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TRANSITION FOR ANCHORED TEMPORARY CONCRETE BARRIER SYSTEM IN ASPHALT PAVEMENT – PHASE II

by

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Technical Report Documentation Page

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16. Abstract

Texas A&M Transportation Institute (TTI) recently developed a pinned-down F-shape temporary concrete barrier system that provides limited deflection and can be used on 4-inch thick asphalt pavement. In some applications, it is possible that a non-anchored free-standing barrier segment may be used with the anchored section. In this project, a transition system was designed and crash tested that allows smooth vehicle transition from the free-standing to the pinned-down anchored barrier system installed on asphalt..

The transition was developed to perform 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 and it was determined the transition from the free-standing to anchored F-shape barrier placed on asphalt pavement performed acceptably for *MASH* Test Level 3.

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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)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

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

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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1. INTRODUCTION

1.1 PROBLEM

Texas A&M Transportation Institute (TTI) recently developed a pinned-down F-shape temporary concrete barrier system that provides limited deflection and can be used on a 4-inch thick asphalt pavement. In certain applications, there is a need to install a non-anchored free-standing barrier segment adjacent to the anchored section. This research was conducted to develop a transition from the non-anchored free-standing concrete barrier placed on asphalt to an anchored section placed on asphalt 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 a short distance into the underlying concrete pavement, thus locking the barrier in place. The pinned-down barrier successfully passed the National Cooperative Research Program (NCHRP) *Report 350* Test Level 3 (TL-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 rigid concrete barrier.

In 2013, TTI conducted a study to develop a transition design that could 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 *(3)*. One of the desired objectives was to keep the transition design relatively simply but 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. 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 1 ½ inch diameter pin used to anchor the existing pinned-down barrier. The design was crash tested in accordance with the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware (MASH)* test 3-21 criteria (5000-lb vehicle, 62 mi/h, and 25 degrees) at the critical impact point (*4*). The transition design from the free-standing to anchored F-shape barrier placed on concrete performed acceptably for *MASH* TL-3.

In 2012, TTI conducted a study to extend the use of the existing pinned down anchored barrier design for placement on asphalt with minimum modifications to the barrier design *(5)*. By performing a series of dynamic subcomponent tests and full-scale impact simulation analyses, the researchers developed an appropriate anchoring design for pinning the barrier to asphalt. This design involves placing the barrier on a 4-inch thick asphalt pad and pinning it to the ground using three steel pins per barrier segment. The pins are 1.5 inches in diameter and pass through slotted holes cast into the toe of the barrier at an inclination of 40 degrees from the ground. A 151-ft long installation was built for *MASH* TL-3 testing. This installation was comprised of 12 pinned down barrier segments and was placed adjacent to a 1.5H:1V slope with a 1-foot lateral offset. *MASH* test 3-11 was performed with a 2005 Dodge Ram 1500 pickup impacting the barrier at a nominal speed and angle of 62 mi/h and 25 degrees, respectively. The test vehicle was successful contained and redirected by the pinned down anchored barrier system. The pinned down anchored barrier design was considered a pass according to *MASH* TL-3 criteria. Maximum dynamic and statc deflections of the barrier system were 17.8 inches and 17 inches, respectively.

Among other anchored concrete barrier designs, Midwest Roadside Safety Facility (MwRSF) has developed a design for the F shape temporary concrete barrier along with various transition details. In 2003, MwRSF developed a concrete bridge deck tie-down system for 12.5-ft long, F-shaped Kansas temporary barriers (*6*). Three anchor bolts were passed through the holes in the barrier and fastened to the bridge deck on the traffic side of the barrier. The maximum static and dynamic deflections were 3.5 inches and 11.3 inches, respectively. Later on in 2005, MwRSF developed an *NCHRP Report 350* compliant tie down design for 12.5-ft long temporary concrete barriers with pin-and-loop type connection for use on asphalt pavements that are at least two inches thick (*7*). The barrier was installed at a 6-inch lateral offset from the edge of a ditch. This tie-down system used three 1.5-inch diameter steel pins that were driven down vertically through holes cast in each barrier segment. The pins were 3-ft long and pinned the barrier to the underlying asphalt ground. The maximum static and dynamic deflections in the test were 11.1 inches and 21.8 inches, respectively.

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

And more recently, in 2009, MwRSF developed a transition design for attaching free-standing F-shape barrier to the rigid concrete barrier (*8*). This design employs the anchored barrier segment developed by MwRSF earlier in 2005 and an intermediate section to transition from the free-standing to the rigid barriers. At one end the anchored barrier segments connect to the free-standing barrier, and at the other end they connect to a rigid concrete barrier. A 42-inch tall single slope barrier was used as the rigid barrier system. The number of pins in the anchored barrier segments was varied to gradually increase the lateral restraint of the barrier over four 12.5-ft long segments. The anchored barrier segments were place on a 3-inch thick asphalt pad. To reduce snagging of the vehicle while transitioning from anchored barrier to the rigid barrier, a nested 12-gauge thrie beam section was used. The rail segment was attached to the traffic side face of the rigid and the anchored barrier segments.

In 1999, California Department of Transportation (Caltrans) developed a pinning/staking configuration for its 20-ft long, NJ profile concrete barriers, connected with a pin-and-loop type connection (*9*). 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 AND SCOPE OF RESEARCH

The objective of this research was to develop a transition design that can be used to transition from the pinned-down F-shape barrier placed on asphalt to free-standing F-shape barrier. The transition was developed to perform in accordance with AASHTO *MASH* TL-3 criteria, using the existing pinned F-shape temporary concrete barrier design to the extent possible.

This transition design was intended to be an extension of the existing design developed by the researchers for use on asphalt pavement. Thus the researchers were to maintain as many features from the previous design as possible. Unless it was determined that some modifications are necessary for a successful design, the researchers were to use the previously developed barrier design without modifications. The anchorage of the barrier was to be modified by changing the number of the anchoring pins. The researchers were to develop an appropriate anchoring design using finite element analysis. A full-scale crash test was to be performed in the end as a final validation of the design. The design developed under this study was required to meet AASHTO *MASH* TL- 3 criteria.

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

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 (*8*). 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. 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 the desired objectives was to keep the transition design relatively simple 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 a single standard F-shape barrier segment in the transition region that connected the free-standing and the anchored barrier segments (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 asphalt pavement, near the anchored barrier end of the installation. The anchor pin used in the transition segment was the same 1½-inch diameter pin used to anchor the existing pinned-down barrier.

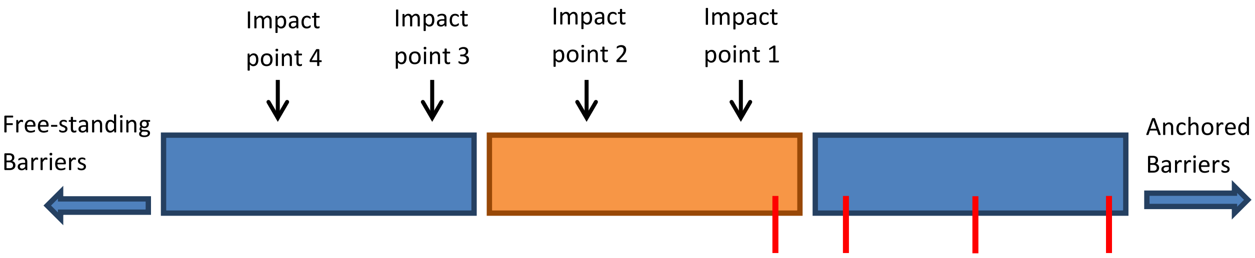

Figure 2.1. Transition design concept and impact location.

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 anchor pin, and the standard anchored barrier system with three anchor pins per segment (Figure 2.2).

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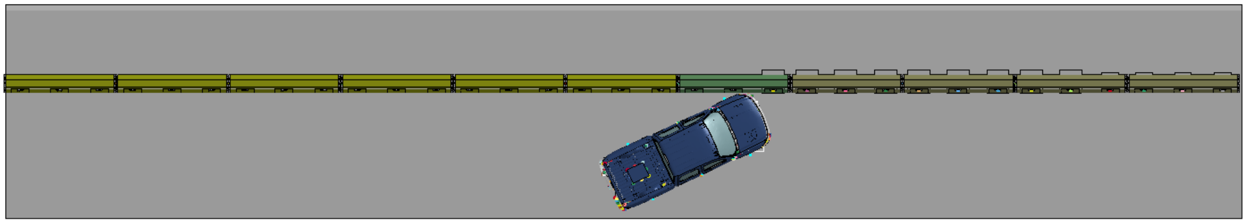
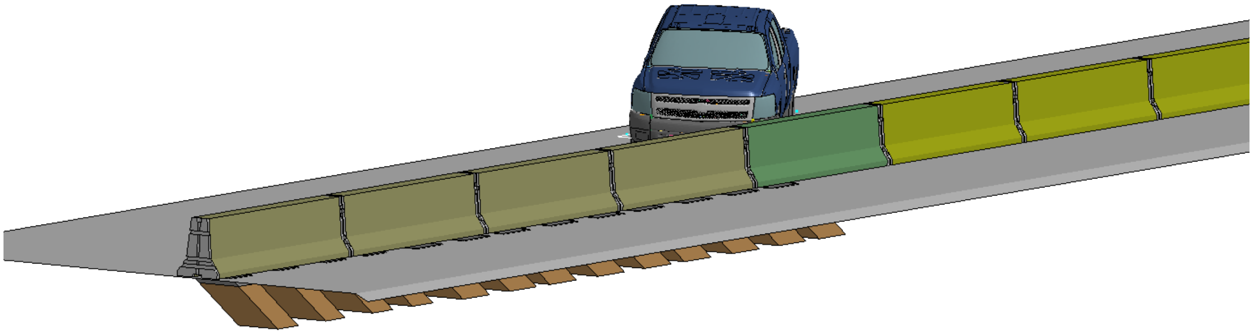
[*] The simulation analysis reported herein is not within the scope of TTI Proving Ground's A2LA Accreditation.

The concrete barrier was modeled using rigid solid elements, with the exception of using elastic material properties for the concrete surrounding the anchoring pins. Slotted holes (4 inches × 1⅞ inches) were built into the model to pass the anchoring pins through the toe of the barrier. The steel pins used to anchor the barrier were 1.5 inches in diameter and 48 inches in length, as used in pull tests developed in a previous research study (*8*). Using this barrier system model, the researchers performed *MASH* test 3-21 vehicle impact simulations (i.e. 5000-lb pickup; impact speed 62.2 mi/h; and impact angle 25 degrees). The vehicle model used in the simulation was a reduced Chevrolet Silverado model developed by National Crash Analysis Center with funding from Federal Highway Administration (FHWA) and National Highway Traffic Safety Administration (NHTSA).



Top View



Iso View

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

Modeling the asphalt pad was somewhat challenging as it involved accommodating the tearing of the asphalt near the top surface of the pad. One approach to modeling the tear would have been to include material failure. However, this method would have significantly complicated the model validation process and could have reduced the robustness of the contact algorithm used to maintain contact between the pin and the asphalt in LS-DYNA. To avoid these complications, the asphalt pad was modeled with two material types. A top thin layer was comprised of Mohr-Coulomb material (MAT173 in LS-DYNA), which is typically used to represent granular materials and has a weaker response. The rest of the asphalt pad was modeled using viscoelastic material (MAT6 in LS-DYNA), which has a relatively stiffer response. This multi-material modeling approach was validated in a previous research study by comparing dynamic force-deflection response with respect to actual developed pull test outcomes (*8*).

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.

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). 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.

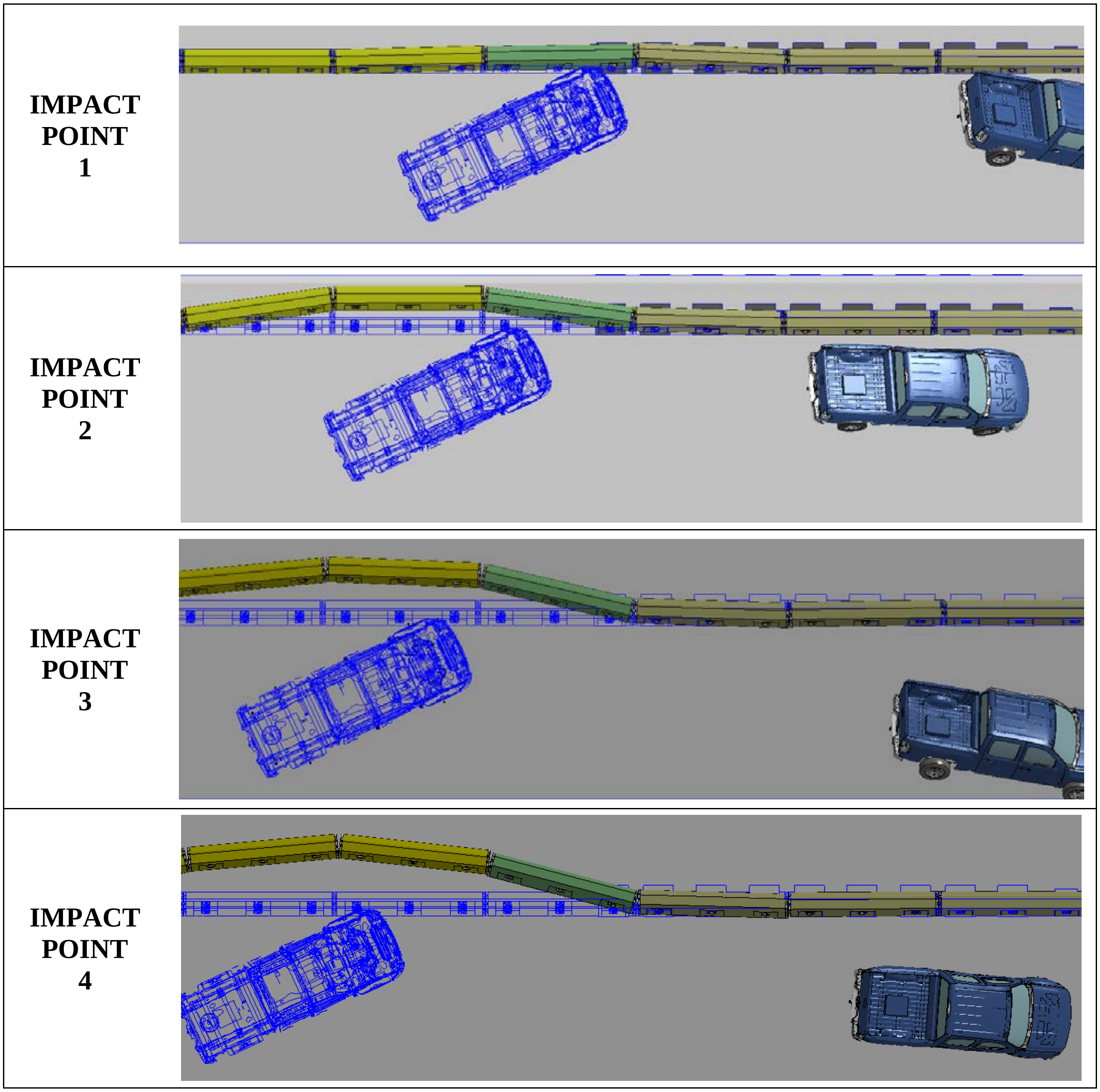


Figure 2.3. Simulation results (top view showing initial state and maximum barrier deflection).

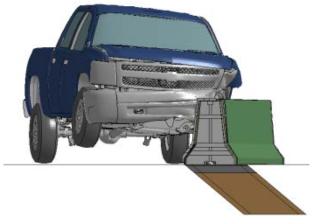
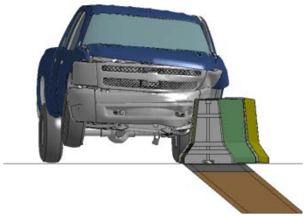
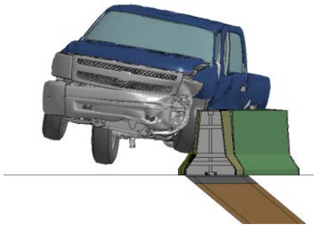
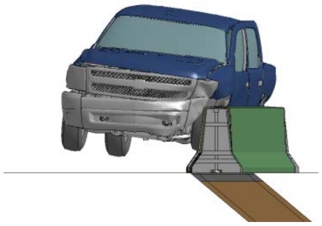
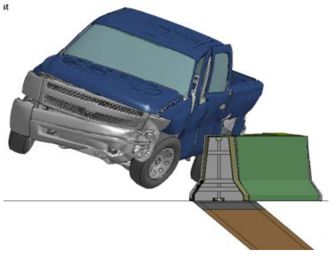
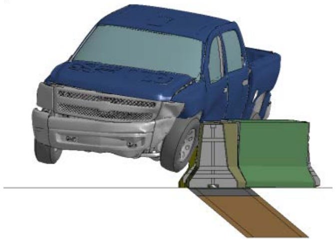
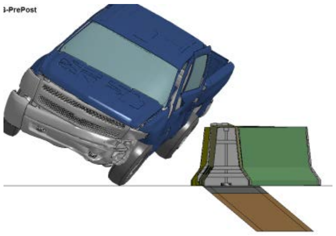
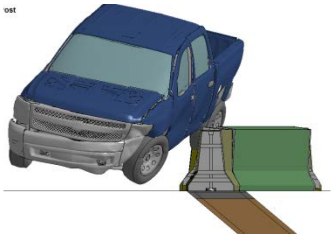
Impact Point #3	**Impact Point #4**
 0.15 sec	 0.15 sec
 0.25 sec	 0.25 sec
 0.35 sec	 0.35 sec
 0.45 sec	 0.45 sec

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 transition barrier segments for 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 25 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* 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 Army Air Corps Base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and 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 inches deep. The apron was constructed in 1942 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, if needed.

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 IN ASPHALT PAVEMENT - CRASH TEST 601651-1 (*MASH* TEST NO. 3-21)

5.1 TEST ARTICLE DESIGN AND CONSTRUCTION

The overall length of the test installation was 163 ft-6 inches. The installation was comprised of thirteen 12 ft-6 inch long precast concrete barrier segments that were 32 inches tall and had the standard “F” profile. The first seven barrier segments (1 to 7) were free-standing and were not anchored to the underlying asphalt pavement. Barrier segment 8 was pinned to the underlying asphalt pavement using a single 1½ inch diameter, 48-inch long steel pin that passed through the inclined slotted hole near the downstream end of the segment. Segments 9 through 13 were pinned using three 1½-inch diameter, 48-inch long steel pins per barrier segment. These pins were passed through the inclined slotted holes in the barrier and driven into the asphalt-soil base. The anchoring pin was fabricated with a 2-inch long tapered tip. The top of each anchoring pin had a ½-inch thick, 4-inch × 4-inch A36 plate cover welded to it. The plate covers were welded at a 5-degree angle from the vertical so that they matched the profile of the barrier’s toe when installed.

The precast concrete barrier segments were 32 inches tall, 24 inches wide at the base, and 9½ 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 (approximately 1½ inch) 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 7¾ inches with 4 inches of concrete cover to the end of the barrier.

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.

Adjacent precast barrier segments were connected using a pin-and-loop type connection. The loops were made of ¾-inch diameter round stock steel. The outer diameter of the loops was 3½ inches and they extended 2 inches beyond the ends of the barrier segment. The barrier connection was comprised of two sets of three loops. When installed, the distance between adjacent barrier segments was ¼ inch. A 1-inch diameter, 30-inch long connecting pin was inserted between the loops to establish the connection. A 2-inch diameter and ¼-inch thick washer was welded 1¾ 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 1⅞-inch wide and 4-inch long slotted holes, inclined 40 degrees from horizontal, were cast into the toe of each barrier segment. These slotted holes started from the traffic face of the barrier and exited near its bottom centerline. Two of the slotted holes were positioned

16 inches away from each face of the barrier. The third slotted hole was positioned at the midpoint of the barrier segment.

The barriers were placed on flat level ground. The underlying ground was comprised of 170-ft long, and 8-ft wide asphalt pad constructed on top of a layer of crushed limestone road base (Type A, Grade 1), which was compacted to 95 percent of standard proctor density. The anchored barriers were pinned to a 4-inch thick asphalt layer (whose total length was 80 ft) on top of a 12-inch thick layer of crushed limestone road base, while the free standing barriers were positioned on a 2-inch thick asphalt layer (whose total length was 90 ft) on top of a 6-inch thick layer of crushed limestone road base. A layer of asphalt binder (CSS-1H tack coat binder) was sprayed at the interface between the asphalt and soil surfaces. The asphalt used was hot mixed Type D with reclaimed asphalt pavement (RAP).

Once the barriers were positioned in place, the slotted holes in the barrier segments that required anchors were used as a guide to drill pilot holes in the underlying asphalt and soil base. The pilot holes were drilled using a 1¾-inch diameter bit. After each pilot hole was drilled, a 1½-inch diameter, 48-inch long anchoring pin was passed through the slotted hole in the barrier and driven into the asphalt-soil base. Thus, barrier segments 9 through 13 were anchored to the ground with three pins.

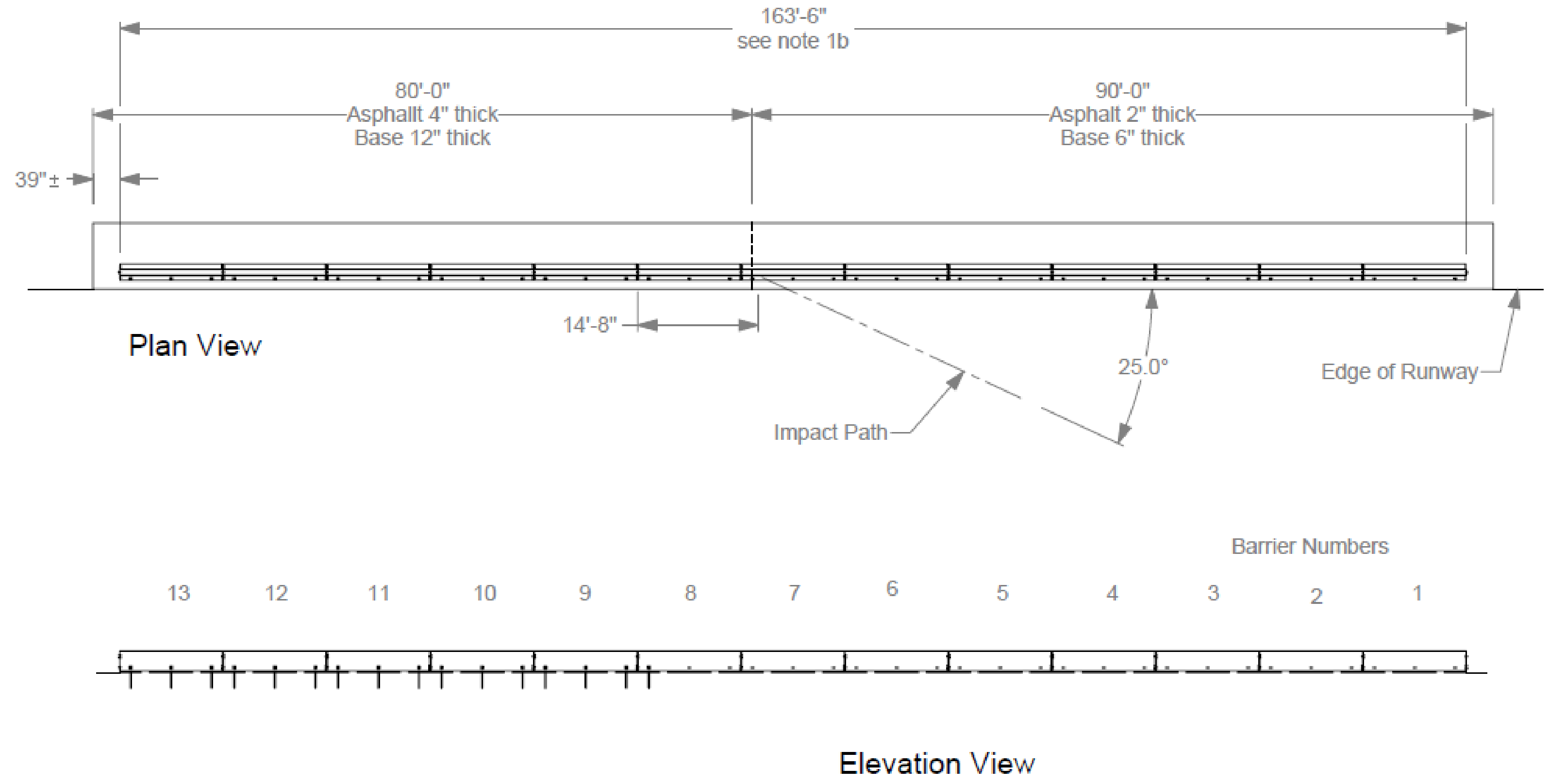
The F-shape temporary concrete barrier segments used in the test installation were donated by WASKEY, Inc. of Baton Rouge, Louisiana (www.waskey.com). Details of the barrier and the pin-down restraint are shown in Figures 5.1 through 5.5. Figure 5.6 shows photographs of the completed test installation.

5.2 MATERIAL SPECIFICATIONS

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

All rebar reinforcement was grade 60 steel material. The loops for the connecting pin, the anchoring pins, and the washers welded on top of the anchoring pins were ASTM A36 steel. The connecting pins between adjacent barrier segments were fabricated from ASTM A449 round and A572 grade 50 plate.

Test Installation



1a. Barriers 1-7 are free-standing, with no anchor pins. Barrier 8 will have one anchor pin in the downstream slot. Barriers 9-13 will have three pins, one in each slot. Place Barriers and insert Connecting Pins. Drill Ø1-3/4" holes through the asphalt, using the slots as a guide. Insert the Anchor Pins and turn them so that the plate washers are as flat against the barriers as possible.

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

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

Project 601651
Pinned Barrier Transition on Asphalt
Drawn By GES
Scale 1:225
Sheet 1 of 6
Test Installation
Approved:
Chiara Dobrovolny:
Date:
2014-02-27

Figure 5.1. Overall layout of the transition from free-standing F-shape barrier to pinned F-shape barrier on asphalt for test 601651-1.

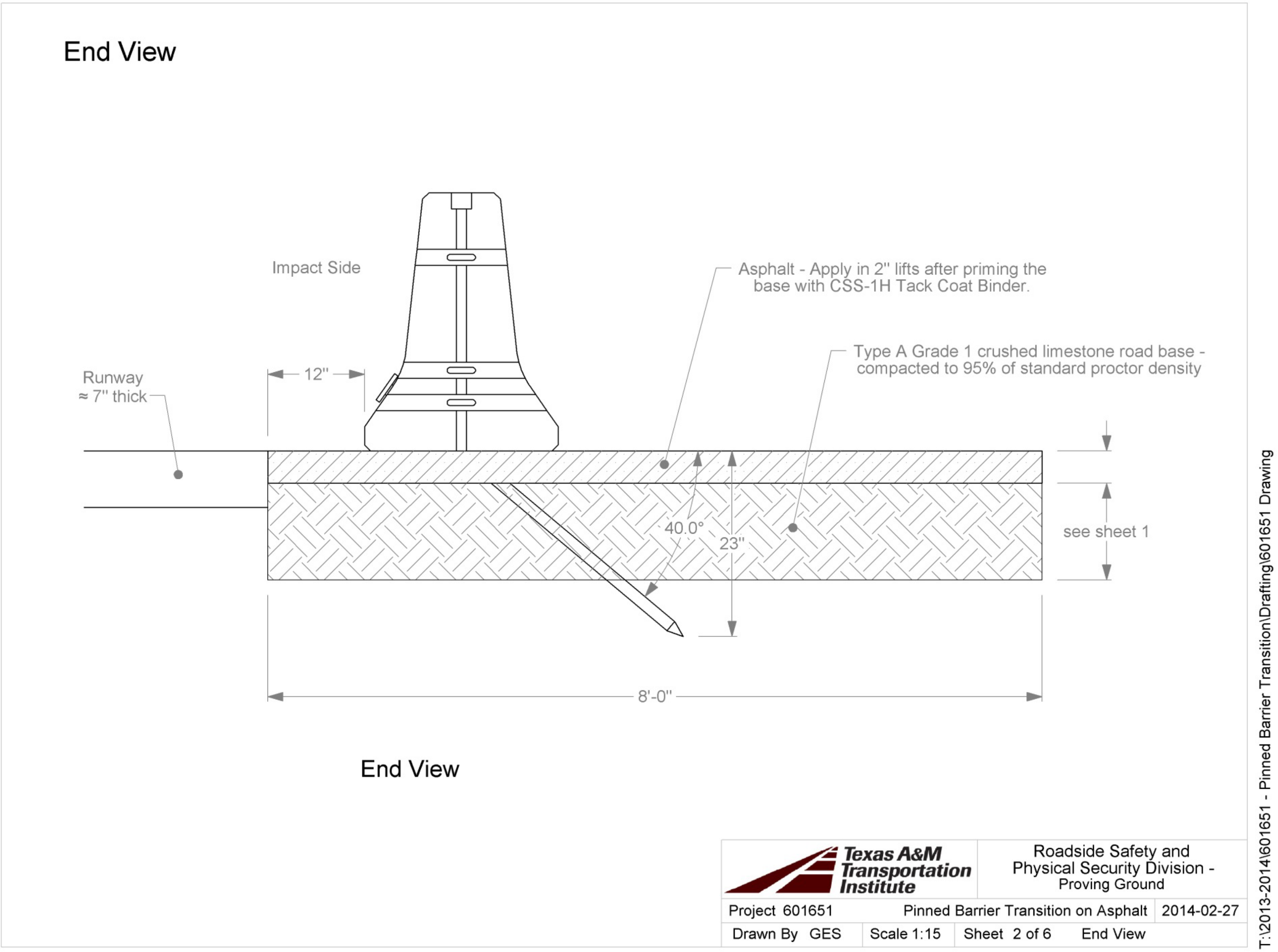


Figure 5.2. Installation cross section for the transition from free-standing F-shape barrier to pinned F-shape barrier on asphalt for test 601651-1.

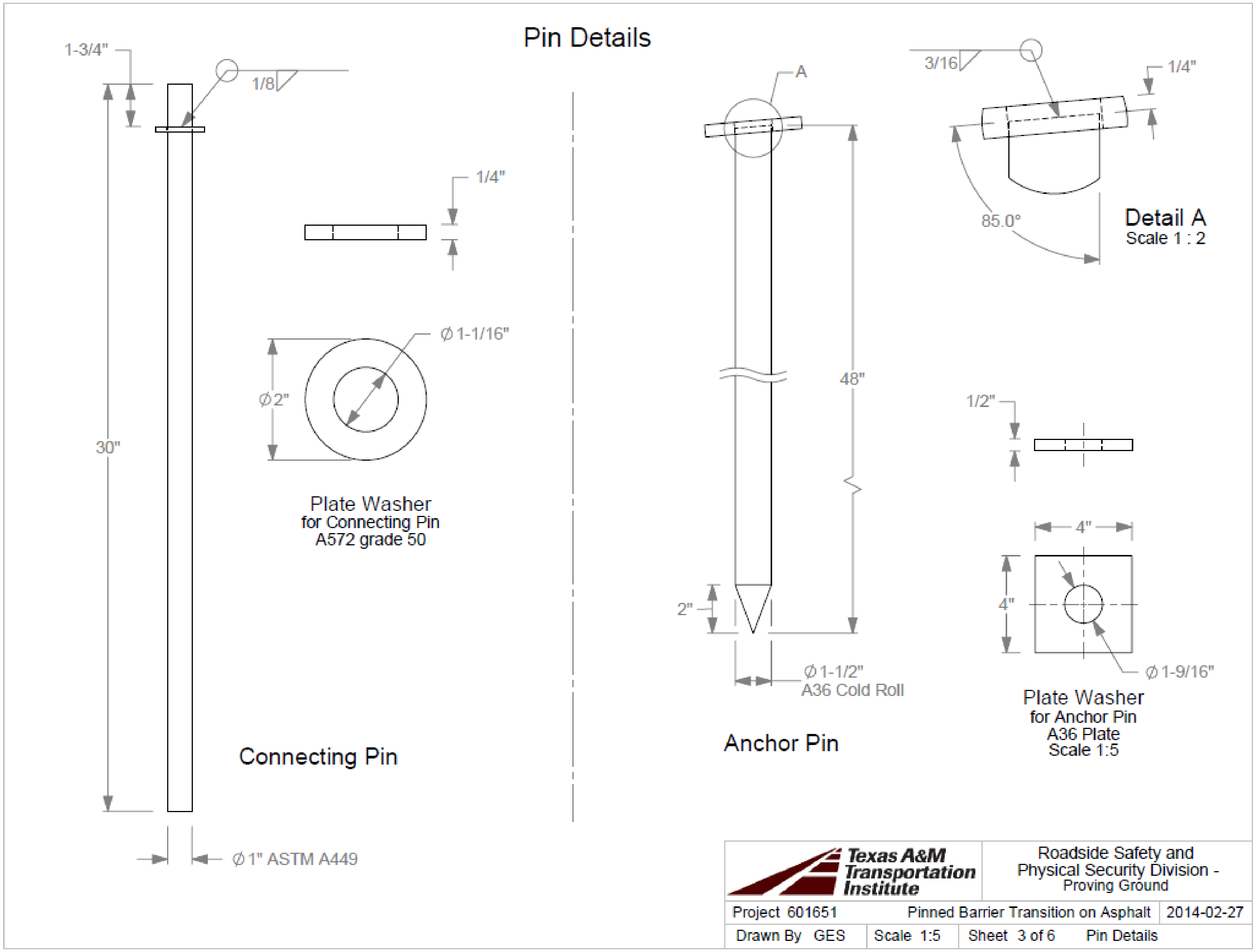
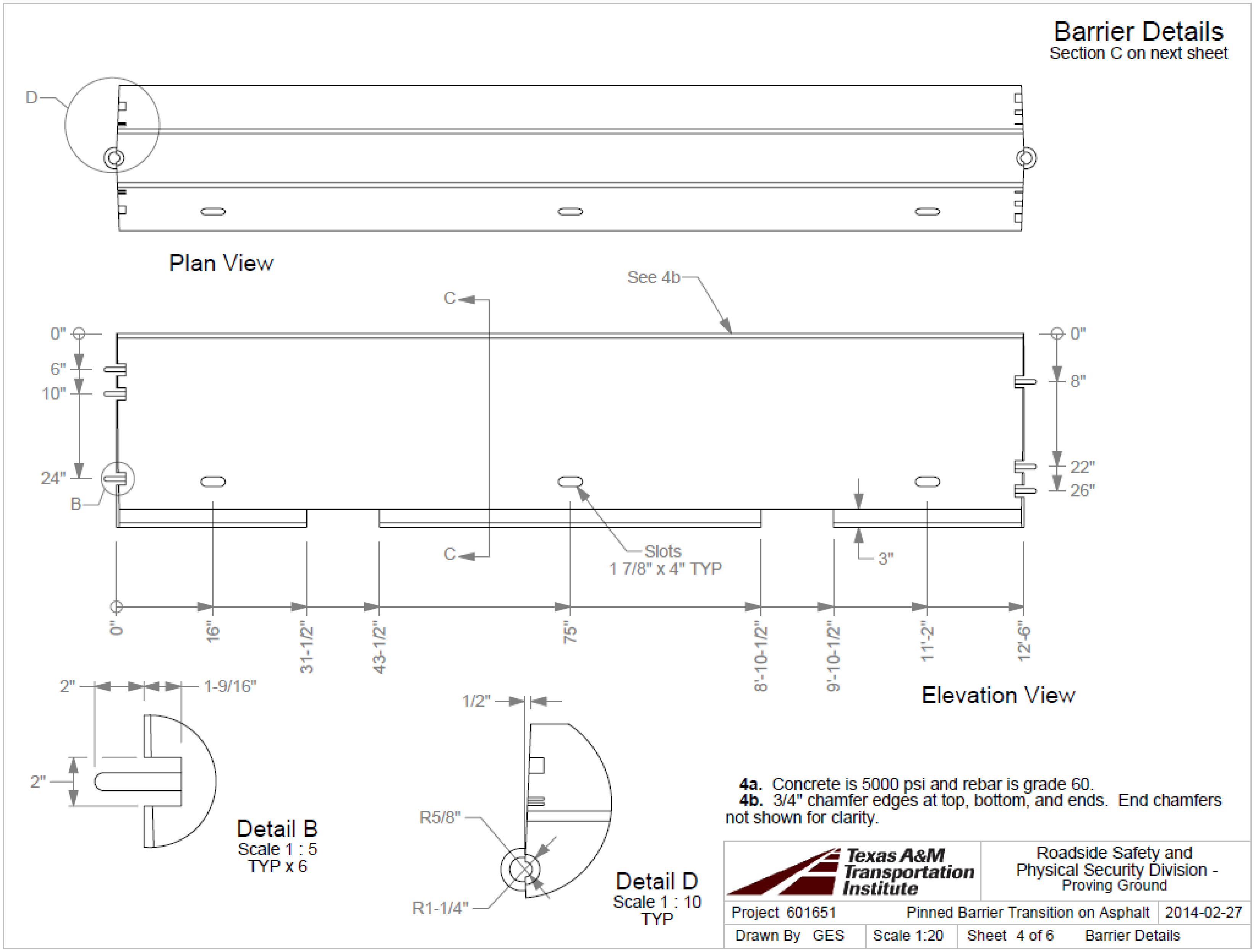


Figure 5.3. Pin details for the transition from free-standing F-shape barrier to pinned F-shape barrier on asphalt for test 601651-1.



4a. Concrete is 5000 psi and rebar is grade 60.
4b. 3/4" chamfer edges at top, bottom, and ends. End chamfers not shown for clarity.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
Project 601651	Pinned Barrier Transition on Asphalt		2014-02-27
Drawn By GES	Scale 1:20	Sheet 4 of 6	Barrier Details

Figure 5.4. Barrier details for the transition from free-standing F-shape barrier to pinned F-shape barrier on asphalt for test 601651-1.

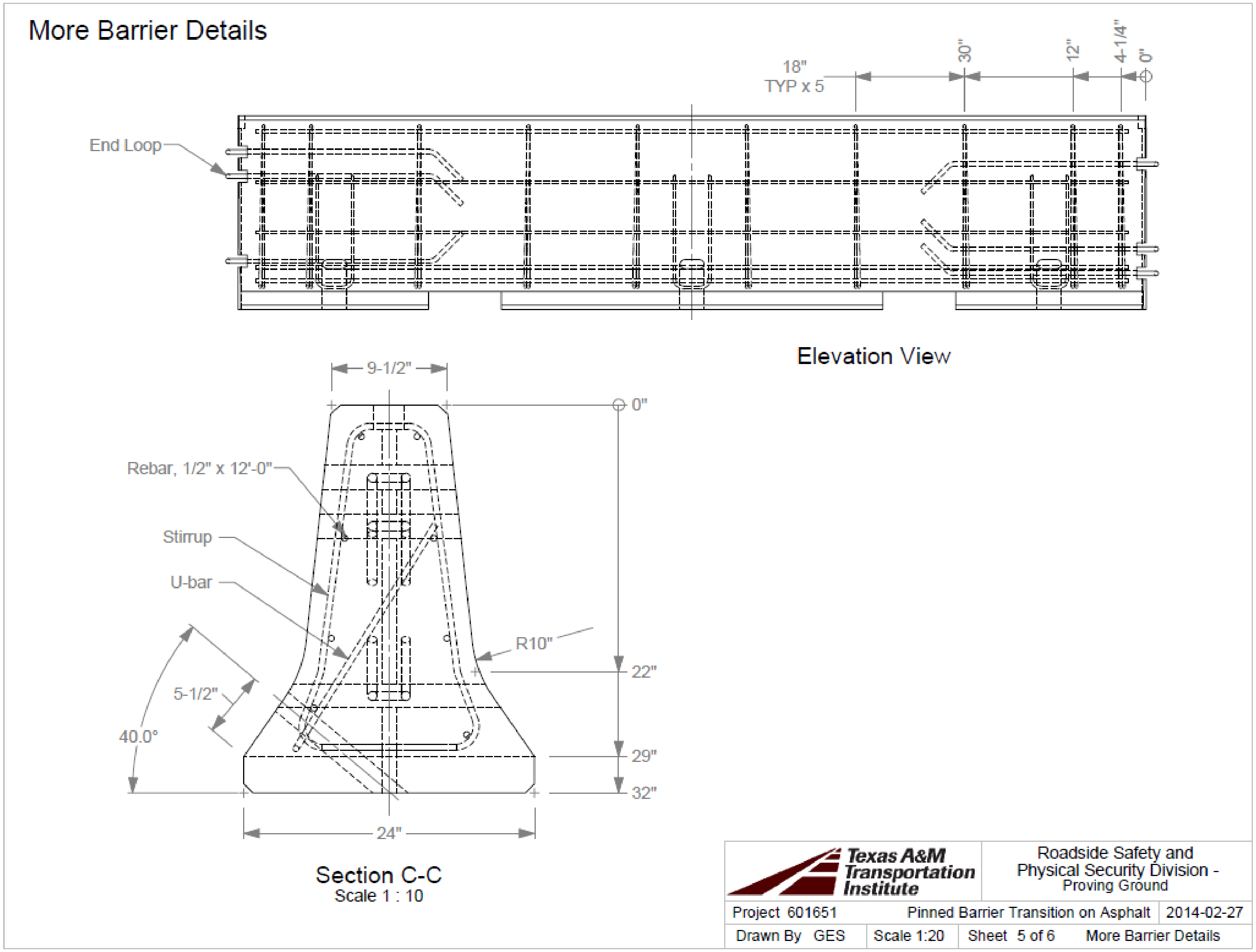


Figure 5.4. Barrier details for the transition from free-standing F-shape barrier to pinned F-shape barrier on asphalt for test 601651-1 (Continued).

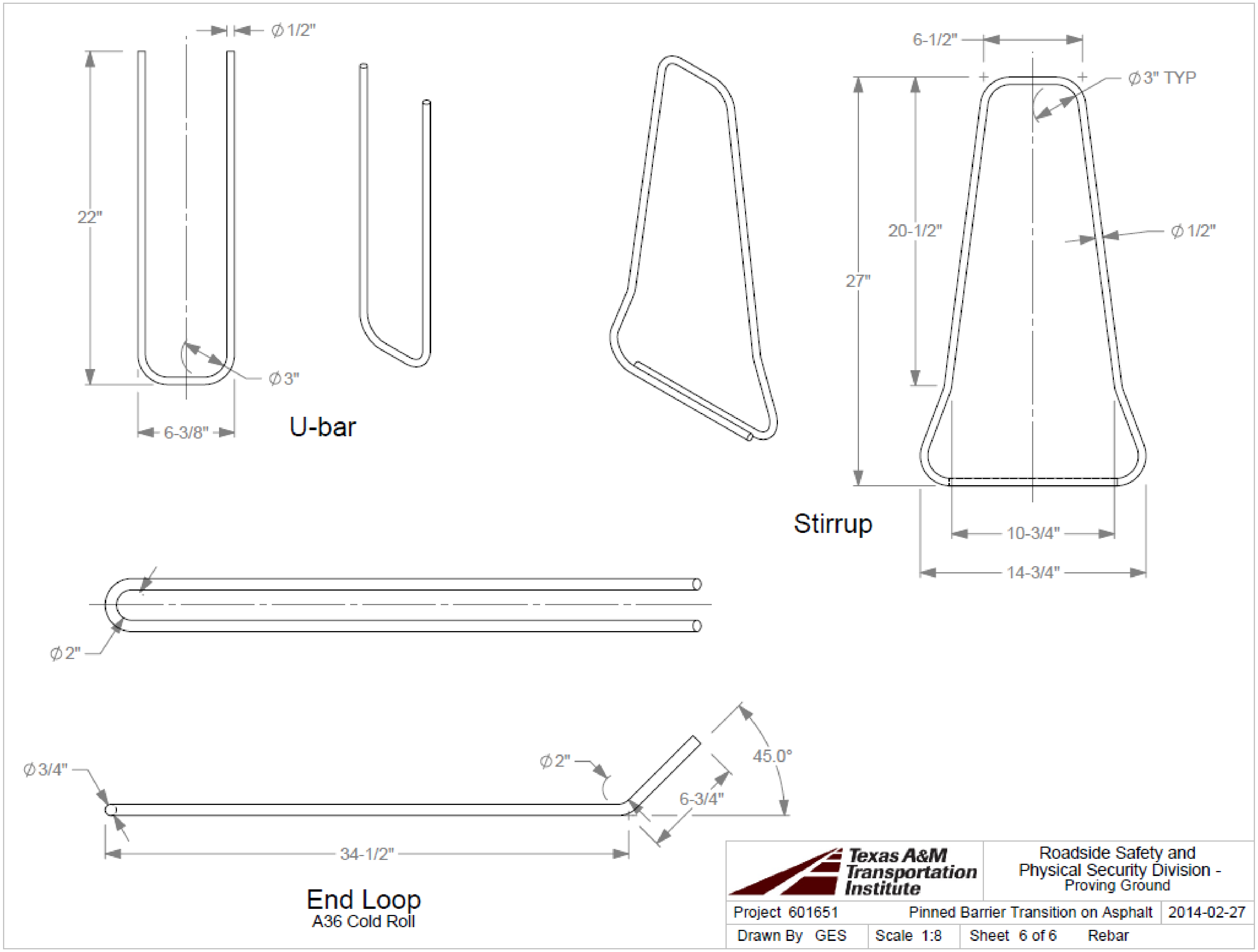


Figure 5.5. End loop details for the transition from free-standing F-shape barrier to pinned F-shape barrier on asphalt for test 601651-1.

Figure 5.6. Transition from free-standing F-shape barrier to pinned F shape barrier on asphalt prior to test 601651-1.

5.3 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH test 3-21 involves a 2270P vehicle weighing 5000 lb ±100 lb and impacting the barrier installation at an impact speed of 62.2 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target impact point was 14 ft 8 inches upstream from the joint between the transition barrier segment 8 and the first anchored barrier segment 9. The 2008 Dodge Ram 1500 pickup used in the test weighed 5012 lb and the actual impact speed and angle were 63.5 mi/h and 25.0 degrees, respectively. The actual impact point was 15.25 ft upstream from the joint between the transition barrier segment 8 and the first anchored barrier segment 9. Target impact severity (IS) was 115.1 kip-ft, and actual IS was 120.7 kip-ft, or 1.0 percent greater than target IS.

5.4 TEST VEHICLE

A 2008 Dodge Ram 1500 pickup truck, shown in Figures 5.7 and 5.8, was used for the crash test. Test inertia weight of the vehicle was 5012 lb, and its gross static weight was 5064 lb. The height to the lower edge of the vehicle front bumper was 14.75 inches, and the height to the upper edge of the front bumper was 27.00 inches. The height to the vehicle's center of gravity was 28.38 inches. Additional dimensions and information on the vehicle are given in Appendix C, Tables C1 and C2. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

5.5 WEATHER CONDITIONS

The crash test was performed the morning of March 28, 2014. Weather conditions at the time of testing were: Wind speed: 6 mi/h; wind direction: 180 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 75°F; relative humidity: 81 percent.

5.6 TEST DESCRIPTION

The 2008 Dodge Ram 1500 pickup, traveling at an impact speed of 63.5 mi/h, impacted the temporary concrete barrier system pinned on asphalt 15 ft – 3 inches upstream from the joint between the transition barrier segment 8 and the first anchored barrier segment 9 at an impact angle of 25.0 degrees. At approximately at 0.010 s, the barrier began to deflect towards the field side at the joint between segments 7 and 8, and at 0.030 s, the downstream end of segment 8 began to deflect towards the traffic side and the upstream end of segment 9 began to deflect towards the traffic side. The upstream end of segment 9 began to deflect toward the field side at 0.101 s, and then began to rotate clockwise at 0.186 s. At 0.189 s, the vehicle began traveling parallel to the barrier, and at 0.231 s, the rear of the vehicle contacted the barrier. The vehicle became airborne at 0.307 and began to roll clockwise. At 0.322 s, the vehicle lost contact with the barrier and was traveling at an exit speed and angle of 49.1 mi/h and 8.6 degrees, respectively. The right front tire touched ground at 0.455 s, and as the vehicle continued forward, it continued to roll clockwise. The vehicle subsequently came to rest upright 181.1 ft downstream of the actual impact point and 12 ft toward traffic lanes from the traffic face of the barrier. Sequential photographs of the test period are shown in Appendix C, Figure C1.

Figure 5.7. Vehicle/installation geometrics for test 601651-1.

Figure 5.8. Vehicle before test 601651-1.

5.7 TEST ARTICLE AND COMPONENT DAMAGE

Damage to the barrier installation is shown in Figures 5.9 and 5.10. The downstream anchor pin on segment 8 pulled upward 4.0 inches, and the pin on the upstream end of segment 9 pulled upward 2.0 inches. Minimal spalling of the concrete segments occurred at the joint between segments 7 and 8. Working width was 44.2 inches, and vehicle intrusion was 31.1 inches. Maximum dynamic deflection during the test was 34.2 inches, and maximum permanent deformation was 33.0 inches.

Table 5.1. Barrier segment movement.

Barrier #	Upstream end	Downstream end
3	½ inch DS*	¾ inch DS
4	1 inch DS	½ inch FS
5	1½ inch DS ½ inch FS	4 inches TS
6	2 inches DS 4 inches TS	22 inches FS
7	22 inches FS	33 inches FS
8	33 inches FS	2½ inches FS
9	1½ inches FS	½ inch TS

* DS = downstream
FS = field side
TS = traffic side

5.8 TEST VEHICLE DAMAGE

Figure 5.11 shows damage to the 2270P vehicle. The front bumper, right front fender, right front tire and wheel rim, right front and rear doors, right rear cab corner, right rear exterior bed, right rear tire and wheel rim, rear bumper, and tailgate were damaged. The windshield sustained stress cracks in the lower left corner. Maximum exterior crush to the vehicle was 15.0 inches in the side plane at the right front corner at bumper height. Maximum occupant compartment deformation was 1.5 inches in the lateral area across the cab in the kick panel area. Photographs of the interior of the vehicle are shown in Figure 5.12. Exterior vehicle crush and occupant compartment measurements are shown in Appendix C, Tables C3 and C4.

Figure 5.9. Vehicle and installation positions after test 601651-1.

Figure 5.10. Installation after test 601651-1.

Figure 5.11. Vehicle after test 601651-1.

Before Test

After Test

Figure 5.12. Interior of vehicle for test 601651-1.

5.9 OCCUPANT RISK VALUES

Data from the accelerometer, located at the vehicle's center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 16.1 ft/s at 0.101 s, the highest 0.010-s occupant ridedown acceleration was 11.6 Gs from 0.241 to 0.251 s, and the maximum 0.050-s average acceleration was -6.7 Gs between 0.022 and 0.072 s. In the lateral direction, the occupant impact velocity was 21.6 ft/s at 0.101 s, the highest 0.010-s occupant ridedown acceleration was 14.9 Gs from 0.243 to 0.253 s, and the maximum 0.050-s average was -11.5 Gs between 0.032 and 0.082 s. Theoretical Head Impact Velocity (THIV) was 29.9 km/h or 8.3 m/s at 0.098 s; Post-Impact Head Decelerations (PHD) was 18.8 Gs between 0.241 and 0.251 s; and Acceleration Severity Index (ASI) was 1.46 between 0.056 and 0.106 s. These data and other pertinent information from the test are summarized in Figure 5.13. Vehicle angular displacements and accelerations versus time traces are presented in Appendix C, Figures C2 through C8.

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 asphalt contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the barrier during the test was 2.8 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 in the kick panel area. (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 50 degrees and 23 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 16.1 ft/s, and lateral occupant impact velocity was 21.6 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:

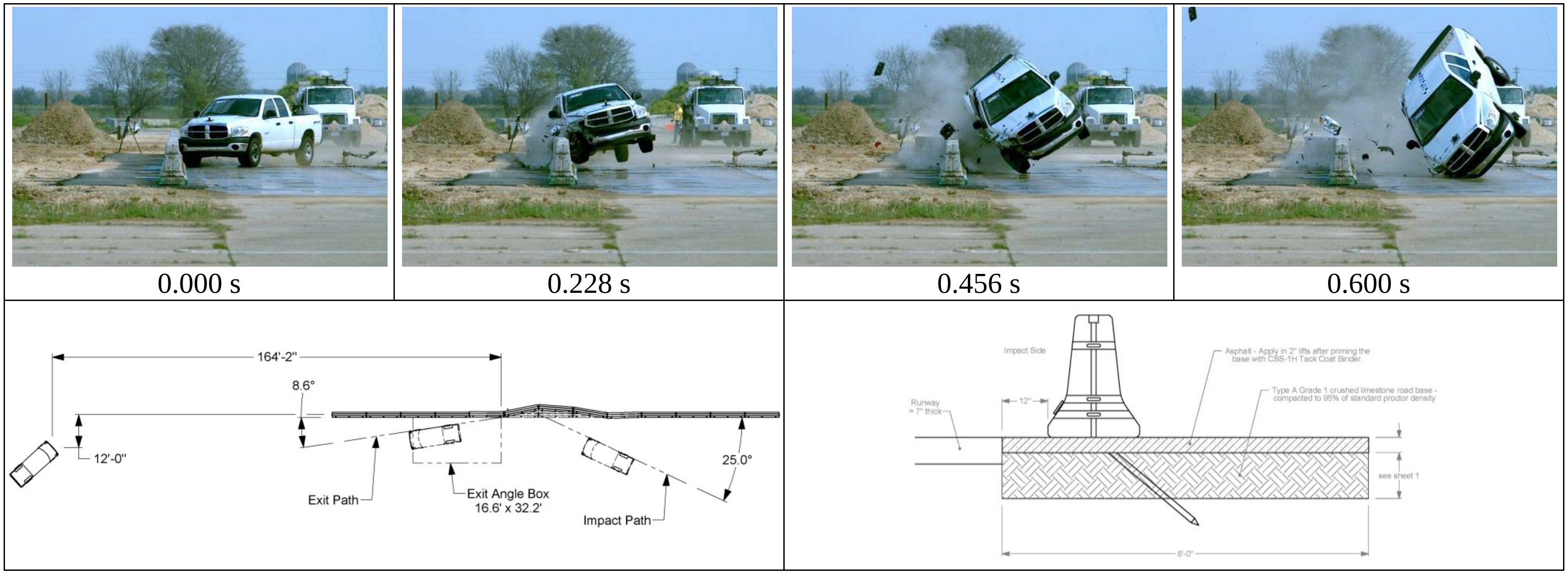
Longitudinal and Lateral Occupant Ridedown Accelerations	
Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Longitudinal ridedown acceleration was 11.6 G, and lateral ridedown acceleration was 14.9 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)



General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-21
TTI Test No.	601651-1
Date	March 28, 2014
Test Article	
Type	Transition
Name	Transition from free-standing F-shape barrier to pinned F-shape barrier on asphalt and soil
Installation Length	163.5 ft
Material or Key Elements	Asphalt pavement, CMB, Transition
Soil Type and Condition	Asphalt and Soil, Dry
Test Vehicle	
Type/Designation	2270P
Make and Model	2008 Dodge Ram 1500 Pickup
Curb	4866 lb
Test Inertial	5012 lb
Dummy	No dummy
Gross Static	5012 lb

Impact Conditions	
Speed	63.5 mph
Angle	25.0 degrees
Location/Orientation	
Impact Severity	120.7 kip-ft
Exit Conditions	
Speed	49.1 mi/h
Angle	8.6 degrees
Occupant Risk Values	
Impact Velocity	
Longitudinal	16.1 ft/s
Lateral	21.6 ft/s
Ridedown Accelerations	
Longitudinal	11.6 G
Lateral	14.9 G
THIV	29.9 km/h
PHD	18.8 G
ASI	1.46
Max. 0.050-s Average	
Longitudinal	-6.7 G
Lateral	-11.5 G
Vertical	-4.2 G

Post-Impact Trajectory	
Stopping Distance	181.1 ft dwnstrm 12 ft twd traffic
Vehicle Stability	
Maximum Yaw Angle	42 degrees
Maximum Pitch Angle	23 degrees
Maximum Roll Angle	50 degrees
Vehicle Snagging	
Vehicle Pocketing	
Test Article Deflections	
Dynamic	34.2 inches
Permanent	33.0 inches
Working Width	44.2 inches
Vehicle Intrusion	31.1 inches
Vehicle Damage	
VDS	01RFQ6
CDC	01FREW4
Max. Exterior Deformation	15.0 inches
OCDI	LF0000000
Max. Occupant Compartment Deformation	1.5 inch

Figure 5.13. Summary of results for *MASH* test 3-21 on transition from the free-standing F-shape barrier to pinned F-shape barrier on asphalt and soil.

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 asphalt 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 2.8 ft. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 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 50 degrees and 23 degrees, respectively. Occupant risk factors were within preferred limits specified in *MASH*. The 2270P vehicle exited within the exit box.

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 asphalt pavement performed acceptably.

6.2 CONCLUSIONS AND IMPLEMENTATION[*]

6.2.1 Conclusions

Previously, TTI had developed a pinned down anchored temporary concrete barrier system for use on asphalt pavements (*8*). The objective of this research was to develop a transition design that can be used to transition from free-standing F-shape barrier to the pinned-down F-shape barrier placed on asphalt. The transition was to be developed for MASH test level 3 criteria, using the existing pinned F-shape temporary concrete barrier design to the extent possible.

The researchers performed finite element analyses to determine the performance of the transition system under *MASH* test 3-21 conditions. Analyses were performed with a 5000-lb pickup truck model impacting the barrier system transitioning from free standing barriers to restrained barriers with three anchoring pins per barrier segment.

A 163.5-ft test installation comprising 13 barrier segments, with pin-and-loop connections, was built for *MASH* test level 3 testing. The barrier segments were placed on flat level ground. The five downstream barrier segments were anchored using three 1.5-inch diameter steel pins per barrier segment. *MASH* test 3-21 was performed with a 2008 Dodge Ram 1500 pickup impacting the barrier at an impact speed and angle of 63.5 mi/h and 25.0 degrees, respectively. The test vehicle was successfully contained and redirected by the pinned down anchored barrier system. The pinned down anchored barrier design meets *MASH* test level 3 criteria, as shown in Table 6.1. The maximum dynamic and static deflections of the barrier system were 34.2 inches and 33.0 inches, respectively.

---

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

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 on asphalt pavement in test 601651-1.

Test Agency: Texas A&M Transportation Institute | Test No.: 601651-1 | Test Date: 2014-03-28

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 2.8 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, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 1.5 inches in the lateral area across the cab in the kick panel area	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 50 degrees and 23 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 16.1 ft/s, and lateral occupant impact velocity was 21.6 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 11.6 G, and lateral ridedown acceleration was 14.9 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

6.2.2 Implementation

As described in this report, the test installation was comprised of an 80-ft section of 4-inch thick asphalt pavement over a 12-inch thick Type-A Grade-1 crushed limestone road base for anchorage of the five pinned barrier segments (9 through 13) and the transition barrier segment 8, and a 90-ft section of 2-inch thick asphalt pavement over a 6-inch thick Type-A Grade-1 crushed limestone road base for the remaining seven free standing barriers (1 through 7). This road base was primarily used to meet *MASH* requirements for the type of soil that should be used for testing, and to be able to compact the 4-inch thick asphalt pavement on top. In a field installation, it may not always be feasible to have a 12-inch thick road base for the anchored barriers. Furthermore, native soil conditions may vary from one site to another. It should be noted that the primary resistance to the deflection of the barrier comes from the asphalt pavement. While differences in soil properties underneath the asphalt layer can have some influence on the lateral deflection of the barrier, their effect is expected to be minimal as long as the sub-base is stable enough to roll and compact the asphalt pavement on top of it. Thus smaller thickness of road base may also be used in combination with native soil if the sub-base can be stabilized to achieve proper compaction of the minimum 4-inch thick asphalt pavement on top.

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

Based on previous research, the anchored barrier segments can be placed adjacent to a 1.5H:1V or flatter slope with a minimum 12-inch offset from the slope break point (*8*). The free standing barrier segments, however, should not be placed adjacent to a slope. Free-standing segments should have at least 5 ft offset from a slope break point or other objects to allow for barrier deflection during the impact event.

The length of the barrier segments used in the test installation was 12 ft 6 inches. This is the minimum segment length of the portable concrete barriers used among the participating Pooled Fund states. While the design was developed using the smallest barrier segment length, it can also be extended for use with longer barrier segments by adding additional anchoring pins if needed.

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

REFERENCES

[1] Sheikh, N.M., Bligh, R.P., and Menges, W.L. (2008). "Crash Testing and Evaluation of the 12 ft Pinned F-shape Temporary Barrier." Texas A&M Transportation Institute, College Station, Texas.

[2] Ross, H.E., Sicking, D.L., Zimmer, R.A., and Michie, J.D. "Recommended Procedures for the Safety Performance Evaluation of Roadside Safety Hardware." *NCHRP Report 350*, National Cooperative Highway Research Program, Washington, DC, 1993.

[3] Sheikh, N.M. and Menges, W.L. (2013). "Development and Testing of a Transition from Free-Standing to Pinned Temporary Concrete Barrier." *Test Report No. 405160-26* Texas A&M Transportation Institute, College Station, Texas.

[4] AASHTO (2009). *Manual for Assessing Safety Hardware*. American Association of State Highway and Transportation Officials, Washington, DC.

[5] Sheikh, N.M. and Menges, W.L. (2012). "Development and Testing of Anchored Temporary Concrete Barrier for Use on Asphalt." *Test Report No. 405160-25-1*, Texas A&M Transportation Institute, College Station, Texas.

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[7] Bielenberg, B.W., Reid, J.D., Faller, R.K., Rohde, J.R., and Sicking, D.L. (2006). "Tie-downs and Transitions for Temporary Concrete Barriers." Transportation Research Record, TRR 1984.

[8] Wiebelhaus, M.J., Terpsma, R.J., Lechtenberg, K.A., Reid, J.D., Faller, R.K., Bielenberg, R.B., Rohde, J.R., and Sicking, D.L. (2009). "Development of Temporary Concrete Barrier to Permanent Concrete Median Barrier Approach Transition." Draft Report to the Midwest State's Regional Pooled Fund Program, Transportation Research Report No. TRP 03-208-09.

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APPENDIX A. SOIL DOCUMENTATION

FIELD DENSITY TEST REPORT

Report Number: A1131064.0027
Service Date: 03/21/14
Report Date: 03/24/14
Task: PO #601651

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

Client

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

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1131064

Material Information

Mat. No.	Proctor Ref. No.	Classification and Description	Laboratory Test Method	Lab Test Data: Optimum Water Content (%)	Lab Test Data: Max. Lab Density (pcf)	Project Requirements: Water Content (%)	Project Requirements: Compaction (%)
1	A1131064.0001B	Crushed stone	ASTM D698	8.3	132.6	8.3 - 12.3	95%

Field Test Data

Test No.	Test Location	Lift / Elev.	Mat. No.	Probe Depth (in)	Wet Density (pcf)	Water Content (pcf)	Water Content (%)		Dry Density (pcf)	Percent Compaction (%)
	PO #601651									
1	North side	Grade	1	12	150.6	6.6	4.6	*	144.0	100+
2	South side	Grade	1	12	148.2	6.2	4.4	*	142.0	100+

Datum: **Serial No:** 30483 **Std. Cnt. M:**670 **Std. Cnt. D:** 2133

Comments: **An asterisk (*) appears next to the test results which do not meet the project requirements as noted above.**

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

Terracon Rep.: Mohammed Mobeen **Start/Stop:** 0900-1030

Reported To:

Contractor:

Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Mark Dornak

Reviewed By: Mark E Dl
Mark E.Dornak, P.E.
Project Manager

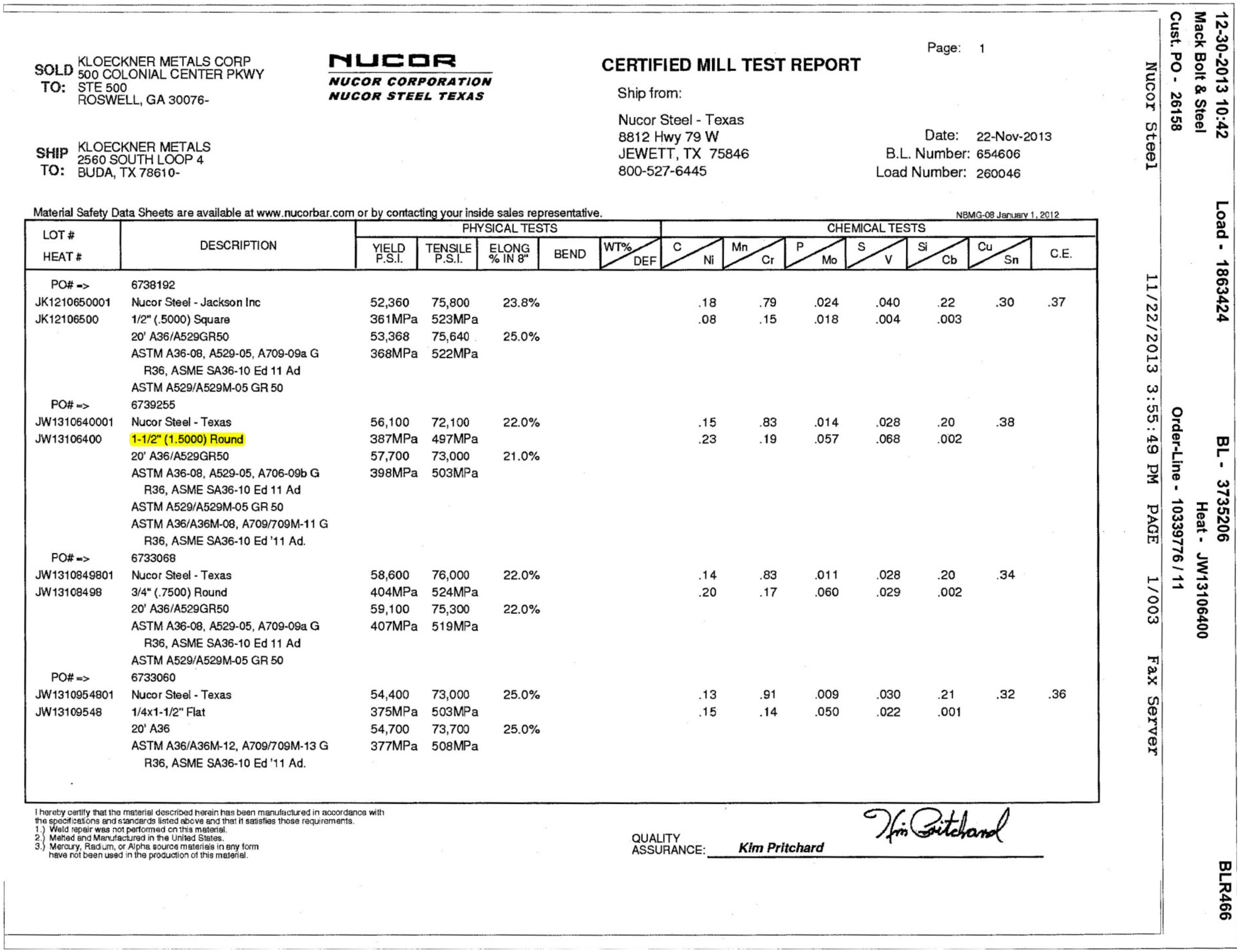
Test Methods: ASTM D6938-07 Method A

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

MATERIAL USED

TEST NUMBER	601651-1
TEST NAME	Pinned Barriers Transition
DATE	2014-03-28

#	DATE RECEIVED	DESCRIPTION	GRADE	YIELD	TENSILE	SUPPLIER
13-090	2014-01-02	Round Stock, Ø1-1/2	see paperwork	56,100	72,100	Mack Bolt & Steel
13-051	2013-11-04	Plate, 4 x 1/2	A36	44.6	64.7	Mack Bolt & Steel
	2011-11-04	12'6" CMB's	x	x	x	Waskey



12-30-2013 10:42 Load - 1863424 BL - 3735206 BLR466
Mack Bolt & Steel Heat - JW13106400
Cust. PO - 26158 Order-Line - 10339776 / 11
Nucor Steel 11/22/2013 3:55:49 PM PAGE 1/003 Fax Server

NUCOR
NUCOR CORPORATION
NUCOR STEEL TEXAS

CERTIFIED MILL TEST REPORT

Page: 1

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

SHIP TO: KLOECKNER METALS
2560 SOUTH LOOP 4
BUDA, TX 78610-

Ship from:

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

Date: 22-Nov-2013
B.L. Number: 654606
Load Number: 260046

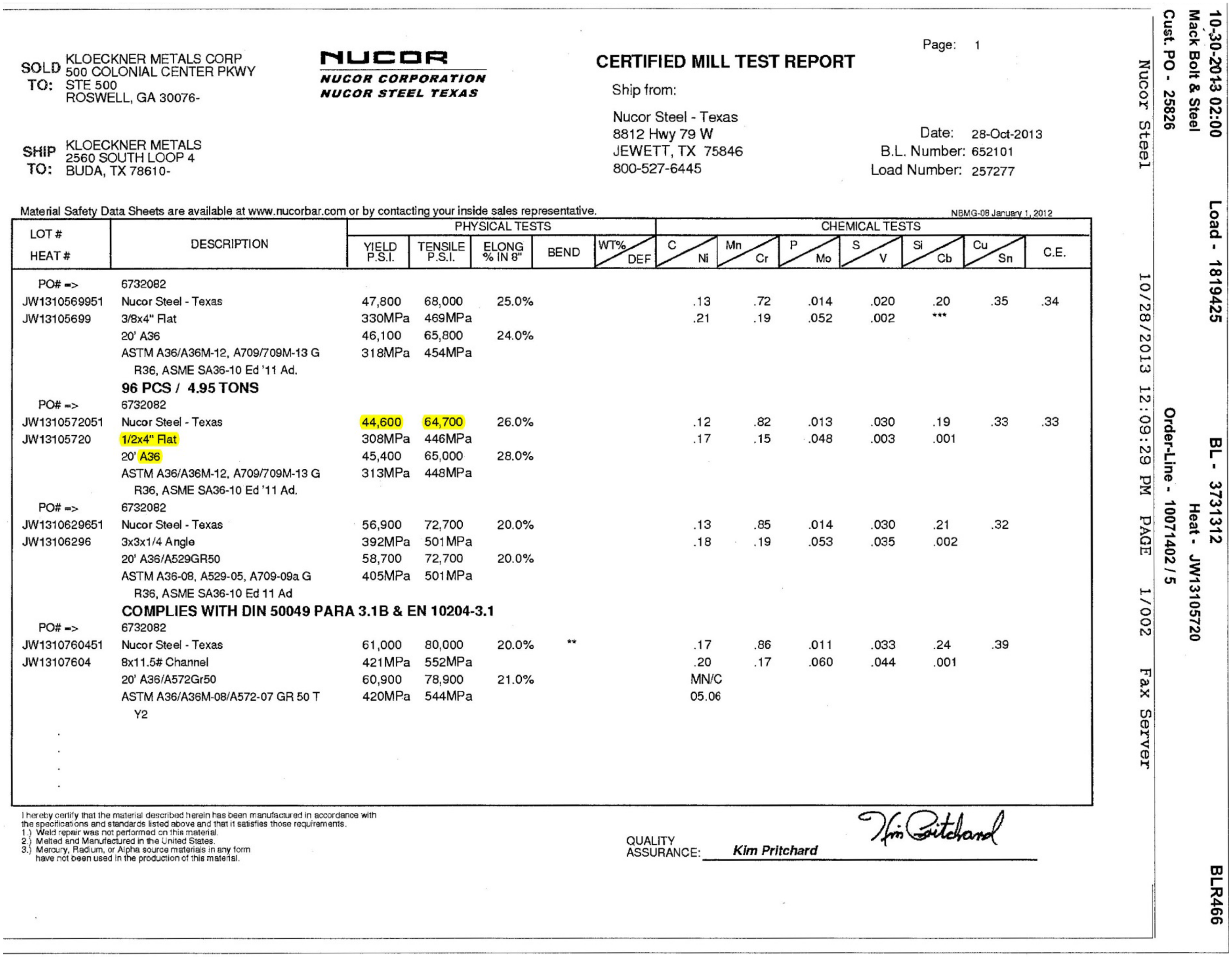
Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative.

NBMG-08 January 1, 2012

LOT # / HEAT #	DESCRIPTION	PHYSICAL TESTS: YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	CHEMICAL TESTS: C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	6738192												
JK1210650001	Nucor Steel - Jackson Inc	52,360	75,800	23.8%			.18	.79	.024	.040	.22	.30	.37
JK12106500	1/2" (.5000) Square	361MPa	523MPa				.08	.15	.018	.004	.003		
	20' A36/A529GR50	53,368	75,640	25.0%									
	ASTM A36-08, A529-05, A709-09a G	368MPa	522MPa										
	R36, ASME SA36-10 Ed 11 Ad												
	ASTM A529/A529M-05 GR 50												
PO# =>	6739255												
JW1310640001	Nucor Steel - Texas	56,100	72,100	22.0%			.15	.83	.014	.028	.20	.38	
JW13106400	1-1/2" (1.5000) Round	387MPa	497MPa				.23	.19	.057	.068	.002		
	20' A36/A529GR50	57,700	73,000	21.0%									
	ASTM A36-08, A529-05, A706-09b G	398MPa	503MPa										
	R36, ASME SA36-10 Ed 11 Ad												
	ASTM A529/A529M-05 GR 50												
	ASTM A36/A36M-08, A709/709M-11 G												
	R36, ASME SA36-10 Ed '11 Ad.												
PO# =>	6733068												
JW1310849801	Nucor Steel - Texas	58,600	76,000	22.0%			.14	.83	.011	.028	.20	.34	
JW13108498	3/4" (.7500) Round	404MPa	524MPa				.20	.17	.060	.029	.002		
	20' A36/A529GR50	59,100	75,300	22.0%									
	ASTM A36-08, A529-05, A709-09a G	407MPa	519MPa										
	R36, ASME SA36-10 Ed 11 Ad												
	ASTM A529/A529M-05 GR 50												
PO# =>	6733060												
JW1310954801	Nucor Steel - Texas	54,400	73,000	25.0%			.13	.91	.009	.030	.21	.32	.36
JW13109548	1/4x1-1/2" Flat	375MPa	503MPa				.15	.14	.050	.022	.001		
	20' A36	54,700	73,700	25.0%									
	ASTM A36/A36M-12, A709/709M-13 G	377MPa	508MPa										
	R36, ASME SA36-10 Ed '11 Ad.												

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

QUALITY ASSURANCE: *Kim Pritchard* Kim Pritchard



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Mack Bolt & Steel Heat - JW13105720
Cust. PO - 25826 Order-Line - 10071402 / 5
Nucor Steel 10/28/2013 12:09:29 PM PAGE 1/002 Fax Server

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

SHIP TO: KLOECKNER METALS
2560 SOUTH LOOP 4
BUDA, TX 78610-

NUCOR
NUCOR CORPORATION
NUCOR STEEL TEXAS

CERTIFIED MILL TEST REPORT

Page: 1

Ship from:

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

Date: 28-Oct-2013
B.L. Number: 652101
Load Number: 257277

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

NBMG-08 January 1, 2012

LOT # / HEAT #	DESCRIPTION	PHYSICAL TESTS: YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	CHEMICAL TESTS: C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	6732082												
JW1310569951	Nucor Steel - Texas	47,800	68,000	25.0%			.13	.72	.014	.020	.20	.35	.34
JW13105699	3/8x4" Flat	330MPa	469MPa				.21	.19	.052	.002	***		
	20' A36	46,100	65,800	24.0%									
	ASTM A36/A36M-12, A709/709M-13 G	318MPa	454MPa										
	R36, ASME SA36-10 Ed '11 Ad.												
	96 PCS / 4.95 TONS												
PO# =>	6732082												
JW1310572051	Nucor Steel - Texas	44,600	64,700	26.0%			.12	.82	.013	.030	.19	.33	.33
JW13105720	1/2x4" Flat	308MPa	446MPa				.17	.15	.048	.003	.001		
	20' A36	45,400	65,000	28.0%									
	ASTM A36/A36M-12, A709/709M-13 G	313MPa	448MPa										
	R36, ASME SA36-10 Ed '11 Ad.												
PO# =>	6732082												
JW1310629651	Nucor Steel - Texas	56,900	72,700	20.0%			.13	.85	.014	.030	.21	.32	
JW13106296	3x3x1/4 Angle	392MPa	501MPa				.18	.19	.053	.035	.002		
	20' A36/A529GR50	58,700	72,700	20.0%									
	ASTM A36-08, A529-05, A709-09a G	405MPa	501MPa										
	R36, ASME SA36-10 Ed 11 Ad												
	COMPLIES WITH DIN 50049 PARA 3.1B & EN 10204-3.1												
PO# =>	6732082												
JW1310760451	Nucor Steel - Texas	61,000	80,000	20.0%	**		.17	.86	.011	.033	.24	.39	
JW13107604	8x11.5# Channel	421MPa	552MPa				.20	.17	.060	.044	.001		
	20' A36/A572Gr50	60,900	78,900	21.0%			MN/C						
	ASTM A36/A36M-08/A572-07 GR 50 T	420MPa	544MPa				05.06						
	Y2												

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

QUALITY ASSURANCE: *Kim Pritchard* Kim Pritchard

APPENDIX C. CRASH TEST NO. 601651-1

C1. VEHICLE PROPERTIES AND INFORMATION

Table C1. Vehicle properties for test 601651-1.

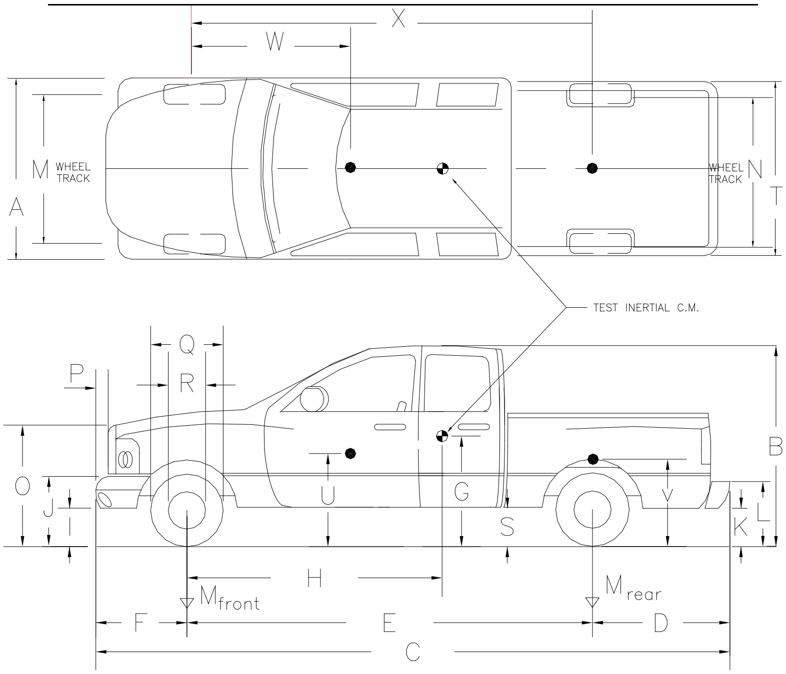
Date: 2014-03-28 Test No.: 601651-1 VIN No.: 1D7HA18NX85604103

Year: 2008 Make: Dodge Model: Ram 1500

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

Tread Type: Highway Odometer: 134803

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	20.00	P	2.88	U	27.50
B	75.00	G	28.38	L	28.50	Q	30.50	V	29.50
C	223.75	H	62.46	M	68.50	R	16.00	W	62.40
D	47.25	I	14.75	N	68.00	S	15.50	X	78.65
E	140.50	J	27.00	O	45.00	T	77.50		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	17.50
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	11.25	Bottom Frame Height - Rear	24.75

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2820	2784	
Back	3900	M_{rear}	2046	2228	
Total	6700	M_{Total}	4866	5012	

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

Mass Distribution:
lb LF: 1407 RF: 1377 LR: 1094 RR: 1134

Table C2. Measurements of vehicle vertical CG for test 601651-1.

Date: 2014-03-28 Test No.: 601651-1 VIN: 1D7HA18NX85604103

Year: 2008 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 134803

Engine: 4.7 liter Transmission: Automatic

Fuel Level: Empty Ballast: 271 lb (440 lb max)

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

Measured Vehicle Weights: (lb)

LF:	1407	RF:	1377	Front Axle:	2784
LR:	1094	RR:	1134	Rear Axle:	2280
Left:	2501	Right:	2511	Total:	5064
					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:	63.26 in	Rear of Front Axle		(63 ±4 inches allowed)
Y:	-0.28 in	Left -	Right +	of Vehicle Centerline
Z:	28.375 in	Above Ground		(minumum 28.0 inches allowed)

Hood Height: 45.00 inches

43 ±4 inches allowed

Front Bumper Height: 27.00 inches

Front Overhang: 36.00 inches

39 ±3 inches allowed

Rear Bumper Height: 20.00 inches

Overall Length: 223.785 inches

237 ±13 inches allowed

Table C3. Exterior crush measurements for test 601651-1.

Date: 2014-03-28 Test No.: 601651-1 VIN No.: 1D7HA18NX85604103

Year: 2008 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	18	12	27	0	1	2	4	9	12	+13.5
2	Side plane at bumper ht	18	15	57	2	3	---	---	13	15	+70
	Measurements recorded										
	in inches										

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

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

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

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

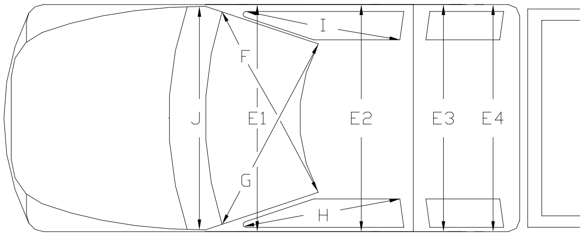
***Measure and document on the vehicle diagram the location of the maximum crush.

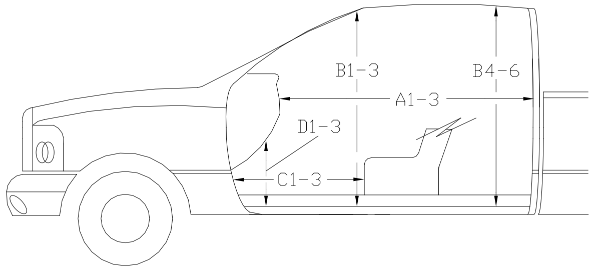
Note: Use as many lines/columns as necessary to describe each damage profile.

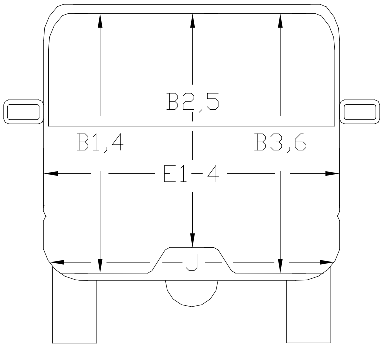
Table C4. Occupant compartment measurements for test 601651-1.

Date: 2014-03-28 Test No.: 601651-1 VIN No.: 1D7HA18NX85604103

Year: 2008 Make: Dodge Model: Ram 1500





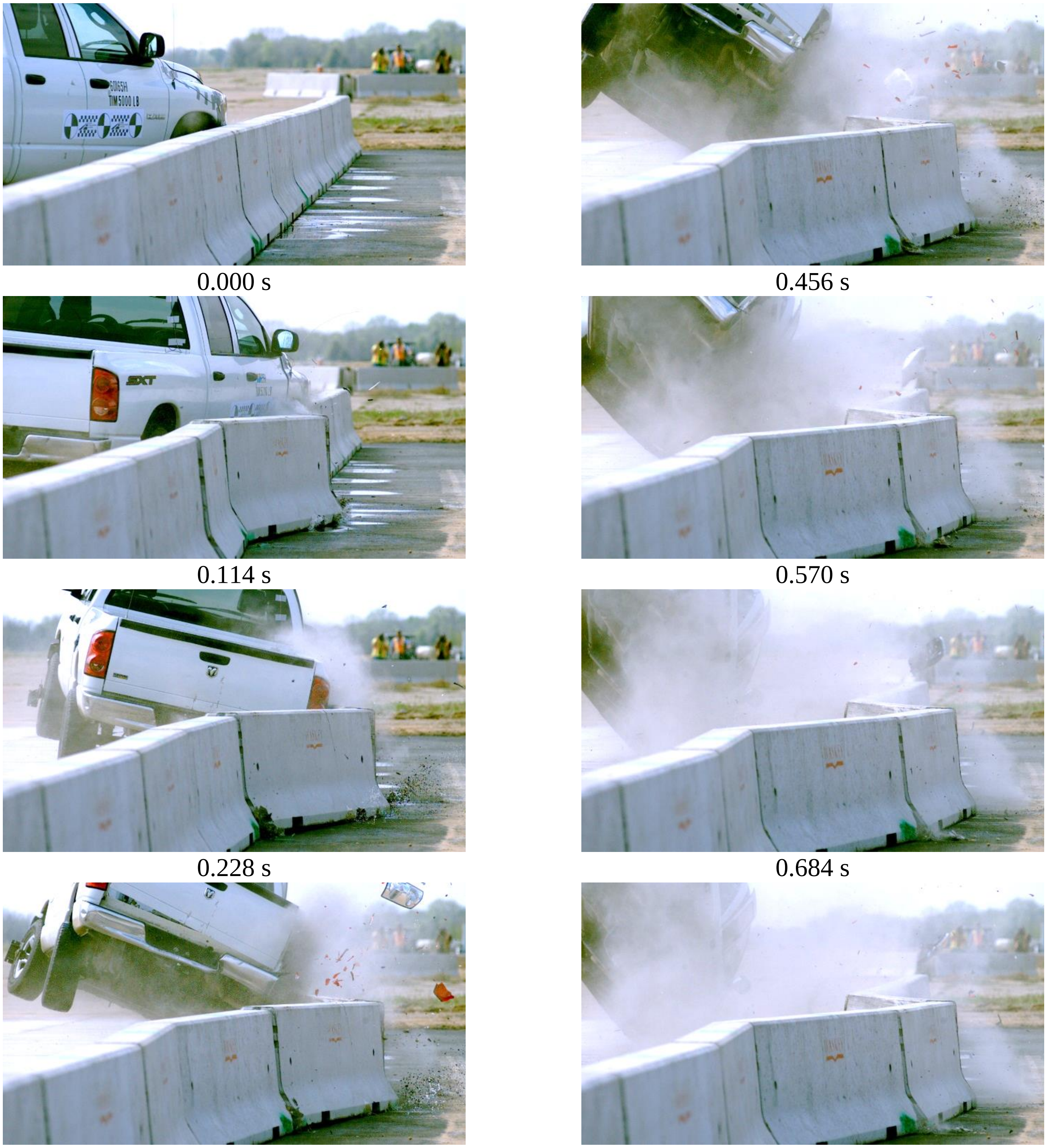


OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	**After** (inches)
A1	65.00	65.00
A2	64.75	64.75
A3	65.25	65.25
B1	45.25	45.25
B2	39.50	39.50
B3	45.25	45.25
B4	42.25	42.25
B5	45.00	45.00
B6	42.25	42.25
C1	29.25	29.25
C2	-----	-----
C3	27.75	27.75
D1	12.75	12.75
D2	-----	-----
D3	11.50	11.50
E1	63.00	62.00
E2	64.50	64.00
E3	64.00	62.50
E4	64.50	63.00
F	60.00	60.00
G	60.00	60.00
H	39.00	39.00
I	39.00	39.00
J*	62.25	62.25

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

C2. SEQUENTIAL PHOTOGRAPHS



0.000 s

0.114 s

0.228 s

0.342 s

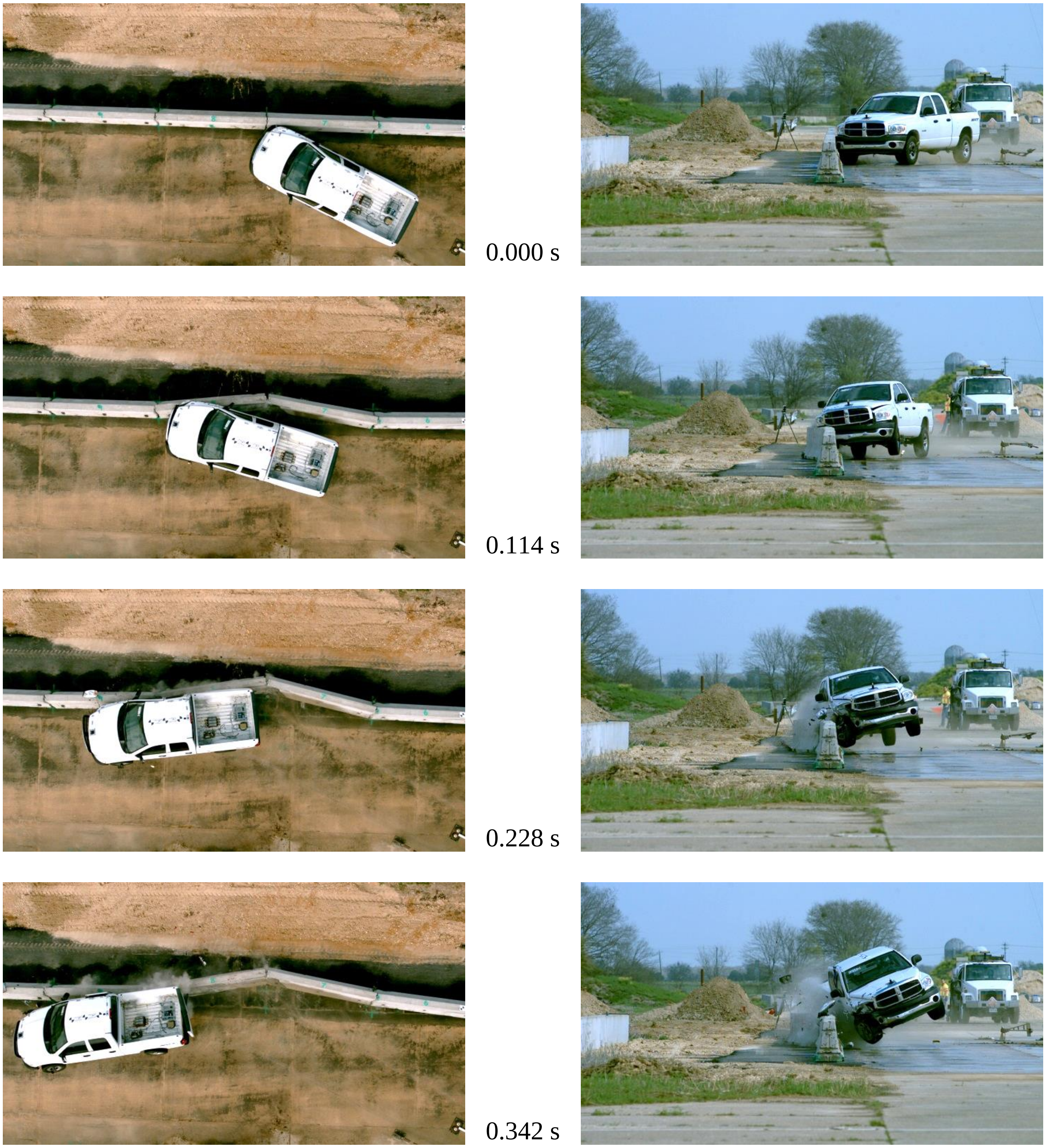
0.456 s

0.570 s

0.684 s

0.739 s

Figure C1. Sequential photographs for test 601651-1
(rear view).



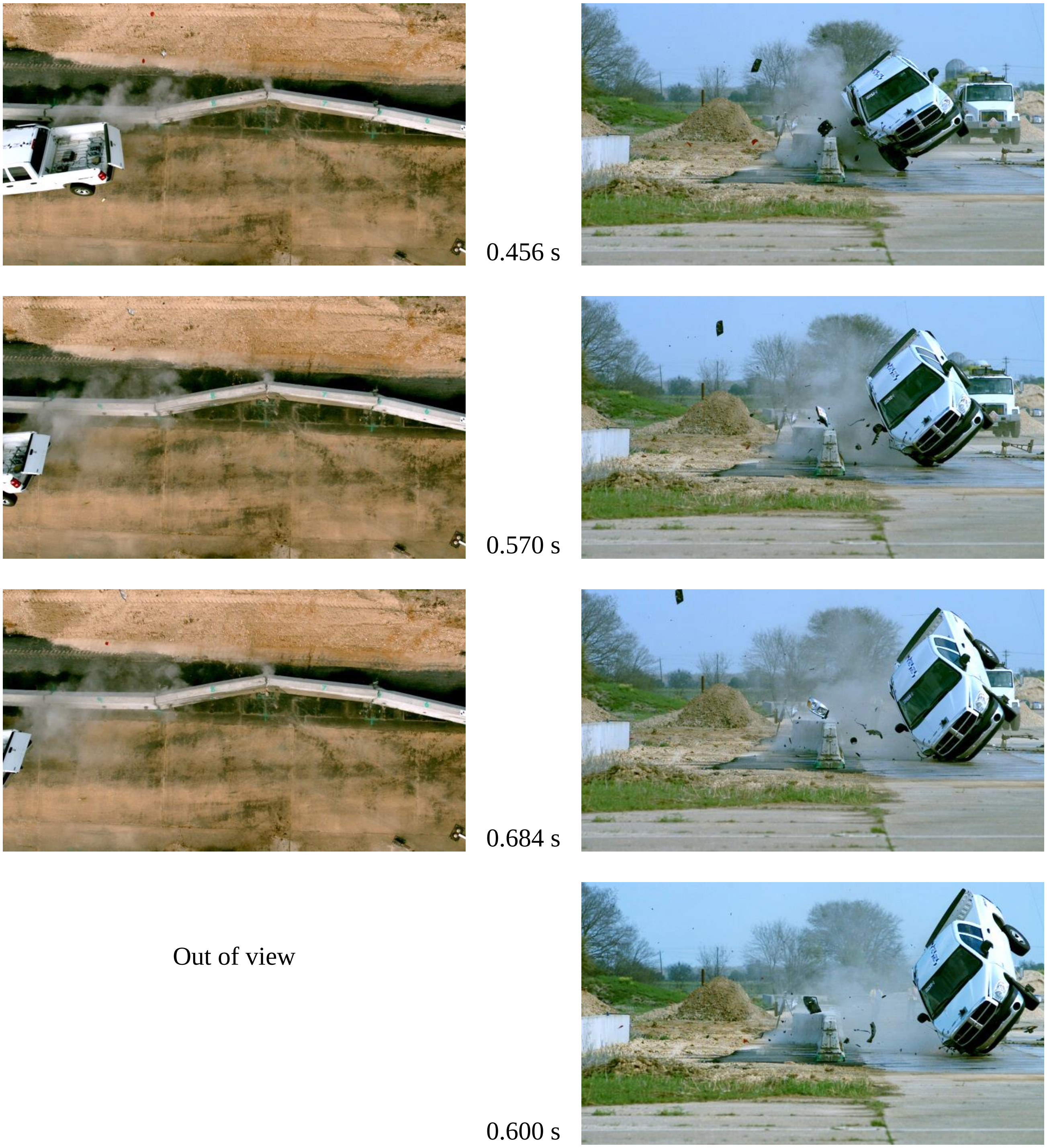
0.000 s

0.114 s

0.228 s

0.342 s

Figure C2. Sequential photographs for test 601651-1
(overhead and frontal views).



0.456 s

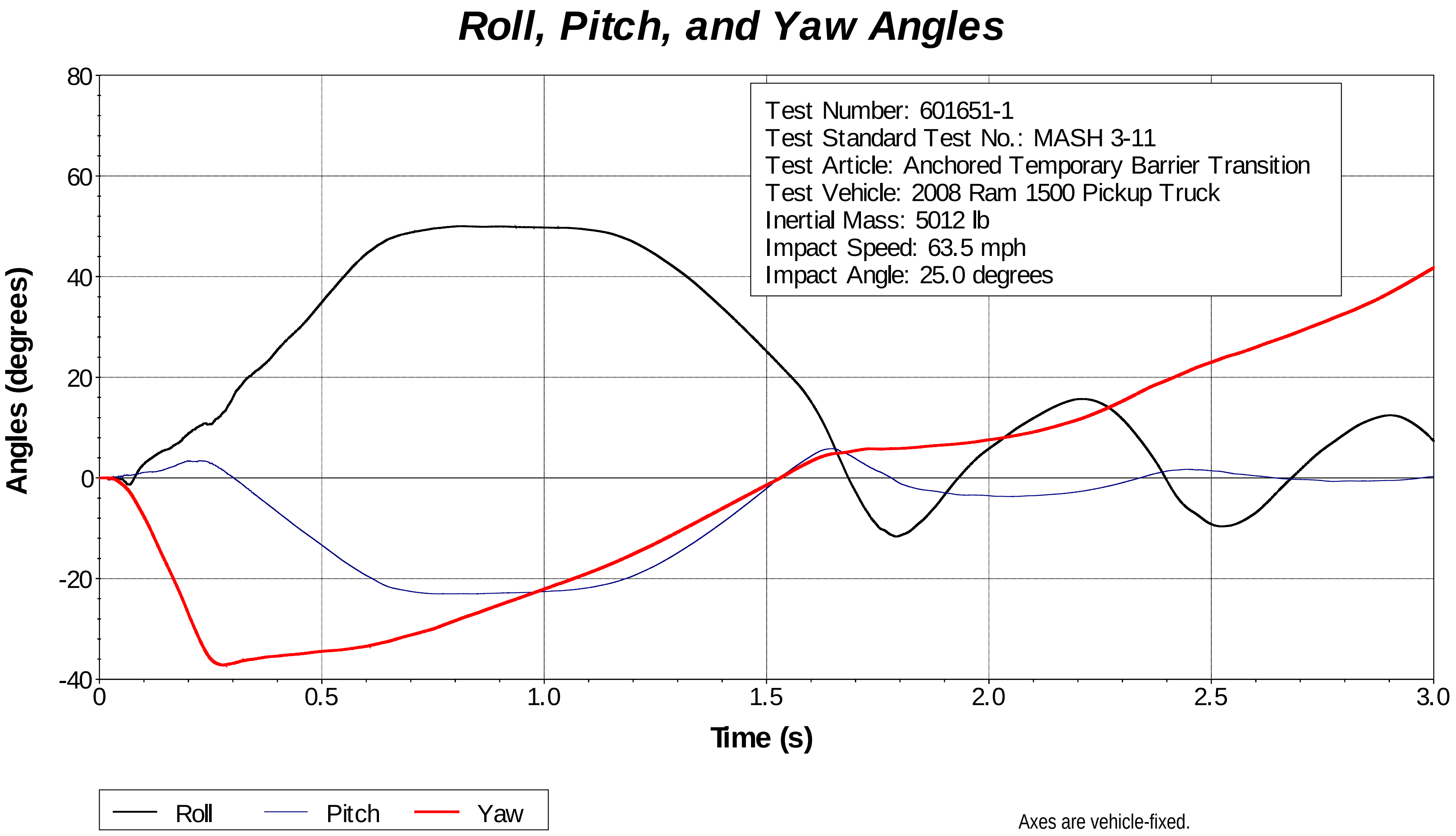
0.570 s

0.684 s

Out of view

0.600 s

Figure C2. Sequential photographs for test 601651-1
(overhead and frontal views) (continued).



Test Number: 601651-1
Test Standard Test No.: MASH 3-11
Test Article: Anchored Temporary Barrier Transition
Test Vehicle: 2008 Ram 1500 Pickup Truck
Inertial Mass: 5012 lb
Impact Speed: 63.5 mph
Impact Angle: 25.0 degrees

Axes are vehicle-fixed.
Sequence for determining
orientation:

1. Yaw.
2. Pitch.
3. Roll.

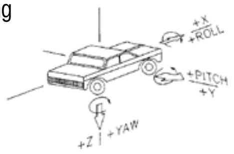


Figure C3. Vehicle angular displacements for test 601651-1.

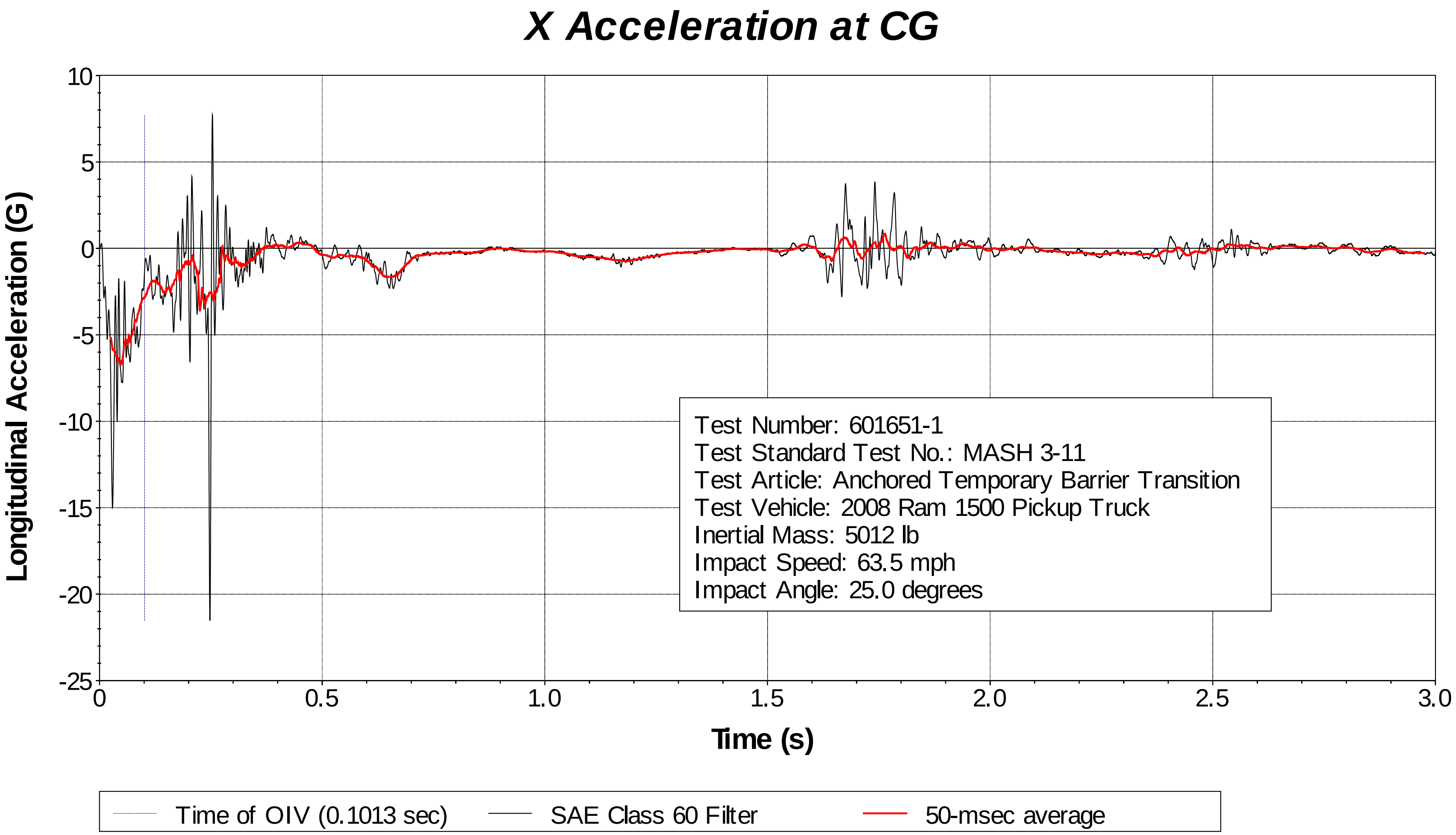


Figure C4. Vehicle longitudinal accelerometer trace for test 601651-1
(accelerometer located at center of gravity).

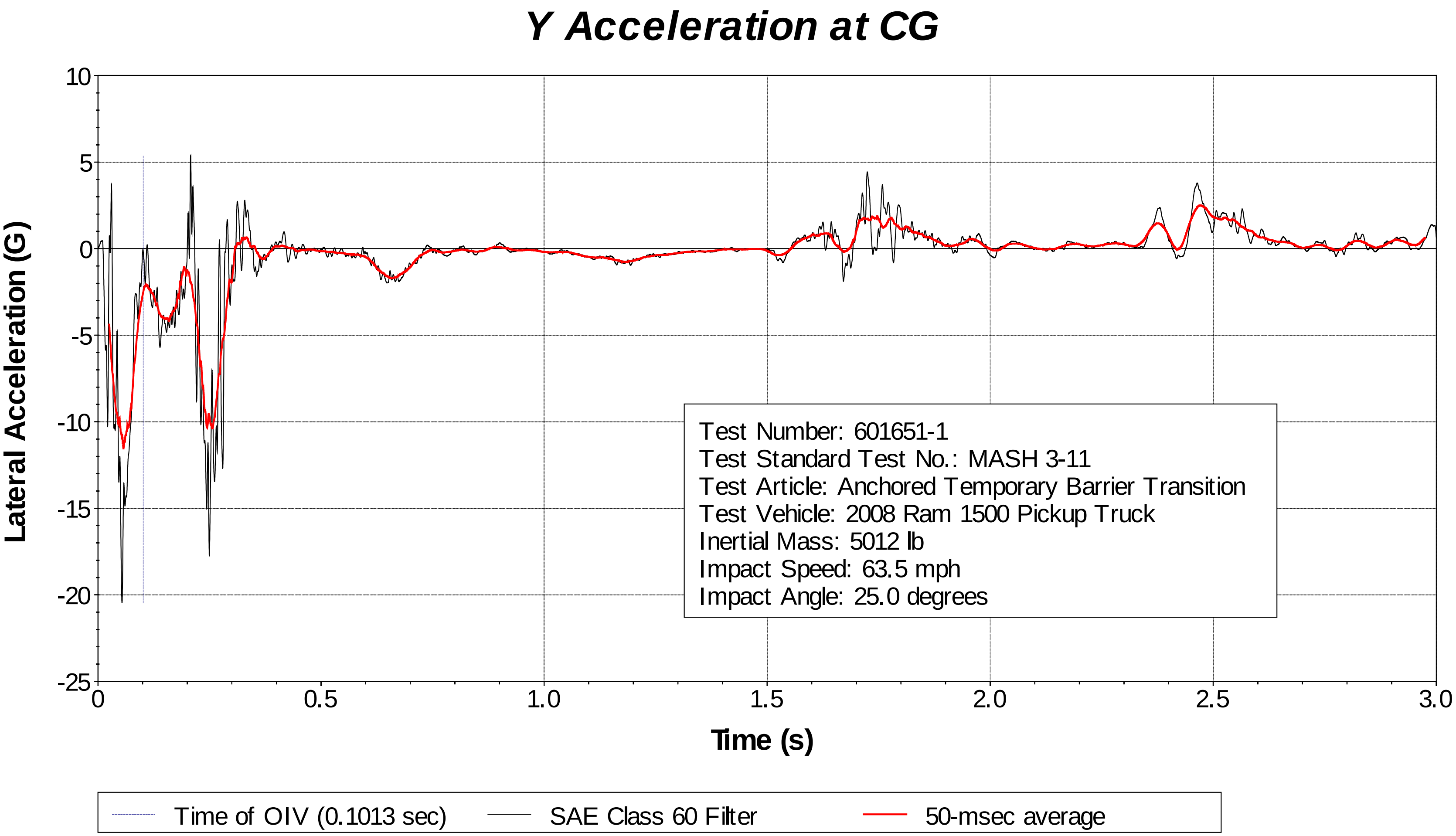


Figure C5. Vehicle lateral accelerometer trace for test 601651-1
(accelerometer located at center of gravity).

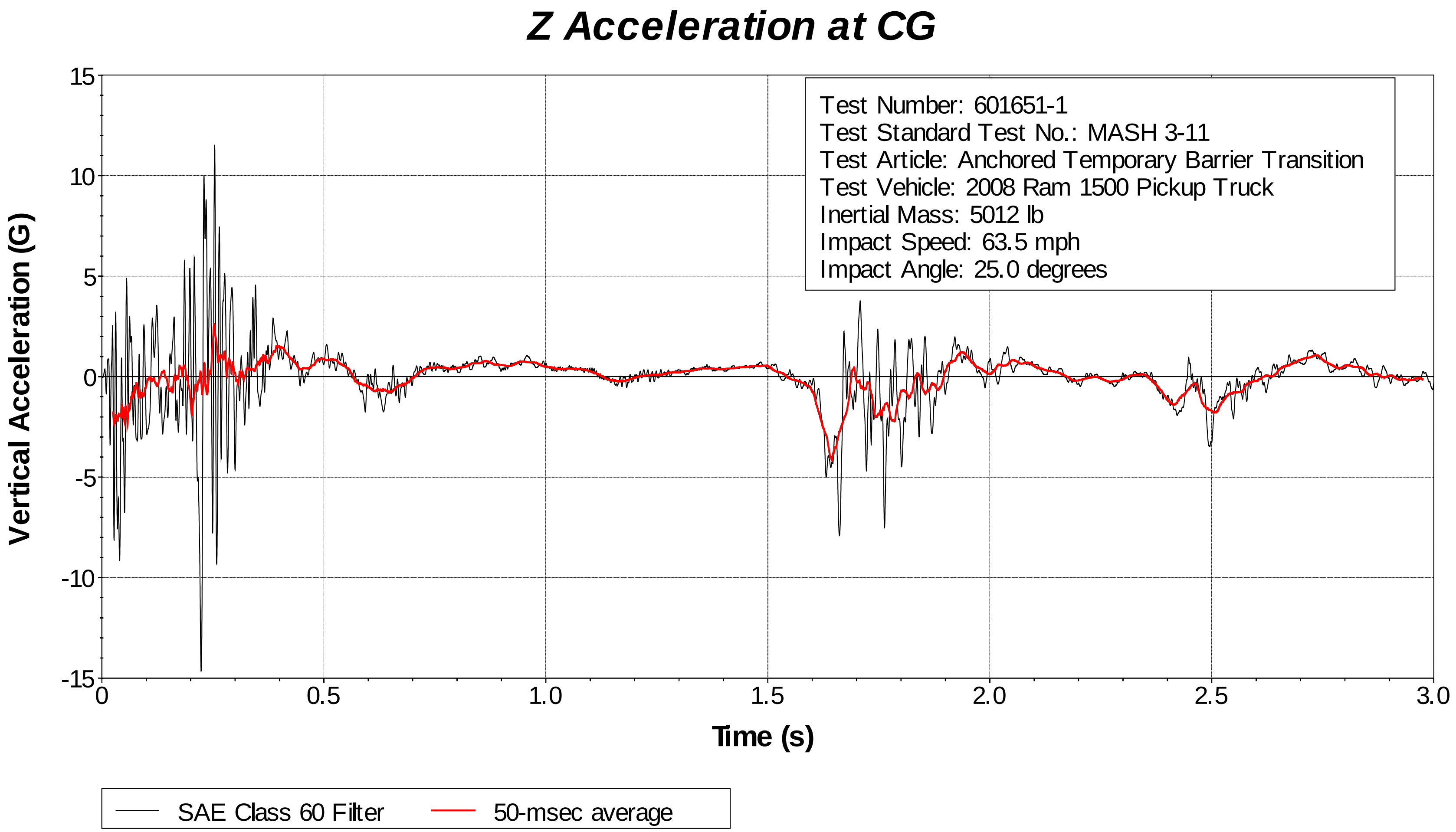


Figure C6. Vehicle vertical accelerometer trace for test 601651-1
(accelerometer located at center of gravity).

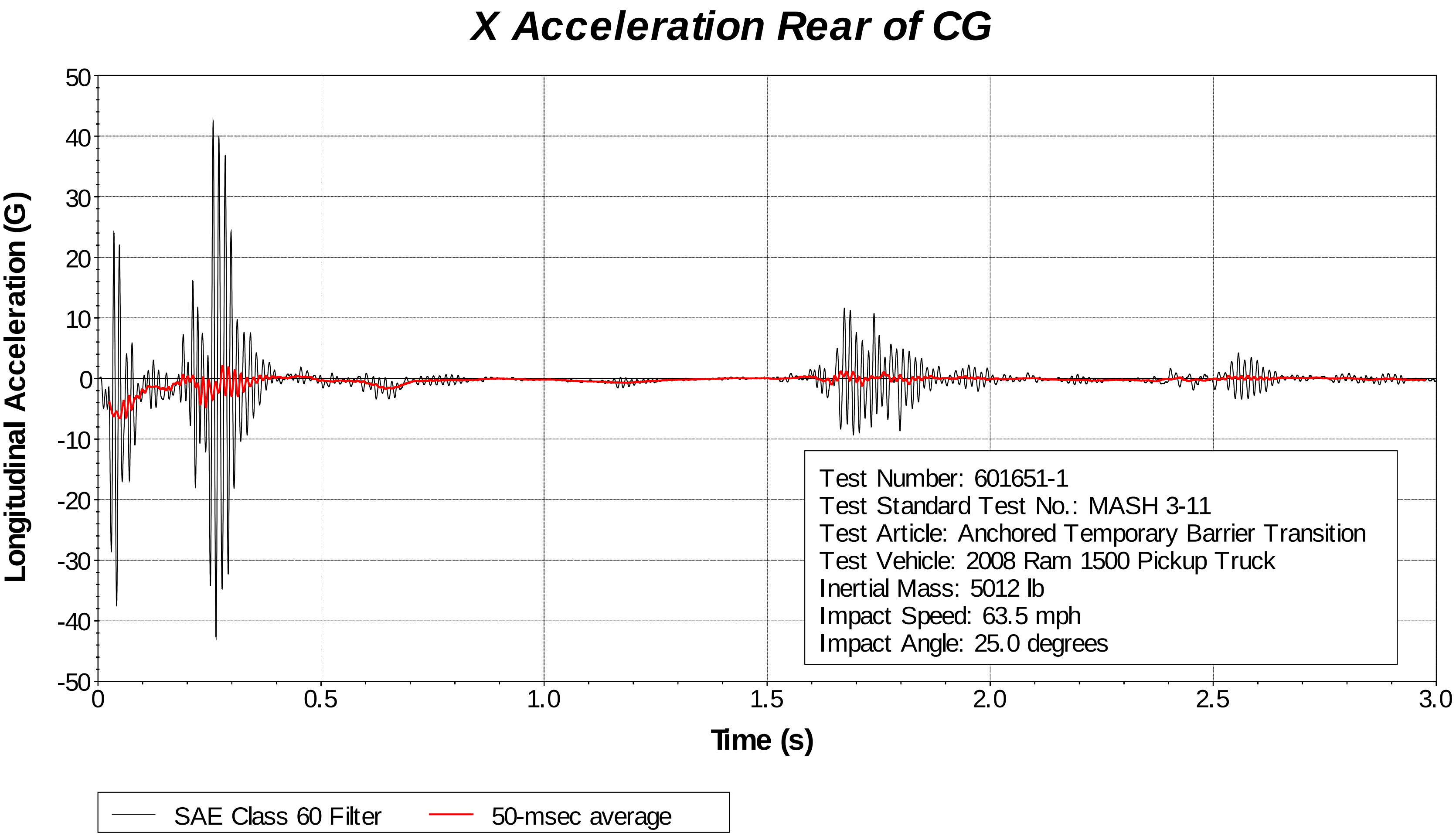


Figure C7. Vehicle longitudinal accelerometer trace for test 601651-1 (accelerometer located rear of center of gravity).

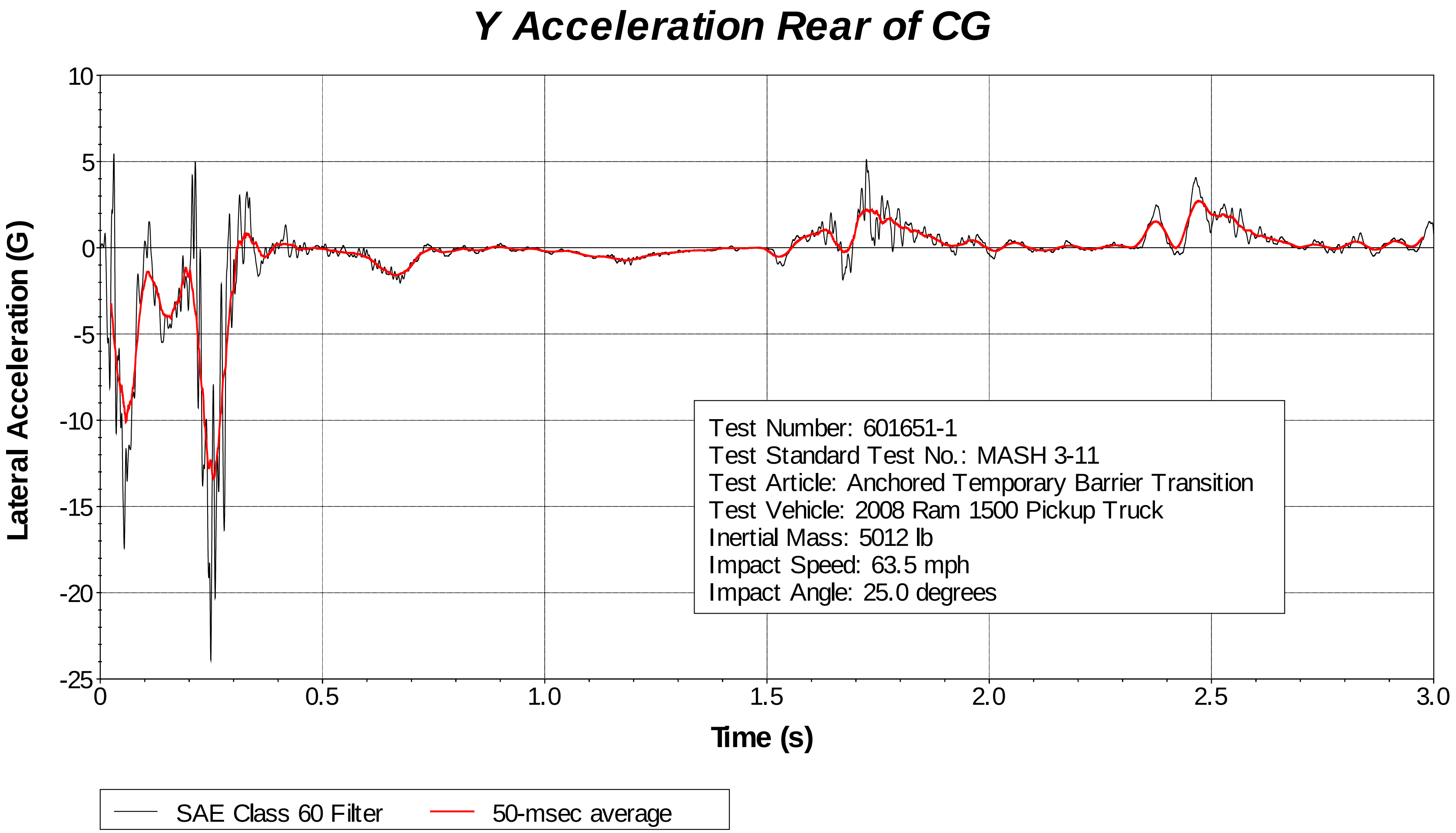


Figure C8. Vehicle lateral accelerometer trace for test 601651-1
(accelerometer located rear of center of gravity).

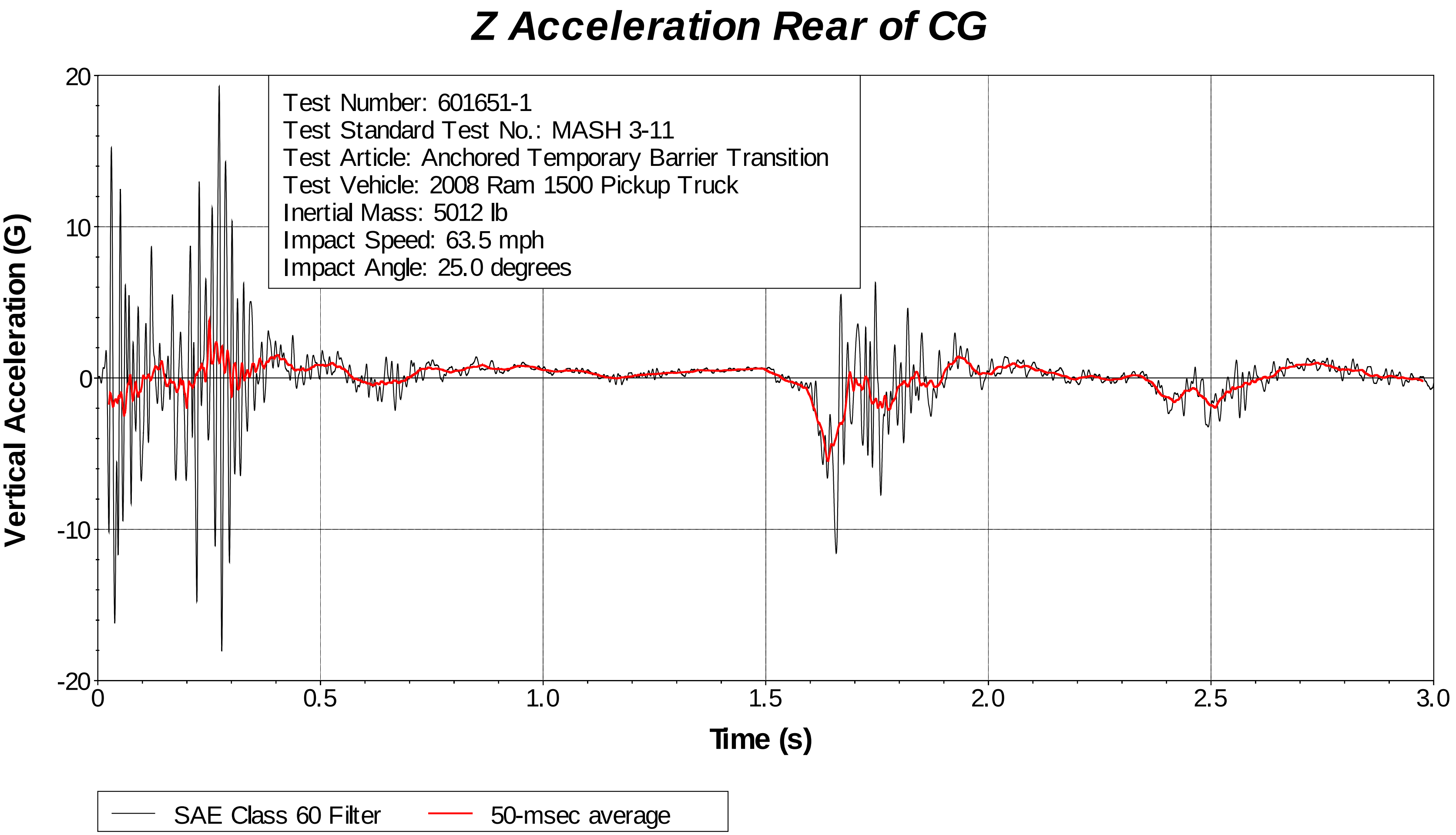


Figure C9. Vehicle vertical accelerometer trace for test 601651-1
(accelerometer located rear of center of gravity).