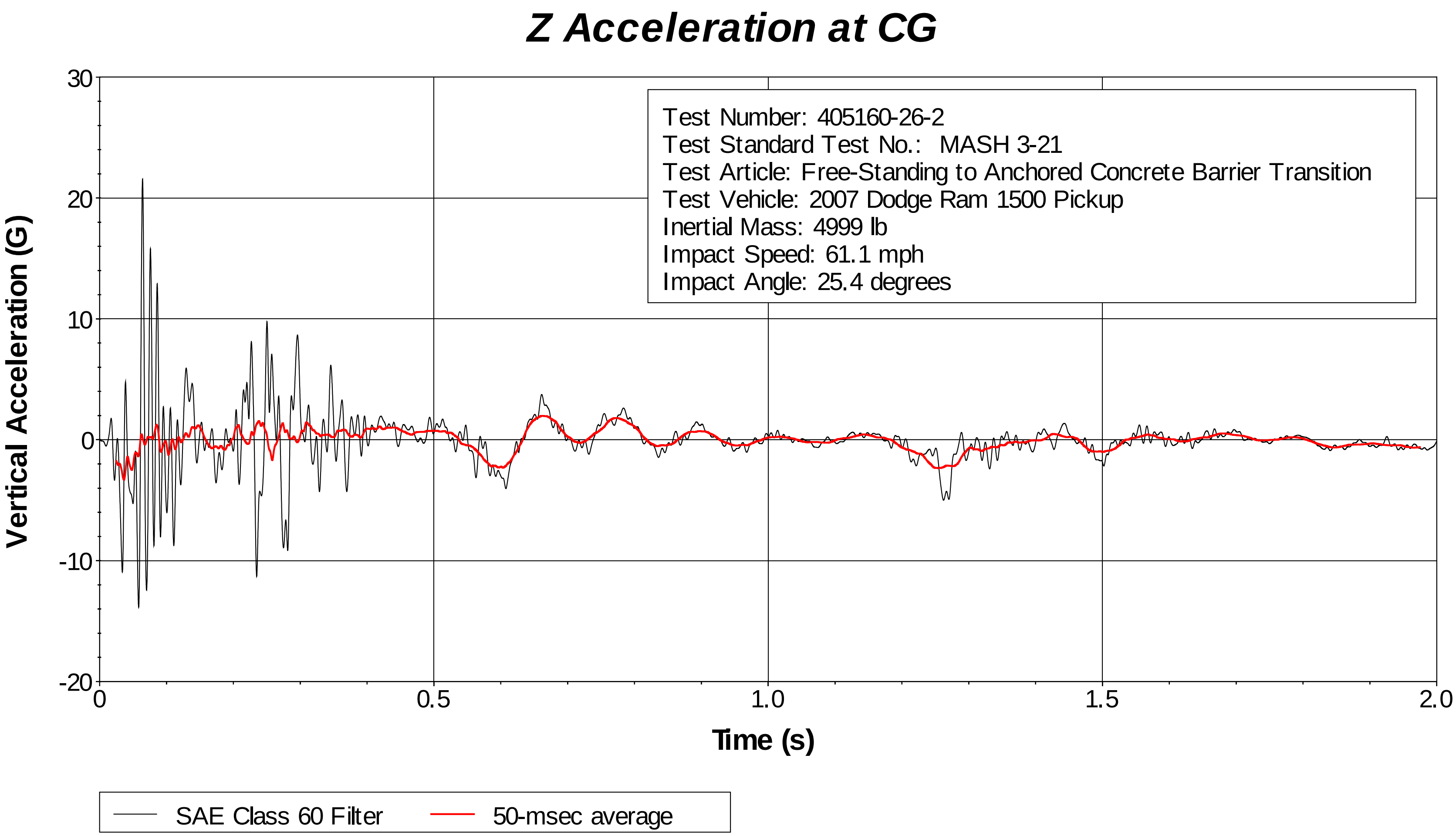


Figure B.6. Vehicle vertical accelerometer trace for test 405160-26-2
(accelerometer located at center of gravity).

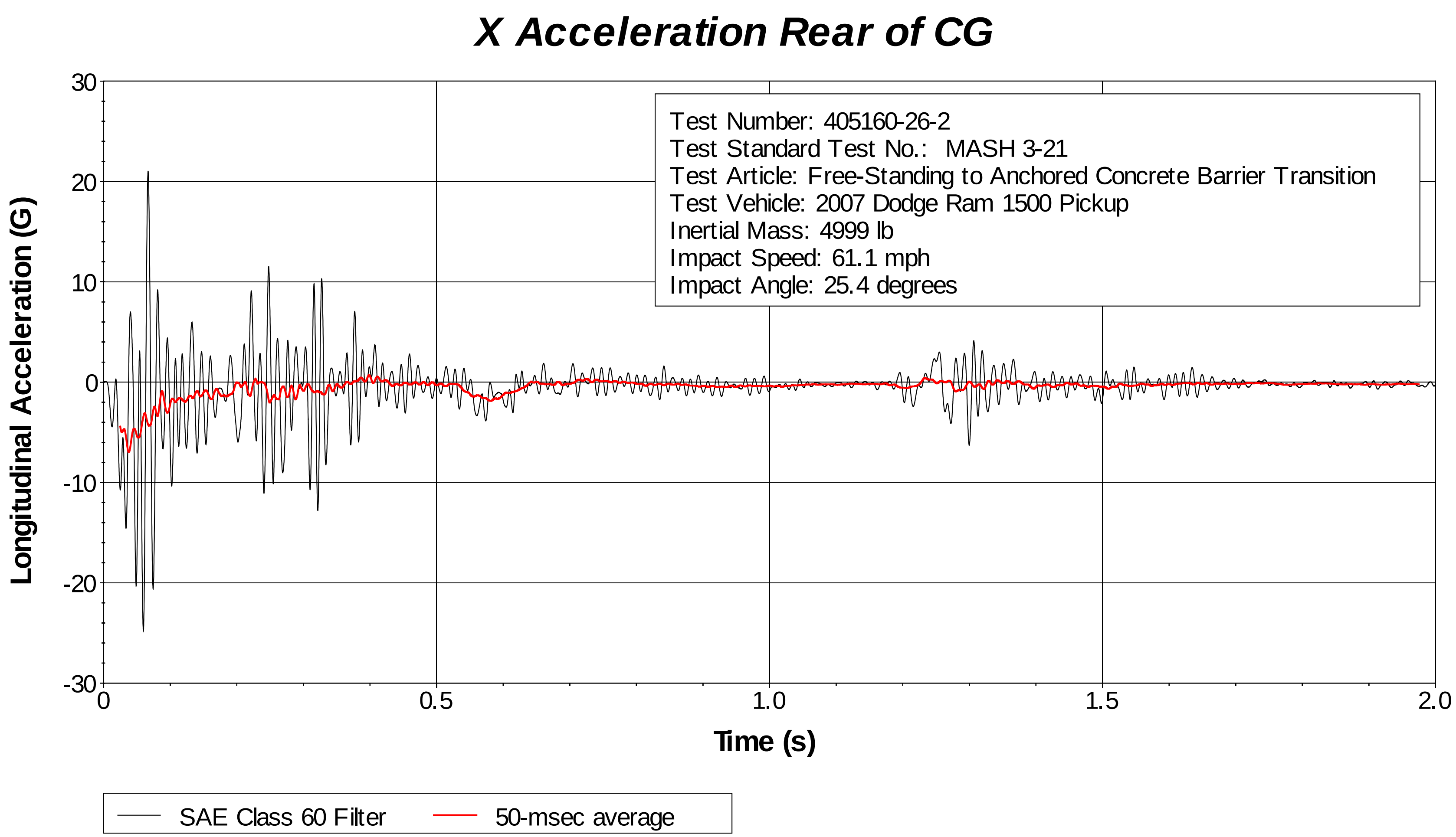


Figure B.7. Vehicle longitudinal accelerometer trace for test 405160-26-2 (accelerometer located rear of CG).

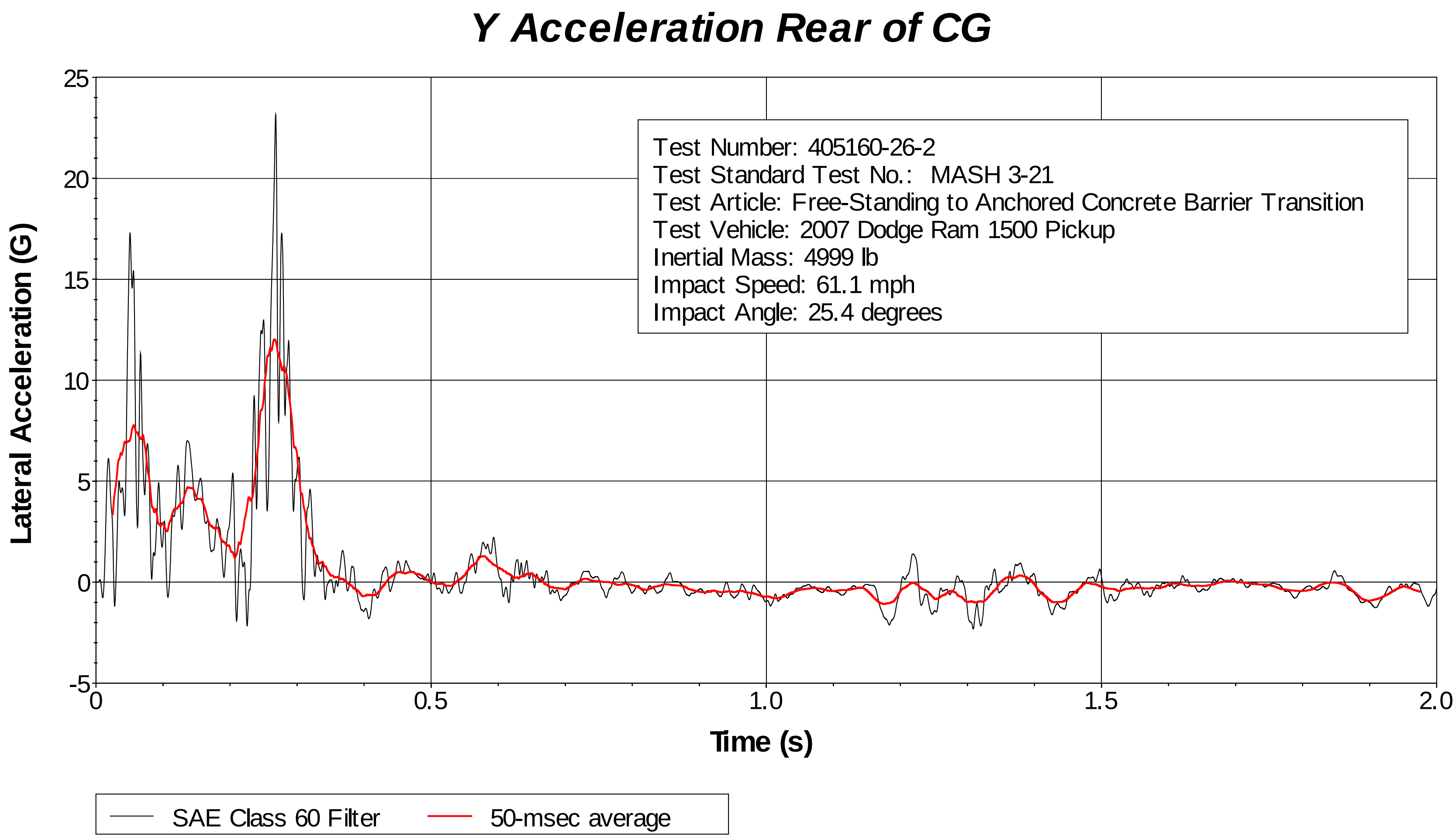


Figure B.8. Vehicle lateral accelerometer trace for test 405160-26-2
(accelerometer located rear of CG).

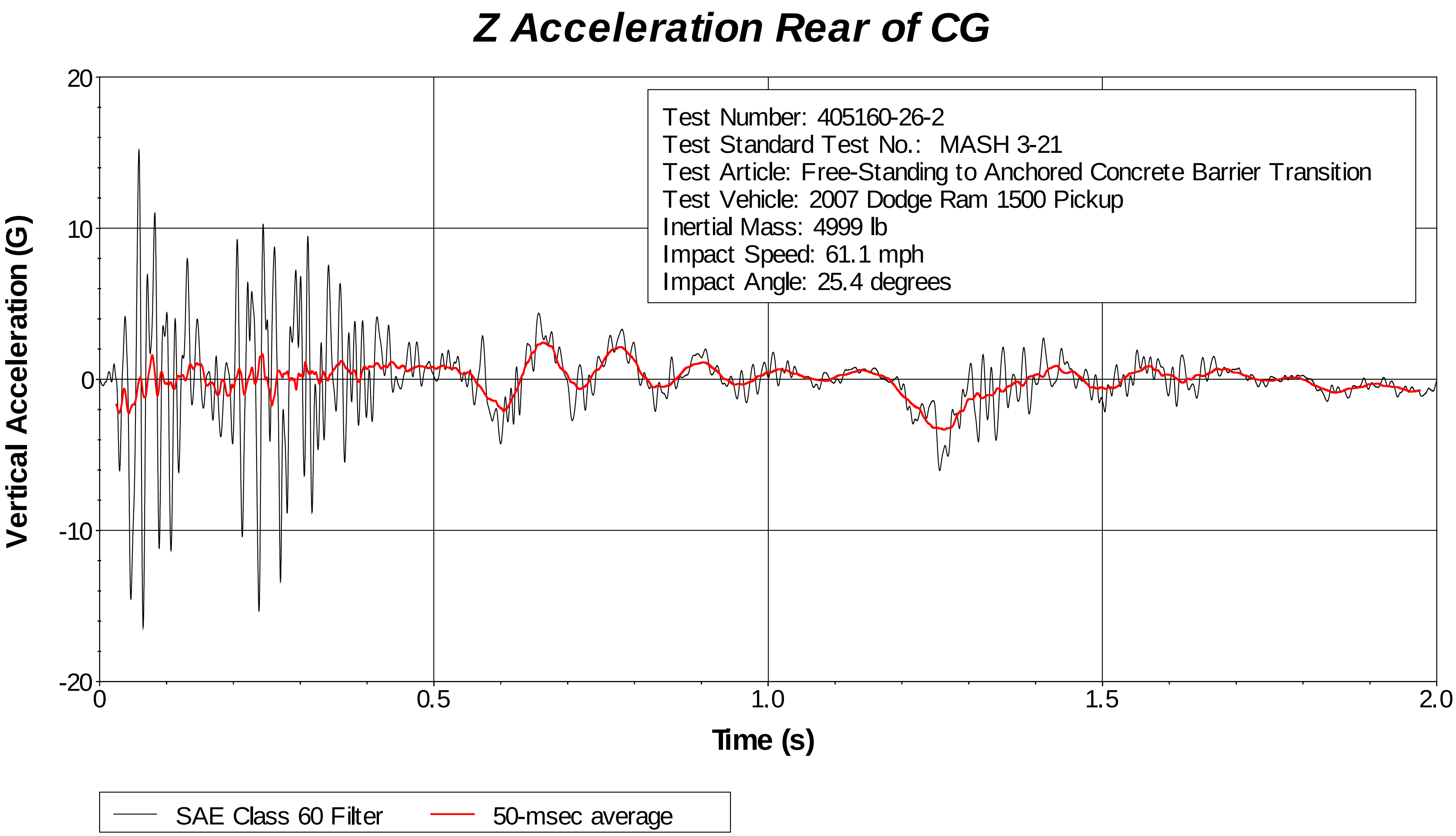


Figure B.9. Vehicle vertical accelerometer trace for test 405160-26-2
(accelerometer located rear of CG).