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MASH TEST 3-11 OF THE WSDOT PIN AND LOOP CONCRETE BARRIER WITH DRAINAGE SLOTS

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Technical Report Documentation Page

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16. Abstract

Simple engineering analyses was performed on the Washington pin and loop barrier to improve the strength for the barrier section from crash impact loading. To further evaluate the free standing precast single slope concrete barrier, a finite element analysis was then performed to determine the maximum lateral deflection of the barrier due to impact from a pickup truck vehicle under *MASH* test level 3 conditions. Additional simulations were performed to determine the potential of wheel snagging for the small passenger vehicle due to the presence of the drainage scupper.

After these analyses were completed, a full-scale crash test was then performed to assess the performance of the Washington DOT pin and loop concrete barrier with drainage slots according to the safety-performance evaluation guidelines included in *MASH*. The crash test was in accordance with Test Level 3 (TL-3) of *MASH*, and involves the 2270P vehicle (a 5000 lb, 1/2-ton, Quad Cab Pickup).

Due to rollover and the occupant compartment deformation caused by the rollover, the Washington DOT pin and loop concrete barrier with drainage slots did not perform acceptably according to the evaluation criteria for *MASH* test 3-11.

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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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TABLE OF CONTENTS

Section Page

LIST OF FIGURES

Page

LIST OF TABLES

1. INTRODUCTION

1.1 PROBLEM

Roadside safety devices perform the important function of reducing serious injury to motorists during roadside encroachments. To maintain the desired level of safety for the motoring public, these safety appurtenances must be designed to accommodate a variety of site conditions, placement locations, and a changing vehicle fleet. As changes are made or in-service problems are encountered, there is a need to assess the compliance of the specific safety device with current vehicle testing criteria, and modify the device or develop a new device with enhanced performance and maintenance characteristics.

1.2 BACKGROUND

Research to update *NCHRP Report 350 (1)* and take the next step in the continued advancement and evolution of roadside safety testing and evaluation was recently completed under NCHRP Project 22-14(02). The results of this research effort is now published by the American Association of State Highway and Transportation Officials (AASHTO), entitled *Manual for Assessing Safety Hardware* (*MASH*) *(2)*, and supersedes *NCHRP Report 350*. Changes incorporated into the new guidelines included new design test vehicles, revised test matrices, and revised impact conditions.

1.3 OBJECTIVES/SCOPE OF RESEARCH

Simple engineering analyses was performed on the Washington pin and loop barrier to improve the strength for the barrier section from crash impact loading. To further evaluate the free standing precast single slope concrete barrier, a finite element analysis was then performed to determine the maximum lateral deflection of the barrier due to impact from a pickup truck vehicle under *MASH* test level 3 conditions. Additional simulations were performed to determine the potential of wheel snagging for the small passenger vehicle due to the presence of the drainage scupper.

After these analyses were completed, a full-scale crash test was then performed to assess the performance of the Washington DOT pin and loop concrete barrier with drainage slots according to the safety-performance evaluation guidelines included in *MASH*. The crash test was in accordance with Test Level 3 (TL-3) of *MASH*, and involves the 2270P vehicle (a 5000 lb, 1/2-ton, Quad Cab Pickup).

2. ENGINEERING ANALYSIS

Engineering analyses* were performed on the Washington pin and loop barrier to improve the strength for the barrier section for crash impact loading. The strength of the barrier section was analyzed using 54 kips of distributed loading applied to the middle of a barrier section over a distance of 4 ft. The basis for these analyses was the AASHTO *LRFD Bridge Design Specification* assuming Test Level 3 impact conditions.*(3)* The end conditions of the barrier section were considered to be pinned with an assumed one-third reduction in the force due to the sliding movement in the barrier section. Considering the geometry of the barrier section, the calculated maximum bending moment from the applied load was approximately 93 kip-ft.

Engineering strength analyses were performed on the barrier section to analyze the bending strength of the barrier section at the mid-span of the section (centerline of the drainage scupper). The bending strength of the original cross-section using three #5 longitudinal bars located on each face of the barrier section within the enclosed stirrups was approximately 53 kip-ft. Additional longitudinal reinforcing steel was added to the barrier section. Two additional #5 longitudinal reinforcing bars were added on each face of the barrier to increase the bending capacity of the section for crash impact loading. With the two additional #5 bars on each face of the barrier section, the bending strength of the barrier was increased to approximately 90 kip-ft of resistance. No further modifications were made to the barrier section details. Please refer to the details included in Chapters 3 and 4 for additional information.

* The engineering analyses results are not covered under TTI Proving Ground's A2LA accreditation.

3. COMPUTER MODELING AND SIMULATION

To evaluate the free standing precast single slope concrete barrier, a full-scale finite element model of the barrier was developed. Finite element analysis* was performed to determine the maximum lateral deflection of the barrier due to impact from a pickup truck vehicle under *Manual for Assessing Safety Hardware (MASH)* test level 3 conditions. Additional simulations were performed to determine the potential of wheel snagging for the small passenger vehicle due to the presence of the drainage scupper.

Finite element analysis was performed using LS-DYNA software. LS-DYNA is a general-purpose, explicit finite element code used to analyze the nonlinear dynamic response of three-dimensional structures.

The finite element model was comprised of 12 concrete barrier segments that were 12.5-ft in length. The finite element mesh of the barrier model, shown in Figure 3.1, was comprised of solid elements with rigid material representation. The barrier segment material was assigned the mass density of reinforced concrete, which made the total mass of the barrier model equivalent to the actual barrier.

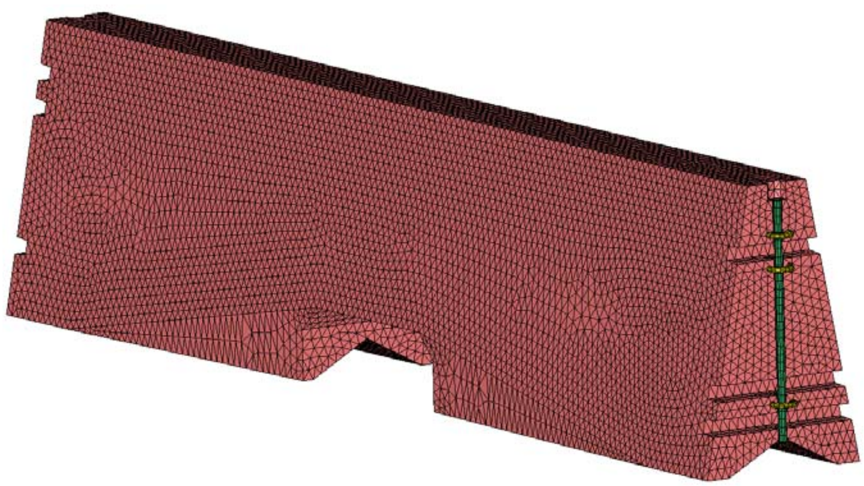


Figure 3.1. Finite element model of the barrier segment and the pin and loop connection.

Adjacent barrier segments were connected using a pin-and-loop type connection comprised of shell and beam elements with elastic-plastic material representation (see Figure 3.1). Failure of the barrier concrete was not incorporated in the model due to the lack of robust concrete damage models. If significant concrete fracture and spalling occurs at the ends of one or more barrier segments during an actual impact, additional joint rotation can occur. This in turn can increase barrier deflection and vehicle instability and climb. Therefore, the results of the simulation represented a lower bound estimate of the overall barrier system deflection. With

* The finite element analysis results are not covered under TTI Proving Ground's A2LA accreditation.

these aspects of the model understood, valuable design and performance information can be gleaned from the simulation results.

The first simulation was performed with a 5000-lb pickup truck vehicle model. The pickup truck model used in the simulations was developed by the National Crash Analysis Center (NCAC) with funding from Federal Highway Administration (FHWA) and the National Highway Traffic Safety Administration (NHTSA).

The full system model of the barrier is shown in Figure 3.2. The simulated impact conditions correspond to Test Designation 3-11 of *MASH*. This test involves a 5000-lb pickup truck impacting the barrier at a speed of 62 mi/h and an angle of 25 degrees. This test is considered to be the critical test for evaluating the structural integrity of the barrier and the maximum dynamic deflection due to impact. The vehicle model impacted the barrier system 4 ft upstream of the joint between the fifth and the sixth barrier segment as shown in Figure 3.2.

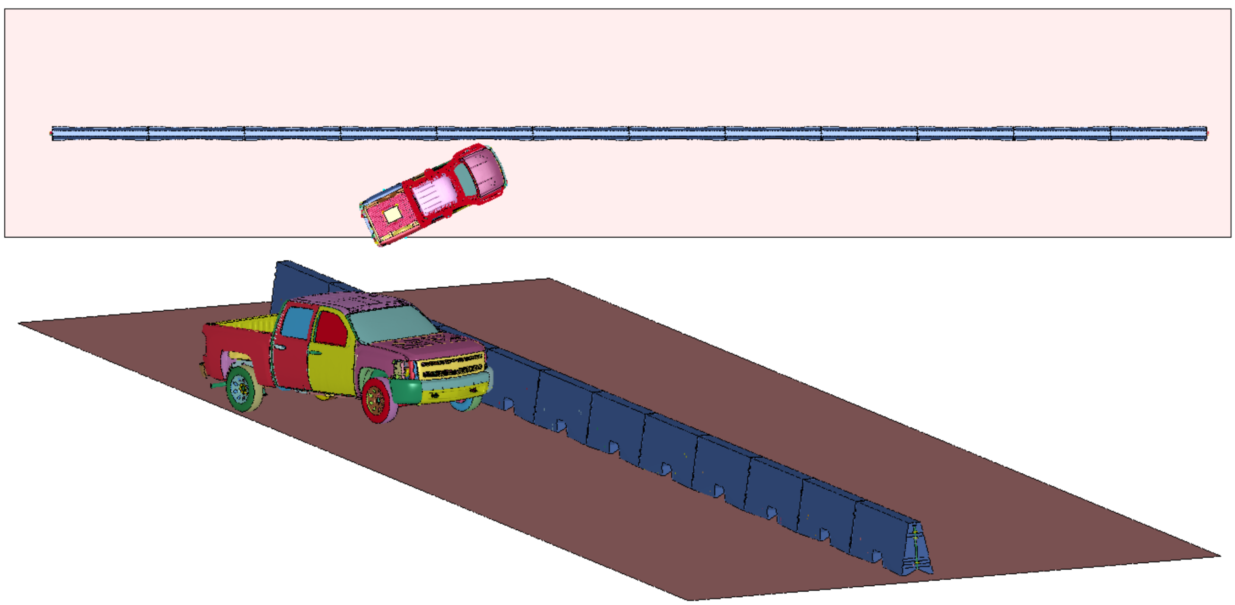


Figure 3.2. System model.

The free standing single slope barrier deflected laterally and had a maximum lateral deflection of 53 inches. Figure 3.3 shows the deformed state of the model after the impact. The deformation of the pin and loop connection at the joint immediately downstream of the impact point is shown in Figure 3.4.

The researchers also performed full-scale vehicle impact analyses using a small passenger car to determine the potential for wheel snagging on the exposed edge of the drainage scupper. A public domain finite element vehicle model corresponded to the 1100C *MASH* design vehicle is not currently available. In the absence of such a model, the researchers used a Ford Taurus model previously developed by NCAC. This vehicle model has a slightly higher mass than the *MASH* vehicle, but the height and location of the vehicle's front tire and wheel are comparable. Since the objective of these simulations was to evaluate snagging potential, use of the slightly heavier vehicle model was deemed acceptable.

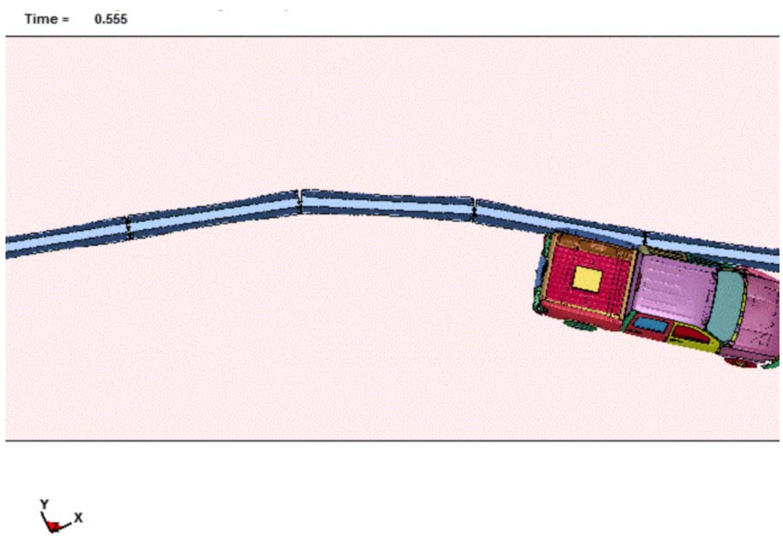


Figure 3.3. Deformed state of the barrier after impact.

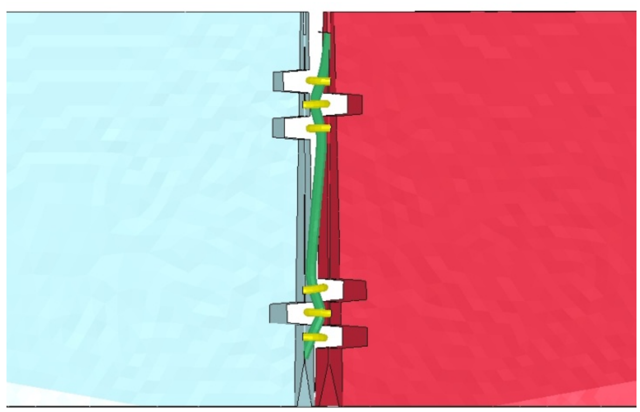


Figure 3.4. Deformed state of the pin and loop connection at the impact joint.

Figure 3.5 shows the system model with the small passenger car model. A total of three simulations were performed at different impact point locations to determine the critical impact point (CIP) that resulted in maximum interaction and snagging of the wheel on the exposed edge of the drainage scupper. Simulations were performed with vehicle impacting 4 ft upstream of the exposed scupper edge, 2.33-ft upstream of the scupper edge, and at the scupper edge. There was no wheel snagging observed in any of the cases simulated. Figure 3.6 shows sequential images of wheel interaction with the scupper for the case in which the vehicle impacted at the exposed edge of the scupper (note: the barrier has been shown transparent for illustrative purposes). For the other two impacts, the interaction of the wheel with the exposed scupper edge was further reduced.

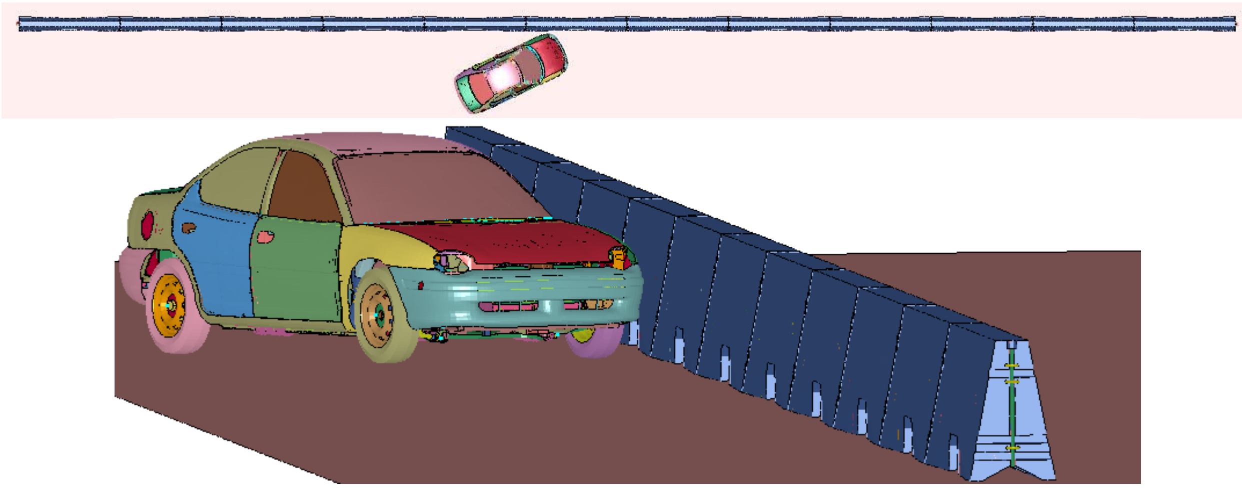


Figure 3.5. System model for small passenger car impact.

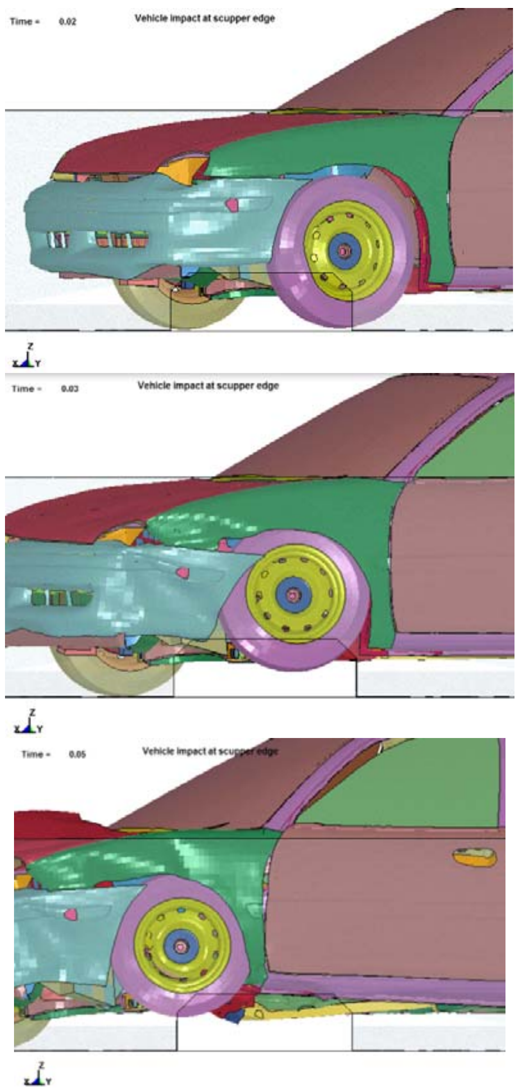


Figure 3.6. Interaction of the passenger car wheel with the exposed edge of the drainage scupper.

4. SYSTEM DETAILS

4.1 TEST ARTICLE DESIGN AND CONSTRUCTION

The Washington Pin and Loop Barrier system tested for this project consisted of precast concrete barrier segments that were 12 ft-6 inch in length and 34 inches in height. The barrier segment was 8 inches wide at the top and 21 inches wide at the base with a uniform single slope surface on each side face of the barrier. A 4-inch high by 15-inch wide "V" shaped slot was constructed in the base of the barrier. This slot was centered in the base of the barrier and continuous along the entire length of the barrier segment. In addition to this longitudinal slot, a transverse drainage scupper opening was constructed at the center of the barrier segment. The drainage scupper opening was 9 inches high by 28 inches in width. This drainage scupper opening would permit drainage from the roadway through the barrier segment and onto roadside water treatment facilities such as ecology embankments. Three 3/4-inch diameter steel loops were constructed on the ends of the barrier segments. These loops served to connect the barrier segments together. Mating loops on each end of the segment permitted the segments to be connected together using 1-inch diameter pins. These pins were placed through the mating loops to connect the barrier segments together. The 3/4-inch steel loops were fabricated using A36 material. The 1-inch diameter steel rods were fabricated from AISI 4142 material and were 31 inches in length.

Vertical reinforcement (stirrups) in each barrier segment consisted of #4 rebar stirrups spaced as close as 4 inches on the ends to 11½ inches toward the center of the barrier segment. The stirrups were spaced on 7-inch centers (3 spaces) immediately above the drainage scupper located in the center of the segment. Longitudinal reinforcement in the barrier segment consisted of twelve #5 bars. The bars located in the bottom of the barrier segment were bent to accommodate the drainage scupper opening located in the center of the barrier segment.

The test installation for this project consisted of 16 barrier segments connected together using the 1-inch diameter AISI 4142 heat-treated pins. The total length of the test installation was approximately 200 ft. The minimum compressive strength of the concrete used to construct the units was specified to be 4000 psi, and strength on the day of testing (9 days of age) was 5335 psi. All reinforcing steel used to construct the barrier units was specified to be Grade 60 material.

For additional information, please refer to the drawings shown as Figures 4.1 and 4.2 and Appendix A. Photographs of the installation are shown in Figure 4.3

4.2 MATERIAL SPECIFICATIONS

All reinforcing steel used to construct the barrier units were Grade 60 material. The 1-inch diameter steel pins used to connect the barriers were fabricated from AISI 4142 material. The minimum compressive strength of the concrete used to construct the units was specified to be 4000 psi, and strength on the day of testing (9 days of age) was 5335 psi. Certification documents are provided in Appendix B.

4.3 SOIL CONDITIONS

The barriers were placed on existing concrete surface, therefore soil conditions are not applicable.

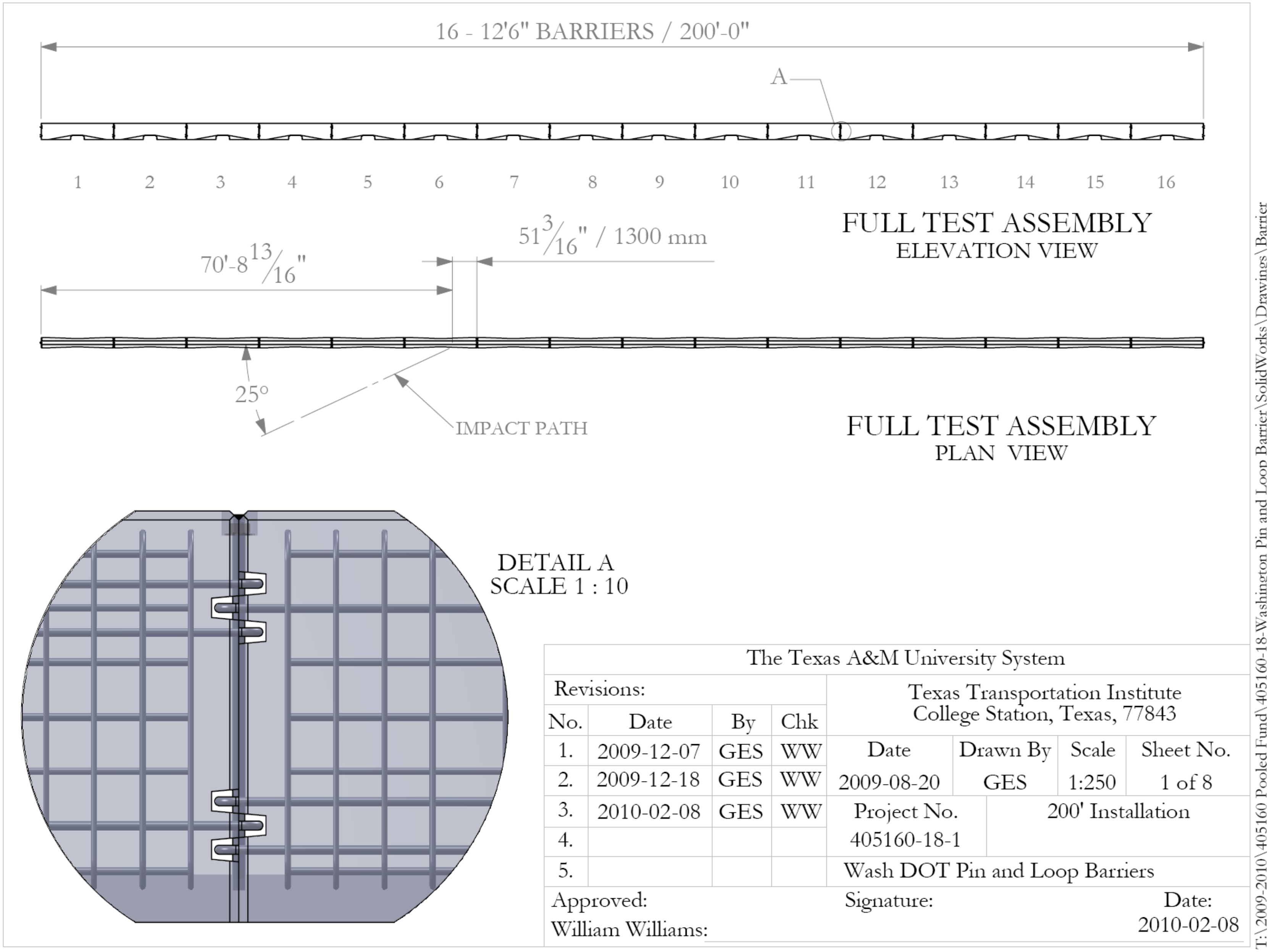


Figure 4.1. Layout of the Washington DOT pin and loop concrete barrier with drainage slots.

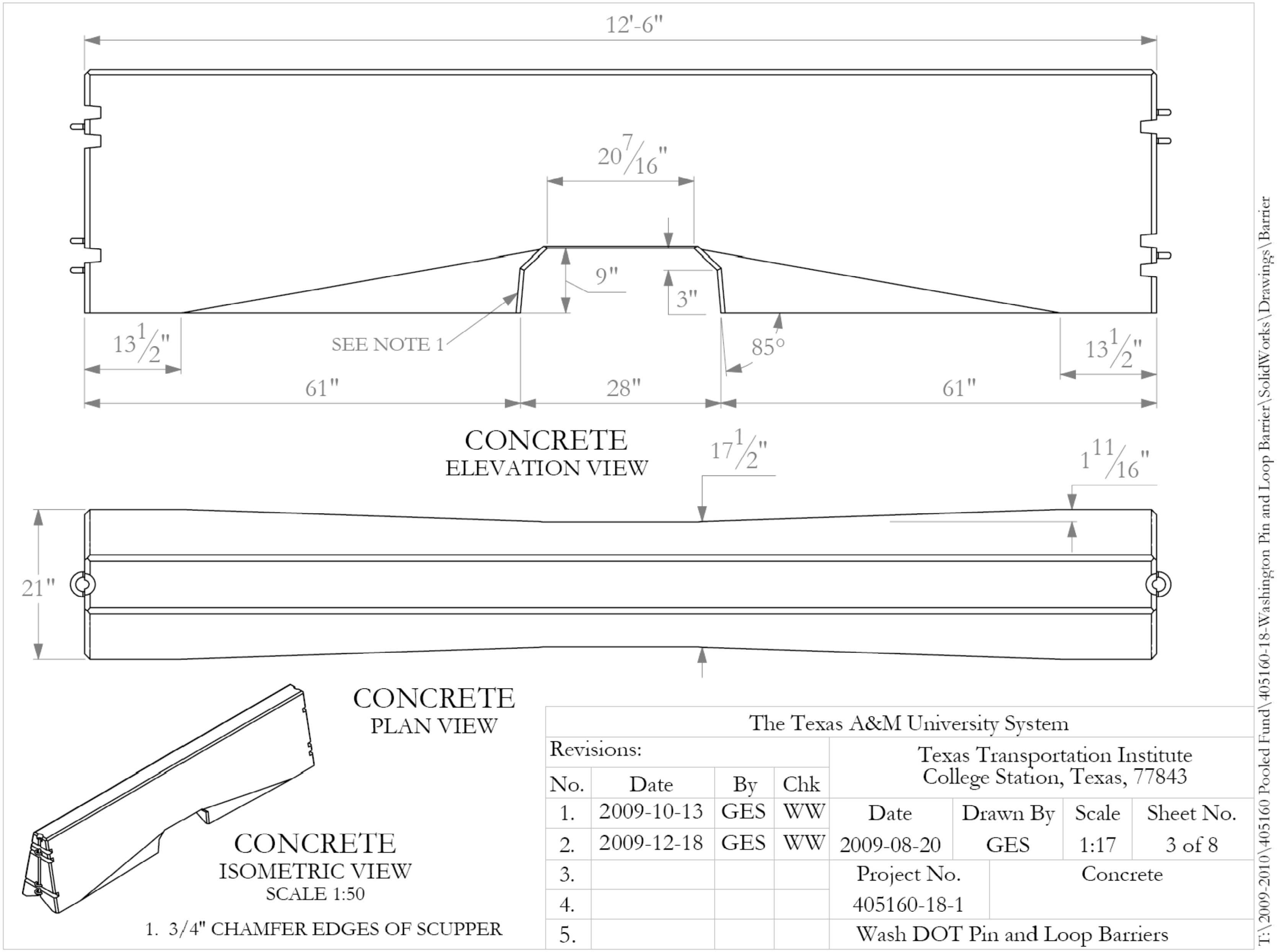


Figure 4.2. Details of the Washington DOT pin and loop concrete barrier with drainage slots.

Figure 4.3. Washington DOT pin and loop concrete barrier with drainage slots prior to testing.

5. TEST REQUIREMENTS AND EVALUATION CRITERIA

5.1 CRASH TEST MATRIX

The test reported herein corresponds to *MASH* test designation 3-11 which involves the 2270P vehicle (a 5000 lb, 1/2 ton, four-door pickup). Target impact conditions were an impact speed of 62 mph and an impact angle of 25 degrees. The minimum vertical center-of-gravity height of the vehicle is specified to be equal to or greater than 28.0 inches. The critical (target) impact point was determined using information provided in *MASH*, and was calculated to be 51.2 inches upstream of joint between segments 6 and 7 (16 total units).

The crash test and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 6 presents brief descriptions of these procedures.

5.2 EVALUATION CRITERIA

The crash test was evaluated in accordance with the criteria presented in *MASH*. The performance of the Washington DOT pin and loop concrete barrier with drainage slots was judged on the basis of three factors: structural adequacy, occupant risk, and post impact vehicle trajectory. Structural adequacy is judged upon the concrete barrier's ability 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.

6. TEST CONDITIONS

6.1 TEST FACILITY

The full-scale crash test reported herein was performed at Texas Transportation Institute (TTI) Proving Ground. TTI Proving Ground is an International Standards Organization (ISO) 17025 accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanical Testing certificate 2821.01. The full-scale crash test was performed according to TTI Proving Ground quality procedures and according to the *MASH* guidelines and standards.

The test facilities at the TTI Proving Ground consist of a 2000 acre complex of research and training facilities situated 10 miles northwest of the main campus of Texas A&M University. The site, formerly an Air Force Base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for the placement of the Washington DOT pin and loop concrete barrier with drainage slots was on the surface of a wide out-of-service apron. The apron consists of an unreinforced jointed concrete pavement in 12.5 ft x 15 ft blocks nominally 8-12 inches deep. The apron is over 50 years old and the joints have some displacement, but are otherwise flat and level.

6.2 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.

6.3 DATA ACQUISITION SYSTEMS

6.3.1 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 is returned to the factory annually for complete recalibration. Accelerometers and rate transducers are also calibrated annually with traceability to the National Institute for Standards and Technology.

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.

6.3.2 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.

6.3.3 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.

7. CRASH TEST 405160-18-1 (*MASH* TEST NO. 3-11)

7.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

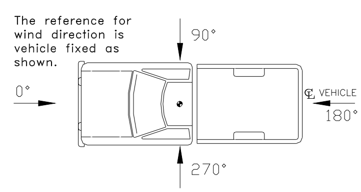
MASH test 3-11 involves a 2270P vehicle weighing 5000 lb ±100 lb and impacting the concrete barrier at an impact speed of 62.2 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target impact point was 51.2 inches upstream of joint between segments 6 and 7 (16 total units). The 2004 Dodge Ram 1500 pickup truck used in the test weighed 4951 lb and the actual impact speed and angle were 60.2 mi/h and 26.2 degrees, respectively. The actual impact point was 51.2 inches upstream of joint between segments 6 and 7.

7.2 TEST VEHICLE

A 2004 Dodge Ram 1500 Quad-Cab pickup truck, shown in figures 7.1 and 7.2, was used for the crash test. Test inertia weight of the vehicle was 4951 lb, and its gross static weight was 4951 lb. The height to the lower edge of the vehicle front bumper was 13.5 inches, and the height to the upper edge of the front bumper was 26.0 inches. The height to the center of gravity was 28.5 inches. Additional dimensions and information on the vehicle are given in Appendix C, Figure C1 and Table C1. 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.

7.3 WEATHER CONDITIONS

The crash test was performed the morning of February 23, 2010. Weather conditions at the time of testing were: Wind speed: 9 mi/h; wind direction: 316 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 43 ºF; relative humidity: 64 percent.



6.4 TEST DESCRIPTION

The 2270P vehicle, traveling at an impact speed of 60.2 mi/h, impacted the Washington DOT pin and loop concrete barrier with drainage slots 51.2 inches upstream of joint between segments 6 and 7 at an impact angle of 26.2 degrees. At approximately 0.017 s after impact, the downstream end of segment 6 began to deflect towards the field side, and at 0.029 s, the vehicle began to redirect. The upstream end of segment 7 began to deflect toward the traffic side at 0.036 s, and the downstream end of segment 7 began to deflect toward the field side at 0.056 s. At 0.077 s, the upstream end of segment 8 began to deflect toward the traffic side, and at 0.147 s, the ends of the barrier at the 8-9 joint began to move toward traffic lanes. The left front corner of the 2270P vehicle contacted the exposed end of segment 8 nearest segment 7 at 0.206 s. The 2270P vehicle began to travel parallel with the barrier at 0.208 s and was traveling at a speed of 49.5 mi/h. The 2270P vehicle exited the view of the overhead camera, and lost contact with the barrier while still airborne at 0.705 s. As the vehicle touched ground, the vehicle rolled 2-3/4 revolutions and came to rest upright 192 ft downstream of impact and 18 ft toward traffic lanes. Sequential photographs of the test period are shown in Appendix C, Figures C2 and C3.

Figure 7.1. Vehicle/installation geometrics for test 405160-18-1.

Figure 7.2. Vehicle before test 405160-18-1.

7.5 TEST ARTICLE AND COMPONENT DAMAGE

Damage to the Washington DOT pin and loop concrete barrier with drainage slots is shown in Figures 7.3 and 7.4. Movement of the segments was noted as shown in Table 7.1.

Table 7.1. Barrier movement at each segment.

Joint	Longitudinal (inches)	Lateral (inches)	Gap Before (inches)	Gap After (inches)	Pour No.
End of 1	0.75 right	0.5 fwd*			
1 at joint 1-2	2.0 right	0	0.12	1.38	1
2 at joint 1-2	3.0 right	0.25 fwd			
2 at joint 2-3	3.0 right	0	0.19	1.5	2
3 at joint 2-3	2.5 right	0			
3 at joint 3-4	2.5 right	0	0.31	1.5	3
4 at joint 3-4	4.5 right	1.75 fwd			
4 at joint 4-5	4.5 right	1.75 fwd	0.25	1.5	2
5 at joint 4-5	2.0 right	1.0 fwd			
5 at joint 5-6	6.0 right	26.0 rwd**	1.0	1.62	3
6 at joint 5-6	6.5 right	28.8 rwd			
6 at joint 6-7	4.0 right	58.5 rwd	0.12	2.5	4
7 at joint 6-7	4.0 right	59.5 rwd			
7 at joint 7-8	0	54.5 rwd	1.0	0	4
8 at joint 7-8	0	54.5 rwd			
8 at joint 8-9	4.0 left	18.75 rwd	0.68	1.25	4
9 at joint 8-9	3.0 left	17.0 rwd			
9 at joint 9-10	1.0 left	8.0 fwd	0.5	1.38	4
10 at joint 9-10	2.0 left	7.0 fwd			
10 at joint 10-11	2.5 left	2.25 fwd	0.18	1.62	1
11 at joint 10-11	2.0 left	1.5 fwd			
11 at joint 11-12	1.5 left	0	1.25	1.38	2
12 at joint 11-12	0	0			
12 at joint 12-13	1.25 left	0	0.19	1.25	1
No further movement					

* fwd = forward
** rwd - rearward

7.6 TEST VEHICLE DAMAGE

The left front and left side of the vehicle was damaged due to impact with the barrier, while the remainder of the damage occurred during rollover, as shown in Figure 7.5. The front bumper, grill, hood, left front fender, left doors, left exterior bed were damaged while in contact with the barrier. Maximum exterior crush to the vehicle was 10.5 inches in the side plane at the left front quarter at bumper height. Maximum occupant compartment deformation was 13.25 inches in the left rear passenger roof area. Exterior vehicle crush and occupant compartment measurements are shown in Appendix C, Tables C1 and C2.

Figure 7.3. Vehicle trajectory after test 405160-18-1.

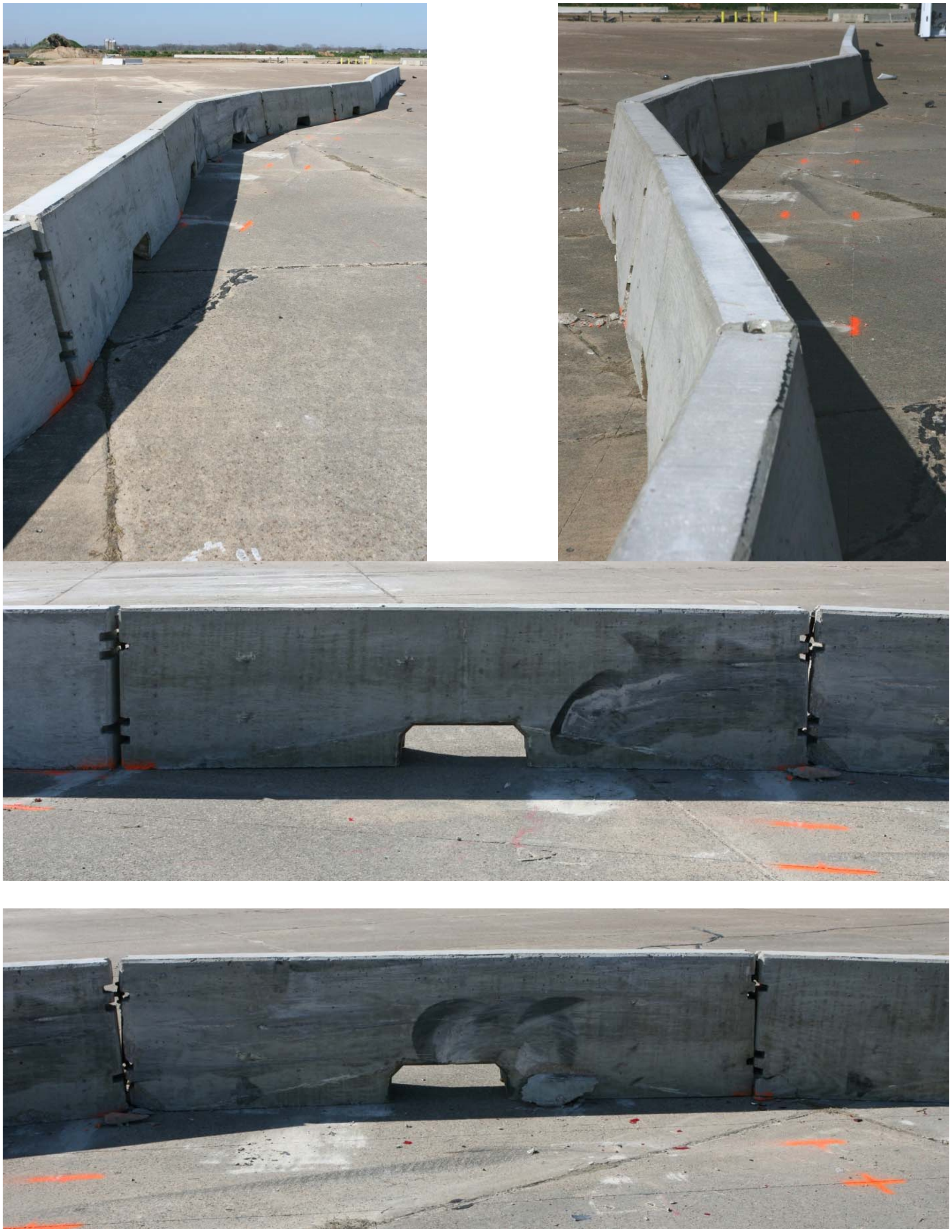
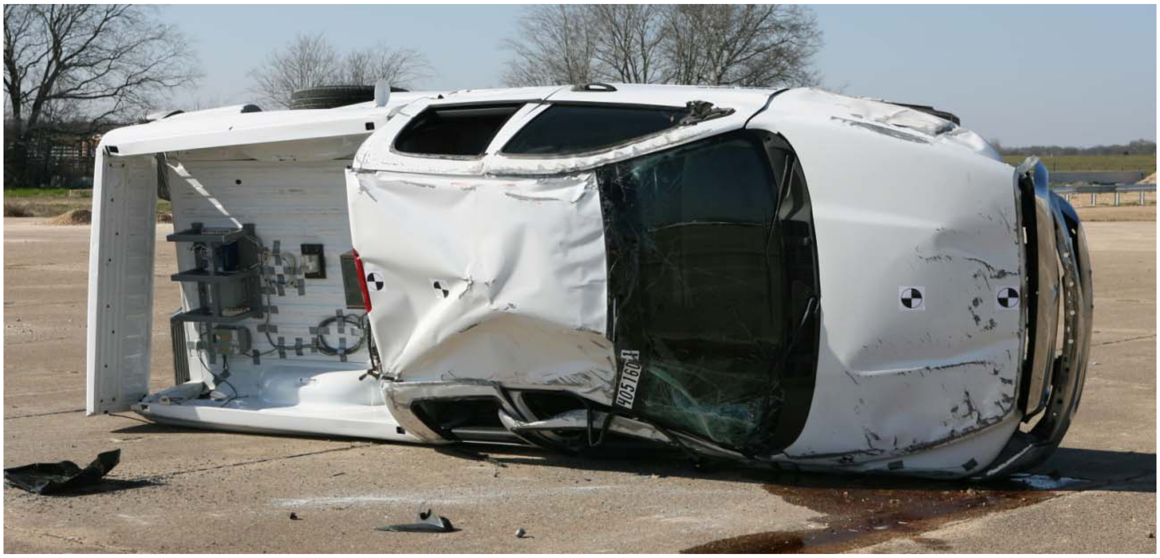


Figure 7.4. Installation after test 405160-18-1.



After being uprighted

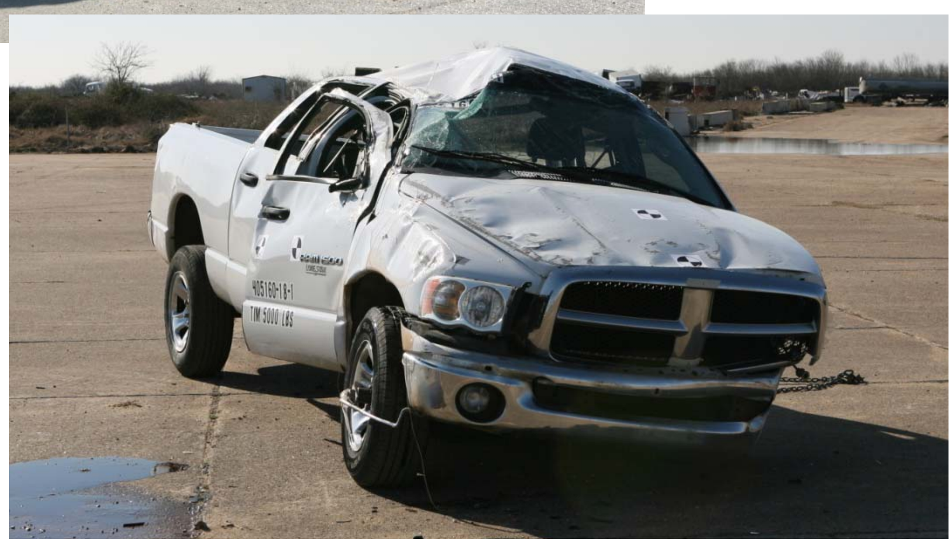


Figure 7.5. Vehicle after test 405160-18-1.

7.7 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 14.8 ft/s at 0.097 s, the highest 0.010-s occupant ridedown acceleration was -6.6 Gs from 0.291 to 0.301 s, and the maximum 0.050-s average acceleration was -7.7 Gs between 0.022 and 0.072 s. In the lateral direction, the occupant impact velocity was 20.0 ft/s at 0.097 s, the highest 0.010-s occupant ridedown acceleration was 11.7 Gs from 0.301 to 0.311 s, and the maximum 0.050-s average was 10.9 Gs between 0.019 and 0.069 s. Theoretical Head Impact Velocity (THIV) was 26.2 km/h or 7.3 m/s at 0.094 s; Post-Impact Head Decelerations (PHD) was 11.8 Gs between 0.301 and 0.311 s; and Acceleration Severity Index (ASI) was 1.40 between 0.022 and 0.072 s. These data and other pertinent information from the test are summarized in Figure 7.6. Vehicle angular displacements and accelerations versus time traces are presented in Appendix C, Figures C4 through C10.

7.8 ASSESSMENT OF TEST RESULTS

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

7.8.1 Structural Adequacy

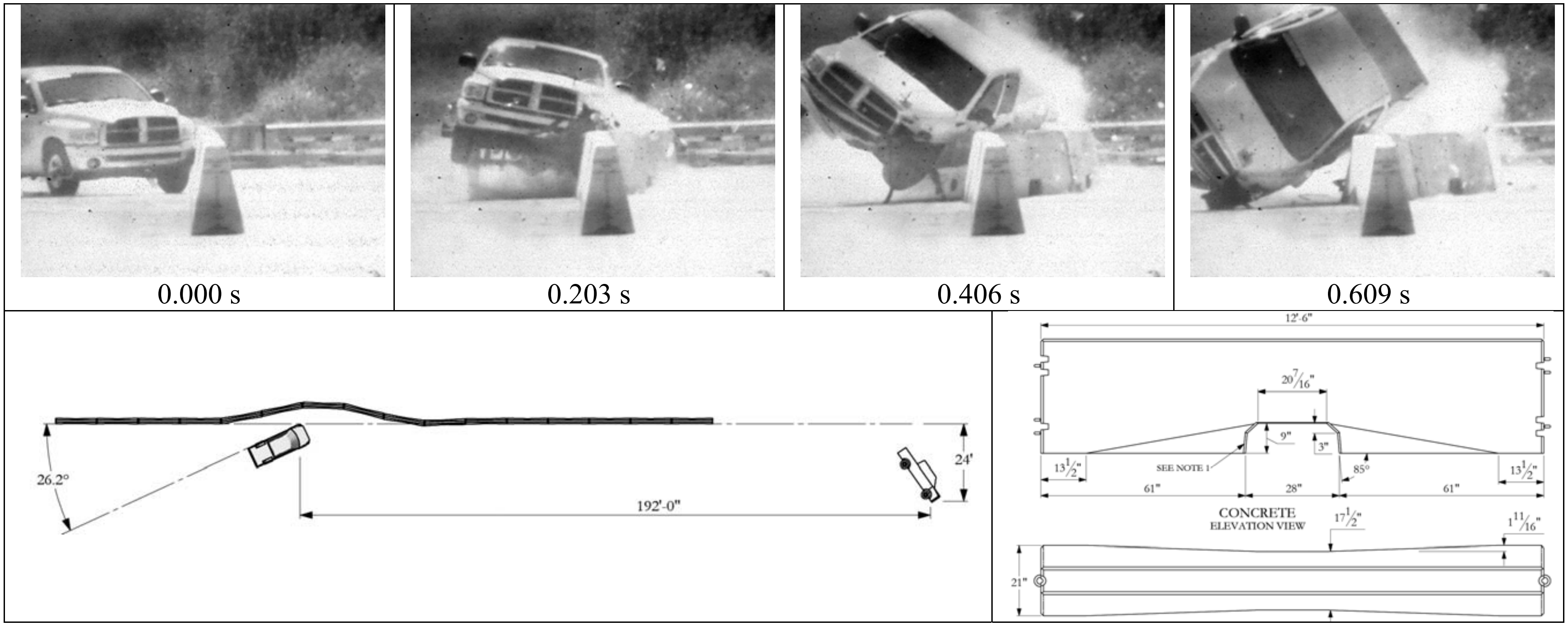
A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.

Results: The Washington DOT pin and loop concrete barrier with drainage slots 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 4.9 ft. (PASS)

7.8.2 Occupant Risk

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

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



General Information
- Test Agency .... Texas Transportation Institute
- MASH Test No. .... *MASH* Test 3-11
- TTI Test No. 405160-18-1
- Date 2010-02-24

Test Article
- Type .... Portable Concrete Median Barrier
- Name .... Washington DOT pin and loop concrete barrier with drainage slots
- Installation Length .... 16 units @ 12.5 ft = 200 ft
- Material or Key Elements .... Reinforced concrete single slope with pin and loop connections

Soil Type and Condition .... Placed on concrete surface, dry

Test Vehicle
- Type/Designation 2270P
- Make and Model .... 2004 Dodge Ram 1500 Quad-Cab Pickup
- Curb .... 4825 lb
- Test Inertial .... 4951 lb
- Dummy .... No dummy
- Gross Static .... 4951 lb

Impact Conditions
- Speed .... 60.2 mi/h
- Angle .... 26.2 degrees
- Location/Orientation ....

Exit Conditions
- Speed .... Out of View
- Angle .... Out of View

Occupant Risk Values
- Impact Velocity
  - Longitudinal .... 14.8 ft/s
  - Lateral .... 20.0 ft/s
- Ridedown Accelerations
  - Longitudinal .... -6.6 Gs
  - Lateral .... 11.7 Gs
- THIV .... 26.2 km/h
- PHD .... 11.8 Gs

Max. 0.050-s Average
- Longitudinal .... -7.7 Gs
- Lateral .... 10.9 Gs
- Vertical .... 5.3 Gs

Post-Impact Trajectory
- Stopping Distance .... 192 ft dwnstream, 18 ft twd traffic

Vehicle Stability
- Maximum Yaw Angle .... 107 degrees
- Maximum Pitch Angle .... -22 degrees
- Maximum Roll Angle .... -931 degrees
- Vehicle Snagging .... No
- Vehicle Pocketing .... No

Test Article Deflections
- Dynamic .... 4.9 ft
- Permanent .... 4.9 ft
- Working Width .... 5.1 ft

Vehicle Damage
- VDS 11LFQ3
- CDC 11FLEW4
- Max. Exterior Deformation .... 10.5 inches
- Max. Occupant Compartment Deformation .... 13.25 inches

Figure 7.6. Summary of results for *MASH* test 3-11 on the Washington DOT pin and loop concrete barrier with drainage slots.

Results: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment or to present undue hazard to others in the area. (PASS)
Maximum occupant compartment deformation was 13.25 inches in the left rear passenger roof area. (FAIL)

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 rolled 2-3/4 revolutions after exiting the barrier. (FAIL)

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 14.8 ft/s, and lateral occupant impact velocity was 20.0 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: Maximum longitudinal ridedeown acceleration was -6.6 Gs, and lateral ridedown acceleration was 11.7 Gs. (PASS)

7.8.3 Vehicle Trajectory

For redirective devices, the vehicle shall exit the barrier within the exit box.

Result: The vehicle exited the barrier within the exit box. (PASS)

8. SUMMARY AND CONCLUSIONS

8.1 SUMMARY OF RESULTS

The Washington DOT pin and loop concrete barrier with drainage slots 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 4.9 ft. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment or to present undue hazard to others in the area. Maximum occupant compartment deformation was 13.25 inches in the left rear passenger roof area, due to rollover. The 2270P vehicle rolled 2-3/4 revolutions after exiting the barrier. Occupant risk factors were within the preferred limits of *MASH*. The vehicle exited the barrier within the exit box.

8.2 CONCLUSIONS

The Washington Pin and Loop Barrier system tested for this project consisted of precast concrete barrier segments that were 12 ft-6 inch in length and 34 inches in height. The barrier segment was 8 inches wide at the top and 21 inches wide at the base with a uniform single slope surface on each side face of the barrier. The barrier was constructed with a 4-inch high by 15-inch wide "V" shaped drainage slot that was continuous along the entire length of the barrier segment. In addition to this longitudinal drainage slot, a transverse drainage scupper opening was constructed at the center of the barrier segment. The drainage scupper opening was 9 inches high by 28 inches in width. Based on the results from the crash test, these drainage slots and scupper opening did not appear in any way to adversely affect the crash performance of the barrier system. Soon after impact, the vehicle rolled over as it was being redirected and exiting away from the barrier system. Due to rollover and the occupant compartment deformation caused by the rollover, the Washington DOT pin and loop concrete barrier with drainage slots and scupper opening did not perform acceptably according to the evaluation criteria for *MASH* test 3-11, as shown in Table 8.1.

Table 8.1. Performance evaluation summary for *MASH* test 3-11 on the Washington DOT pin and loop concrete barrier with drainage slots.

Test Agency: Texas Transportation Institute	Test No.: 405160-18-1	Test Date: 2010-02-24
***MASH* 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 Washington DOT pin and loop concrete barrier with drainage slots 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 4.9 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.*	Maximum dynamic deflection of the barrier during the test was 4.9 ft. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment or to present undue 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 13.25 inches in the left rear passenger roof area due to rollover.	Fail
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 rolled 3 revolutions after exiting the barrier.	Fail
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 9.1 m/s (30 ft/s), or at least below the maximum allowable value of 12.2 m/s (40 ft/s).*	Longitudinal occupant impact velocity was 14.8 ft/s, and lateral occupant impact velocity was 20.0 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.*	Maximum longitudinal ridedeown acceleration was -6.6 Gs, and lateral ridedown acceleration was 11.7 Gs.	Pass
Vehicle Trajectory		
The vehicle shall exit the barrier within the exit box.	The vehicle exited the barrier within the exit box.	Pass

REFERENCES

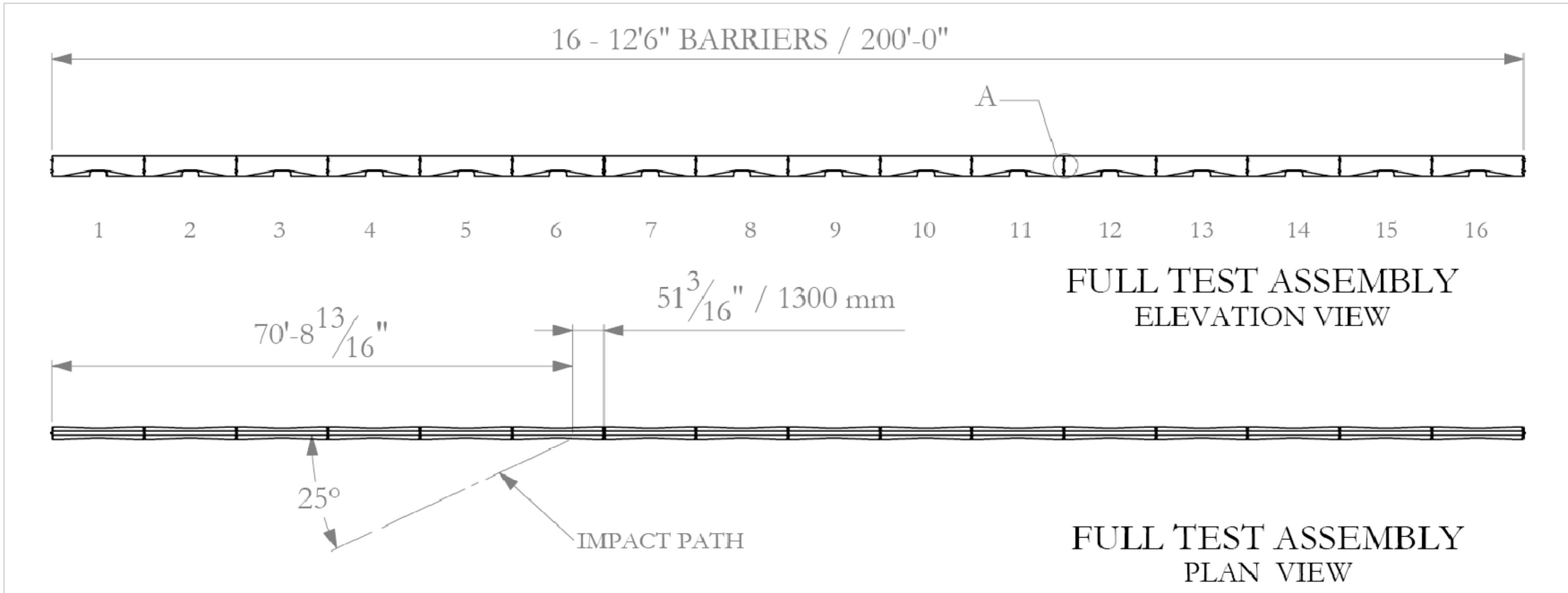
1. Ross, Jr., H.E., Sicking, D.L., Zimmer, R.A. and Michie, J.D., "Recommended Procedures for the Safety Performance Evaluation of Highway Features," National Cooperative Highway Research Program *Report 350*, Transportation Research Board, National Research Council, Washington, D.C., 1993.

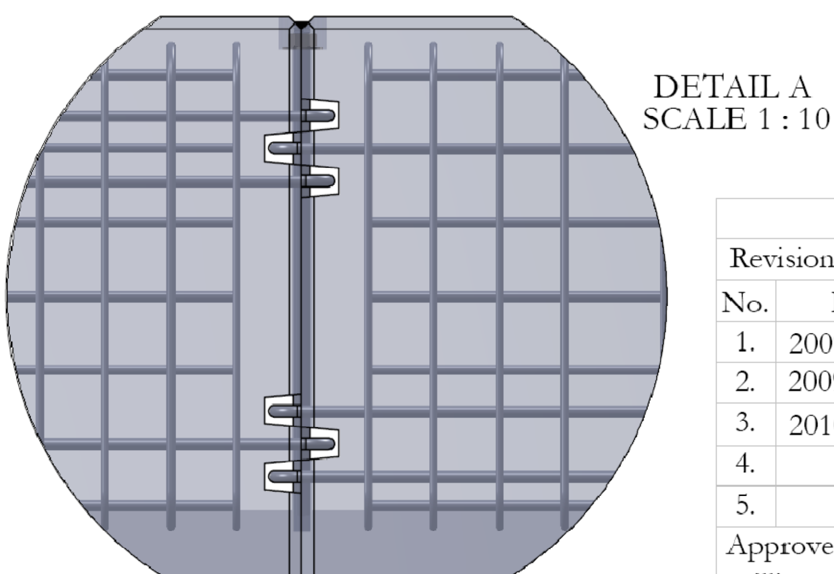
2. American Association of State Highway and Transportation Officials (AASHTO), *Manual for Assessing Safety Hardware*, Washington, D.C., 2009.

3. American Association of State Highway and Transportation Officials (AASHTO), " LRFD Bridge Design Specifications," Washington, DC, 2008.

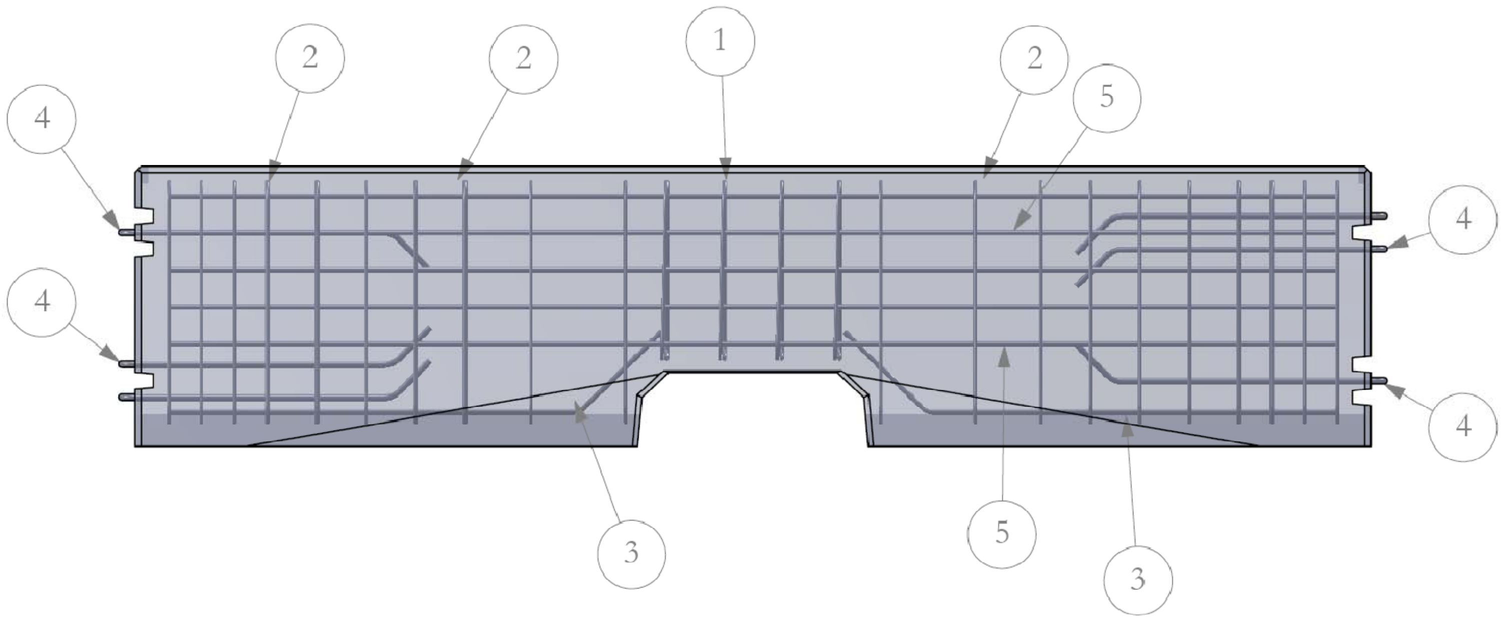
APPENDIX A. DETAILS OF TEST ARTICLE

T:\2009-2010\405160 Pooled Fund\405160-18-Washington Pin and Loop Barrier\SolidWorks\Drawings\Barrier





The Texas A&M University System							
Revisions:				Texas Transportation Institute College Station, Texas, 77843			
No.	Date	By	Chk				
1.	2009-12-07	GES	WW	Date	Drawn By	Scale	Sheet No.
2.	2009-12-18	GES	WW	2009-08-20	GES	1:250	1 of 8
3.	2010-02-08	GES	WW	Project No.	200' Installation		
4.				405160-18-1			
5.				Wash DOT Pin and Loop Barriers			
Approved: William Williams:				Signature:		Date: 2010-02-08	



#	PART	QTY.
1	Rebar Stirrup, #4 center	4
2	Rebar Stirrup, #4 ends	20
3	Rebar, #5 Bent	4
4	End Loop, A36 3/4" Rod	6
5	Rebar, #5 - 11' 10 1/2"	10
6	Concrete, tapered scupper	1

1. ALL REBAR IS GRADE 60.
2. CONCRETE STRENGTH - 4000 PSI.
3. BENT REBAR DETAILED ON PAGE 7.

The Texas A&M University System

Texas Transportation Institute
College Station, Texas, 77843

Revisions:

No.	Date	By	Chk
1.	2009-10-28	GES	WW
2.			
3.			
4.			
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Date	Drawn By	Scale	Sheet No.
2009-08-20	GES	1:20	2 of 8

Project No. 405160-18-1

Parts List

Wash DOT Pin and Loop Barriers

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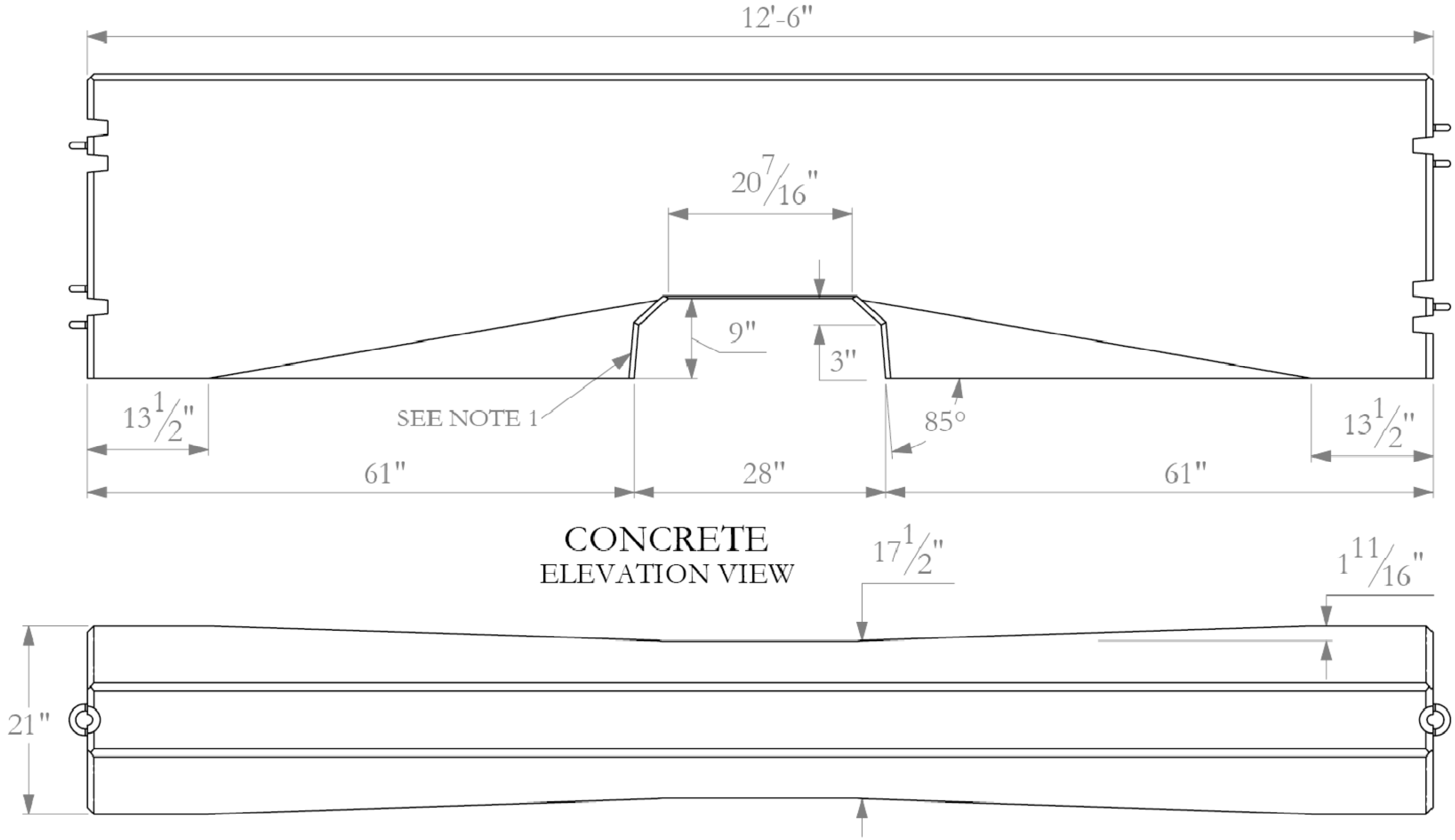
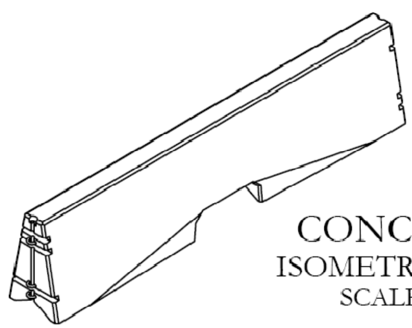


CONCRETE
ELEVATION VIEW

CONCRETE
PLAN VIEW



CONCRETE
ISOMETRIC VIEW
SCALE 1:50

1. 3/4" CHAMFER EDGES OF SCUPPER

The Texas A&M University System							
Revisions:				Texas Transportation Institute College Station, Texas, 77843			
No.	Date	By	Chk				
1.	2009-10-13	GES	WW	Date	Drawn By	Scale	Sheet No.
2.	2009-12-18	GES	WW	2009-08-20	GES	1:17	3 of 8
3.				Project No.	Concrete		
4.				405160-18-1			
5.				Wash DOT Pin and Loop Barriers			

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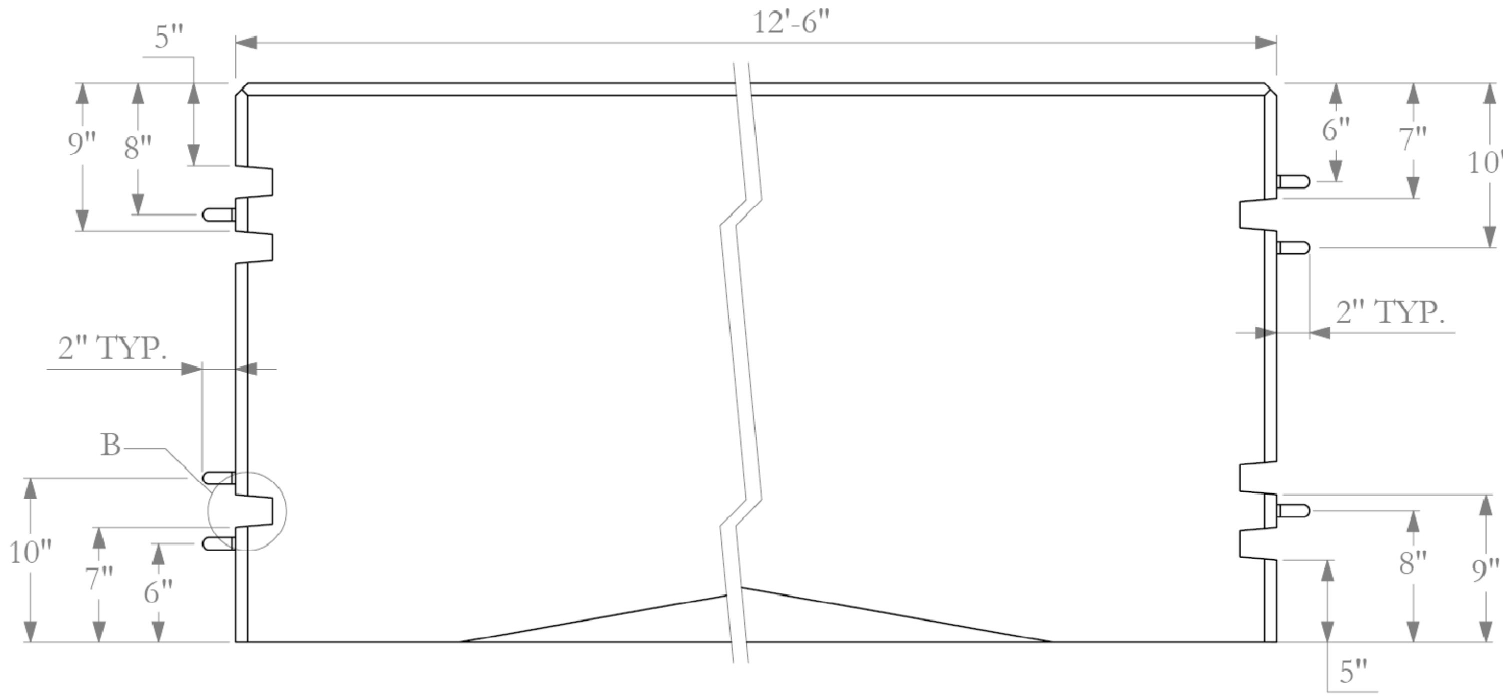

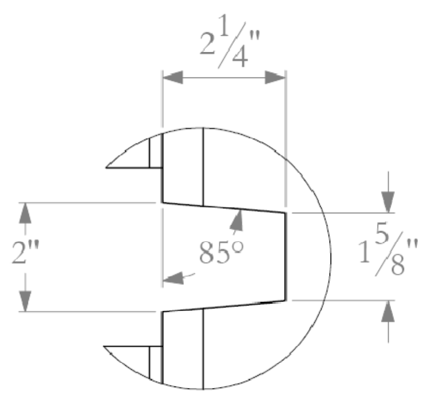

DETAIL B
SCALE 1 : 3
TYPICAL 6 SLOTS

The Texas A&M University System							
Revisions:				Texas Transportation Institute College Station, Texas, 77843			
No.	Date	By	Chk				
1.				Date	Drawn By	Scale	Sheet No.
2.				2009-08-20	GES	1:10	4 of 8
3.				Project No.	Loops		
4.				405160-18-1			
5.				Wash DOT Pin and Loop Barriers			

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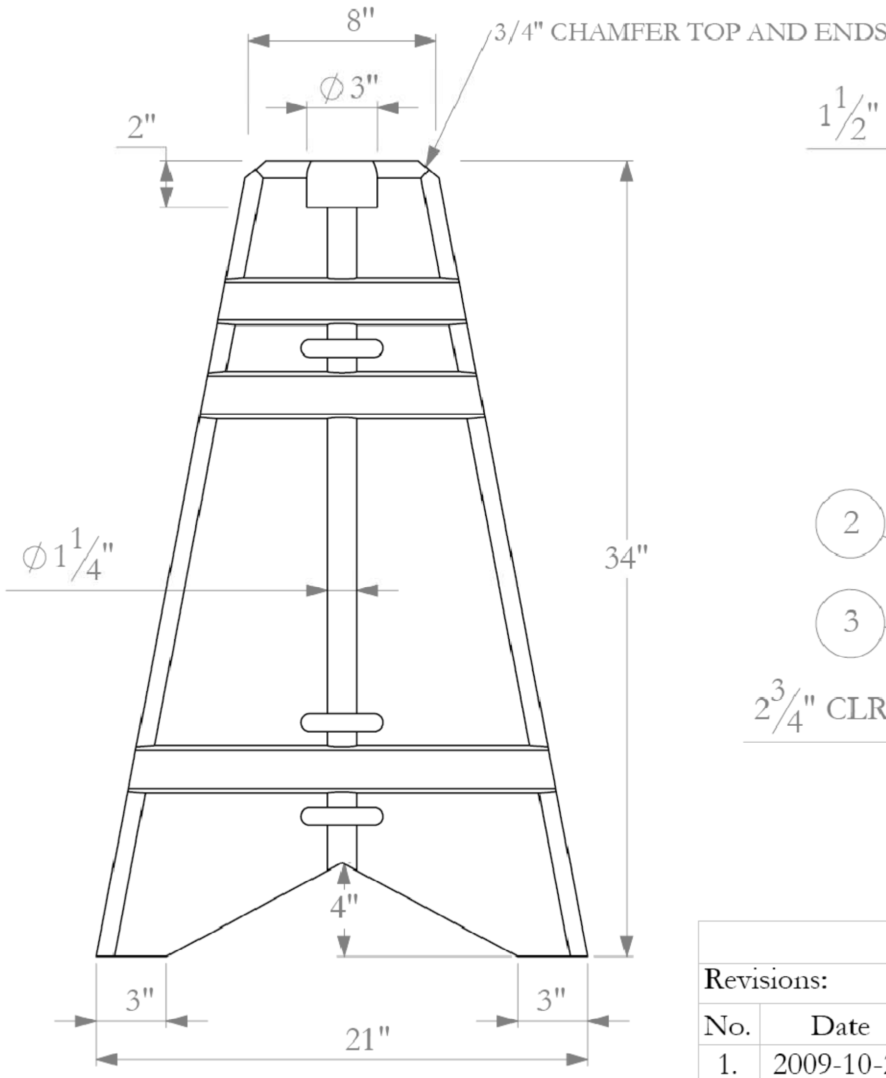
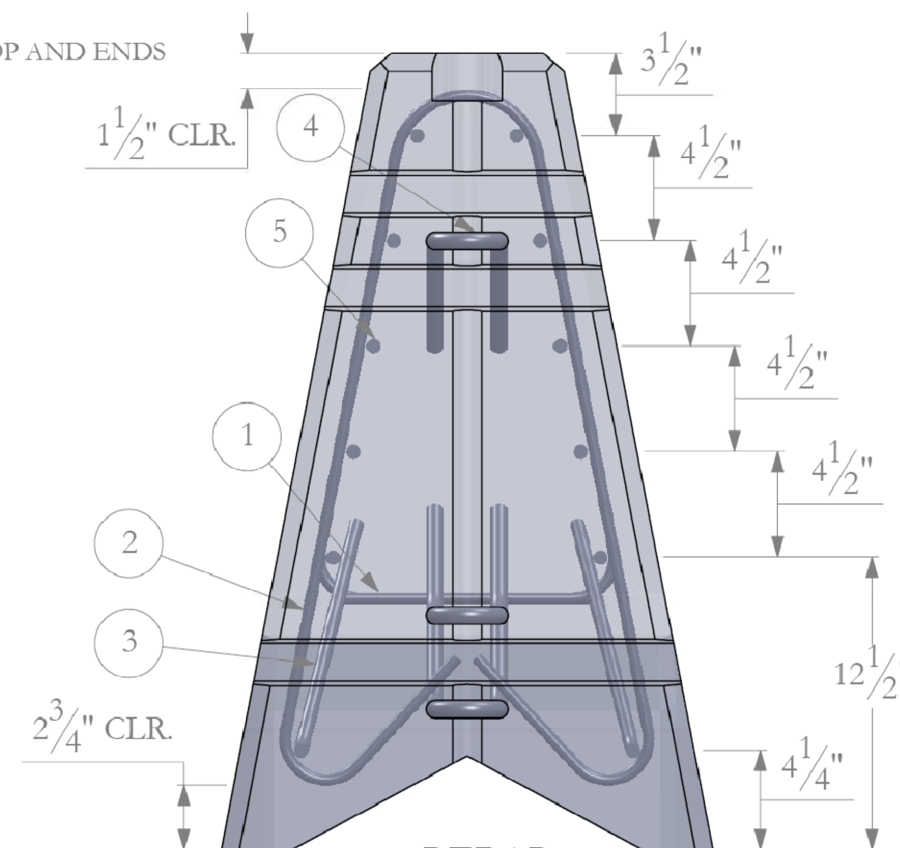


CONCRETE
ELEVATION VIEW - END



REBAR
ELEVATION VIEW - END

The Texas A&M University System							
Revisions:				Texas Transportation Institute College Station, Texas, 77843			
No.	Date	By	Chk				
1.	2009-10-22	GES	WW	Date	Drawn By	Scale	Sheet No.
2.				2009-08-20	GES	1:7	5 of 8
3.				Project No.	End Views		
4.				405160-18-1			
5.				Wash DOT Pin and Loop Barriers			

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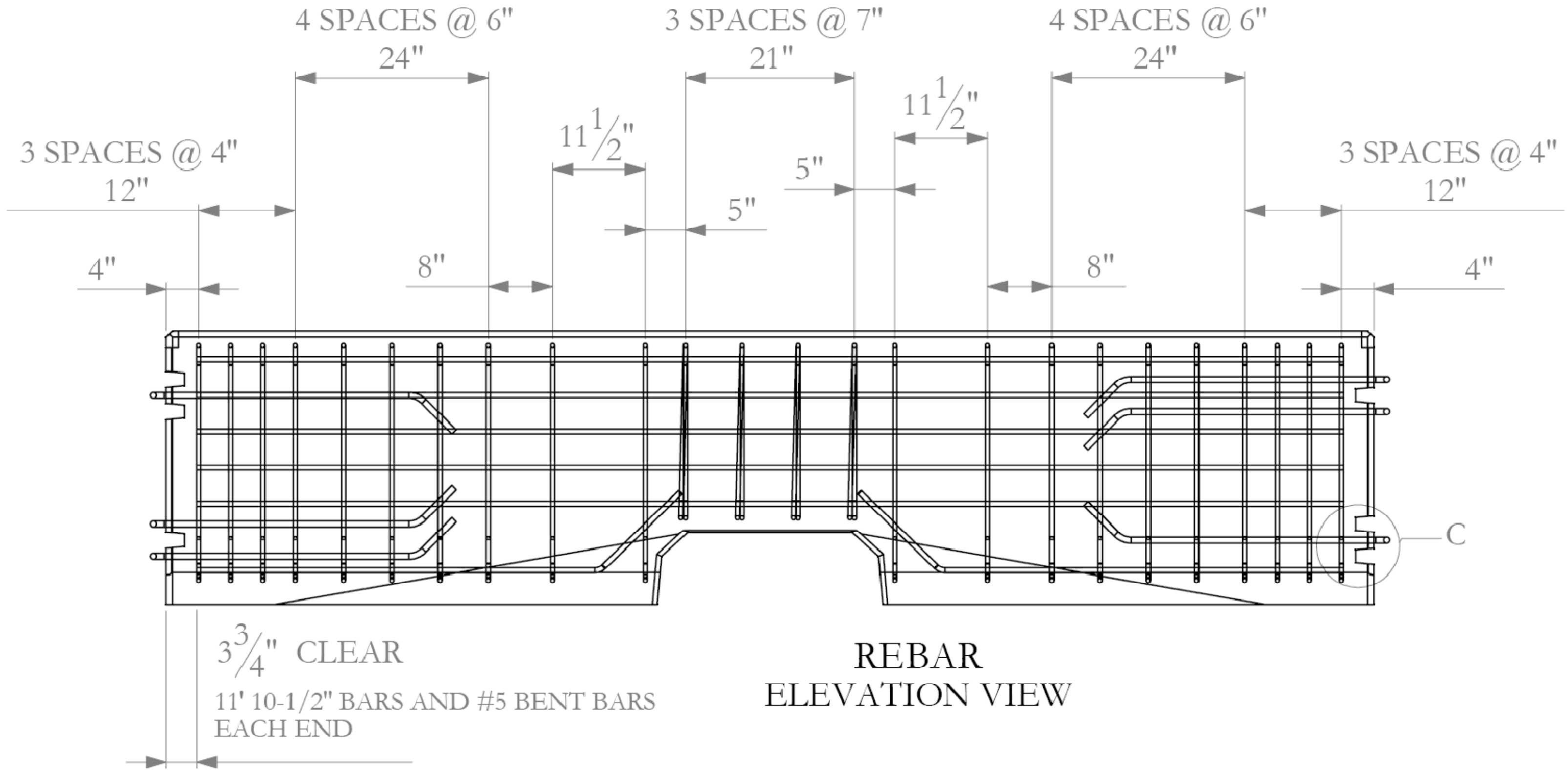
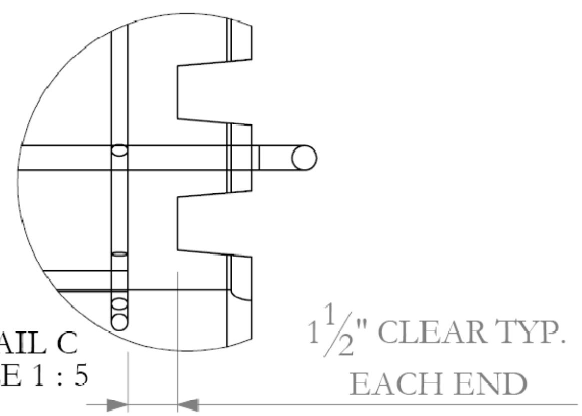


REBAR
ELEVATION VIEW



DETAIL C
SCALE 1 : 5

*ALL DIMENSIONS FOR REBAR AND STIRRUPS ARE TO CENTERLINE UNLESS OTHERWISE NOTED.

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Revisions:			
No.	Date	By	Chk
1.	2009-10-28	GES	WW
2.			
3.			
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Date	Drawn By	Scale	Sheet No.
2009-08-20	GES	1:20	6 of 8

Project No.	Rebar - Elevation
405160-18-1	

Wash DOT Pin and Loop Barriers

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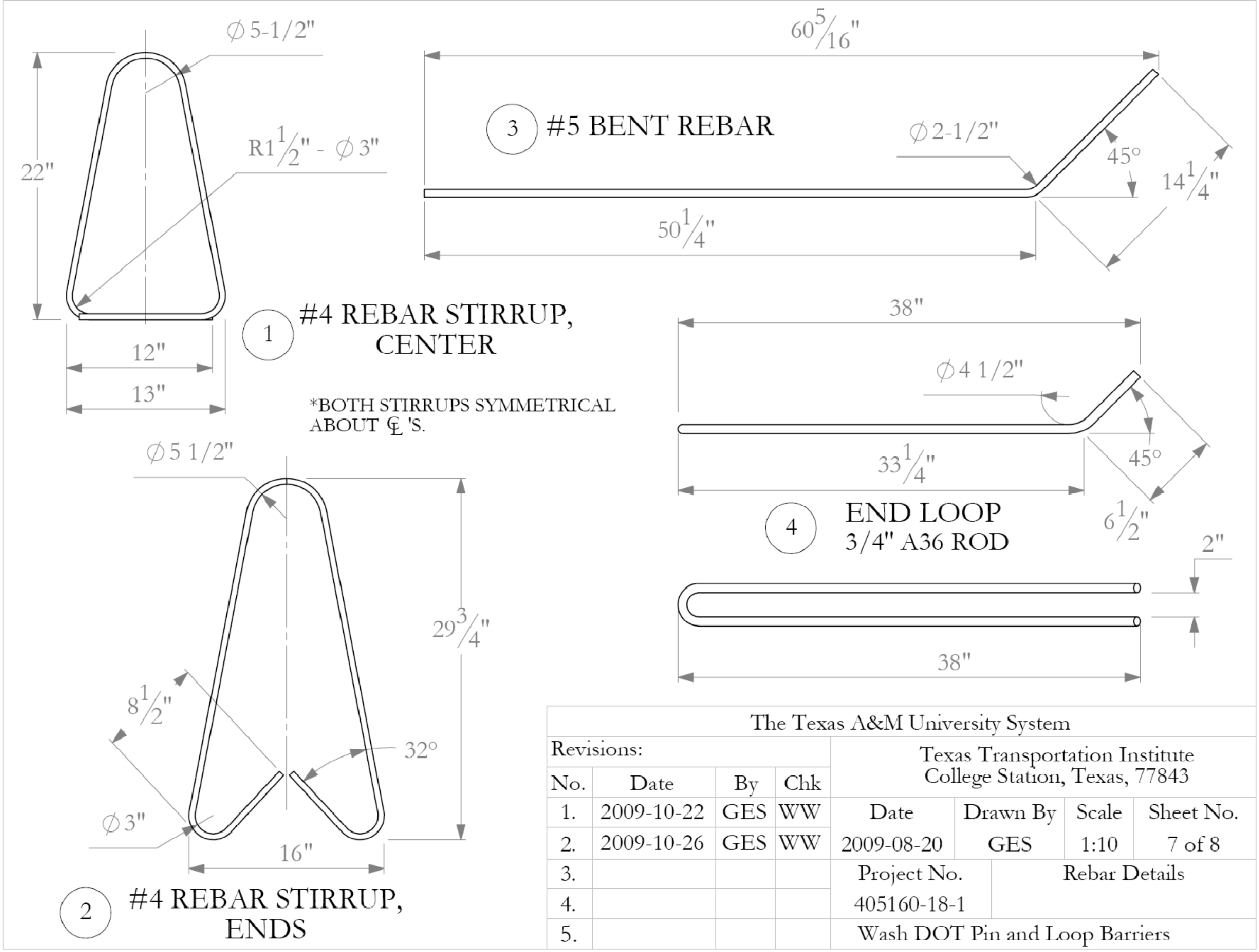
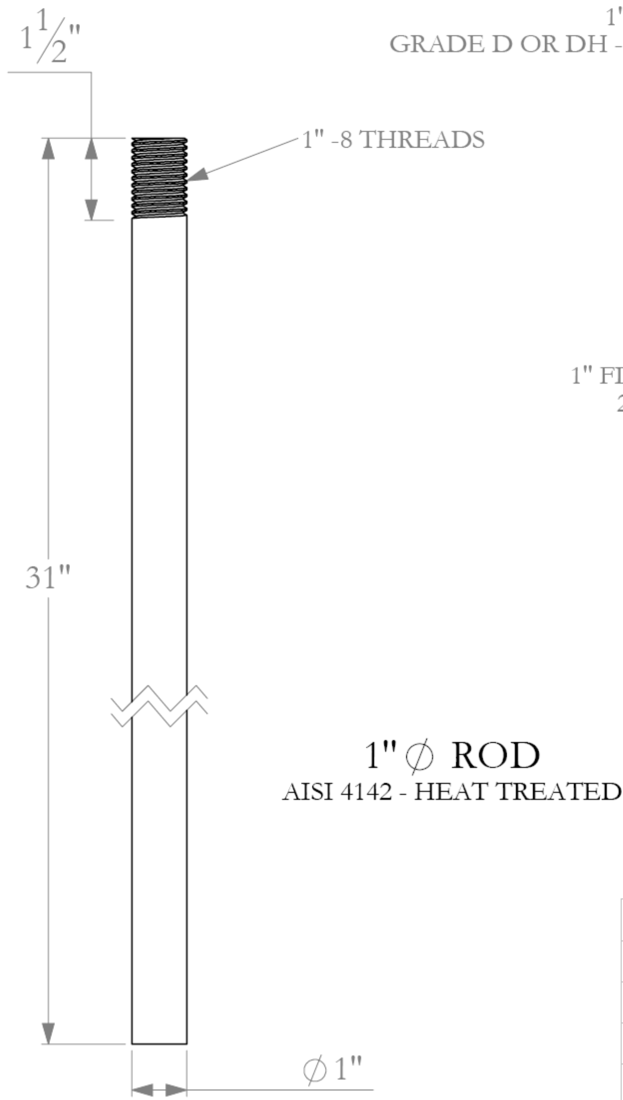
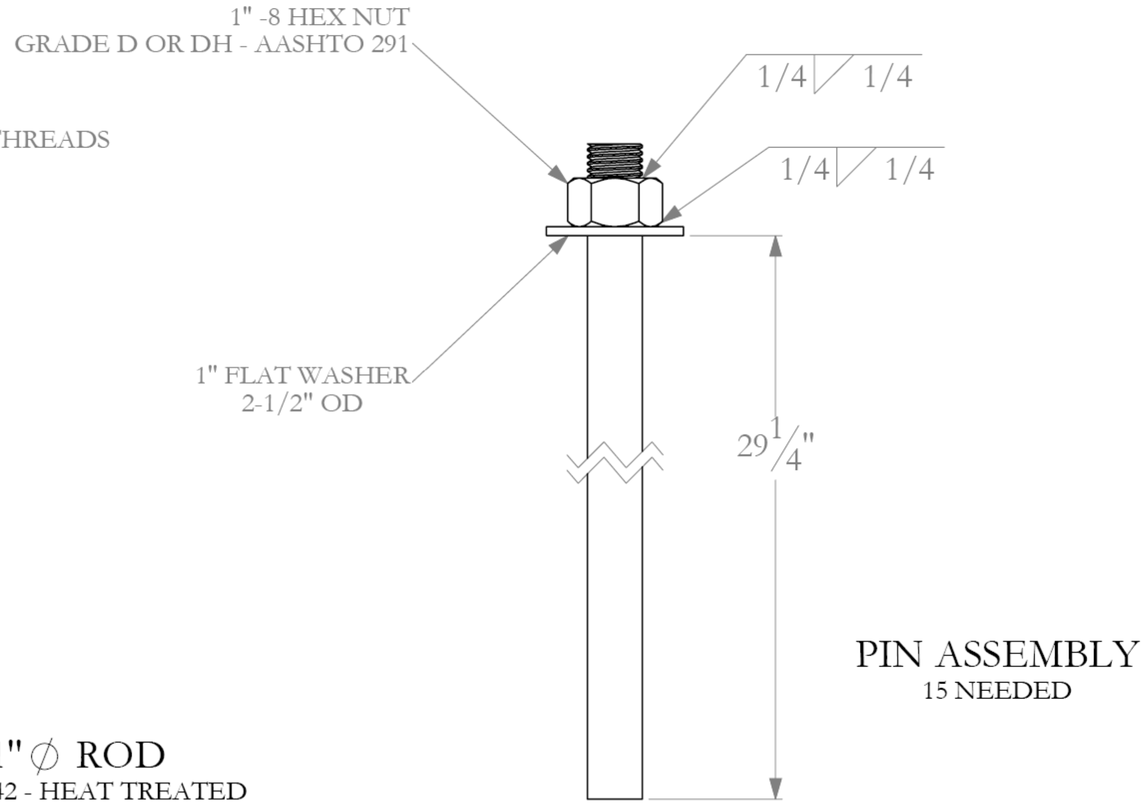


The Texas A&M University System							
Revisions:				Texas Transportation Institute College Station, Texas, 77843			
No.	Date	By	Chk				
1.	2009-10-22	GES	WW	Date	Drawn By	Scale	Sheet No.
2.	2009-10-26	GES	WW	2009-08-20	GES	1:10	7 of 8
3.				Project No.	Rebar Details		
4.				405160-18-1			
5.				Wash DOT Pin and Loop Barriers			

T:\2009-2010\405160\405160 Pooled Fund\405160-18-Washington Pin and Loop Barrier\SolidWorks\Drawings\Barrier





The Texas A&M University System							
Revisions:				Texas Transportation Institute College Station, Texas, 77843			
No.	Date	By	Chk				
1.	2009-10-22	GES	WW	Date	Drawn By	Scale	Sheet No.
2.	2010-02-08	GES	WW	2009-08-20	GES	1:3	8 of 8
3.				Project No.	Pins		
4.				405160-18-1			
5.				Wash DOT Pin and Loop Barriers			

APPENDIX B. SUPPORTING CERTIFICATION DOCMENTS

MATERIAL USED

TEST NUMBER 405160-18-1 WashDOT CMB's

DATE 2010-02-24

DATE RECEIVED	ITEM NUMBER	DESCRIPTION	SUPPLIER	HEAT #
2009-11-05	Nut 1"-1	1" -8 heavy hex	Mack	U890846
2009-11-05	Rod 1"-1	1" x 31" 105ASTM F1554	Mack	M32658
2009-11-05	Washer 1"-1	F436 Structural	Mack	
2009-10-06	Rebar 04-10	1/2" x 20' grd 60	CMC-SHEPLERS	3011717
2009 10 06	Rebar 05 8	5/8" x 20' grd 60	CMC SHEPLERS	301190
2009-10-16	Round Stock .75-1	3/4" x 20' A36 cold roll - RED	Mack	JK090099201

B&G Manufacturing Co, Inc EEO/AA
3067 Unionville Pike, P.O. Box 904, Hatfield, PA 19440-0904
General Telephone: 215-822-1925

B&G Manufacturing Company

Customer:
Mack Bolt, Steel & Machine
5875 Hwy 21 E
Bryan TX 77808

Quality certificate

Date
01/30/2009
Purchase order item/date
16241 / 01/30/2009

Delivery item/date
80404001 000010 / 01/30/2009
Order item/date
288370 000020 / 01/30/2009
Page 1 of 1

We certify that the material or fasteners supplied were manufactured, sampled, tested and inspected in accordance with the specification and other requirements designated in the purchase order and was found to meet those requirements. While in our possession, the material did not come in contact with mercury.

Material Number : 3762
Batch 0000258745 / Quantity 500 EA
Heat Number: U890846
Specification / Description
HVY HEX NUTS ASTM A194 GR. 2H
1.000-8

Characteristic	Unit	Value
Specifications	-	ASTM-A194-06A GR.2H
Heat Number	-	U890846
Carbon Content	%	0.4200
Chromium Content	%	0.1700
Copper Content	%	0.1100
Manganese Content	%	0.6500
Nickel Content	%	0.0600
Phosphorus Content	%	0.0130
Silicon Content	%	0.1700
Sulfur Content	%	0.0130
Hardness Test 24 Hour-RB		104
Hardness RC		31
Proof Load	lbf	106000
Tempering Temperature	°F	968
Macro Etch Testing	-	Pass - -
Condition	-	Quenched and Tempered -
-		

If you have any questions concerning this document, please contact our customer service dept at 215-996-3301.

B&G Manufacturing Co. Inc. By: Teresa Williams
Certification Service Specialist

CERTIFICATE OF TEST

Certification Date
4-JAN-2010

CUSTOMER ORDER NUMBER
17860

CUSTOMER PART NUMBER

EARLE M. JORGENSEN COMPANY
6201 LUMBERDALE
HOUSTON TX 77092

Invoice Number
T706811

SOLD TO: MACK BOLT & STEEL

SHIP TO: MACK BOLT & STEEL
CODCO CHECK**COD**COD**COD**C

Description: 4142 CF HEAT TREATED S/R OR STRESS FREE BAR
1 RD X 12' R/L Line Total: 24 FT
HEAT: M32658 ITEM: 506038

Specifications:
ASTM A434 CL BC 06 ASTM A193 GR B7 08

CHEMICAL ANALYSIS

C	MN	P	S	SI	NI	CR	MO
0.42	0.9	0.011	0.031	0.23	0.11	0.94	0.18
CU	SN	AL	V	NB			
0.2	0.017	0.022	0.006	0.002			
C	MN	P	S	SI	NI	CR	MO
0.42	0.9	0.011	0.031	0.23	0.11	0.94	0.18
CU	SN	AL	V	NB			
0.2	0.017	0.022	0.006	0.002			

RCPT: R796943
MILL : GERDAU MACSTEEL (CF ALLOY) COUNTRY OF ORIGIN : USA

MECHANICAL PROPERTIES

DESCRIPTION	YLD STR KSI	ULT TEN KSI	%ELONG IN 02 IN	%RED IN AREA	HARDNESS BHN
	134.0	144.0	34.9	56.0	301

IDEAL DIAMETER : 5.26 IN GRAIN SIZE :5 -

MICHAEL ROSCH

The above data were transcribed from the manufacturer's Certificate of Test after verification for completeness and specification requirements of the information on the certificate. All test results remain on file subject to examination.

We hereby certify that the material covered by this report will meet the applicable requirements described herein, including any specification forming a part of the description.

The willful recording of false, fictitious, or fraudulent statements in connection with test results may be punishable as a felony under federal statutes.

Material did not come in contact with mercury while in our possession.

MANAGER, QUALITY ASSURANCE

CERTIFICATE OF TEST

Certification Date
4-JAN-2010

17860
CUSTOMER ORDER NUMBER

EARLE M. JORGENSEN COMPANY
6201 LUMBERDALE
HOUSTON TX 77092

Invoice Number
T706811

CUSTOMER PART NUMBER

MACK BOLT & STEEL

MACK BOLT & STEEL
CODCO CHECK**COD**COD**COD**C

SOLD TO:

SHIP TO:

Description: 4142 CF HEAT TREATED S/R OR STRESS FREE BAR
1 RD X 12' R/L
Line Total: 24 FT
HEAT: M32658
ITEM: 506038

VACUUM DEGASSED MATERIAL IS FREE FROM MERCURY CONTAMINATION
NO WELD REPAIR PERFORMED ON MATERIAL
THERMAL TREATMENT: OK
AUST TEMP 1650 TIME .70
QUENCH 0
TEMPER TEMP 1400 TIME .70
MACRO: OK

COMMENTS
RED RATIO 42.1 TO 1.0
ACCEPTED FOR 1E0360 PN 6D-5664 PER JPW 8-31-09
ACCEPTED FOR 1E0509 PN 299-5231 M/P PER EM 10-13-09

MICHAEL BOSCH

The above data were transcribed from the manufacturer's Certificate of Test after verification for completeness and specification requirements of the information on the certificate. All test results remain on file subject to examination.

We hereby certify that the material covered by this report will meet the applicable requirements described herein, including any specification forming a part of the description.

The willful recording of false, fictitious, or fraudulent statements in connection with test results may be punishable as a felony under federal statutes.

Material did not come in contact with mercury while in our possession.

[signature]

MANAGER, QUALITY ASSURANCE

45

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

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

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

Daniel J. Schacht

Quality Assurance Manager

HEAT NO.:3011190 SECTION: REBAR 16MM (#5) 20'0" 420/60 GRADE: ASTM A615-08b Gr 420/60 ROLL DATE: 08/08/2009 MELT DATE: 08/08/2009	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 80174241 BOL#: 70054471 CUST PO#: 12432-T CUST P/N: DLVRY LBS / HEAT: 21900.000 LB DLVRY PCS / HEAT: 1050 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.39%				
Mn	0.99%				
P	0.012%				
S	0.027%				
Si	0.26%				
Cu	0.26%				
Cr	0.22%				
Ni	0.16%				
Mo	0.060%				
V	0.002%				
Cb	0.001%				
Sn	0.012%				
Al	0.004%				
Yield Strength test 1	69.3ksi				
Tensile Strength test 1	106.3ksi				
Elongation test 1	14%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	2.188IN				
Bend Test	Passed				

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

EMARKS :

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

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

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

Daniel J. Schacht
Quality Assurance Manager

HEAT NO.:3011717 SECTION: REBAR 13MM (#4) 20'0" 420/60 GRADE: ASTM A615-08b Gr 420/60 ROLL DATE: 09/03/2009 MELT DATE: 09/02/2009	S O L D T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	S H I P T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 80185205 BOL#: 70058133 CUST PO#: 2432-FF CUST P/N: DLVRY LBS / HEAT: 28483.000 LB DLVRY PCS / HEAT: 2132 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.40%				
Mn	0.72%				
P	0.011%				
S	0.038%				
Si	0.19%				
Cu	0.32%				
Cr	0.20%				
Ni	0.21%				
Mo	0.093%				
V	0.002%				
Cb	0.005%				
Sn	0.012%				
Al	0.002%				
Yield Strength test 1	65.5ksi				
Tensile Strength test 1	101.4ksi				
Elongation test 1	14%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	1.750IN				
Bend Test	Passed				

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

REMARKS :

09/03/2009 15:23:46

47

Page: 1

SOLD TO:

NUCOR

BAR MILL GROUP
NUCOR STEEL JACKSON, INC.

CERTIFIED MILL TEST REPORT

Ship from:
Nucor Steel Jackson, Inc.
3630 Fourth Street
Flowood, MS 39232
800-723-1623

SHIP TO:

Date: 8-Jul-2009
B.L. Number: 365647
Load Number: 94478

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

NBMG-08 March 21, 2009

HEAT NUM.	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# =>	HOU-129269*												
JK0910099201	Nucor Steel - Jackson Inc	44,761	69,190	26.3%			.15	.69	.007	.040	.21	.32	.31
	3/4" Rd 20'	309MPa	477MPa				.10	.06	.013	.001	.002		
	A36	45,973	68,280	25.0%									
	ASTM A^6/A36M-08	317MPa	471MPa										
	ASTM A709/A709M-08 GR 36 [250]												
	ASME SA36-2007 EDITION												
PO# =>	HOU-129269*												
JK0910121001	Nucor Steel - Jackson Inc	58,156	79,260	25.0%			.15	.67	.013	.040	.18	.40	.33
	2x2x1/8" Eq Ang	401MPa	546MPa				.10	.15	.024	.002	.001		
	20' A36	57,583	78,700	25.0%									
	ASTM A36/A36M-08	397MPa	543MPa										
	ASME SA36-2007 EDITION												
PO# =>	HOU-129269*												
JK0910121101	Nucor Steel - Jackson Inc	56,816	79,270	25.0%			.14	.62	.010	.040	.23	.38	.31
	2x2x1/8" Eq Ang	392MPa	547MPa				.11	.13	.027	.002	.003		
	20' A36	51,136	71,160	30.0%									
	ASTM A36/A36M-08	353MPa	491MPa										
	ASME SA36-2007 EDITION												

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

ALL MANUFACTURING PROCESSES OF THE STEEL MATERIALS IN THIS PRODUCT, INCLUDING MELTING, HAVE OCCURRED WITHIN THE UNITED STATES. ALL PRODUCTS PRODUCED ARE WELD FREE [illegible]

QUALITY ASSURANCE: Curtis Taft

Curtis Taft

Texas Transportation Institute Proving Ground 3100 SH 47, Bldg 7091 Bryan, TX 77807 Texas A&M University College Station, TX 77843 Phone 979-845-6375	5.7.2 Concrete Break	Doc. No. *5_7_2_Concrete_Break.doc*	Revision Date: 2010-02-12
Subject: **Quality Policy Form**	Revised by: W. L. Menges Approved by: C. E. Buth	Revision: 4	Page: 1 of 1

Project No.: 405160-18-1

Casting Date: 2010-02-15

Placement: BARRIERS

Mix Design P.S.I.: 4000

Truck No.	Batch Ticket	Yards

Printed name of Technician taking sample: GLENN SCHROEDER

Signature of Technician taking sample: Glenn Schroeder

Printed name of Technician breaking sample: GLENN SCHROEDER

Signature of Technician breaking sample: Glenn Schroeder

Break Date	Cylinder Age	Truck No.	Total Load (Pounds)	PSI Break	Average
2010-02-24	9 DAYS		146,000	5164	
			149,500	5288	5335
			157,000	5553	

APPENDIX C. CRASH TEST NO. 405160-18-1

C1. VEHICLE PROPERTIES AND INFORMATION

Date: 2010-02-23 Test No.: 405160-18-1 VIN No.: 1D7HA18N34J149787

Year: 2004 Make: Dodge Model: Ram 1500

Tire Size: 245/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 438834

Note any damage to the vehicle prior to test: ______

● Denotes accelerometer location.

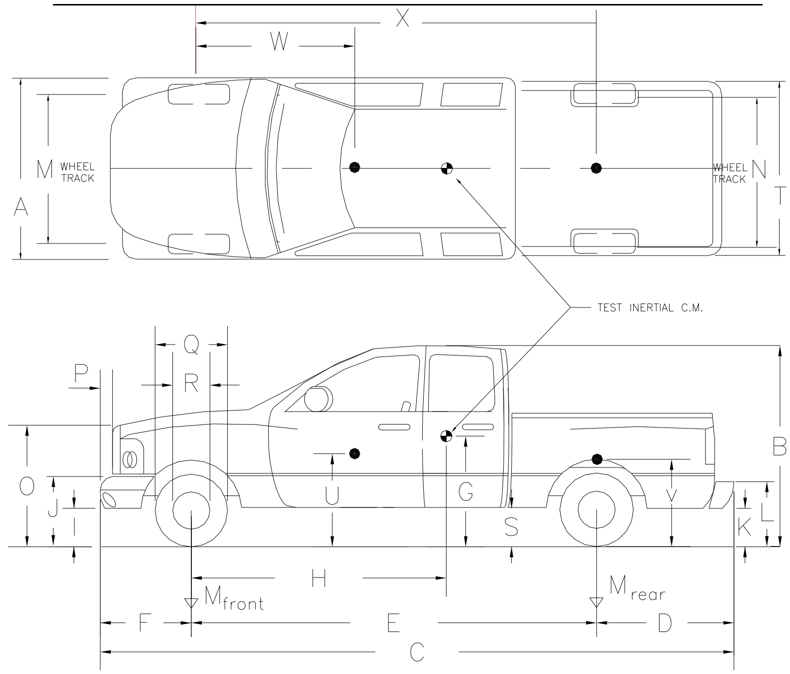
NOTES: ______

Engine Type: V-8
Engine CID: 4.7 liter

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

Optional Equipment: ______

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



Geometry: inches

A	77.00	F	39.00	K	20.50	P	3.00	U	27.50
B	73.25	G	28.50	L	28.75	Q	29.50	V	33.00
C	227.00	H	62.43	M	68.25	R	18.50	W	59.50
D	47.50	I	13.50	N	67.25	S	14.25	X	140.50
E	140.50	J	26.00	O	44.75	T	75.50		

Wheel Center Ht Front	14.125	Wheel Well Clearance (FR)	6.125	Frame Ht (FR)	16.625
Wheel Center Ht Rear	14.25	Wheel Well Clearance (RR)	11.25	Frame Ht (RR)	24.25

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial		Gross Static	
Front	3650	M_{front}	2708	2751	Allowable		Allowable
Back	3900	M_{rear}	2117	2200	Range		Range
Total	6650	M_{Total}	4825	4951	5000 ±110 lb		5000 ±110 lb

Mass Distribution:
lb LF: 1385 RF: 1366 LR: 1098 RR: 1102

Figure C1. Vehicle properties for test 405160-18-1.

Table C1. Measurements of vehicle vertical CG for test 405160-18-1.

Date: 2010-02-23 Test No.: 405160-18-1 VIN: 1D7HA18N34J149787

Year: 2004 Make: Dodge Model: Ram 1500

Body Style: Quad-Cab Mileage: 438834

Engine: 4.7 liter Transmission: Automatic

Fuel Level: empty Ballast: 241 lb at front of bed (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 245/70R17

Measured Vehicle Weights: (lb)

LF:	1392	RF:	1375	Front Axle:	2767
LR:	1083	RR:	1112	Rear Axle:	2195
Left:	2475	Right:	2487	Total:	4962

5000 ±110 lb allowed

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

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

Center of Gravity, SAE J874 Suspension Method

X: 62.15 in Rear of Front Axle (63 ±4 inches allowed)

Y: 0.08 in Left - Right + of Vehicle Centerline

Z: 28.5 in Above Ground (minumum 28.0 inches allowed)

Hood Height: 44.75 inches Front Bumper Height: 26.00 inches

43 ±4 inches allowed

Front Overhang: 39.0 inches Rear Bumper Height: 28.75 inches

39 ±3 inches allowed

Overall Length: 227.0 inches

237 ±13 inches allowed

Table C2. Exterior crush measurements for test 405160-18-1.

Date: 2010-02-23 Test No.: 405160-18-1 VIN No.: 1D7HA18N34J149787

Year: 2004 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	16	10	18	10	5	4	4	3	2	-17
2	Side plane at bumper ht	16	10.5	46	0.5	2.25	4.75	7	8.25	10.5	+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).

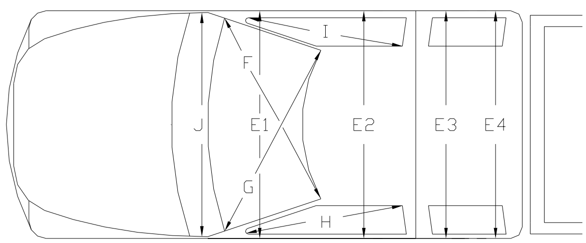
***Measure and document on the vehicle diagram the location of the maximum crush.

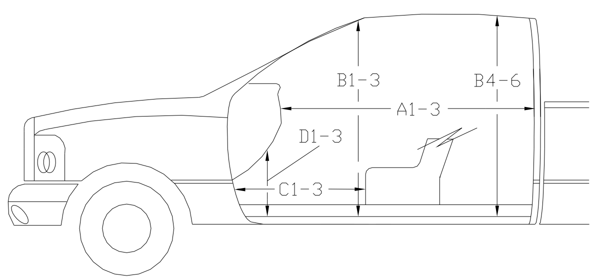
Note: Use as many lines/columns as necessary to describe each damage profile.

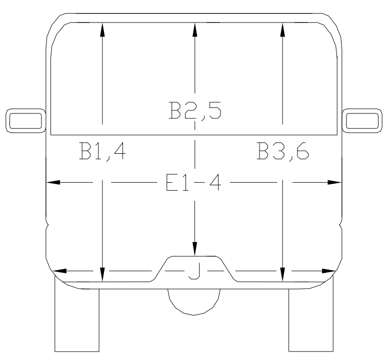
Table C3. Occupant compartment measurements for test 405160-18-1.

Date: 2010-02-23 Test No.: 405160-18-1 VIN No.: 1D7HA18N34J149787

Year: 2004 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	64.50	64.25
A2	64.75	64.25
A3	65.25	65.00
B1	45.25	45.75
B2	39.12	42.50
B3	45.25	40.25
B4	42.12	28.50
B5	42.50	39.25
B6	42.12	42.00
C1	29.5	-----
C2	-----	-----
C3	27.25	-----
D1	12.75	12.00
D2	2.50	-----
D3	11.50	11.25
E1	65.00	NA
E2	64.50	NA
E3	64.25	65.75
E4	64.25	66.00
F	60.00	57.12
G	60.00	53.25
H	39.50	NA
I	39.50	37.00
J*	62.00	-----

C2. SEQUENTIAL PHOTOGRAPHS

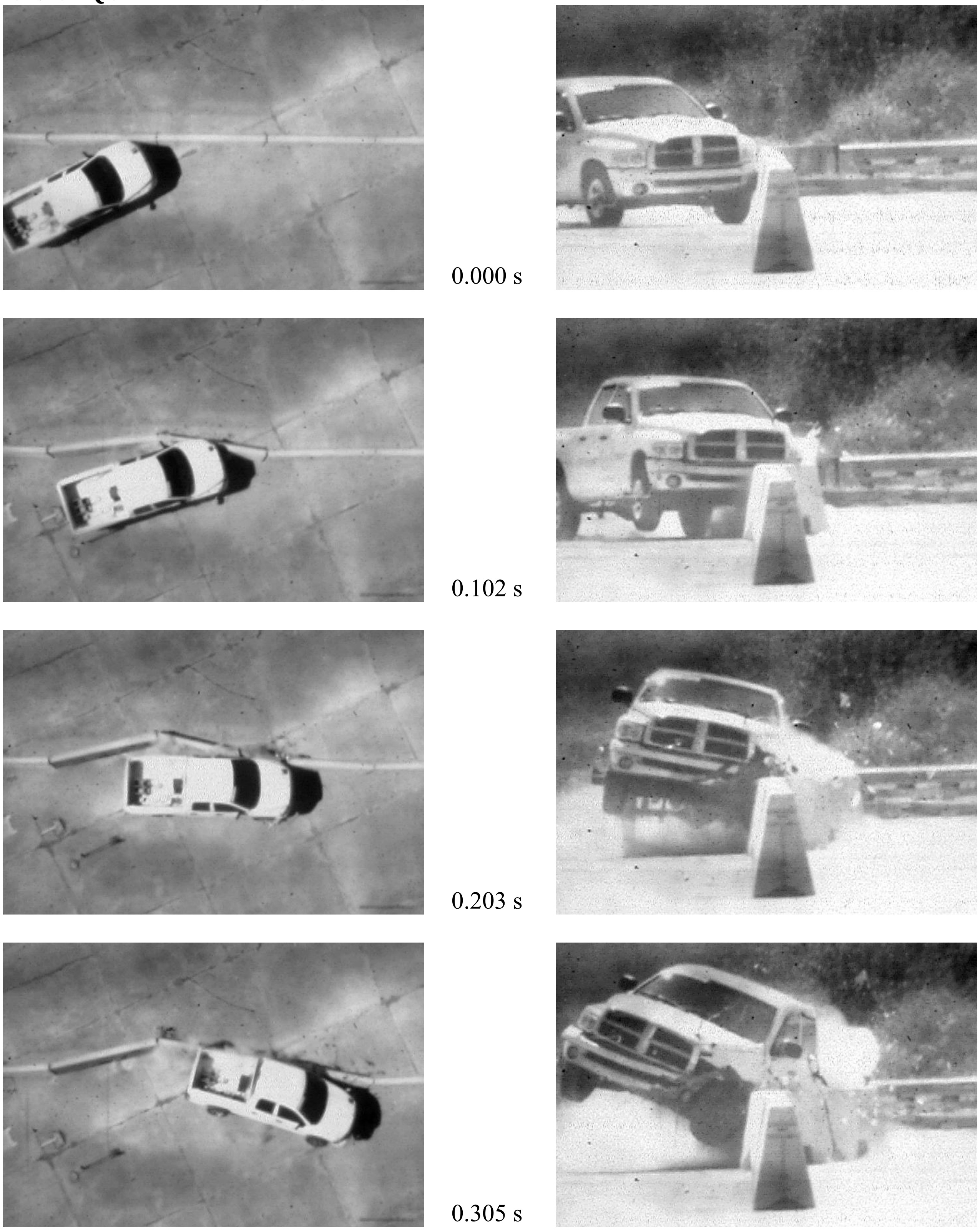
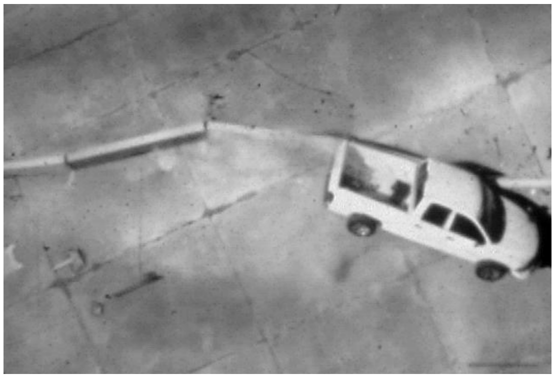


Figure C2. Sequential photographs for test 405160-18-1
(overhead and frontal views).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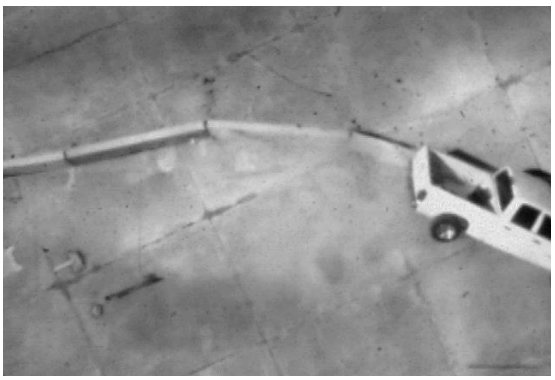
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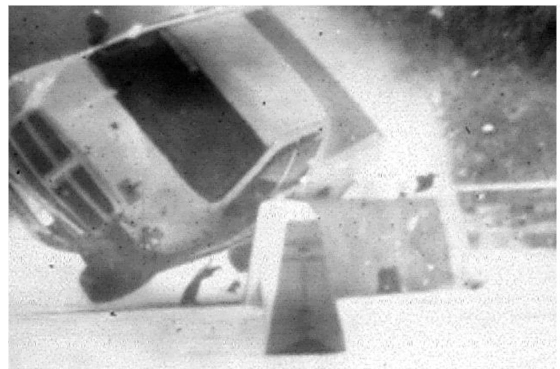

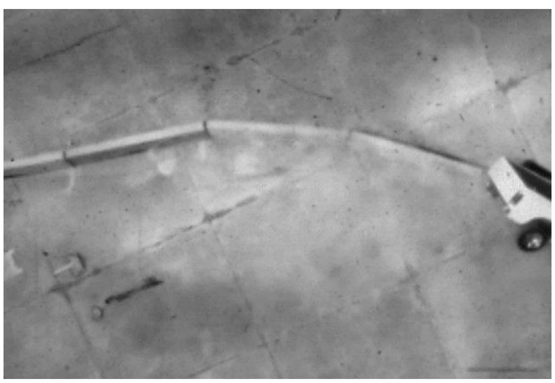
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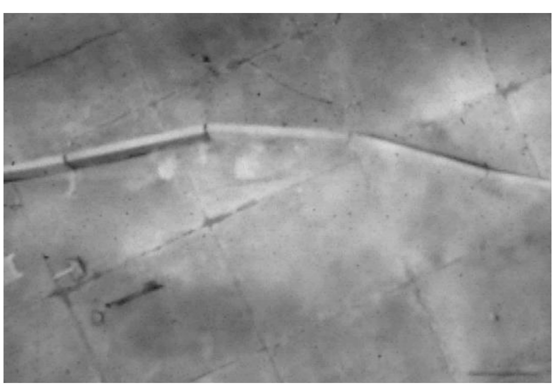
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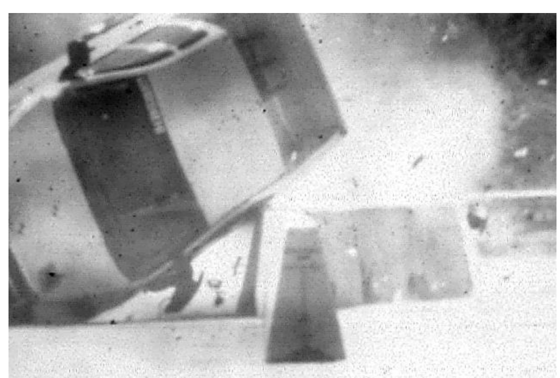
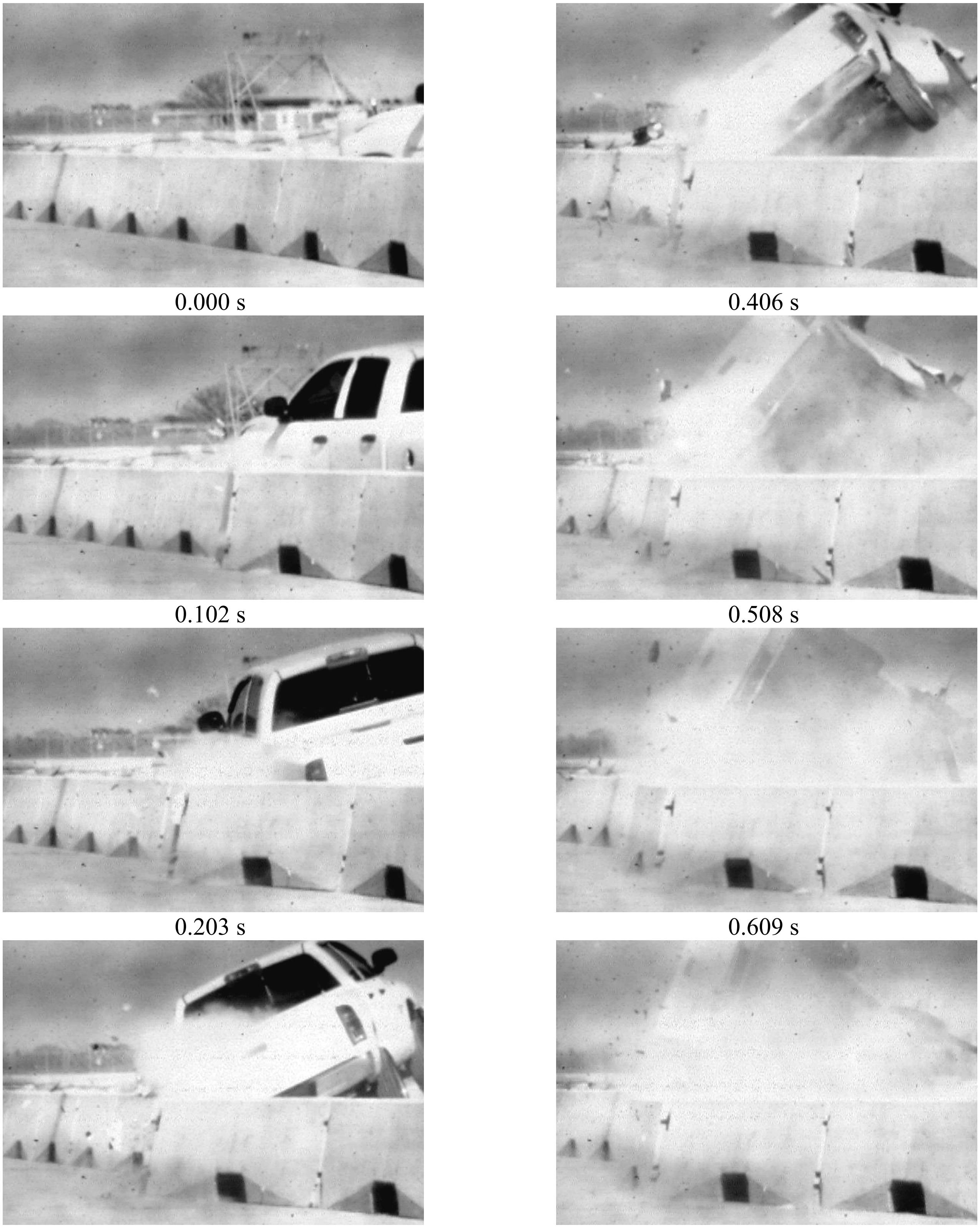


Figure C2. Sequential photographs for test 405160-18-1
(overhead and frontal views) (continued).



0.000 s 0.406 s
0.102 s 0.508 s
0.203 s 0.609 s
0.305 s 0.704 s

Figure C3. Sequential photographs for test 405160-18-1
(rear view).

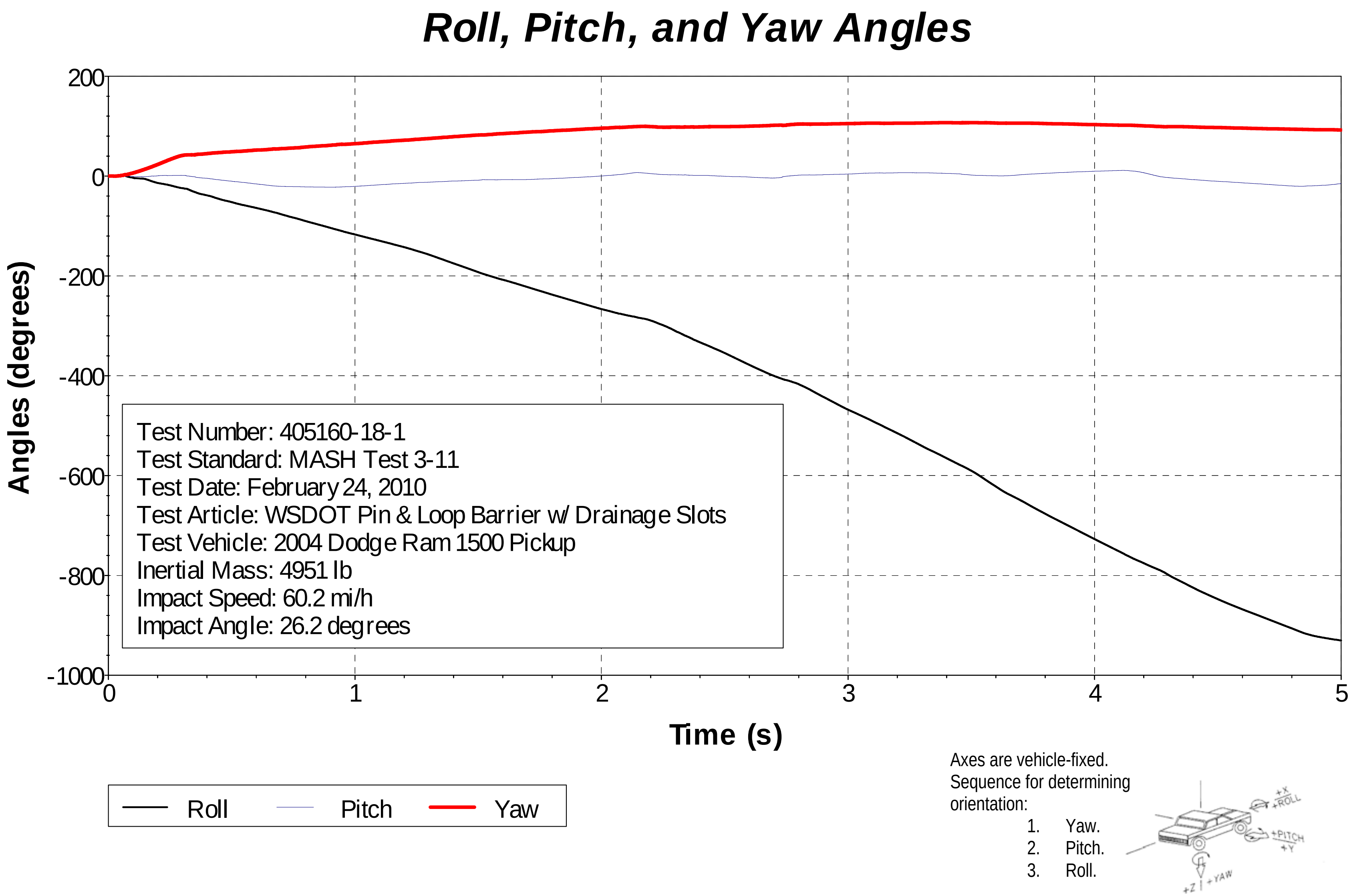


Figure C4. Vehicle angular displacements for test 405160-18-1.

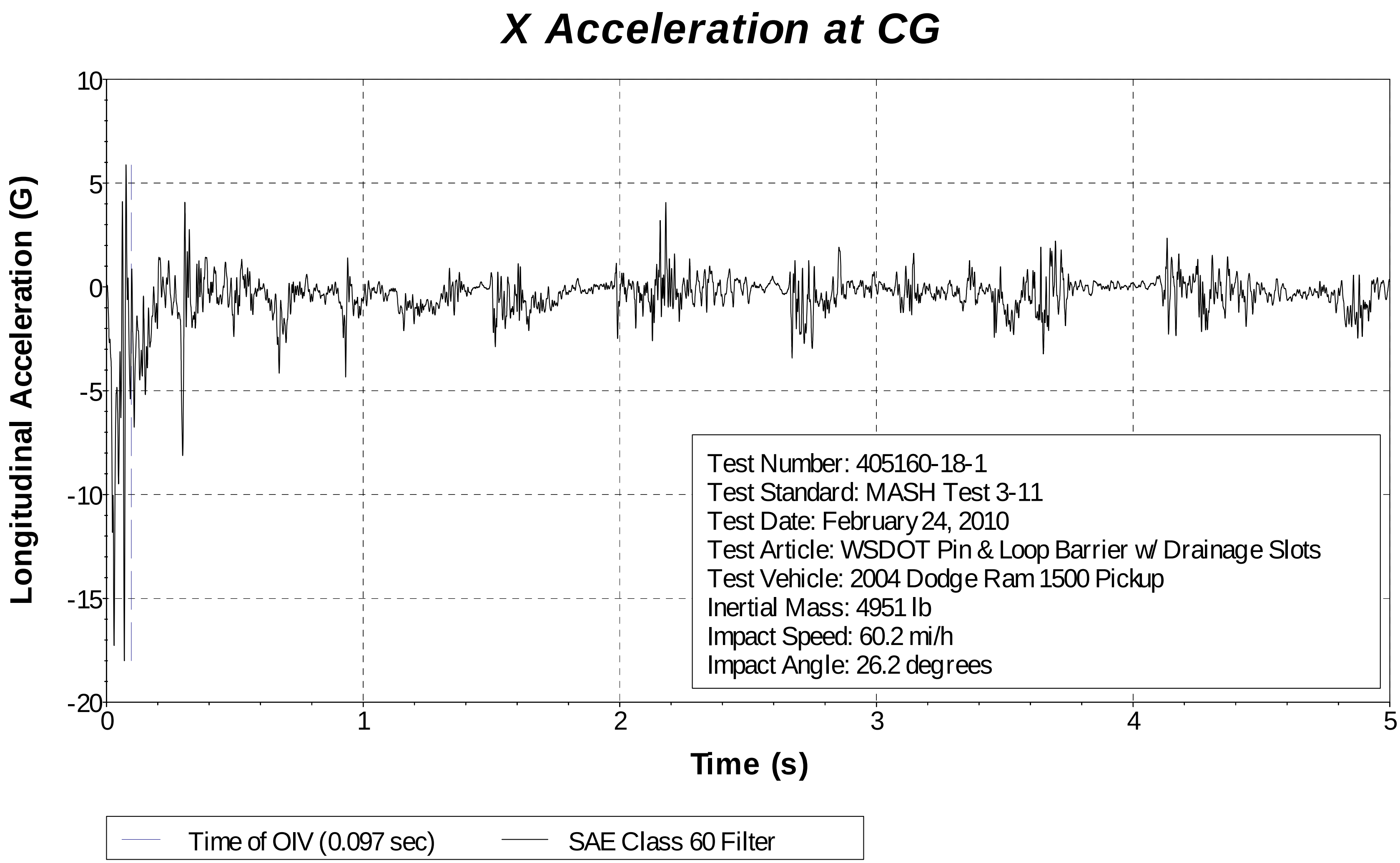


Figure C5. Vehicle longitudinal accelerometer trace for test 405160-18-1
(accelerometer located at center of gravity).

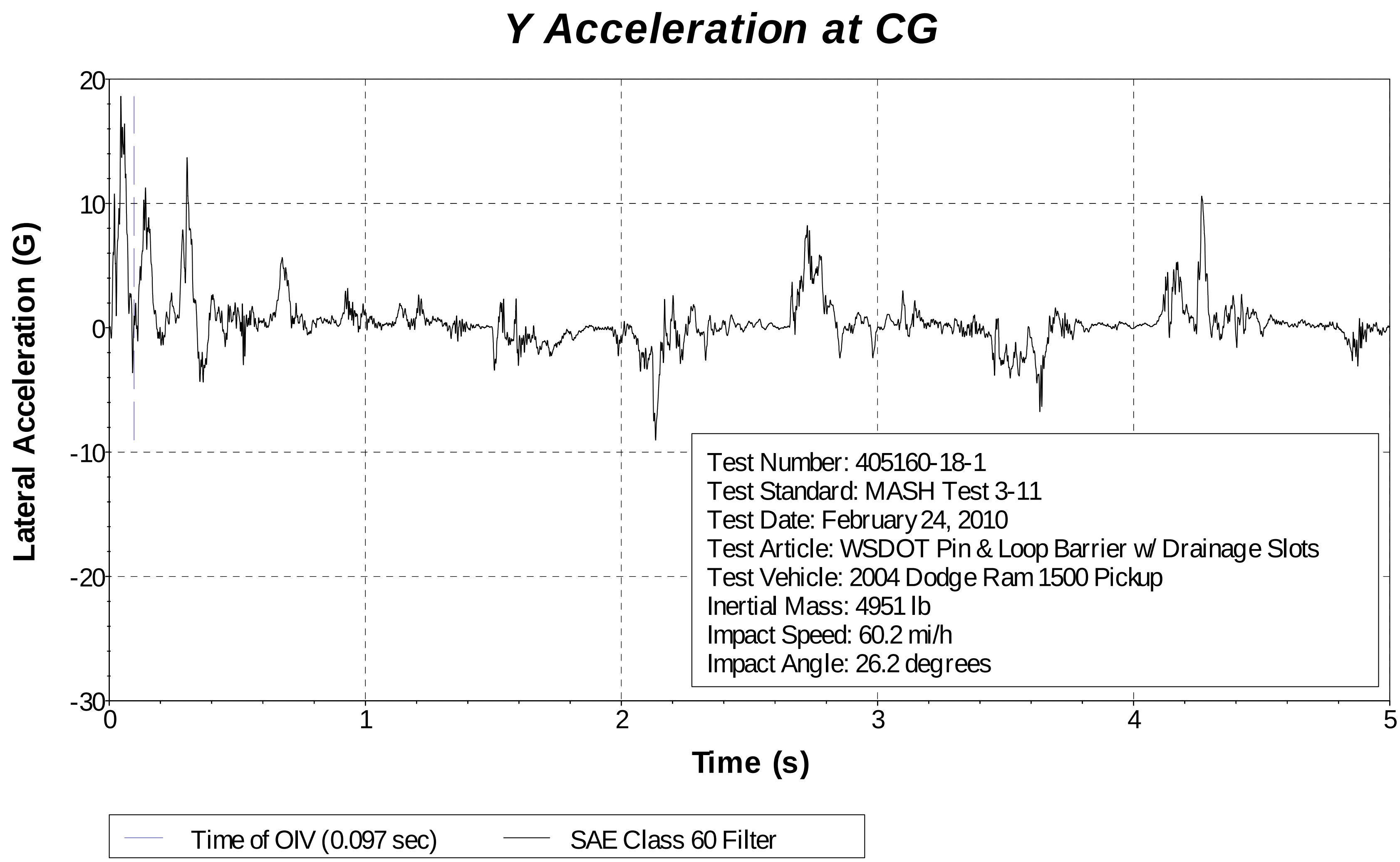


Figure C6. Vehicle lateral accelerometer trace for test 405160-18-1 (accelerometer located at center of gravity).

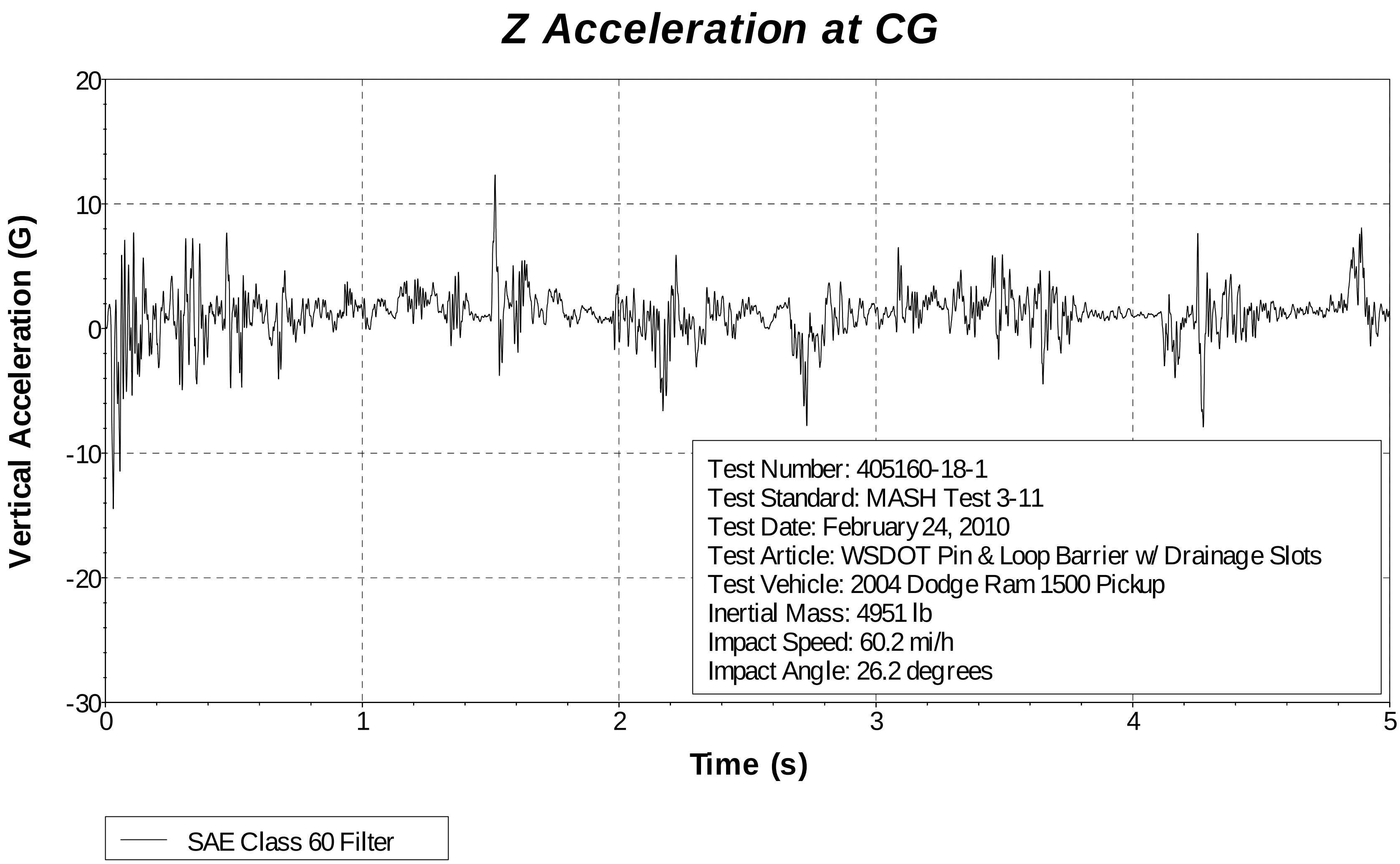


Figure C7. Vehicle vertical accelerometer trace for test 405160-18-1
(accelerometer located at center of gravity).

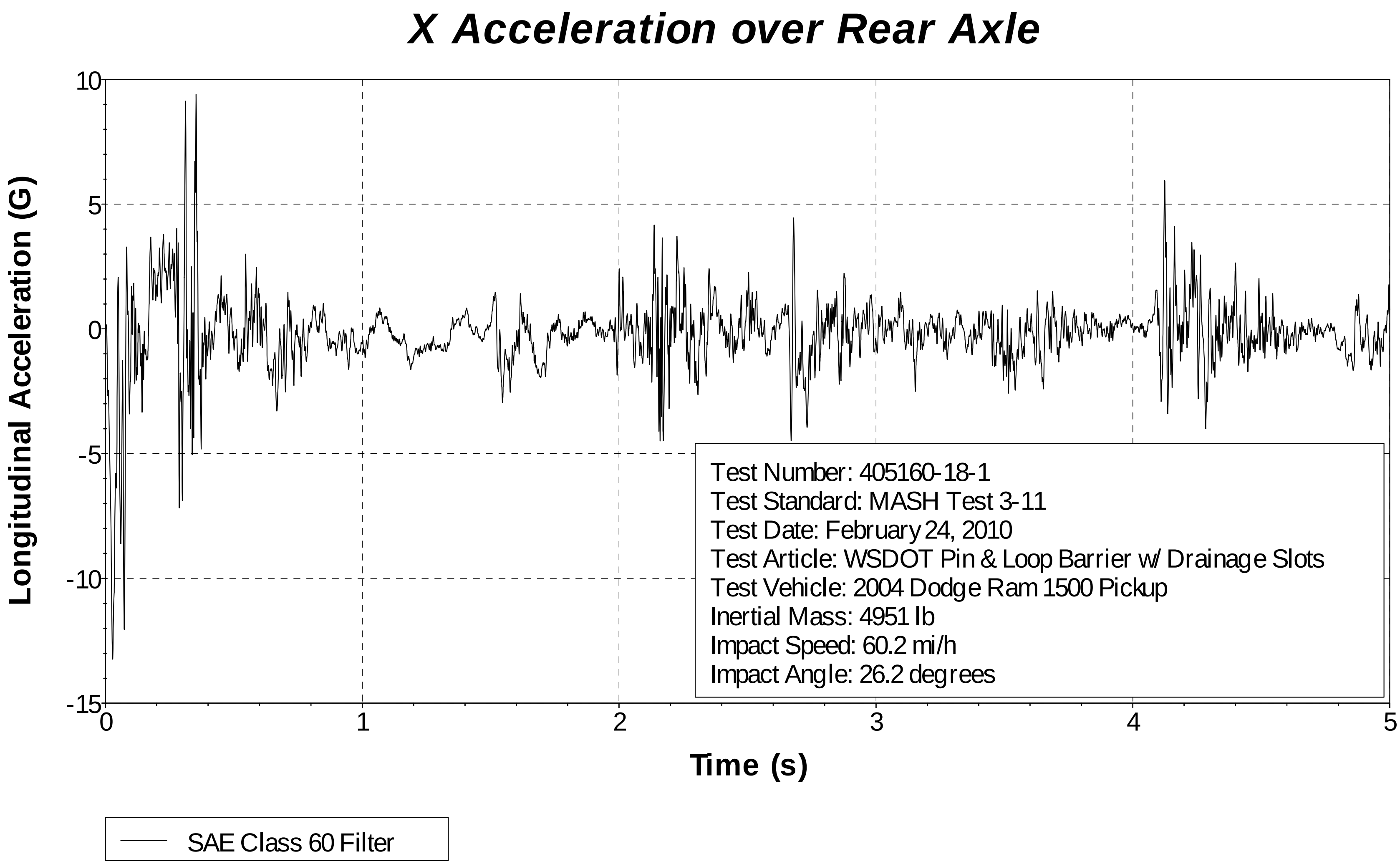


Figure C8. Vehicle longitudinal accelerometer trace for test 405160-18-1 (accelerometer located over rear axle).

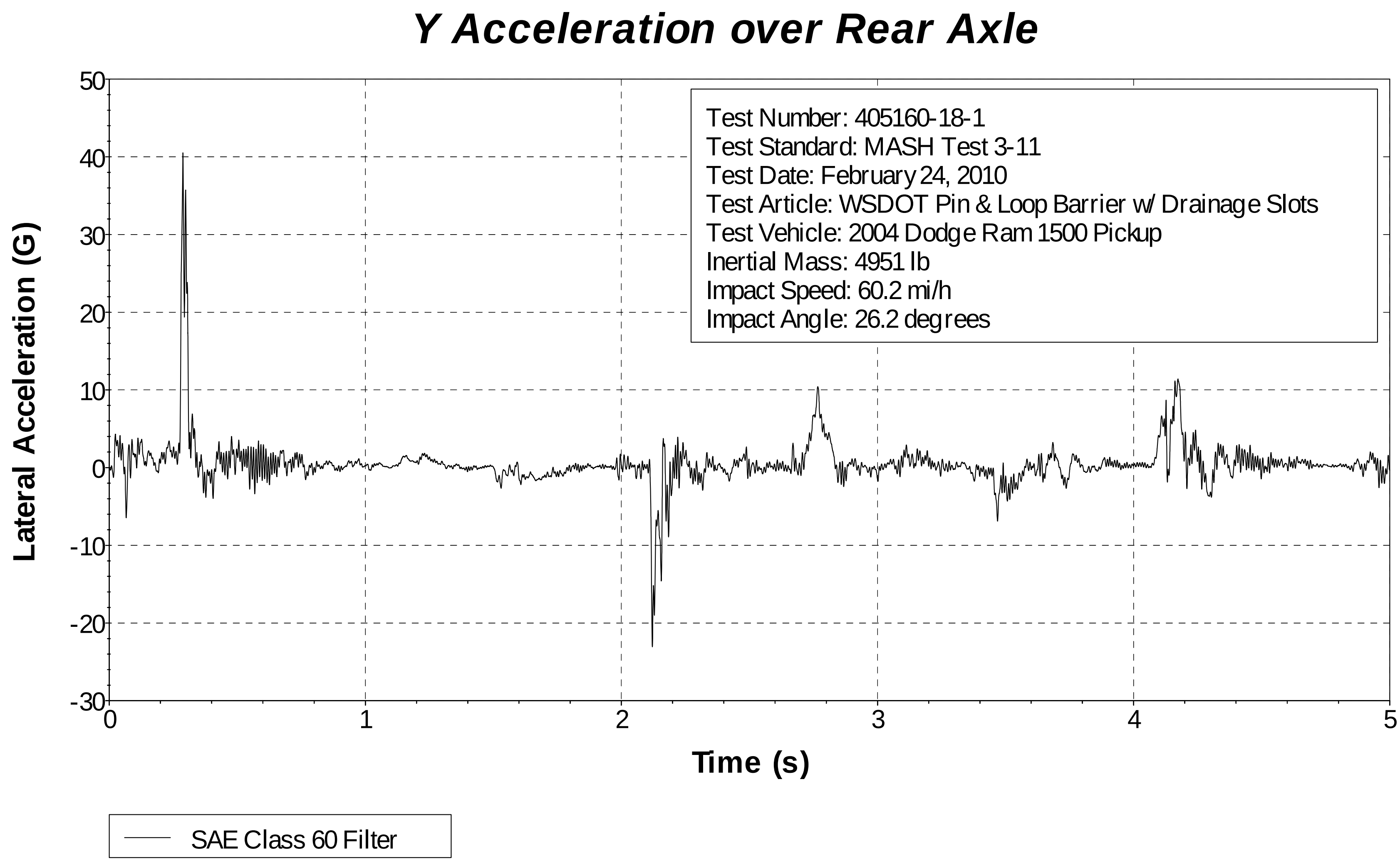


Figure C9. Vehicle lateral accelerometer trace for test 405160-18-1 (accelerometer located over rear axle).

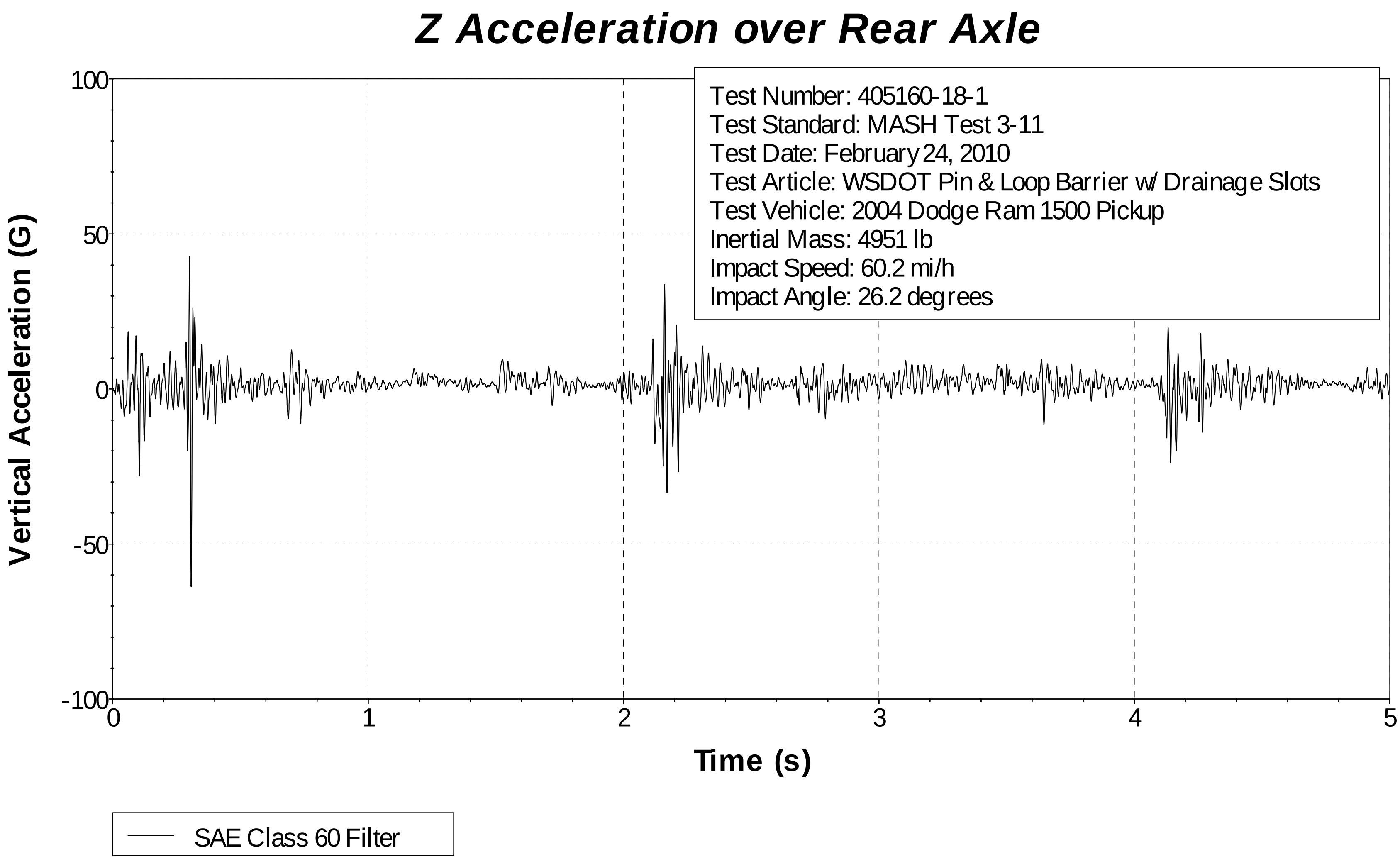


Figure C10. Vehicle vertical accelerometer trace for test 405160-18-1 (accelerometer located over rear axle).