TTI: 9-1002

MASH TEST 3-37 OF THE TxDOT 31-INCH W-BEAM DOWNSTREAM ANCHOR TERMINAL

ISO 17025 Laboratory
Testing Certificate # 2821.01

Crash testing performed at:
TTI Proving Ground
3100 SH 47, Building 7091
Bryan, TX 77807

Test Report 9-1002-6

Cooperative Research Program

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
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16. Abstract

The objective of this study was to develop a suitable replacement for the downstream “turndown” guardrail anchor system. The “turndown” guardrail anchor system does not meet mandated test requirements under *MASH* for upstream anchor application terminals; however, it does meet downstream requirements for previous crash testing standards. Due to its low cost, TxDOT has used this anchor system with 27-inch guardrail in downstream applications when it is outside of the clear zone of opposing traffic. With the new federally mandated increase in guardrail height, TxDOT is considering increasing its standard guardrail height to 31 inches. This increase in height increases the risk of a small sedan wedging under the guardrail and snagging on the “turndown” anchor system. The current “turndown” anchor design does not include a releasable connection detail for reverse direction impacts. For this reason, TxDOT has decided to develop a new downstream anchor system rather than test the 31-inch configuration of the “turndown” anchor system.

This anchor system utilized standard parts found in the AASHTO-ARTBA-AGC *Guide to Standardized Highway Barrier Hardware* when possible. This terminal is nonproprietary to allow for competitive bidding to reduce costs. As this system will be developed for the sole purpose of anchoring the downstream end of guardrail system, the testing matrix will include the optional crash test (3-37) found in *MASH* for testing terminals in a reverse direction impact condition.

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation, and its contents are not intended for construction, bidding, or permit purposes. In addition, the above-listed agencies assume no liability for its contents or use thereof. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report. The engineer in charge of the project was Roger P. Bligh, P.E. (Texas, #78550).

TTI PROVING GROUND DISCLAIMER

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 results of the crash testing reported herein apply only to the article being tested.

ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01

Crash testing performed at:
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This research project was conducted under a cooperative program between the Texas Transportation Institute, the Texas Department of Transportation, and the Federal Highway Administration. The TxDOT project director for this research was Rory Meza, P.E. with the Design Division. Bobby Dye with the Design Division served as project advisor and was also actively involved in this research. The TxDOT research engineer was Wade Odell, P.E. with the Research and Technology Implementation Office. The authors acknowledge and appreciate their guidance and assistance.

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CHAPTER 1. INTRODUCTION

1.1 INTRODUCTION

This project was set up to provide Texas Department of Transportation (TxDOT) with a mechanism to quickly and effectively evaluate high-priority issues related to roadside safety devices. Roadside safety devices shield motorists from roadside hazards such as non-traversable terrain and fixed objects. To maintain the desired level of safety for the motoring public, these safety devices must be designed to accommodate a variety of site conditions, placement locations, and a changing vehicle fleet. Periodically, there is a need to assess the compliance of existing safety devices with current vehicle testing criteria and develop new devices that address identified needs.

Under this project, roadside safety issues were identified and prioritized for investigation. The selected safety issues were evaluated through crash data analyses, engineering analyses, computer simulation, dynamic impact testing, and full-scale crash testing as appropriate. Factors such as impact performance, maintenance, and cost were considered. Each roadside safety issue is addressed with a separate work plan, and the results are summarized in an individual test report.

One problem prioritized by the TxDOT review panel included the development of a suitable replacement for the downstream “turndown” guardrail anchor system. The “turndown” guardrail anchor system does not meet mandated test requirements under the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) (*1*) for upstream anchor application. However, it does meet downstream requirements for previous crash testing standards. Due to its low costs, TxDOT has used this anchor system with 27-inch guardrail in downstream applications when it is outside of the clear zone of opposing traffic. With the new federally mandated increase in guardrail height, TxDOT is considering increasing its standard guardrail height to 31 inches. This increase in height increases the risk of a small sedan wedging under the guardrail and snagging on the “turndown” anchor system. The current “turndown” anchor design does not include a releasable connection detail for reverse direction impacts. For this reason, TxDOT has decided to develop a new downstream anchor system rather than test the 31-inch configuration of the “turndown” anchor system.

The anchor system should utilize standard parts found in the American Association of State Highway and Transportation Officials-American Road and Transportation Builders Association-Association of General Contractors of America (AASHTO-ARTBA-AGC) *Guide to Standardized Highway Barrier Hardware* when possible (*2*). The terminal should be nonproprietary to allow for competitive bidding to reduce costs. As this system will be developed for the sole purpose of anchoring the downstream end of guardrail system, the testing matrix will include the optional crash test (3-37) found in *MASH* for testing terminals in a reverse direction impact condition.

1.2 BACKGROUND

AASHTO published *MASH* in October 2009. *MASH* supersedes *National Cooperative Highway Research Program (NCHRP) Report 350* (*3*) as the recommended guidance for the safety performance evaluation of roadside safety features. Changes incorporated into the new guidelines include new design test vehicles, revised test matrices, and revised impact conditions.

The test matrix found in *NCHRP Report 350* and *MASH* for developing guardrail terminals has generally been costly for states to develop nonproprietary designs. The current *MASH* testing matrix includes a total of eight tests, inflating the cost for development of an end terminal to over $500,000. For this reason, private entities have developed most of the systems that are currently available, which are considered proprietary to protect their extensive investment. This, combined with the increased cost due to the added complexity associated with safely redirecting, absorbing, or gating an impact upstream of the length of need (LON), have increased the cost of terminals.

Terminals developed for end-on impacts are required to have upstream anchorage and downstream anchorage of guardrails when inside the clear zone of opposing travel lanes. This, however, is not the case for downstream anchor systems installed outside of the clear zone of opposing travel lanes. By removing the end-on impact condition, an anchor system cost and complexity can be dramatically reduced. One instance of this is the TxDOT downstream “turndown” anchor system. The TxDOT “turndown” guardrail anchor system does not meet mandated test requirements under *MASH* for upstream anchor application. However, it does meet downstream requirements for previous crash testing standards. Due to its low cost, TxDOT has used this anchor system with 27-inch guardrails in downstream applications when it is outside of the clear zone of opposing traffic.

With the new federally mandated increase in guardrail height, TxDOT is considering increasing its standard guardrail height to 31 inches. This increase in height increases the risk of a small sedan wedging under the guardrail and snagging on the “turndown” anchor system. The current “turndown” anchor design does not include a releasable connection detail for reverse direction impacts. For this reason, TxDOT has decided to develop a new downstream anchor system rather than test the 31-inch configuration of the “turndown” anchor system.

1.3 OBJECTIVES/SCOPE OF RESEARCH

The objective of this test was to develop and evaluate the performance of the TxDOT 31-inch W-Beam Downstream Anchor Terminal according to the *MASH* standards for Test Level 3 (TL-3) terminals. The test performed was *MASH* test 3-37, which typically involves a 2270P (5004 lb) pickup truck impacting the critical impact point (CIP) of the terminal in the reverse direction of traffic at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. This test will evaluate the ability of the terminal to successfully release when a heavy vehicle impacts it. However, in the test reported here, the 1100C (2425 lb) small car was used to maximize the risk of wedging the vehicle under the raised 31-inch guardrail, increasing the risk of snagging on the anchor post. The anchor system used standard parts found in the AASHTO-

ARTBA-AGC *Guide to Standardized Highway Barrier Hardware* when possible. This terminal is nonproprietary to allow for competitive bidding to reduce costs.

This report gives the details of the TxDOT 31-inch W-Beam Downstream Anchor Terminal, test conditions, description of the test performed, and an assessment of the test results.

CHAPTER 2. SYSTEM DETAILS

2.1 TEST ARTICLE DESIGN AND CONSTRUCTION

The TxDOT 31-inch W-Beam Downstream Anchor Terminal had a total length of 118 ft–9 inches. The upstream end of the installation was anchored using a standard 31-inch ET terminal. The length of need was supported using a standard 72-inch W6×8.5 steel line post with an 8-inch wood blockout. Posts were spaced ever 75 inches with the rail splices falling at the mid-span between posts. This system provided a length of need of 87 ft–6 inches.

The test article is a modification of a breakaway cable terminal (BCT). All components of the terminal were standard, off-the-shelf parts from the AASHTO-ARTBA-AGC *Guide to Standardized Highway Barrier Hardware*. The terminal utilizes two 6-inch × 8-inch × 72-inch foundation tubes. In each foundation tube, a 6-inch × 8-inch wooden breakaway post was placed. These foundations were spaced 72 inches from center to center. The two foundation tubes were then linked together at ground level using two C3×5 channel sections. This design was a simplification of the original welded channel section found in the AASHTO-ARTBA-AGC *Guide to Standardized Highway Barrier Hardware*. A 9 ft-4.5 inch anchor rail segment was used to facilitate the attachment to a 31-inch guardrail installation with splices placed at the mid-span. This leads to a terminal length of only 9 ft-4 inches.

The anchor post was not bolted to the rail to prevent the rail from fracturing the anchor post in the event of a reverse direction impact. Instead, a standard “shelf angle bracket” (ARTBA #FPP02) supported the rail in the vertical direction in the event of a redirection impact upstream of the guardrail anchor terminal. A W-beam end section (ARTBA #RWE03a) was used to finish the end of the rail, and a standard breakaway anchor cable (ARTBA #FCA01) was used in conjunction with a guardrail anchor bracket (ARTBA #FPA01) to anchor the system. Figure 2.1 and Appendix A give further system details and installation details, and Figure 2.2 presents photographs of the installation.

2.2 MATERIAL SPECIFICATIONS

All rolled steel shapes were fabricated to meet American Society for Testing and Materials (ASTM) A36 specifications, and the foundation tubes, according to ASTM A500 grade B specifications. All other components were manufactured to meet specifications defined in the AASHTO-ARTBA-AGC *Guide to Standardized Highway Barrier Hardware*.

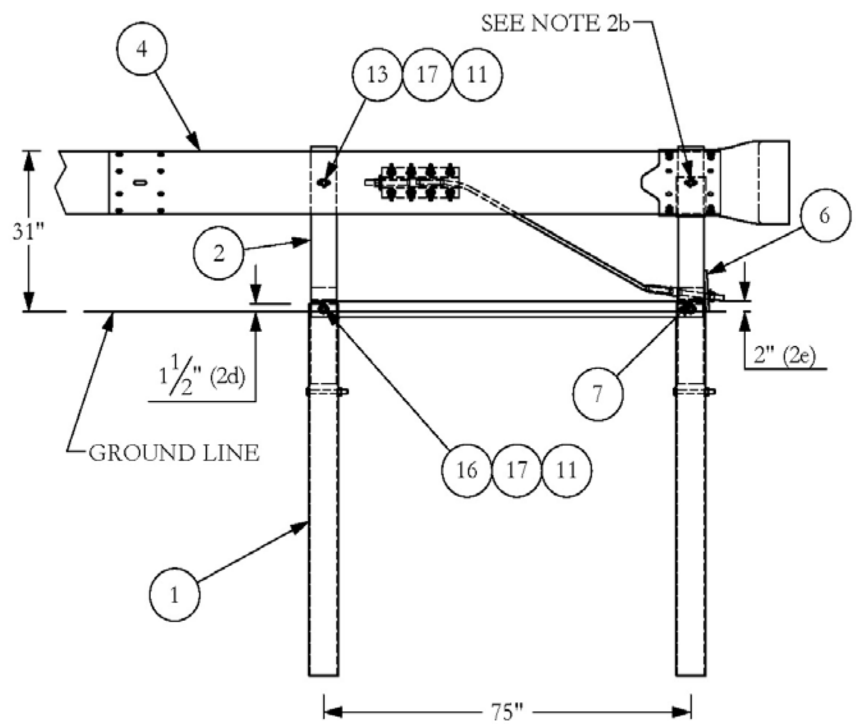
2.3 SOIL CONDITIONS

In accordance with Appendix B of *MASH*, soil strength was measured on the day of the crash test (see Appendix C, Figure C1). During construction of the TxDOT 31-inch W-Beam Downstream Anchor Terminal for the full-scale crash test, two W6×16 posts were installed in the immediate vicinity of the terminal using the same fill materials and installation procedures followed for the terminal and used in the reference tests (see Appendix C, Figure C2).

As determined from the reference tests shown in Appendix C, Figure C2, the minimum static post load required for deflections of 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, is 3940 lb, 5500 lb, and 6540 lb, respectively (90 percent of static load for the initial reference installation). On the day of the test, April 20, 2011, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 9515 lbf, 9242 lbf, and 8909 lbf, respectively. The strength of the backfill material met minimum requirements.

#	PART NAME	QTY.	ARTBA
1	6 x 8 x 72" Foundation Tube	2	
2	Tube Post for Terminal	2	
3	Strut, Channel	2	
4	Rail for Terminal	1	
5	Shelf Angle Bracket	1	FPP02
6	BCT Bearing Plate	1	FPB01
7	BCT Post Sleeve	1	FMM02
8	Guardrail Anchor Bracket	1	FPA01
9	W-beam End Section	1	RWE03a
10	BCT Cable Anchor	1	FCA01
11	Nut, Recessed Guardrail	20	FBB
12	Bolt, Button-head 1-1/4"	4	FBB01
13	Bolt, Button-head 10"	2	FBB03
14	Bolt, 5/8 -11 x 2 hex	8	FBX16a
15	Bolt, 5/8 -11 x 8 hex	4	FBX16a
16	Bolt, 5/8 -11 x 10 hex	2	FBX16a
17	Washer, 5/8 flat	18	FWC16a

DOWNSTREAM TERMINAL
ELEVATION VIEW



2a. All hardware is A307 unless otherwise indicated.
2b. Rail is supported by Shelf Angle Bracket (5) at Post 20 and does not attach to post.
2c. Parts 1, 2, 11, 13, and 15 - 17 callouts at Post 19 or 20 typical at both locations.
2d. Foundation Tube protrudes 1-1/2" above ground line.
2e. Top edge of Strut at 2" above ground line.

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No.	Date	By	Chk				
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3.				Project No.	Sheet Name		
4.				420021-1	Downstream Terminal		
5.				TxDOT Downstream W-beam Terminal			

T:\2010-2011\420021\-1 Downstream Terminal\Drafting\Drawings\420021-1 Drawing

Figure 2.1. Details of the TxDOT 31-inch W-Beam Downstream Anchor Terminal Installation.

Figure 2.2. TxDOT 31-inch W-Beam Downstream Anchor Terminal before Test No. 420021-1.

CHAPTER 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 CRASH TEST MATRIX

According to *MASH*, up to eight tests are recommended to evaluate W-beam guardrail terminals to test level three (TL-3). Details of these tests are described below.

1. ***MASH* test designation 3-30**: An 1100C (2425 lb) passenger car impacting the terminal end-on at a nominal impact speed and angle of 62 mi/h and 0 degree, respectively, with the quarter point of the vehicle aligned with the centerline of the nose of the terminal. This test is primarily intended to evaluate occupant risk and vehicle trajectory criteria.

2. ***MASH* test designation 3-31**: A 2270P (5000 lb) pickup truck impacting the terminal end-on at a nominal impact speed and angle of 62 mi/h and 0 degree, respectively, with the centerline of the vehicle aligned with the centerline of the nose of the terminal. This test is primarily intended to evaluate occupant risk and vehicle trajectory criteria.

3. ***MASH* test designation 3-32**: An 1100C (2425 lb) passenger car impacting the terminal end on at a nominal impact speed of 62 mi/h and the critical impact angle ranging from 5 to 15 degrees, with the centerline of the vehicle aligned with the centerline of the nose of the terminal. The test is primarily intended to evaluate occupant risk and vehicle trajectory criteria.

4. ***MASH* test designation 3-33**: A 2270P (5000 lb) pickup truck impacting the terminal end-on at a nominal impact speed of 62 mi/h and the critical impact angle ranging from 5 to 15 degrees, with the centerline of the vehicle aligned with the centerline of the nose of the terminal. The test is primarily intended to evaluate occupant risk and vehicle trajectory criteria.

5. ***MASH* test designation 3-34**: An 1100C (2425 lb) passenger car impacting the terminal at a nominal impact speed and angle of 62 mi/h and 15 degrees, respectively, with the corner of the bumper aligned with the critical impact point (CIP) of the length of need (LON) of the terminal. The test is primarily intended to evaluate occupant risk and vehicle trajectory criteria.

6. ***MASH* test designation 3-35**: A 2270P (5000 lb) pickup truck impacting the terminal at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively, with the corner of the bumper aligned with the beginning of the LON of the terminal. The test is primarily intended to evaluate structural adequacy and vehicle trajectory criteria.

7. ***MASH* test designation 3-37**: A 2270P (5000 lb) pickup truck impacting the terminal at a nominal impact speed and angle of 62 mi/h and 25 degrees,

respectively, midpoint between the nose and the end of the terminal in the reverse direction. This test is intended to evaluate the performance of a terminal for a "reverse" hit.

8. ***MASH* test designation 3-38**: A 1500C (3300 lb) passenger car impacting the terminal end-on at a nominal impact speed and angle of 62 mi/h and 0 degree, respectively, with the centerline of the vehicle aligned with the centerline of the nose of the terminal. This test is intended to evaluate the performance of a staged energy-absorbing terminal when impacted by a mid-size vehicle.

The test reported here corresponds to *MASH* test designation 3-37. However, the vehicle used in the test reported here was the 1100C (2425 lb) small car due to its higher risk of wedging under the breakaway anchor cable in a reverse direction impact event. This, in turn, would lead to a higher risk of snagging on the anchor cable and anchor post, possibly causing elevated occupant risk numbers. The target impact point was 15 ft-7.5 inches upstream of downstream anchor post (37 inches upstream of post 18). This impact location was determined to be the CIP through review of the previous length-of-need test on the 31-inch guardrail with 8-inch blockouts (*4*).

The crash test and data analysis procedures were in accordance with the 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 TxDOT 31-inch W-Beam Downstream Anchor Terminal is judged on the basis of three factors: structural adequacy, occupant risk, and post-impact vehicle trajectory. Structural adequacy is judged on the ability of the TxDOT 31-inch W-Beam Downstream Anchor Terminal to contain and redirect the vehicle, or bring the vehicle to a controlled stop in a predictable manner. Occupant risk criteria evaluate 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 here, and are listed in further detail under the assessment of the crash test.

CHAPTER 4. CRASH TEST PROCEDURES

4.1 TEST FACILITY

The full-scale crash test reported here 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 Texas Transportation Institute Proving Ground is a 2000-acre complex of research and training facilities located 10 miles northwest of the main campus of Texas A&M University. Formerly an Air Force base, the site 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 construction and testing of the TxDOT 31-inch W-Beam Downstream Anchor Terminal evaluated under this project was along the edge of an out-of-service apron. The apron is an unreinforced jointed-concrete pavement in 12.5 ft × 15 ft blocks nominally 8–12 inches deep. It is over 50 years old, and its joints have some displacement, but are otherwise flat and level.

4.2 VEHICLE TOW AND GUIDANCE PROCEDURES

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

4.3 DATA ACQUISITION SYSTEMS

4.3.1 Vehicle Instrumentation and Data Processing

The test vehicle was instrumented with a self-contained, on-board data acquisition system. The signal conditioning and acquisition system is a 16-channel, Tiny Data Acquisition System (TDAS) Pro produced by Diversified Technical Systems, Inc. The accelerometers, that measure the *x*, *y*, and *z* axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra small, solid state units designed 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 the data are recorded, internal batteries back these up inside the unit, 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 Test Risk Assessment Program (TRAP) software then processes the raw data 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 that of the initial impact.

4.3.2 Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50^{th} percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the 1100C vehicle. The dummy was uninstrumented.

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-digital video camera and still cameras recorded and documented conditions of the test vehicle and installation before and after the test.

CHAPTER 5. CRASH TEST RESULTS

5.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

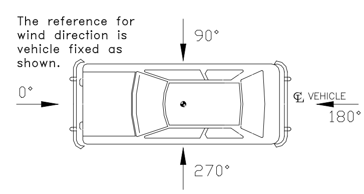
MASH test 3-37 involves a 2270P vehicle weighing 5000 lb ±100 lb impacting the terminal in the reverse direction of travel at an impact speed of 62.2 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. An 1100C impact vehicle was substituted for the 2270P due to its higher risk of wedging under the breakaway anchor cable in a reverse direction impact event. The target impact point was 15 ft-7.5 inches upstream of downstream anchor post (37 inches upstream of post 18). The 2004 Kia Rio used in the test weighed 2420 lb and the actual impact speed and angle were 61.9 mi/h and 25.3 degrees, respectively. The actual impact point was 36 inches upstream of post 18.

5.2 TEST VEHICLE

The 2004 Kia Rio, shown in Figures 5.1 and 5.2, was used for the crash test. Test inertia weight of the vehicle was 2420 lb, and its gross static weight was 2585 lb. The height to the lower edge of the vehicle bumper was 8.5 inches, and it was 22.75 inches to the upper edge of the bumper. Table D1 in Appendix D gives additional dimensions and information on the vehicle. 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.

5.3 WEATHER CONDITIONS

The test was performed on the morning of April 20, 2011. No rainfall was recorded for the 10 days prior to the test. Weather conditions at the time of testing were: Wind speed: 9 mi/h; Wind direction: 180 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); Temperature: 81°F, Relative humidity: 71 percent.



5.4 TEST DESCRIPTION

The 2004 Kia Rio, traveling at an impact speed of 61.9 mi/h, impacted the terminal 37 inches upstream of post 18 at an impact angle of 25.3 degrees. At approximately 0.024 s after impact, the left front corner of the vehicle contacted post 18, and at 0.054 s, the vehicle began to redirect. The rail segment at the end of the terminal separated from post 20 at 0.059 s, and post 19 and 20 began to deflect toward the field side at 0.070 s. At 0.095 s, the vehicle contacted post 19, and at 0.097 s, post 19 began to shatter. At 0.160 s, post 20 began to rise upward, and at 0.176 s, the front of the vehicle contacted post 20, which continued to rise upward. The vehicle lost contact with the terminal at 0.217 s, and was traveling at an exit speed and angle of 40.2 mi/h and 18.4 degrees, respectively. Brakes on the vehicle were applied at 0.540 s after impact, and the vehicle came to rest 140 ft downstream of impact and 7.5 ft toward traffic lanes. Figures E1 and D2 in Appendix E show sequential photographs of the test period.

Figure 5.1. Vehicle/Installation Geometrics for Test No. 420021-1.

Figure 5.2. Vehicle before Test No. 420021-1.

5.5 DAMAGE TO TEST INSTALLATION

Figures 5.3 and 5.4 show the damage to the TxDOT 31-inch W-Beam Downstream Anchor Terminal. The soil was disturbed around post 15, and post 16 was leaning downstream 0.25 inch. Post 17 was leaning toward the field side 1.5 inches and there was a 0.25 inch gap in the soil on the upstream side of the post, and 1.0 inch on the downstream side. Post 18 was leaning 30 degrees downstream and was pushed toward the field side 5.5 inches. Post 19 fractured at ground level and was resting 50 ft toward the field side directly behind its original position. Post 20 fractured at ground level and was resting 82.5 ft downstream of impact and 30 ft toward the field side. The W-beam rail element detached from posts 18 through 20. The end of the guardrail was resting on the ground approximately 16 ft toward the field. Working width was 16 ft. Length of contact of the car with the rail element was 15.6 ft. Maximum dynamic deflection of the W-beam rail element was 16 ft.

5.6 VEHICLE DAMAGE

As shown in Figure 5.5, the vehicle sustained damage to the front and left front quarter. The left strut and tower and left lower ball joint were damaged. The front bumper, hood, radiator and support, left front tire and wheel rim, and left front fender were also damaged. The windshield sustained stress cracks from the left lower corner, and the left side of the floor pan was very slightly damaged. Maximum exterior crush to the vehicle was 14.0 inches in the side plane at the left front corner at bumper height. No occupant compartment deformation occurred. Photographs of the interior of the vehicle are shown in Figure 5.6. Appendix D, Tables D2 and D3 have data on the exterior crush and occupant compartment deformation.

5.7 OCCUPANT RISK FACTORS

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 21.0 ft/s at 0.140 s, the highest 0.010-s occupant ridedown acceleration was 9.7 Gs from 0.163 s to 0.173 s, and the maximum 0.050-s average acceleration was −7.5 Gs between 0.033 s and 0.083 s. In the lateral direction, the occupant impact velocity was 14.8 ft/s at 0.140 s, the highest 0.010-s occupant ridedown acceleration was 6.6 Gs from 0.140 s to 0.150 s, and the maximum 0.050-s average was 5.6 Gs between 0.030 s and 0.080 s. Theoretical Head Impact Velocity (THIV) was 27.2 km/h or 7.6 m/s at 0.136 s; Post-Impact Head Decelerations (PHD) was 10.2 Gs between 0.163 s and 0.173 s; and Acceleration Severity Index (ASI) was 0.86 between 0.029 s and 0.079 s. Figure 5.7 summarizes these data and other pertinent information from the test. Appendix F, Figures F1 through F7 present data on vehicle angular displacements and accelerations versus time traces. .

Figure 5.3. Vehicle/Installation Positions after Test No. 420021-1.

Figure 5.4. Installation after Test No. 420021-1.

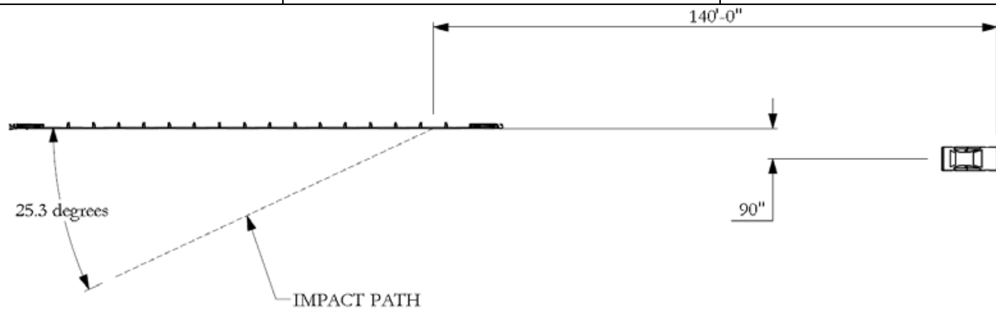
Figure 5.5. Vehicle after Test No. 420021-1.

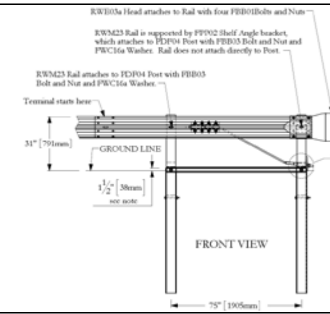
Before Test

After Test

Figure 5.6. Interior of Vehicle for Test No. 420021-1.

0.000 s | 0.072 s | 0.144 s | 0.217S s





General Information
- Test Agency: Texas Transportation Institute (TTI)
- Test Standard Test No.: MASH Test 3-37
- TTI Test No.: 420021-1
- Test Date: 2011-04-20

Test Article
- Type: Terminal
- Name: TxDOT 31-inch W-Beam Downstream Anchor Terminal
- Installation Length: 118 ft 9 inches
- Material or Key Elements: W-beam guardrail with modified breakaway cable terminal

Soil Type and Condition: Standard Soil, Dry

Test Vehicle
- Type/Designation: 1100C
- Make and Model: 2004 Kia Rio
- Curb: 2384 lb
- Test Inertial: 2420 lb
- Dummy: 165 lb
- Gross Static: 2585 lb

Impact Conditions
- Speed: 61.9 mi/h
- Angle: 25.3 degrees
- Location/Orientation: 36 inches upstrm of post 18

Exit Conditions
- Speed: 40.2 mi/h
- Angle: 18.4 degrees

Occupant Risk Values
- Impact Velocity
  - Longitudinal: 21.0 ft/s
  - Lateral: 14.8 ft/s
- Ridedown Accelerations
  - Longitudinal: 9.7 G
  - Lateral: 6.6 G
- THIV: 27.2 km/h
- PHD: 10.2 G
- ASI: 0.86
- Max. 0.050-s Average
  - Longitudinal: -7.5 G
  - Lateral: 5.6 G
  - Vertical: -3.7 G

Post-Impact Trajectory
- Stopping Distance: 140 ft dwnstrm 7.5 ft twd traffic

Vehicle Stability
- Maximum Yaw Angle: 31 degrees
- Maximum Pitch Angle: -4 degrees
- Maximum Roll Angle: -11 degrees
- Vehicle Snagging: No
- Vehicle Pocketing: No

Test Article Deflections
- Dynamic: Rail released
- Permanent: 16 ft
- Working Width: 16 ft

Vehicle Damage
- VDS: 11LFQ5
- CDC: 11FDEW3
- Max. Exterior Deformation: 14.0 inches
- OCDI: LF0000000
- Max. Occupant Compartment Deformation: 0

Figure 5.7. Summary of Results for *MASH* Test 3-37 on the TxDOT 31-inch W-Beam Downstream Anchor Terminal.

CHAPTER 6. SUMMARY AND CONCLUSIONS

6.1 ASSESSMENT OF TEST RESULTS

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

6.1.1 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 TxDOT 31-inch W-Beam Downstream Anchor Terminal contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the W-beam rail element was 16 ft. (PASS)

6.1.2 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: Post 19 fractured at ground level and was resting 50 ft toward the field side directly behind its original position. Post 20 fractured at ground level and was resting 82.5 ft downstream of impact and 30 ft toward the field side. These fragments did not penetrate, nor to show potential for penetrating the occupant compartment.

No deformation or intrusion of the occupant compartment occurred. (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 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were −11 and −4 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 21.0 ft/s, and lateral occupant impact velocity was 14.8 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 9.7 G, and lateral ridedown acceleration was 6.6 G. (PASS)

6.1.3 Vehicle Trajectory

N. Vehicle trajectory behind the test article is acceptable.

Result: The 1100C vehicle came to rest 7.5 ft toward the traffic side. (N/A)

6.2 CONCLUSIONS

Table 6.1 shows that the TxDOT 31-inch W-Beam Downstream Anchor Terminal performed acceptably for *MASH* test 3-37. The terminal successfully released the anchor cable and the vehicle gated through without snagging on the anchor post in an impact downstream of the length of need of the barrier system. Previous crash testing has shown that this anchor system provides sufficient capacity to redirect a vehicle impact in the LON of a connected guardrail system. The TxDOT 31-inch W-Beam Downstream Anchor Terminal would, therefore, be acceptable to provide anchorage for guardrail systems, provided it is only installed in a downstream configuration outside of the clear zone of opposing traffic lanes.

Table 6.1. Performance Evaluation Summary for *MASH* Test 3-37 on the TxDOT 31-inch W-Beam Downstream Anchor Terminal.

Test Agency: Texas Transportation Institute | Test No.: 420021-1 | Test Date: 2011-04-20

***MASH* Test 3-37 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 TxDOT 31-inch W-Beam Downstream Anchor Terminal contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the W-beam rail element was 16 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.*	Posts 19 and 20 fractured at ground level, with 19 resting 50 ft toward the field side directly behind its original position, and 20 resting 82.5 ft downstream of impact and 30 ft toward the field side. These fragments did not penetrate, nor showed potential for penetrating, the occupant compartment.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No deformation or intrusion of the occupant compartment occurred.	Pass
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were −11 and −4 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 21.0 ft/s, and lateral occupant impact velocity was 14.8 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 9.7 G, and lateral ridedown acceleration was 6.6 G.	Pass
Vehicle Trajectory N. *Vehicle trajectory behind the test article is acceptable.*	The 1100C vehicle came to rest 7.5 ft toward the traffic side.	N/A

CHAPTER 7. IMPLEMENTATION STATEMENT

Installation details for the TxDOT 31-inch W-Beam Downstream Anchor Terminal are included in Appendix A and the AASHTO-ARTBA-AGC *Guide to Standardized Highway Barrier Hardware*. The Design Division should review these details. If the Division chooses to add this terminal to its current list of hardware standards, then they should develop a standard detail sheet that districts could use across the state as a nonproprietary alternative method for anchoring downstream ends of guardrails outside the clear zone of opposing traffic lanes.

REFERENCES

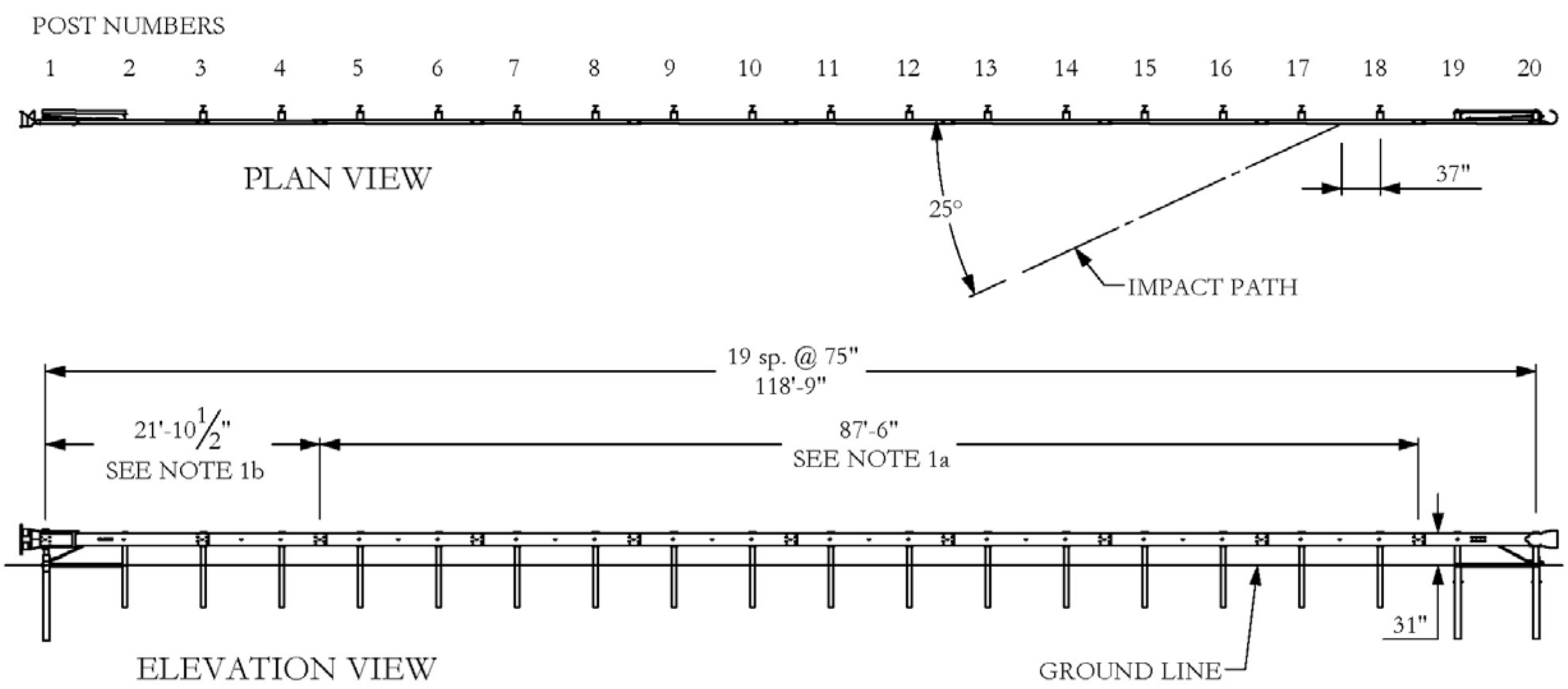
1. AASHTO, *Manual for Assessing Safety Hardware*, American Association of State Highway and Transportation Officials, Washington, DC, 2009.

2. AASHTO-ARTBA-AGC Task Force 13, *A Guide to Standardized Highway Barrier Hardware*, American Association of State Highway and Transportation Officials-American Road and Transportation Builders of America-Associated General Contractors of America, http://guides.roadsafellc.com/Documents/Hardware/Guide/intro.html, accessed October 25, 2011.

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

4. R.P. Bligh, A. Abu-Odeh, W.L. Menges, *MASH Test 3-10 on 31-Inch W-Beam Guardrail with Standard Offset Blocks*, Test Report No. 9-1002-4, Texas Transportation Institute, March 2011.

420021-1 TEST INSTALLATION



1a. SLP Posts (W6x8.5 x 72") with 8" Wood Block-outs and standard hardware at locations 3 - 18. 4-space 12-1/2' W-beam Guardrail with standard hardware from midspan between locations 4 and 5 to between 18 and 19.

1b. Upstream Terminal (Posts 1 - 4) has CRP Post at Post 1, SYTP at Post 2, with 3" Angle Strut and standard hardware. Also 12-1/2' ET rail and ET head with standard hardware. 9' 4-1/2" 12 gauge W-beam from Post 3 to midspan between Posts 4 and 5.

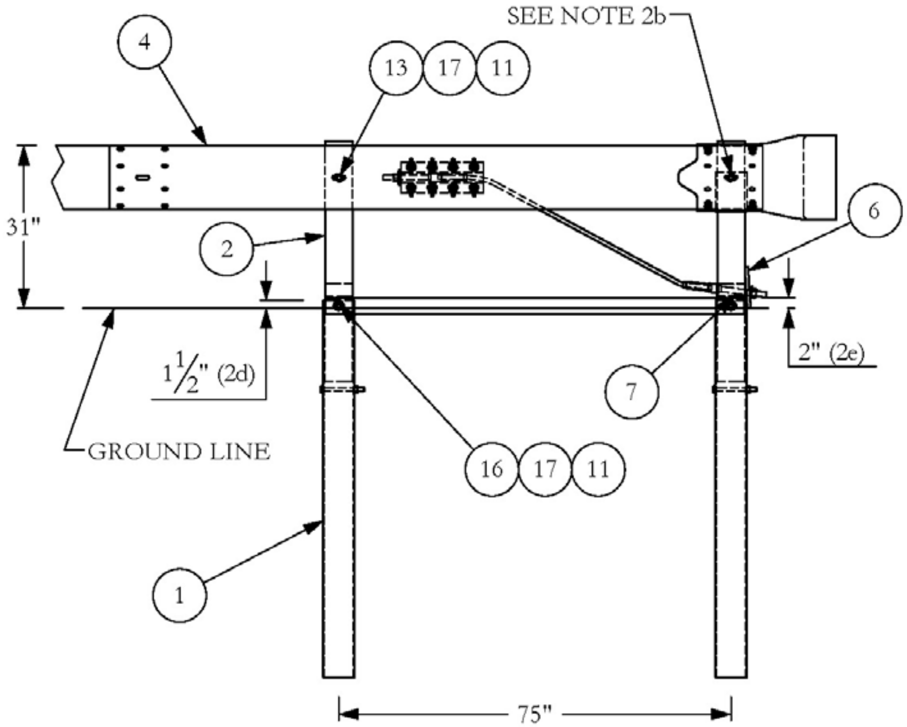
The Texas A&M University System							
Revisions:				Texas Transportation Institute College Station, Texas 77843			
No.	Date	By	Chk				
1.	2011-04-05	GS	DA	Date	Drawn By	Scale	Sheet No.
2.	2011-04-25	GS	RB	2011-03-30	GES	1:150	1 of 5
3.				Project No.		Sheet Name	
4.				420021-1		Test Installation	
5.				TxDOT Downstream W-beam Terminal			
Approved: Roger Bligh:				Signature: Roger Bligh		Date: 2011-04-25	

T:\2010-2011\420021\-1 Downstream Terminal\Drafting\Drawings\420021-1 Drawing

#	PART NAME	QTY.	ARTBA
1	6 x 8 x 72" Foundation Tube	2	
2	Tube Post for Terminal	2	
3	Strut, Channel	2	
4	Rail for Terminal	1	
5	Shelf Angle Bracket	1	FPP02
6	BCT Bearing Plate	1	FPB01
7	BCT Post Sleeve	1	FMM02
8	Guardrail Anchor Bracket	1	FPA01
9	W-beam End Section	1	RWE03a
10	BCT Cable Anchor	1	FCA01
11	Nut, Recessed Guardrail	20	FBB
12	Bolt, Button-head 1-1/4"	4	FBB01
13	Bolt, Button-head 10"	2	FBB03
14	Bolt, 5/8 -11 x 2 hex	8	FBX16a
15	Bolt, 5/8 -11 x 8 hex	4	FBX16a
16	Bolt, 5/8 -11 x 10 hex	2	FBX16a
17	Washer, 5/8 flat	18	FWC16a

2a. All hardware is A307 unless otherwise indicated.
2b. Rail is supported by Shelf Angle Bracket (5) at Post 20 and does not attach to post.
2c. Parts 1, 2, 11, 13, and 15 - 17 callouts at Post 19 or 20 typical at both locations.
2d. Foundation Tube protrudes 1-1/2" above ground line.
2e. Top edge of Strut at 2" above ground line.

DOWNSTREAM TERMINAL
ELEVATION VIEW



The Texas A&M University System							
Revisions:				Texas Transportation Institute College Station, Texas 77843			
No.	Date	By	Chk				
1.	2011-04-05	GS	DA	Date	Drawn By	Scale	Sheet No.
2.				2011-03-30	GES	1:30	2 of 5
3.				Project No.		Sheet Name	
4.				420021-1		Downstream Terminal	
5.				TxDOT Downstream W-beam Terminal			

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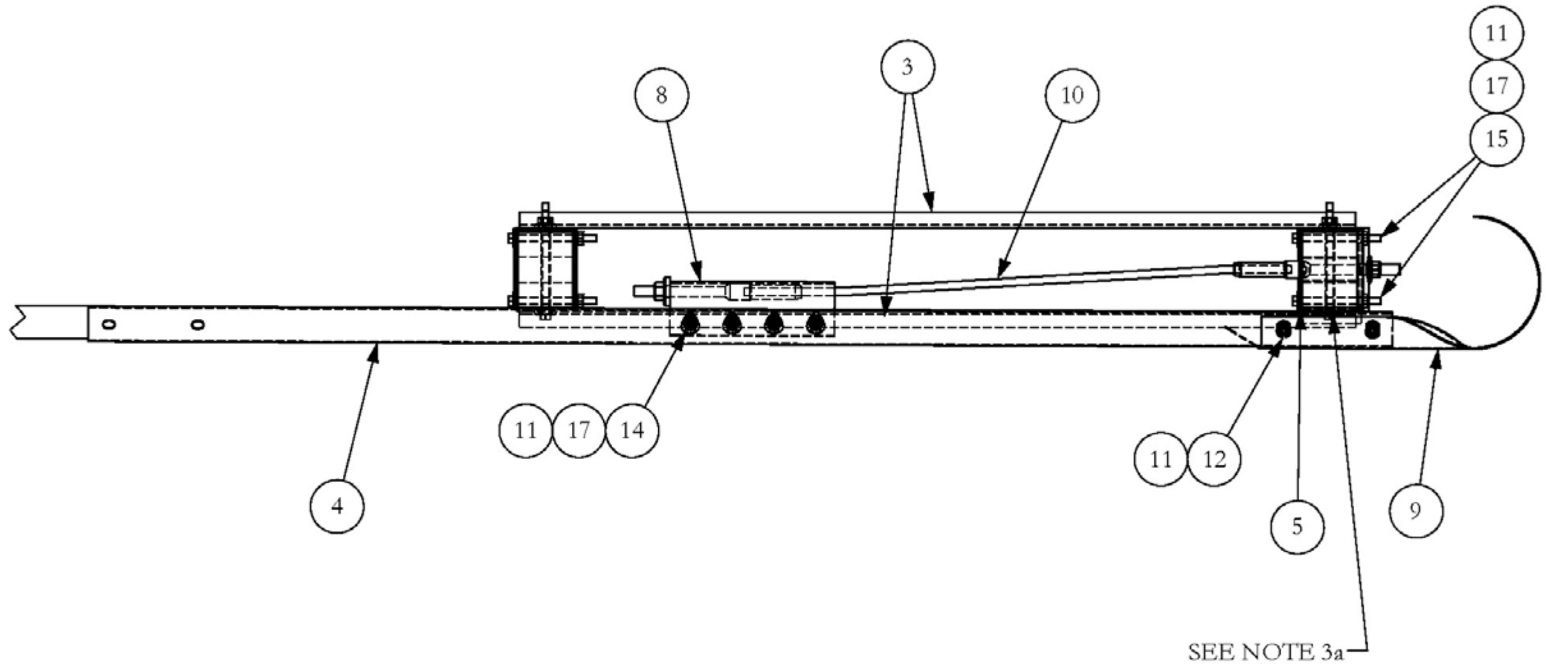
DOWNSTREAM TERMINAL
PLAN VIEW



3a. Rail is supported by Shelf Angle Bracket (5) at Post 20 and does not attach to post.

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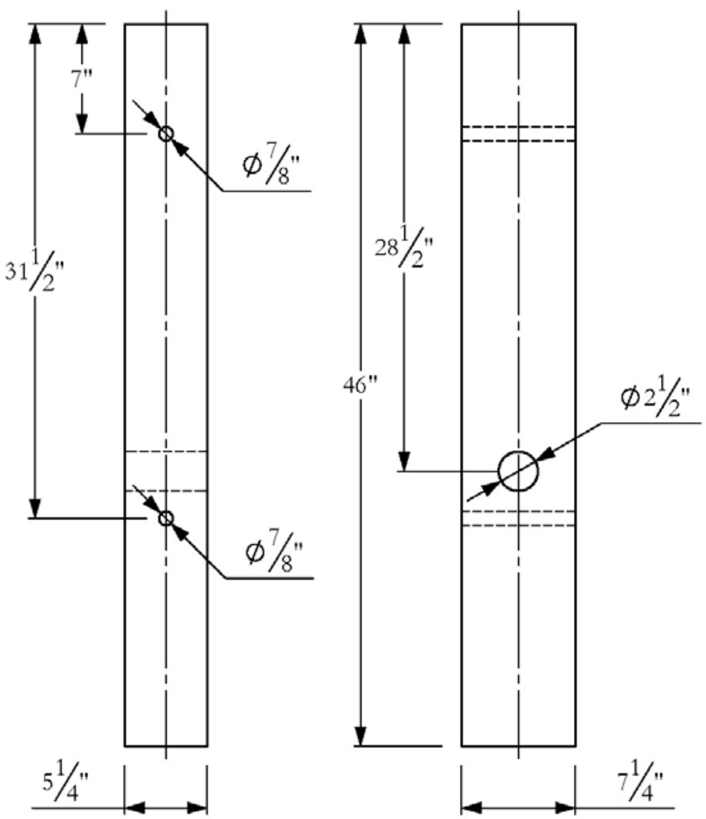
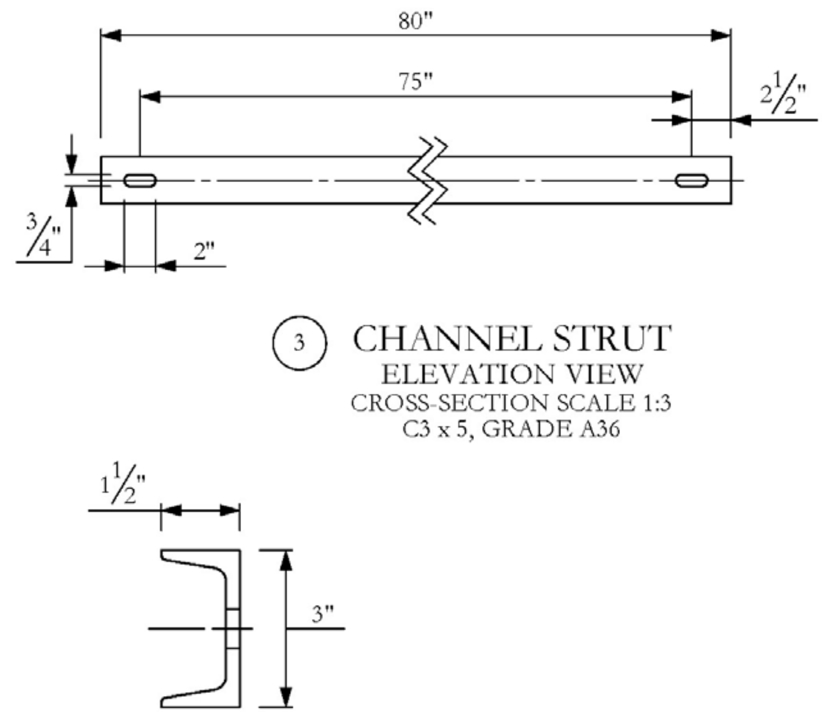
Revisions:				Texas Transportation Institute College Station, Texas 77843			
No.	Date	By	Chk				
1.	2011-04-05	GS	DA	Date	Drawn By	Scale	Sheet No.
2.				2011-03-30	GES	1:15	3 of 5
3.				Project No.	Sheet Name		
4.				420021-1	Terminal - Plan View		
5.				TxDOT Downstream W-beam Terminal			



(2) TUBE POST FOR TERMINAL
ELEVATION VIEWS
TREATED S4S YELLOW PINE



(3) CHANNEL STRUT
ELEVATION VIEW
CROSS-SECTION SCALE 1:3
C3 x 5, GRADE A36

The Texas A&M University System							
Revisions:				Texas Transportation Institute College Station, Texas 77843			
No.	Date	By	Chk				
1.	2011-04-25	GS	RB	Date	Drawn By	Scale	Sheet No.
2.				2011-03-30	GES	1:10	4 of 5
3.				Project No.	Sheet Name		
4.				420021-1	Parts a		
5.				TxDOT Downstream W-beam Terminal			

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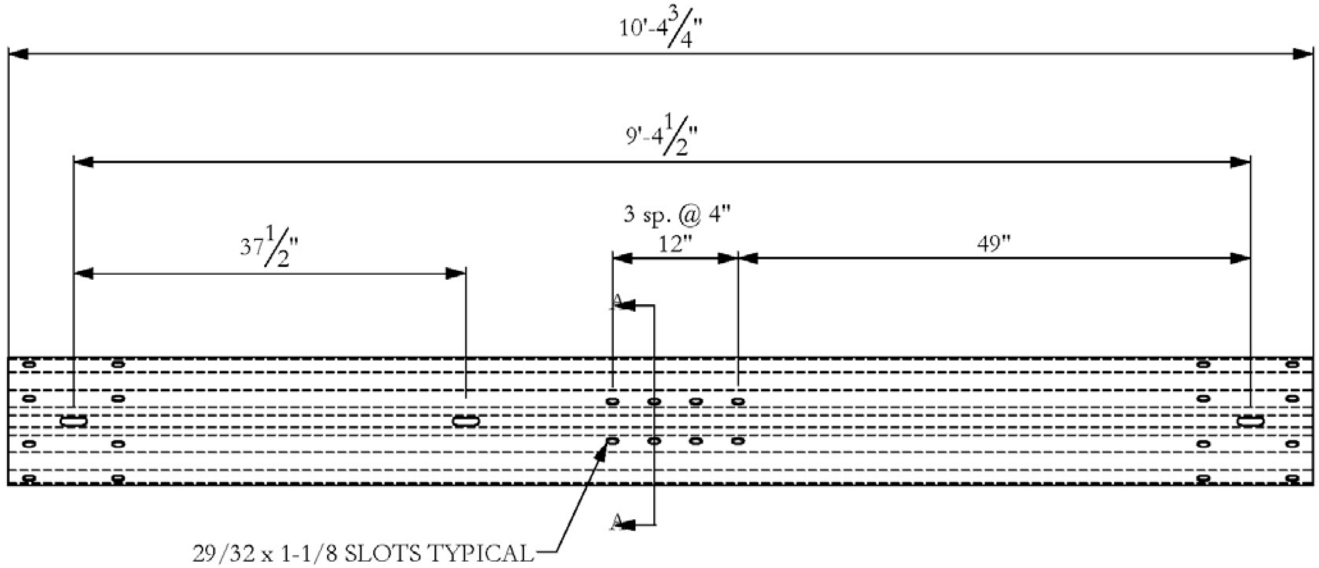
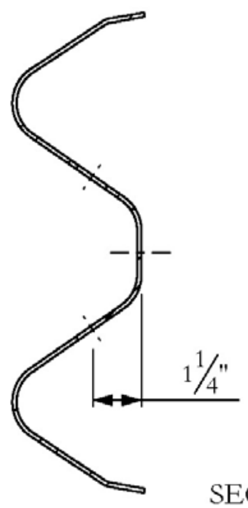


(4) RAIL FOR TERMINAL

12 GAUGE W-BEAM



SECTION A-A
SCALE 1 : 4

5a. See ARTBA #RWM02a for all dimensions not shown here.

The Texas A&M University System

Revisions:			
No.	Date	By	Chk
1.			
2.			
3.			
4.			
5.			

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College Station, Texas 77843

Date	Drawn By	Scale	Sheet No.
2011-03-30	GES	1:15	5 of 5

Project No.	Sheet Name
420021-1	Parts b

TxDOT Downstream W-beam Terminal

T:\2010-2011\420021\-1 Downstream Terminal\Drafting\Drawings\420021-1 Drawing

APPENDIX B. CERTIFICATION DOCUMENTATION

MATERIAL USED

TEST NUMBER 420021-1

TEST NAME TxDOT Downstream W-beam Terminal

DATE 2011-04-20

DATE RECEIVED	ITEM NUMBER	DESCRIPTION	SUPPLIER	HEAT #	NOTE
2011-04-01	Channel-01	C3x5 x 20'	Mack Bolt & Steel	JW1010766402	1
2010-06-11	W-beam 9	12ga 4-sp 19'-4.5" BLK	Trinity	various - see file	2
2010-04-27	Strap 6-9	6x1/4x20' A36 ORA	Aleron	SP203417	3
2009-04-30	Cable-SWG 4	3/4" X 6'6" DBL SWG RED	Trinity	generic Trinity	
2010-11-29	W-beam 04	12 ga. 4-space	Trinity Industries	several - see list	
2008 08 12	POST-SLP-1	6x8.5x72" YEL	TRINITY	11812600/11812610	

1. Used for strut on downstream anchor.
2. Terminal Rail
3. Used to make shelf angle bracket at Post 20.

04-01-2011 08:05 Load - 990222 BL - 3657015 BLR466
Mack Bolt & Steel Heat - JW1010734601
Cust. PO - 20526 Order-Line - 6149531 / 2
Nucor Steel 12/30/2010 11:46:03 AM PAGE 1/002 Fax Server

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: 30-Dec-2010
B.L. Number: 559947
Load Number: 174056

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

NBMG-08 March 24, 2009

HEAT NUM.*	DESCRIPTION	PHYSICAL TESTS: 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# =>	6305763												
JW1010662501	Nucor Steel - Texas	54,800	71,300	20.0%			10	.81	.010	.031	.19	.33	
	8x11.5# Channel	378MPa	492MPa				.16	.16	.047	.003	.016		
	20' 0" A36/A572GR50	56,800	72,800	20.0%									
	ASTM A36/A36M-08 ASTM A572/A572-07 GR 50 TY1	392MPa	502MPa										
PO# =>	6307762												
JW1010734601	Nucor Steel - Texas	54,100	76,200	21.0%			.11	.81	.011	.036	.21	.42	.39
	3x5.0# Channel	373MPa	525MPa				.31	.23	.087	.002	.011		
	40' 0" A36/A529 GR50	54,600	75,900	21.0%									
	ASTM A36-08, A529-05, A709-09a G R36, ASME SA36-07 Ed 09 Ad	376MPa	523MPa										
	COMPLIES WITH DIN 50049 PARA 3.1B & EN 10204-3.1												
PO# =>	6306916												
JW1010766402	Nucor Steel - Texas	50,900	67,500	22.0%			11	.77	.008	.030	.18	.39	.32
	1/4x10" Flat	351MPa	465MPa				.19	.16	.057	.002	.002		
	20' A36	50,700	65,700	21.0%									
	ASTM A36/A36M-08, A709/A709M-09a GR36, ASME SA36-07 Ed 09 Ad ASTM A709/A709M-08 GR 36 ASME SA36-2007 EDITION-2009 ADDENDA	350MPa	453MPa										

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

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

QUALITY ASSURANCE: Nathan Stewart

Certified Analysis

Trinity Highway Products , LLC

2548 N.E. 28th St.

Ft Worth, TX 76111

Customer: SAMPLES,TESTING,TRAINING MTRLS

2525 STEMMONS FRWY

DALLAS, TX 75207

Order Number: 1072852

Customer PO:

BOL Number: 31302

Document #: 2

Shipped To: TX

Use State: TX

As of: 6/25/10

Project: SAMPLES-TESTING THIS ORDER FOR END TERMINALS ONLY!

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
4	10967G	12/9'4.5/3'1.5/S	M-180	A	2	100929	557,000	77,800	26.0	0.190	0.750	0.009	0.001	0.020	0.140	0.00	0.050	0.002	4
			M-180	A	2	100928	63,610	80,920	25.2	0.190	0.750	0.011	0.004	0.030	0.090	0.000	0.040	0.000	4
			M-180	A	2	101800	50,000	73,300	30.0	0.190	0.750	0.012	0.002	0.020	0.120	0.000	0.070	0.002	4
			A-500		2	202248	53,600	75,500	29.0	0.190	0.780	0.011	0.020	0.120	0.120	0.000	0.050	0.002	4
			M-180	A	2	202249	51,800	74,500	30.0	0.190	0.790	0.010	0.002	0.020	0.120	0.000	0.050	0.002	4
2	33795G	SYT-3"AN STRT 3-HL 6'6	A-36			V906151	52,710	75,060	29.5	0.130	0.700	0.011	0.022	0.200	0.240	0.00	0.100	0.021	4

39

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

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

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.

ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36

ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.

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

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 25th day of June, 2010

Notary Public:
Commission Expires:

DANIELLA LEE ROBINSON
Notary Public, State of Texas
My Commission Expires
November 05, 2013

Trinity Highway Products, LLC

Certified By: [signature]
Quality Assurance

SOLD TO: ALAMO IRON WORKS INC - DIP
STEEL SERV CTR/AP#66365
PO BOX 231
SAN ANTONIO, TX 78291-0231

SHIP TO: ALAMO IRON WORKS INC - DIP
943 AT&T CENTER PKWY
SAN ANTONIO, TX 78219-0000

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NUCOR CORPORATION
NUCOR STEEL TEXAS

CERTIFIED MILL TEST REPORT

Page: 2

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

Date: 13-Apr-2010
B.L. Number: 540065
Load Number: 156435

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

NBMG-08 March 24, 2009

HEAT NUM. *	DESCRIPTION	PHYSICAL TESTS: 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# =>	SP203417												
JW1010177401	Nucor Steel - Texas	46,300	68,800	26.0%			.11	.72	.018	.040	.16	.25	.32
	3x2x1/4 Angle	319MPa	474MPa				.14	.24	.080	.003	.002		
	20' A36	46,000	67,100	25.0%									
	ASTM A36/A36M-08, A709/709M-09 GR36, ASME SA36-07	317MPa	463MPa										
PO# =>	SP203417												
JW1010199101	Nucor Steel - Texas	48,600	64,600	26.0%			.10	.66	.014	.020	.20	.34	.27
	1/4x1" Flat	335MPa	445MPa				.14	.13	.032	.002	.001		
	20' A36	49,500	65,100	27.0%									
	ASTM A36/A36M-08, A709/A709M-07 GR36, ASME SA36-07	341MPa	449MPa										
PO# =>	SP203417												
JW1010203201	Nucor Steel - Texas	47,400	66,200	30.0%			.12	.75	.020	.020	.19	.34	.32
	1/4x3" Flat	327MPa	456MPa				.12	.18	.039	.003	.003		
	20 ' A36	46,900	66,200	30.0%									
	ASTM A36/A36M-08, A709/A709M-07 GR36, ASME SA36-07	323MPa	456MPa										
PO# =>	SP203417												
JW1010242001	Nucor Steel - Texas	46,300	64,000	27.0%			.09	.51	.013	.020	.15	.26	.23
	1/4x6" Flat	319MPa	441MPa				.11	.13	.024	.002	.001		
	20' A36	47,600	65,400	28.0%									
	ASTM A36/A36M-08, A709/A709M-07 GR36, ASME SA36-07	328MPa	451MPa										

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

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

QUALITY ASSURANCE: Ben Cave

Ben R Cave

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

Customer: SAMPLES, TESTING MATERIALS
2525 STEMMONS FRWY

DALLAS, TX 75207

Sales Order: 1072852
Customer PO:
BOL # 27227
Document # 1

Print Date: 4/28/09
Project: SAMPLES-TESTING THIS ORDER FOR END TERMI
Shipped To: TX
Use State: TX

Trinity Highway Products, LLC

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

NCHRP Report 350 Compliant

Pieces	Description
4	3/16X12.5X16 CAB ANC BRKT
4	CBL 3/4X6'6/DBL SWG/NOHWD
20	1" ROUND WASHER F844
20	1" HEX NUT A563

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

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

State of Texas, County of Tarrant. Sworn and Subscribed before me this day of April, 2009

RACHEL R. MEDINA
Notary Public
STATE OF TEXAS
My Comm. Exp. 07/13/2009

Notary Public:
Commission Expires: /

Trinity Highway Products, LLC

Certified By: ______________________
Quality Assurance

Certified Analysis

Trinity Highway Products , LLC
1170 N. State St.
Girard, OH 44420
Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207

Order Number: 1138956
Customer PO:
BOL Number: 45213
Document #: 1
Shipped To: TX
Use State: TX

As of: 11/23/10

Project: SAMPLES-TESTING THIS ORDER FOR ETS ONLY!

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
50	11G	12/12'6/3'1.5/S	M-180	A	2	115269	63,300	80,810	24.4	0.190	0.730	0.012	0.005	0.020	0.120	0.00	0.050	0.000	4
			M-180	A	2	130794	63,340	81,340	26.6	0.190	0.750	0.011	0.003	0.030	0.110	0.000	0.060	0.000	4
			M-180	A	2	130795	67,780	82,110	26.0	0.180	0.740	0.014	0.004	0.020	0.150	0.000	0.060	0.000	4
			M-180	A	2	130796	62,260	83,370	23.6	0.190	0.730	0.010	0.003	0.030	0.140	0.000	0.060	0.000	4
			M-180	A	2	130873	57,900	80,400	21.3	0.210	0.900	0.018	0.006	0.018	0.020	0.000	0.020	0.000	4
			M-180	A	2	130873	66,280	84,600	21.0	0.190	0.750	0.015	0.004	0.020	0.140	0.000	0.060	0.000	4
			M-180	A	2	130875	62,030	79,880	23.0	0.190	0.740	0.013	0.003	0.020	0.160	0.000	0.060	0.000	4
			M-180	A	2	130875	64,300	84,800	20.2	0.220	0.880	0.019	0.007	0.020	0.030	0.000	0.020	0.000	4

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

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ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36

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

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

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Ohio, County of Trumbull. Sworn and subscribed before me this 23rd day of November, 2010

Notary Public: Angela A. Koleszar
Commission Expires: / /

NOTARIAL SEAL — STATE OF OHIO
ANGELA A KOLESZAR
NOTARY PUBLIC - OHIO
MY COMMISSION EXPIRES JUNE 22, 2015

Trinity Highway Products , LLC
Certified By: [signature]
Quality Assurance

Certified Analysis

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

DALLAS, TX 75207
Project: T-8 TESTING **Must include certs with truck!!!*

Order Number: 1069934
Customer PO: SAMPLES
BOL Number: 24967
Document #: 1
Shipped To: TX
Use State: TX

As of: 8/8/08

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
50	545G	6'0 POST/DB:DDR	A-709			11812600	48,700	69,700	24.3	0.120	0.730	0.011	0.042	0.230	0.240	0.000	0.120	0.002	4
	545G		A-36			11812610	46,400	66,000	26.4	0.110	0.730	0.008	0.039	0.200	0.230	0.000	0.120	0.001	4

Item # - POST-SLP-1
6 x 8.5 x 72" YEL
MFG - TRINITY

Item # - BLK-OUT-RT-1
6X8X14 WOOD RED
MFG - TRINITY

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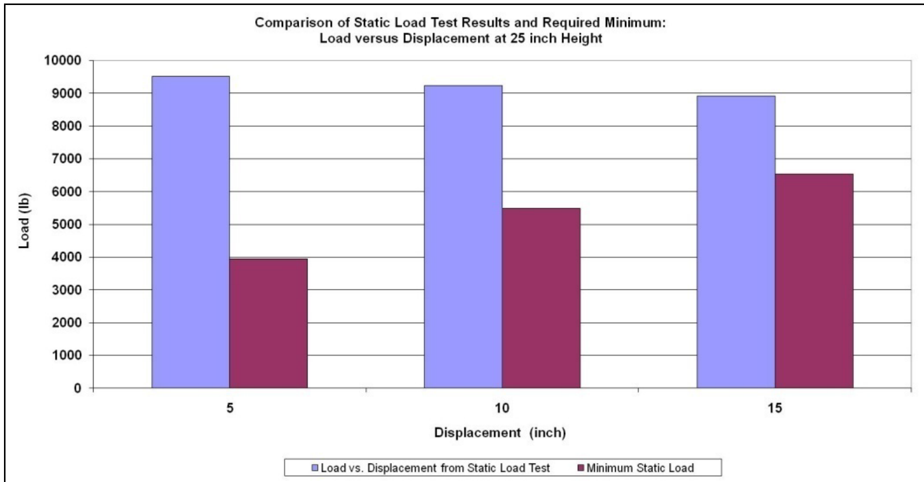
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 8th day of August, 2008

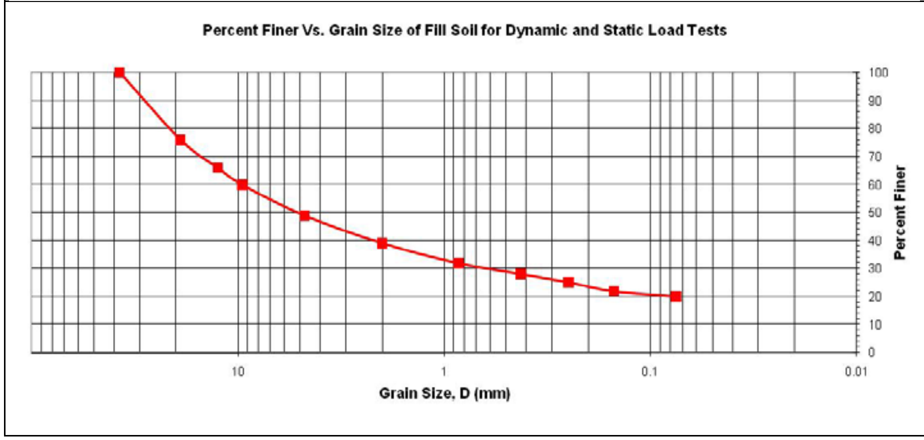
Notary Public:
Commission Expires:

RACHEL R. MEDINA
Notary Public
State of Texas
My Commission Expires
July 13, 2009

Trinity Highway Products , LLC
Certified By: Stefanie Ingle

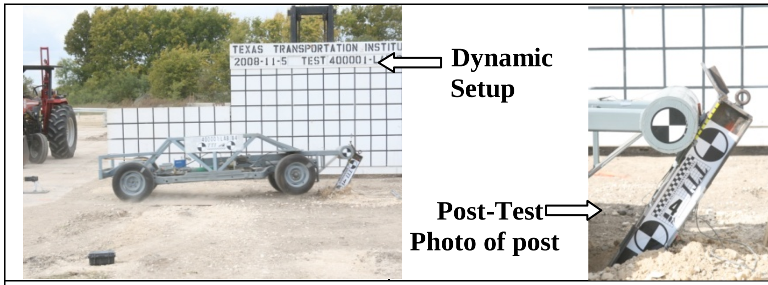


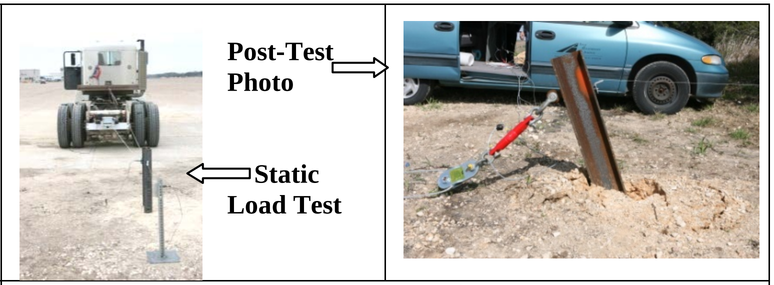
Static Load Setup

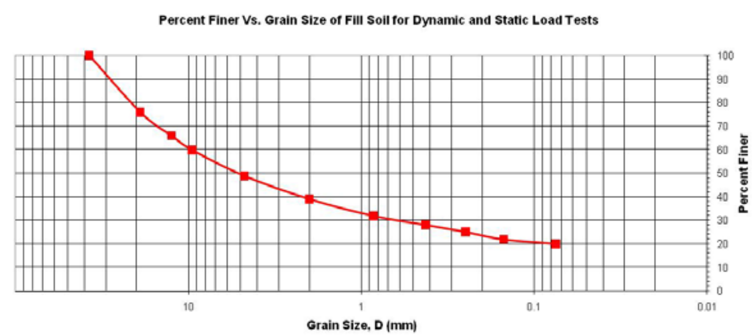


Post-Test Photo of Post

Date	2011-04-20
Test Facility and Site Location	TTI Proving Ground—3100 SH 47, Bryan, TX
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor







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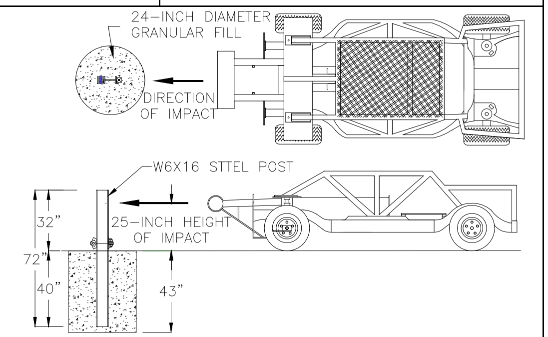
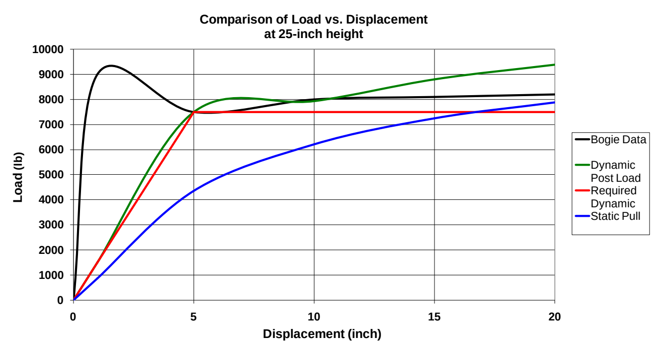
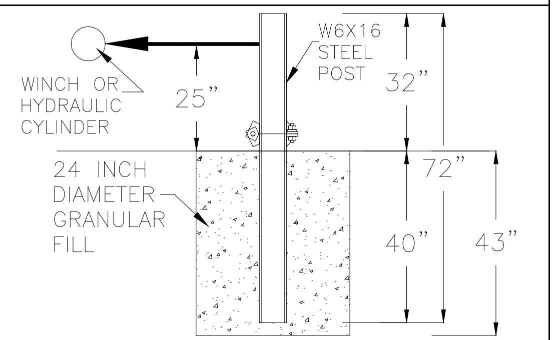




Static Load Test Installation Details



Date	2008-11-05
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis above)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor
Bogie Weight	5009 lb
Impact Velocity	20.5 mph

APPENDIX D. TEST VEHICLE PROPERTIES AND INFORMATION

Table D1. Vehicle Properties for Test No. 420021-1.

Date: 2011-04-20 Test No.: 420021-1 VIN No.: KNADC125646294690

Year: 2004 Make: Kia Model: Rio

Tire Inflation Pressure: 32 psi Odometer: 101440 Tire Size: 185/65R14

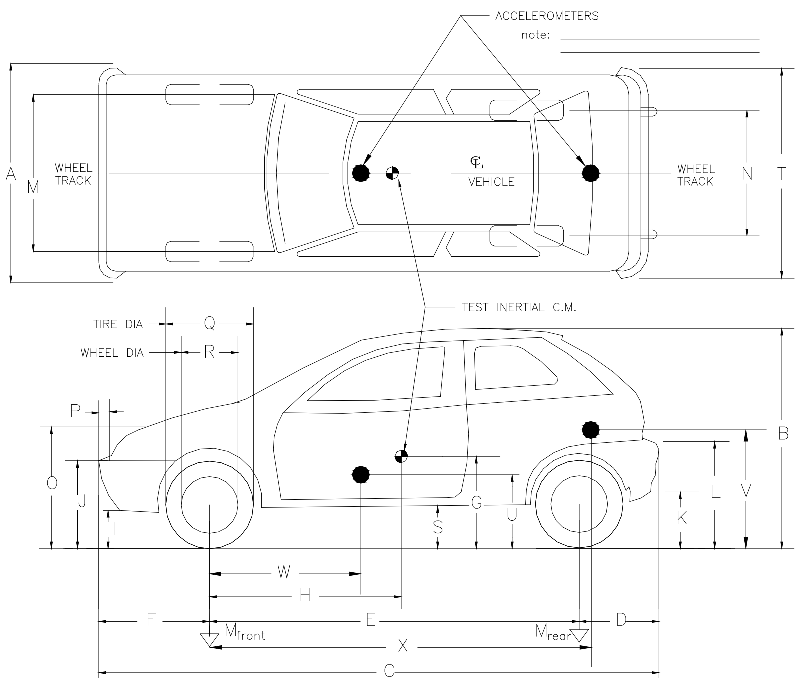
Describe any damage to the vehicle prior to test: ______

● Denotes accelerometer location.

NOTES: ______

Engine Type: ______
Engine CID: ______
Transmission Type:
____ Auto or ____ Manual
____ FWD ____ RWD ____ 4WD
Optional Equipment: ______

Dummy Data:
Type: 50th percentile male
Mass: 165 lb
Seat Position: Driver



Geometry: inches

A	62.50	F	32.00	K	12.00	P	3.25	U	15.50
B	56.12	G		L	24.25	Q	22.50	V	21.50
C	164.25	H	34.05	M	56.50	R	15.50	W	35.50
D	37.00	I	8.50	N	57.00	S	8.62	X	104.50
E	95.25	J	22.75	O	28.00	T	63.00		

Wheel Center Ht Front 10.75 Wheel Center Ht Rear 11.125

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial		Gross Static	
Front	1691	M_{front}	1530	1555	Allowable	1653	Allowable
Back	1559	M_{rear}	854	865	Range	932	Range =
Total	3250	M_{Total}	2384	2420	2420 ±55 lb	2585	2585 ±55 lb

Mass Distribution:
lb LF: 785 RF: 770 LR: 416 RR: 449

Table D2. Exterior Crush Measurements for Test No. 420021-1.

Date: 2011-04-20 Test No.: 420021-1 VIN No.: KNADC125646294690

Year: 2004 Make: Kia Model: Rio

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	24.0	11.0	30.0	11.0	7.0	4.5	3.0	1.5	0	-15.0
2	Side plane at bumper ht	24.0	14.0	40.0	0	3.0	7.0	11.0	13.3	14.0	+60.0
	Measurements recorded										
	in inches										

[1]Table taken from the 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).

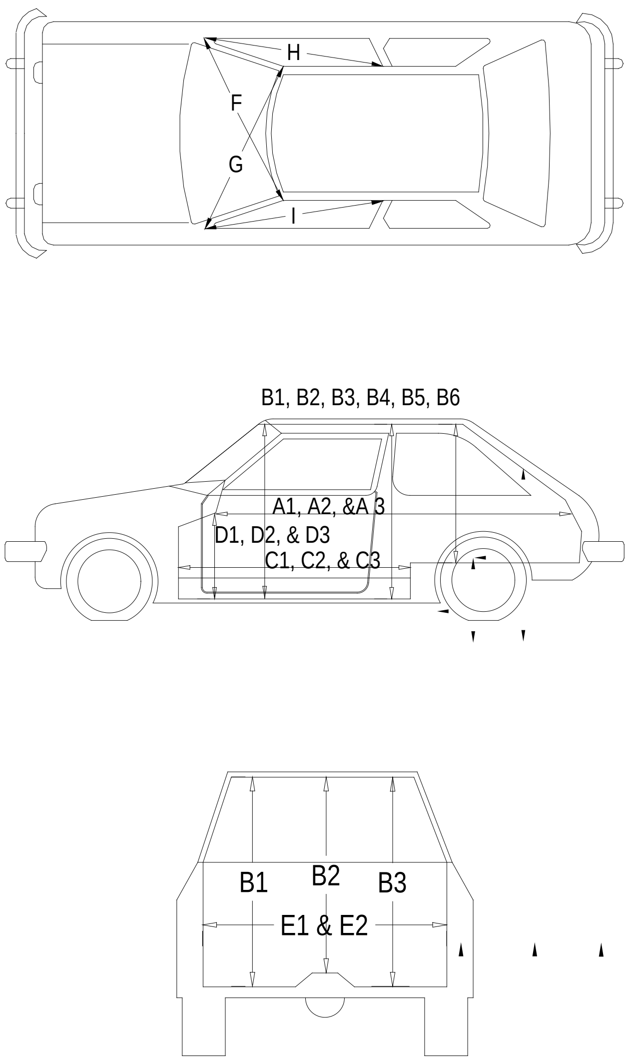
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table D3. Occupant Compartment Measurements for Test No. 420021-1.

Date: 2011-04-20 Test No.: 420021-1 VIN No.: KNADC125646294690

Year: 2004 Make: Kia Model: Rio



OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	67.12	67.12
A2	65.25	65.25
A3	67.25	67.25
B1	40.00	40.00
B2	35.50	35.50
B3	40.00	40.00
B4	34.75	34.75
B5	34.50	34.50
B6	34.75	34.75
C1	26.75	26.75
C2	-----	-----
C3	26.75	26.75
D1	9.75	9.75
D2	-----	-----
D3	9.00	9.00
E1	49.25	49.25
E2	50.50	50.50
F	49.00	49.00
G	49.00	49.00
H	36.25	36.25
I	36.25	36.25
J*	50.25	50.25

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

APPENDIX E. SEQUENTIAL PHOTOGRAPHS

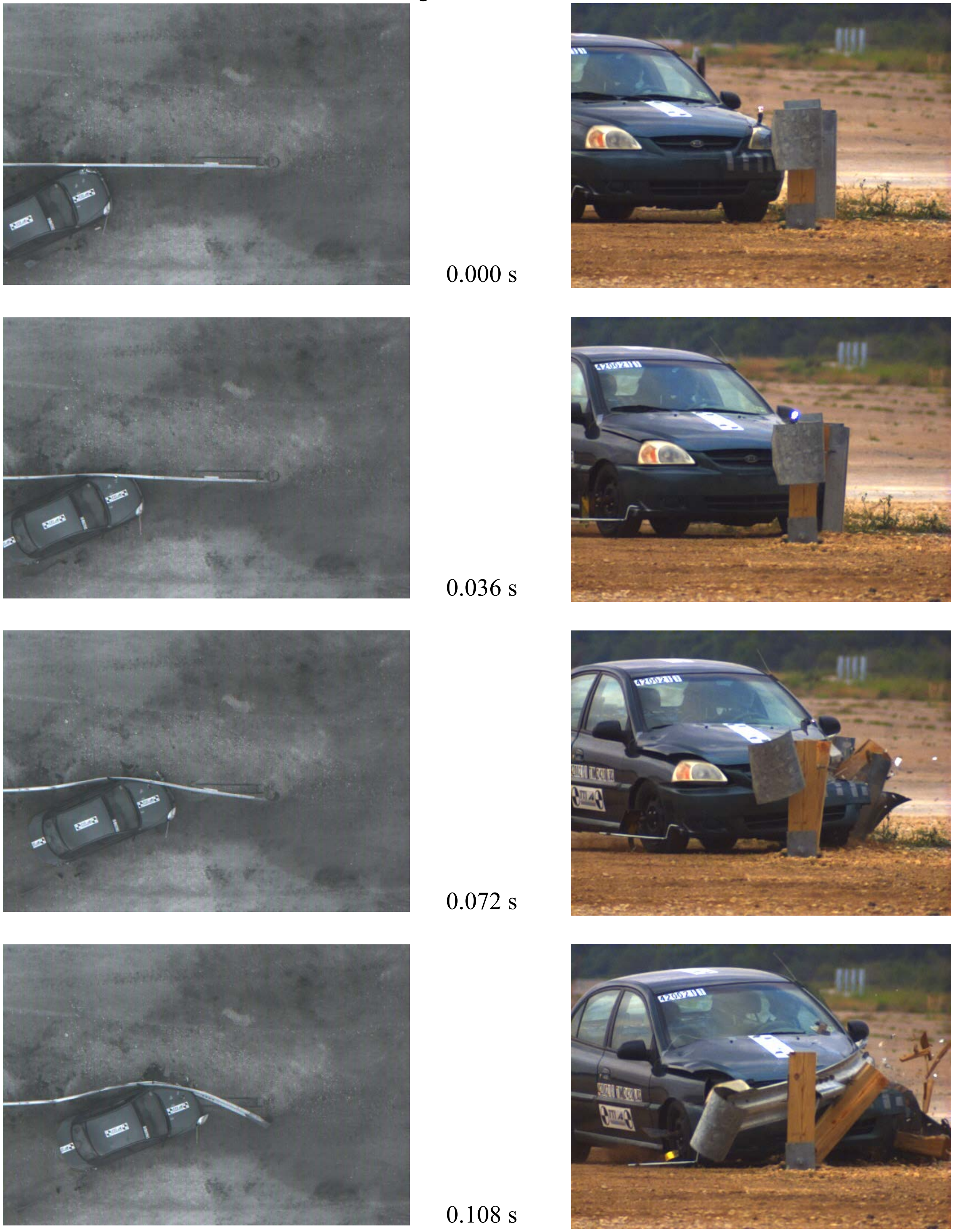


Figure E1. Sequential Photographs for Test No. 420021-1 (Overhead and Frontal Views).

0.144s

0.180 s

0.217 s

0.252 s

Figure E1. Sequential Photographs for Test No. 420021-1 (Overhead and Frontal Views) (continued).

0.000 s

0.036 s

0.072 s

0.108 s

0.144 s

0.180 s

0.217 s

0.252 s

Figure E2. Sequential Photographs for Test No. 420021-1 (Rear View).

APPENDIX F. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS

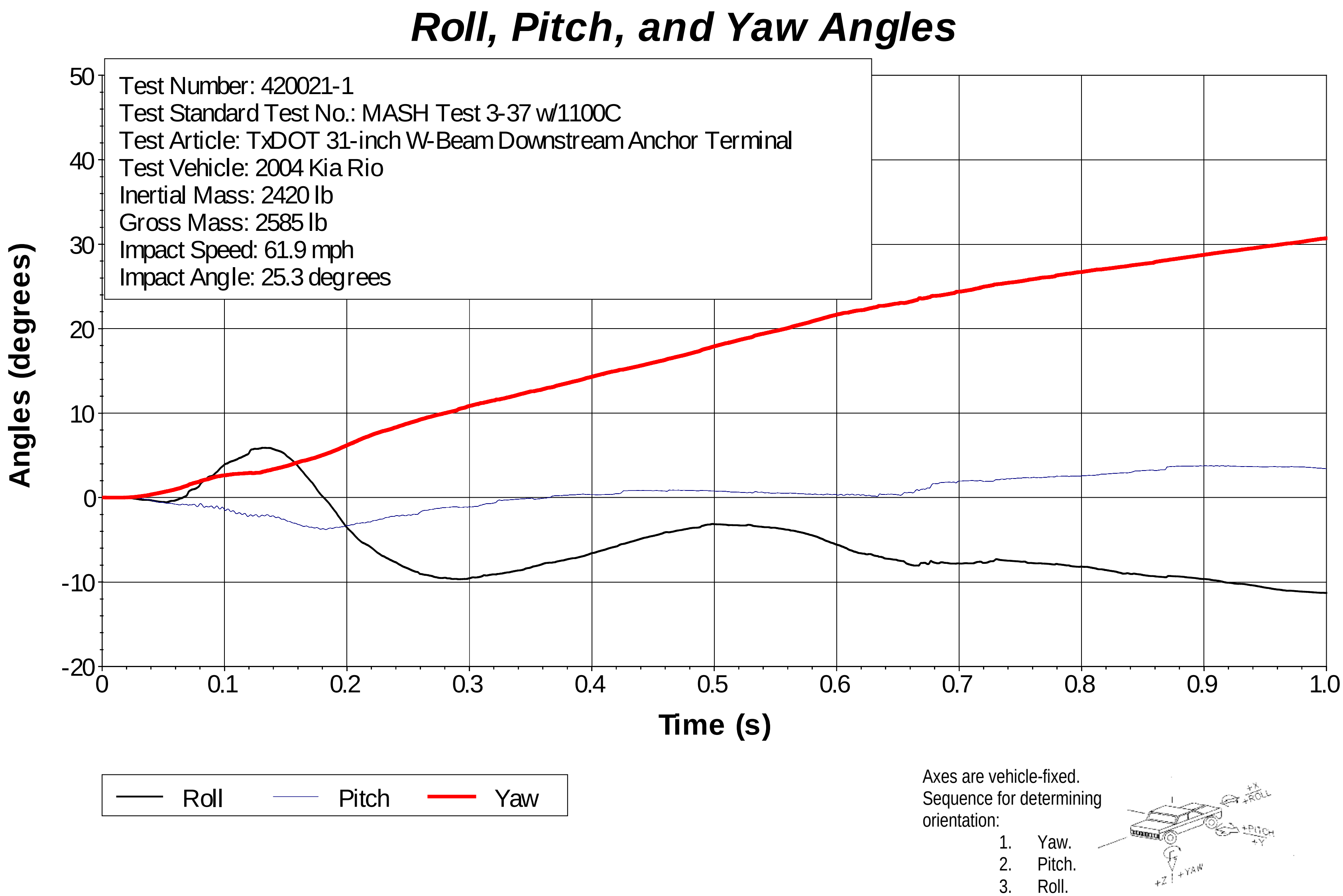


Figure F1. Vehicle Angular Displacements for Test No. 420021-1.

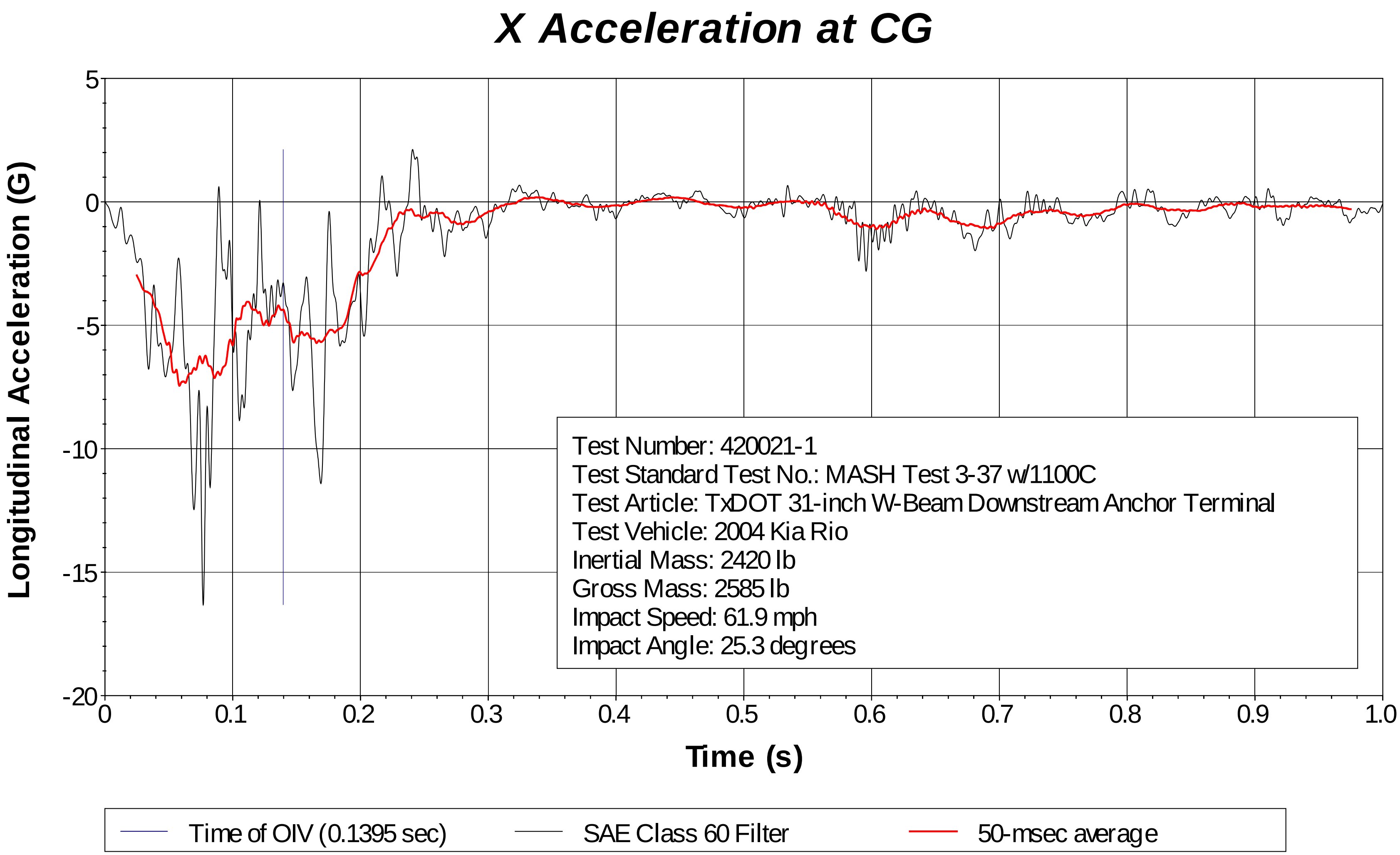


Figure F2. Vehicle Longitudinal Accelerometer Trace for Test No. 420021-1 (Accelerometer Located at Center of Gravity).

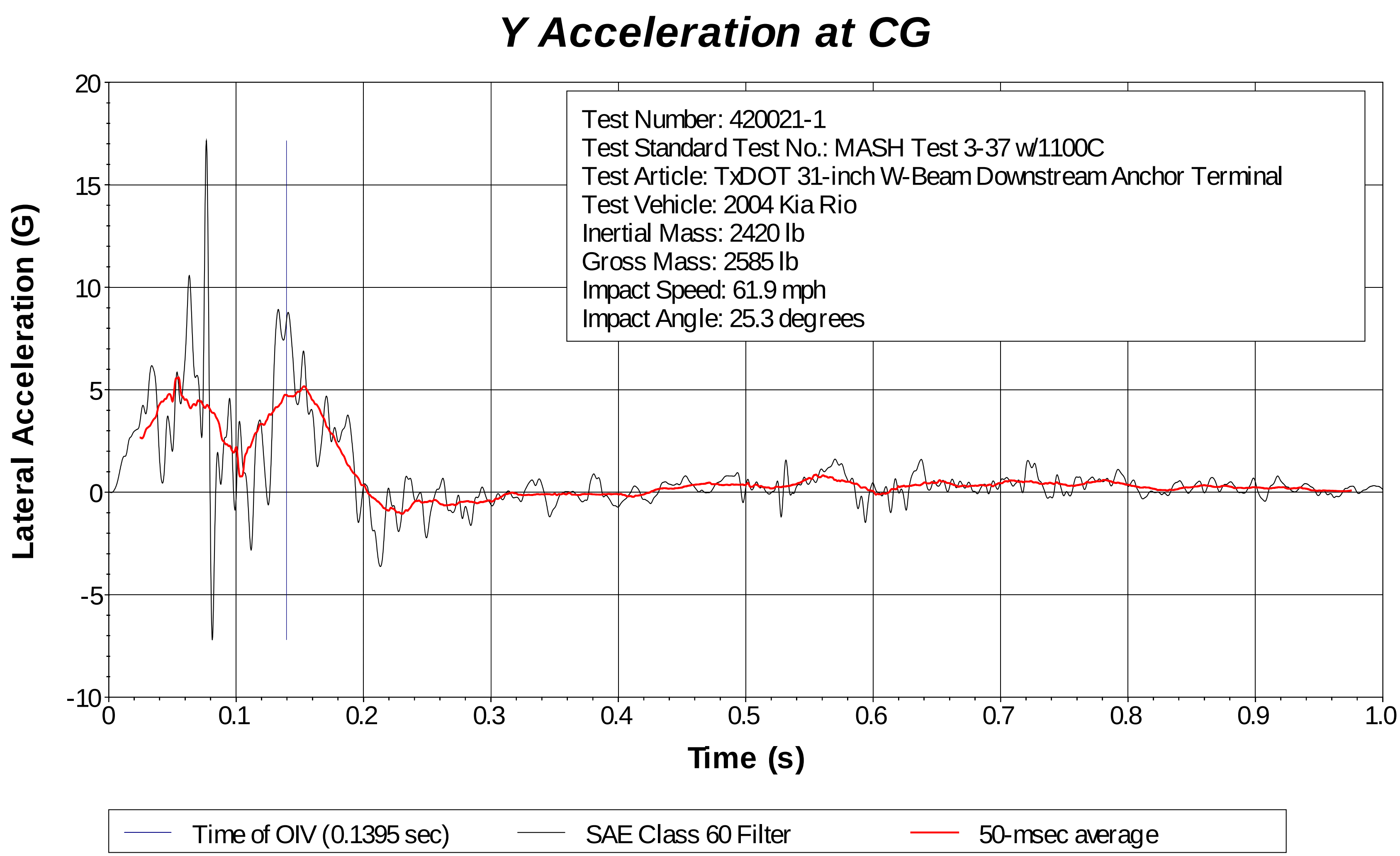


Figure F3. Vehicle Lateral Accelerometer Trace for Test No. 420021-1 (Accelerometer Located at Center of Gravity).

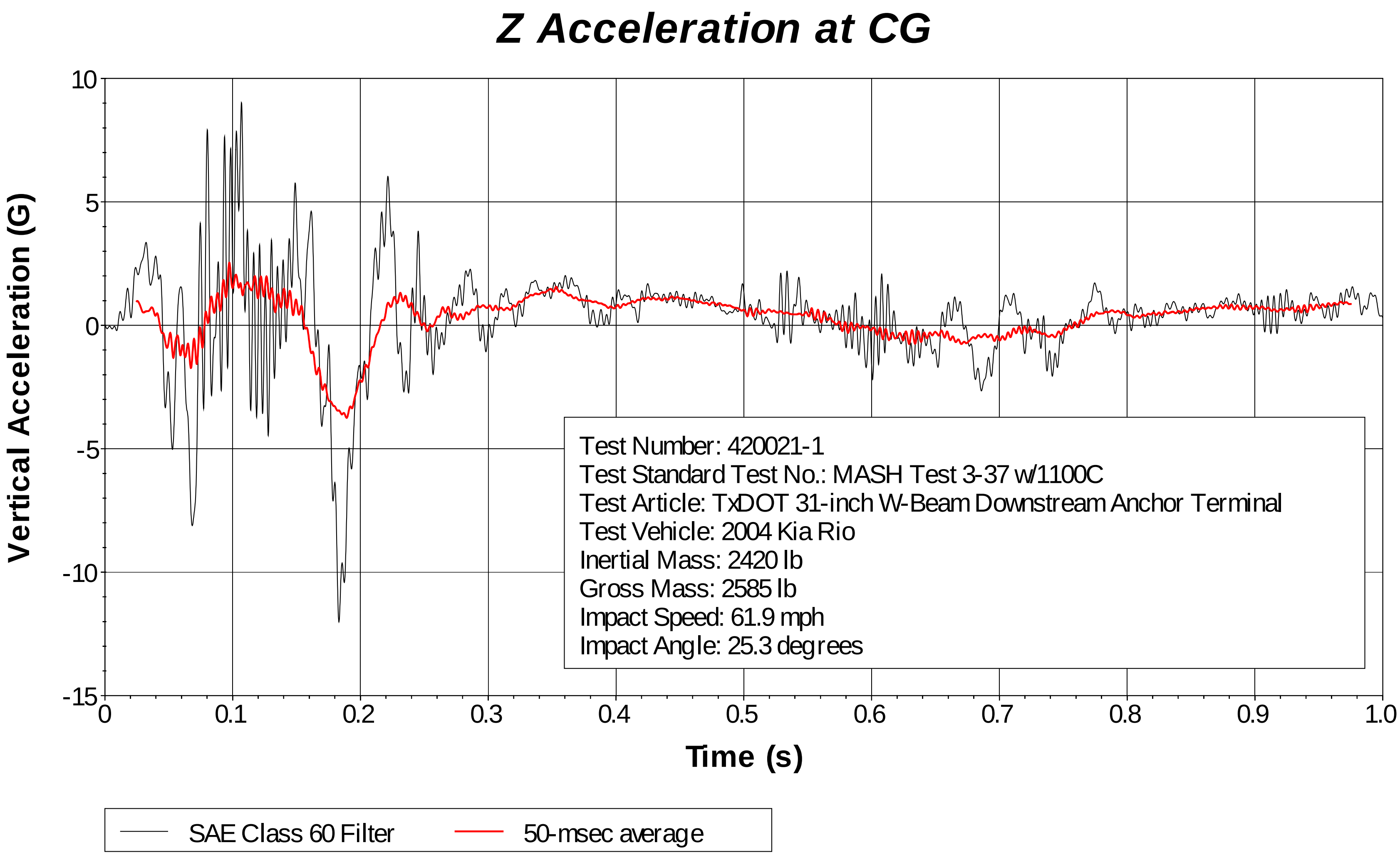


Figure F4. Vehicle Vertical Accelerometer Trace for Test No. 420021-1 (Accelerometer Located at Center of Gravity).

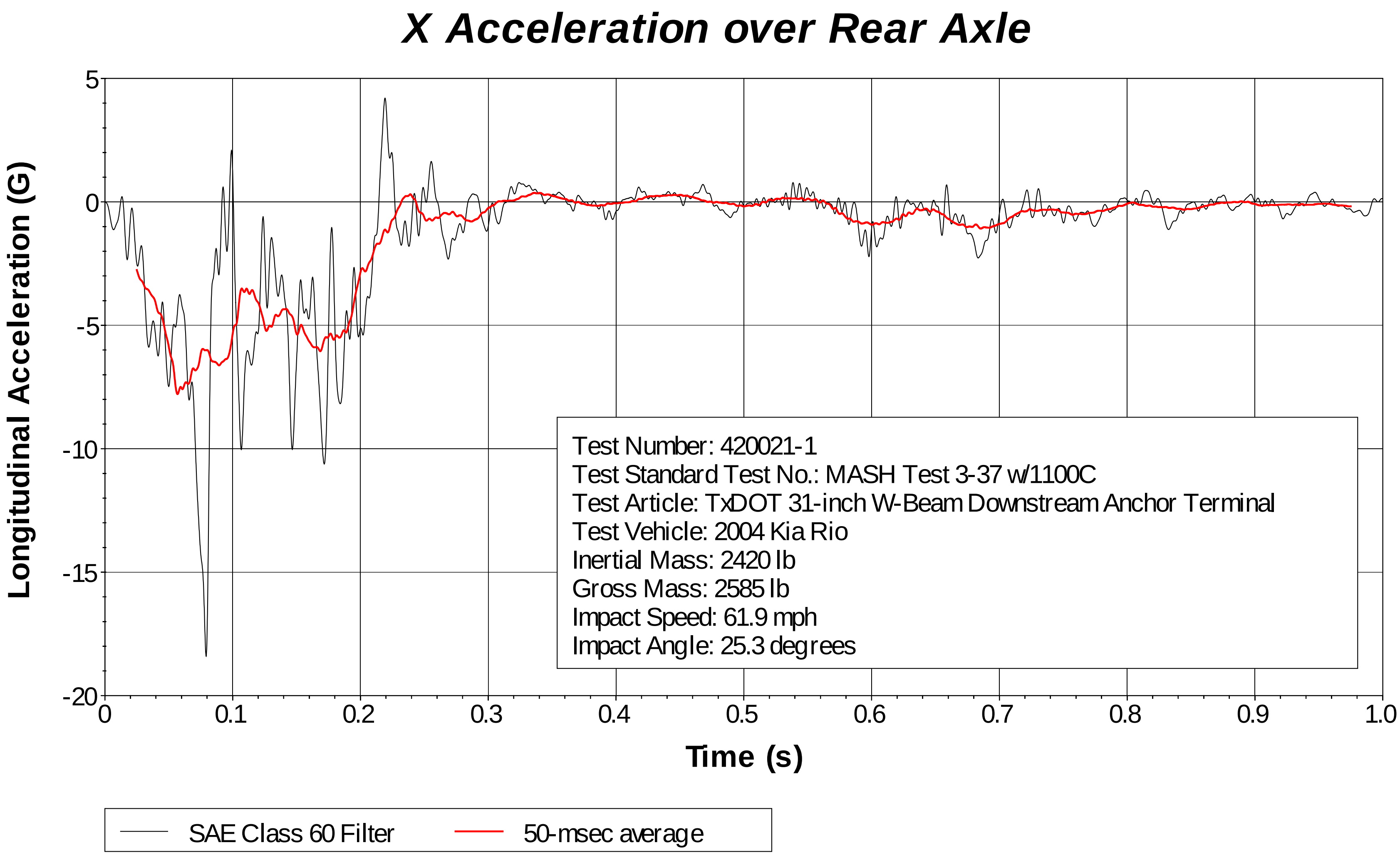


Figure F5. Vehicle Longitudinal Accelerometer Trace for Test No. 420021-1 (Accelerometer Located over Rear Axle).

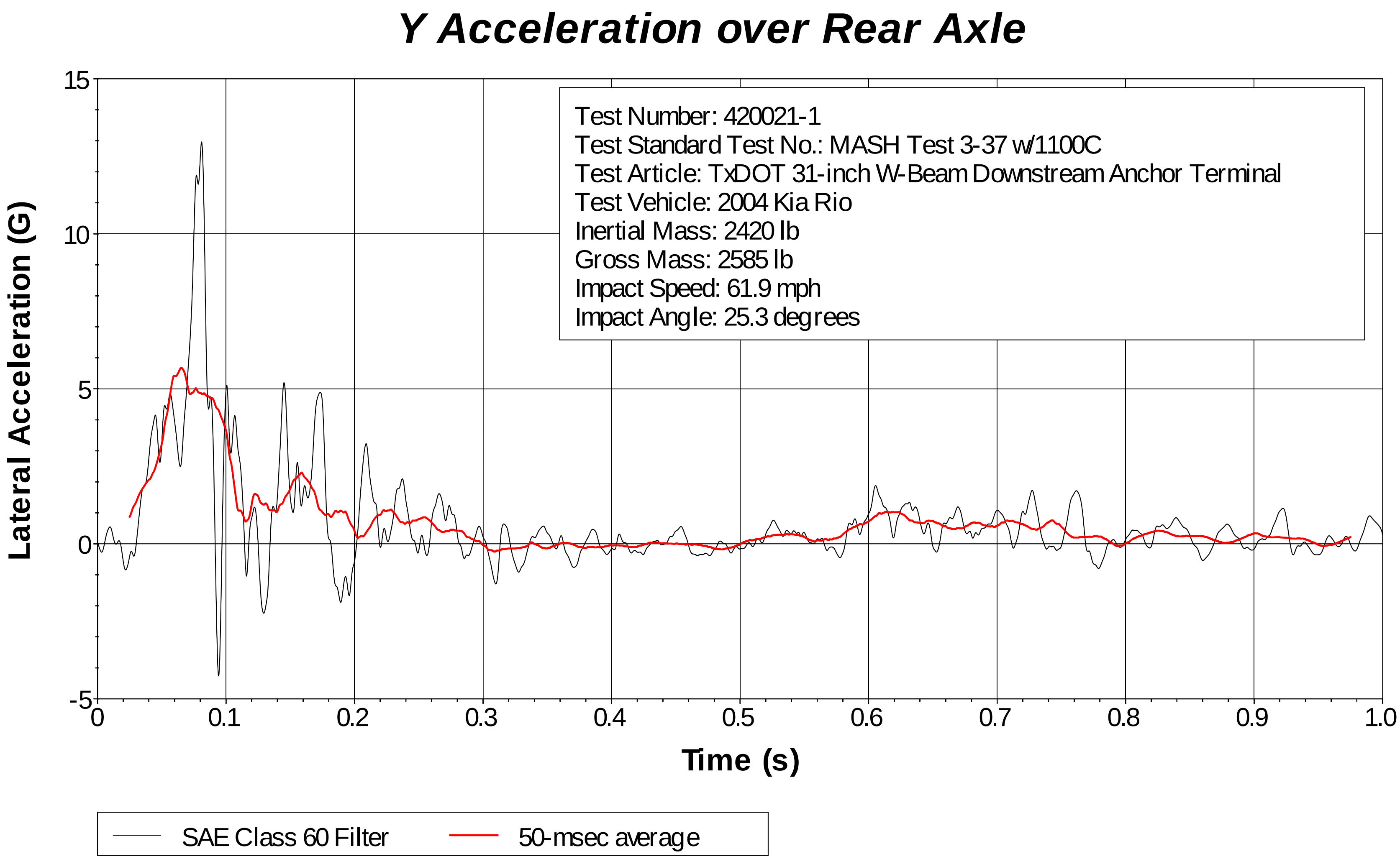


Figure F6. Vehicle Lateral Accelerometer Trace for Test No. 420021-1 (Accelerometer Located over Rear Axle).

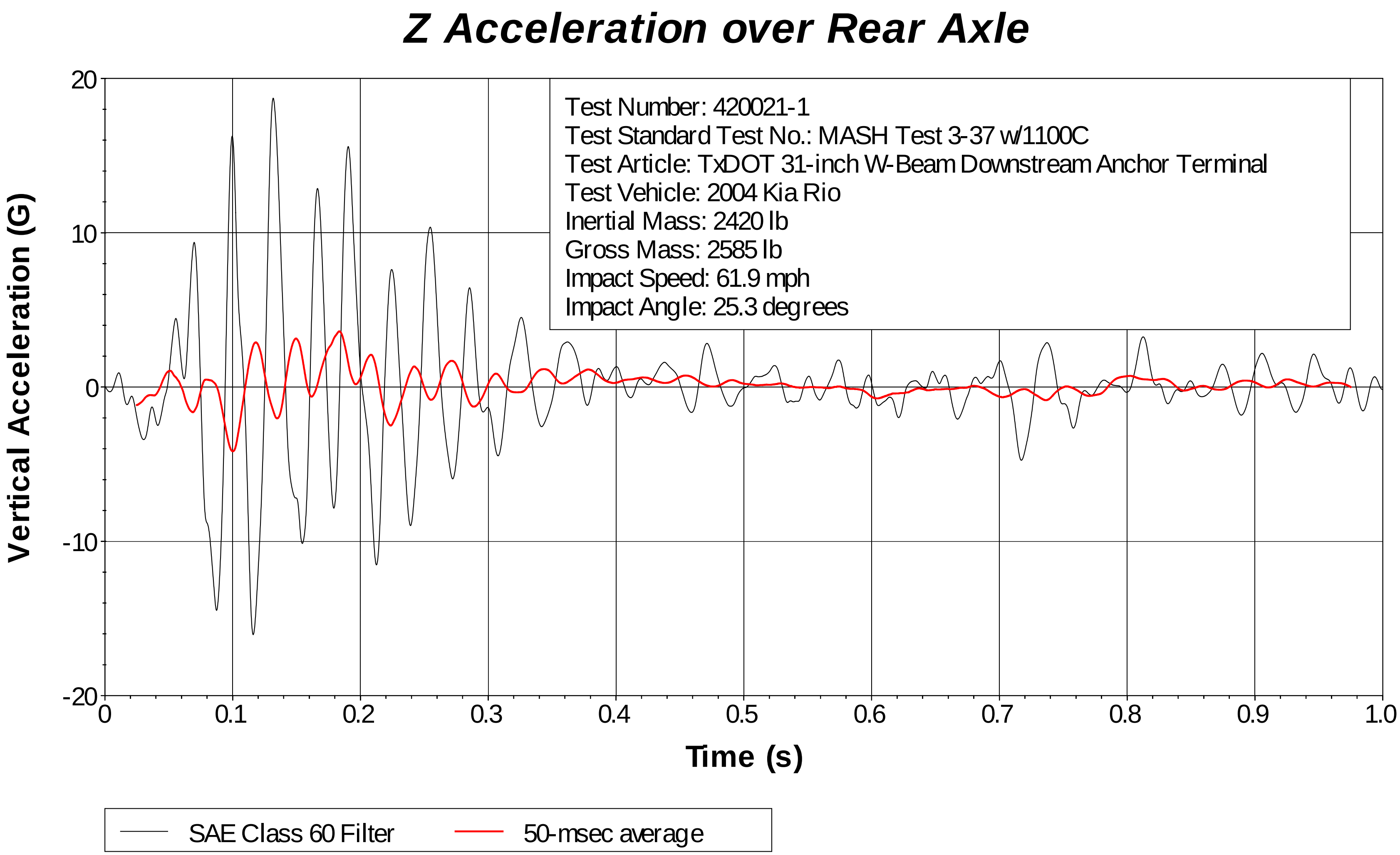


Figure F7. Vehicle Vertical Accelerometer Trace for Test No. 420021-1 (Accelerometer Located over Rear Axle).