TTI: 0-7086

Texas A&M Transportation Institute

MASH TEST 4-12 ON T2P RETROFIT BRIDGE RAIL

ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01

Crash testing performed at:
TTI Proving Ground
1254 Avenue A, Building 7091
Bryan, TX 77807

Test Report 0-7086-R5

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
http://tti.tamu.edu/documents/0-7086-R5.pdf

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-22/0-7086-R5		

4. Title and Subtitle	5. Report Date
MASH TEST 4-12 ON T2P RETROFIT BRIDGE RAIL	Published: September 2021
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
William F. Williams, Wanda L. Menges, William J. L. Schroeder, Bill L. Griffith, Sarah A. Wegenast, and Darrell L. Kuhn	Report 0-7086-R5

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Texas A&M Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	11. Contract or Grant No. Project 0-7086

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Texas Department of Transportation Research and Technology Implementation Office 125 E. 11th Street Austin, Texas 78701-2483	Technical Report: September 2020–August 2021
	14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Roadside Safety Device Analysis, Testing, and Evaluation Program
URL: http://tti.tamu.edu/documents/0-7086-R5.pdf

16. Abstract

The purpose of the test reported herein was to assess the performance of a retrofit rail for the Texas Department of Transportation (TxDOT) T2P bridge rail according to the safety-performance evaluation guidelines included in the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*). The crash test was performed in accordance with *MASH* Test 4-12, which involves a 10000S vehicle weighing 22,000 lb impacting the retrofit bridge rail while traveling at a nominal impact speed and angle of 56 mi/h and 15 degrees.

This report provides details on the TxDOT T2P retrofit bridge rail, the crash test and results, and the performance assessment of the TxDOT T2P retrofit bridge rail for *MASH* Test 4-12 longitudinal barrier evaluation criteria.

The TxDOT T2P retrofit bridge rail met the performance criteria for *MASH* Test 4-12 for longitudinal barriers.

17. Key Words	18. Distribution Statement
Longitudinal Barriers, Bridge Rail, Retrofit Rail, Tubular Rail Elements, *MASH*, Crash Testing, Roadside Safety	No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia http://www.ntis.gov

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	78	

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Report 0-7086-R5
Project 0-7086
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Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

Published: September 2021

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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 FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer (researcher) in charge of the project was William F. Williams, P.E., #71898.

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.

TTI PROVING GROUND DISCLAIMER

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

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ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. The authors would like to thank Taya Retterer, bridge standards engineer with the TxDOT Bridge Division, for her assistance on this project. Taya's input and guidance made this truly a great research project.

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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 yards	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 1000L 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
		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	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 (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in^2

*SI is the symbol for the International System of Units

Chapter 1. INTRODUCTION

1.1. BACKGROUND

Roadway departure crashes are the most common type of crash in Texas. These crashes represent over 45 percent of all fatal crashes and 34 percent of all serious injury crashes. Texas data show that there were 9,560 fatal and 30,766 serious injury roadway departure crashes from 2010–2016. Roadside safety devices shield motorists from roadside hazards such as non-traversable terrain and fixed objects, thereby reducing injuries and fatalities associated with roadway departure crashes. To improve the safety of the motoring public, there is a need to develop new or improved safety devices that accommodate a variety of site conditions and placement locations, as well as a changing vehicle fleet. To this end, researchers at the Texas A&M Transportation Institute (TTI) have sought to provide the Texas Department of Transportation (TxDOT) with a mechanism to quickly and effectively address high-priority issues related to roadside safety devices. TTI researchers provide results on new and improved safety features that minimize the consequences of vehicles leaving the road and reduce injuries and fatalities associated with roadway departure crashes. The researchers have developed roadside safety devices to meet the 2016 edition of the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) roadside safety criteria to address the continuing trend of larger vehicles in the statewide vehicle fleet (*1*).

1.2. OBJECTIVE

The purpose of the test reported herein was to assess the performance of a retrofit rail for TxDOT's T2P bridge rail according to the safety-performance evaluation guidelines included in *MASH*. The crash test was performed in accordance with *MASH* Test 4-12, which involves a 10000S vehicle weighing 22,000 lb impacting the retrofit bridge rail while traveling at a nominal impact speed and angle of 56 mi/h and 15 degrees.

This report provides details on the TxDOT T2P retrofit bridge rail, the crash test and results, and the performance assessment of the TxDOT T2P retrofit bridge rail for *MASH* Test 4-12 longitudinal barrier evaluation criteria.

Chapter 2. SYSTEM DETAILS

2.1. TEST ARTICLE AND INSTALLATION DETAILS

The test installation was 124 ft long and consisted of three steel rails attached to steel posts, which were mounted on a cantilevered reinforced concrete deck and curb. The deck was 6 inches thick, and the curb was 9 inches tall. The top rail was a hollow structural section (HSS) 4½-inch-diameter section, and the two lower rails were HSS rectangular sections, 2 inches tall and 6 inches wide. Internal rail sleeves measuring 28 inches long were centered at each rail splice. The distance from the top of the deck to the top of each rail was 18 inches, 28 inches, and 42 inches.

The posts were fabricated from ¾-inch-thick plates. They were spaced at 96-inch centers, and each was secured to the deck by four ⅞-inch-diameter bolts that were cast in the concrete.

Figure 2.1 presents the overall information on the TxDOT T2P retrofit bridge rail, and Figure 2.2 provides photographs of the installation. Appendix A provides further details on the TxDOT T2P retrofit bridge rail. Drawings were provided by the TTI Proving Ground, and construction was performed Tucker Construction and supervised by TTI Proving Ground personnel.

2.2. DESIGN MODIFICATIONS DURING TEST

No modifications were made to the installation during the testing phase.

2.3. MATERIAL SPECIFICATIONS

The specified compressive strength of the concrete used in the deck and curb was 4000 psi. Table 2.1 shows the average compressive strengths of the concrete on the date of the test, July 23, 2021.

Table 2.1. Concrete Strengths.

Location	Design Strength (psi)	Average Strength (psi)	Age (days)	Detailed Location
Wall and Deck	3600	4713	97	South Half of Wall and Deck
Wall and Deck	3600	5113	97	North Half of Wall and Deck
Curb	4000	4487	38	100% of curb

Appendix B provides material certification documents for the materials used to install/construct the TxDOT T2P retrofit bridge rail.

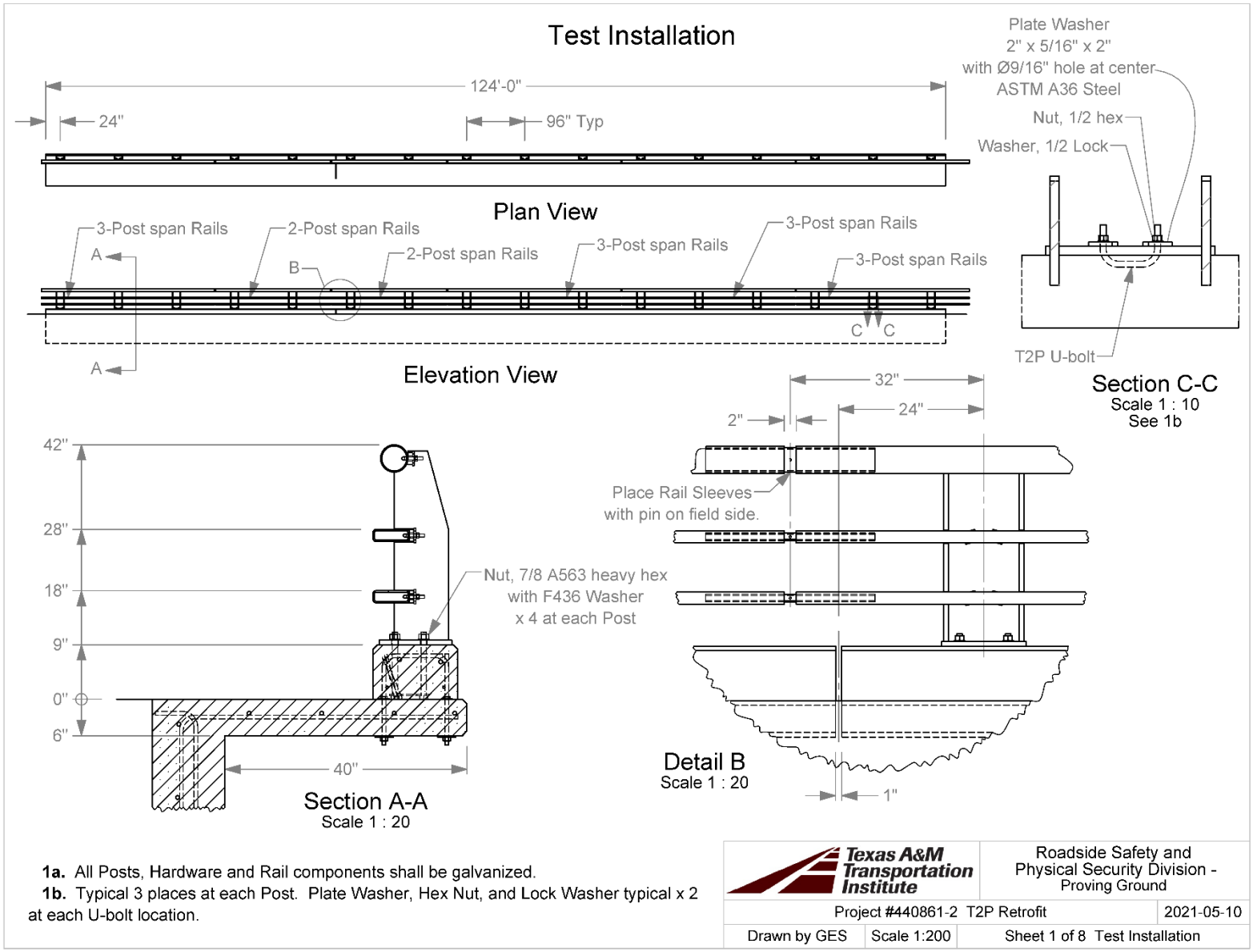


Figure 2.1. TxDOT T2P Retrofit Bridge Rail Details.

Figure 2.2. TxDOT T2P Retrofit Bridge Rail prior to Testing.

Chapter 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1. CRASH TEST PERFORMED/MATRIX

Table 3.1 shows the test conditions and evaluation criteria for *MASH* TL-4 for longitudinal barriers. *MASH* Tests 4-10 and 4-11 were not performed for this project since these tests were performed previously on the TxDOT T2P bridge rail. The researchers felt that only *MASH* Test 4-12 (strength test) was necessary for this retrofit bridge rail design.

Table 3.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-4 Longitudinal Barriers.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Longitudinal Barrier	4-10	1100C	62 mi/h	25°	A, D, F, H, I
	4-11	2270P	62 mi/h	25°	A, D, F, H, I
	4-12	10000S	56 mi/h	15°	A, D, G

The target critical impact point (CIP) for *MASH* Test 4-12 was determined using the information provided in *MASH* Section 2.2.1 and Section 2.3.2. Figure 3.1 shows the target CIP for *MASH* Test 4-12 on the TxDOT T2P retrofit bridge rail.

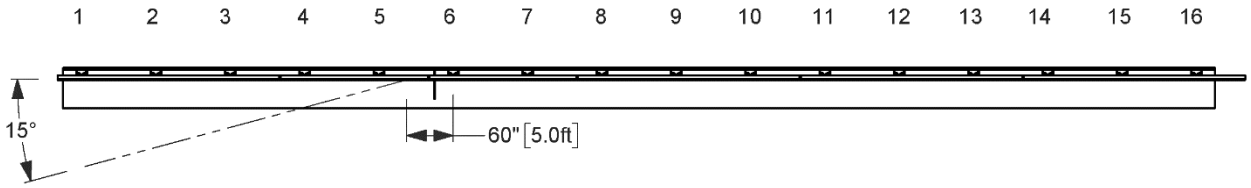


Figure 3.1. Target CIP for *MASH* Test 4-12 on TxDOT T2P Retrofit Bridge Rail.

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

3.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2 and 5-1 of *MASH* were used to evaluate the crash test reported herein. Table 3.1 lists the test conditions and evaluation criteria required for *MASH* Test 4-12, and Table 3.2 provides detailed information on the evaluation criteria. An evaluation of the crash test results is presented in Chapter 6.

Table 3.2. Evaluation Criteria Required for *MASH* TL-4 Longitudinal Barriers.

Evaluation Factors	Evaluation Criteria		*MASH* Test
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.*	*4-10, 4-11, and 4-12*
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 undue hazard to other traffic, pedestrians, or personnel in a work zone.* *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.*	*4-10, 4-11, and 4-12*
	F.	*The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	*4-10 and 4-11*
	G.	*It is preferable, although not essential, that the vehicle remain upright during and after the collision.*	*4-12*
	H.	*Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.*	*4-10 and 4-11*
	I.	*The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.*	*4-10 and 4-11*

Chapter 4. TEST CONDITIONS

4.1. TEST FACILITY

The full-scale crash test reported herein was performed at the TTI Proving Ground, an International Standards Organization (ISO)/International Electrotechnical Commission (IEC) 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, as well as *MASH* guidelines and standards.

The test facilities of the TTI Proving Ground are located on The Texas A&M University System RELLIS Campus, which consists of a 2000-acre complex of research and training facilities situated 10 mi northwest of the flagship campus of Texas A&M University. The site, formerly a United States Army Air Corps base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, highway pavement durability and efficacy, and roadside safety hardware and perimeter protective device evaluation. The site selected for construction and testing of the TxDOT T2P retrofit bridge rail was along the edge of an out-of-service apron. The apron consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches deep. The aprons were built in 1942, and the joints have some displacement but are otherwise flat and level.

4.2. VEHICLE TOW AND GUIDANCE SYSTEM

The 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 and 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 2:1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released and ran unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site.

4.3. DATA ACQUISITION SYSTEM

4.3.1. Vehicle Instrumentation and Data Processing

The test vehicle was instrumented with a self-contained onboard data acquisition system. The signal conditioning and acquisition system is a multichannel data acquisition system (DAS) produced by Diversified Technical Systems Inc. The accelerometers, which 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 data acquisition hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each channel 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 samples per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back up the data inside the unit in case the primary battery cable is severed. Initial contact of a pressure tape switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data are downloaded from the DAS 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 DAS is returned to the factory annually for complete recalibration and to ensure that all instrumentation used in the vehicle conforms to the specifications outlined by SAE J211. All accelerometers are calibrated annually by means of an ENDEVCO® 2901 precision primary vibration standard. This standard and its support instruments are checked annually and receive a National Institute of Standards Technology (NIST) traceable calibration. The rate transducers used in the DAS receive calibration via a Genisco Rate-of-Turn table. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel per SAE J211. Calibrations and evaluations are also made anytime data are suspect. Acceleration data are measured with an expanded uncertainty of ±1.7 percent at a confidence factor of 95 percent (k = 2).

TRAP uses the DAS-captured data to compute the occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and 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 an SAE Class 180-Hz low-pass digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the data from the roll, pitch, and yaw 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 being initial impact. Rate-of-rotation data are measured with an expanded uncertainty of ±0.7 percent at a confidence factor of 95 percent (k = 2).

4.3.2. Anthropomorphic Dummy Instrumentation

MASH does not recommend or require use of a dummy in the 10000S vehicle, and no dummy was placed in the vehicle.

4.3.3. Photographic Instrumentation Data Processing

Photographic coverage of the test included three digital high-speed cameras:

- One placed overhead with a field of view perpendicular to the ground and directly over the impact point.
- One placed upstream from the installation at an angle to have a field of view of the interaction of the rear of the vehicle with the installation.
- A third placed with a field of view parallel to and aligned with the installation at the downstream end.

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the TxDOT T2P retrofit bridge rail. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of the test vehicle and the installation before and after the test.

Chapter 5. *MASH* TEST 4-12 (CRASH TEST NO. 440861-2)

5.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 4-12 involves a 10000S vehicle weighing 22,000 lb ± 660 lb impacting the CIP of the longitudinal barrier at an impact speed of 56 mi/h ± 2.5 mi/h and an angle of 15 degrees ± 1.5 degrees. The CIP for *MASH* Test 4-12 on the TxDOT T2P retrofit bridge rail was 5 ft ± 1 ft upstream of the centerline of post 6. Figure 3.1 and Figure 5.1 depict the target impact setup.

Figure 5.1. TxDOT T2P Retrofit Bridge Rail/Test Vehicle Geometrics for Test No. 440861-2.

The 10000S vehicle weighed 22,540 lb, and the actual impact speed and angle were 56.3 mi/h and 14.2 degrees. The actual impact point was 4.4 ft upstream of the centerline of post 6. Minimum target impact severity (IS) was 142 kip-ft, and actual IS was 144 kip-ft.

5.2. WEATHER CONDITIONS

The test was performed on the morning of July 23, 2021. Weather conditions at the time of testing were as follows: wind speed: 8 mi/h; wind direction: 209 degrees (vehicle was traveling at a heading of 335 degrees); temperature: 86°F; relative humidity: 71 percent.

5.3. TEST VEHICLE

Figure 5.2 shows the 2012 Hino 338 single-unit truck (SUT) used for the crash test. The vehicle's test inertia weight was 22,540 lb, and its gross static weight was 22,540 lb. The height to the lower edge of the vehicle bumper was 18.75 inches, and the height to the upper edge of the bumper was 31.50 inches. The height to the center of gravity of the vehicle's ballast was 63.75 inches. Table C.1 in Appendix C.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 5.2. Test Vehicle before Test No. 440861-2.

5.4. TEST DESCRIPTION

Table 5.1 lists events that occurred during Test No. 440861-2. Figures C.1 and C.2 in Appendix C.2 present sequential photographs during the test.

Table 5.1. Events during Test No. 440861-2.

Time (s)	Events
0.000	Vehicle impacts retrofit bridge rail
0.035	Vehicle's front driver-side tire lifts off the pavement
0.050	Vehicle begins to redirect
0.141	Vehicle's right front tire lifts off the pavement
0.245	Vehicle's right rear tire lifts off the pavement
0.264	Vehicle travels parallel with the retrofit bridge rail
0.248	Vehicle's rear bumper contacts the retrofit bridge rail
0.381	Vehicle's left front tire makes contact with the pavement
1.328	Vehicle's right front tire makes contact with the pavement

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 65.6 ft for heavy vehicles). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied at 2.7 s after impact, and the vehicle subsequently came to rest 241 ft downstream of the point of impact and 12 ft toward the field side of the bridge rail.

5.5. DAMAGE TO TEST INSTALLATION

Figure 5.3 and Figure 5.4 show the damage to the TxDOT T2P retrofit bridge rail, and Table 5.2 shows post lean after the test. There was major cracking of the deck on the traffic side of the curb up to the edge of the field joint, which extended from post 3 to 2 ft downstream from post 10. There was also cracking under the deck from the field joint to 1 ft downstream from post 7, which ran along the anchor bolts, and from the field joint to post 7, there was a crack where the deck and wall intersected. The curb had some spalling and exposed rebar on the traffic and field side at post 6, and the curb downstream of the field joint was 3 inches lower on the field side and 1¼ inches lower on the traffic side than the curb upstream of the joint. The lower

rail was deformed just downstream of impact and was 6 inches lower than its pre-impact height. The existing cracks in the curb were outlined in black, and the cracks that occurred post-impact were outlined in red. Working width* was 64.4 inches, and height of working width was 144.3 inches. Maximum dynamic deflection during the test was 14.9 inches, and maximum permanent deformation was 9.0 inches.

5.6. DAMAGE TO TEST VEHICLE

Figure 5.5 shows the damage sustained by the vehicle. The front bumper, hood, left front tire and rim, left front U-bolts, left rear outer tire and rim, and left rear corner of the cargo box were damaged. No damage to the fuel tank was observed. Maximum exterior crush to the vehicle was 10.0 inches in the front plane at the left front corner at bumper height. No occupant compartment deformation or intrusion was noted. Figure 5.6 shows the interior of the vehicle.

5.7. VEHICLE INSTRUMENTATION

Data from the accelerometers were digitized for informational purposes only and are reported in Figure 5.7. Figure C.3 in Appendix C.3 shows the vehicle angular displacements, and

* Per *MASH*, "The working width is the maximum dynamic lateral position of any major part of the system or vehicle. These measurements are all relative to the pre-impact traffic face of the test article." In other words, working width is the total barrier width plus the maximum dynamic intrusion of any portion of the barrier or test vehicle past the field side edge of the barrier.

Figures C.4 through C.9 in Appendix C.4 show acceleration versus time traces. Figure 5.7 summarizes pertinent information from the test.

Table 5.2. Post Lean after Test No. 440861-2.

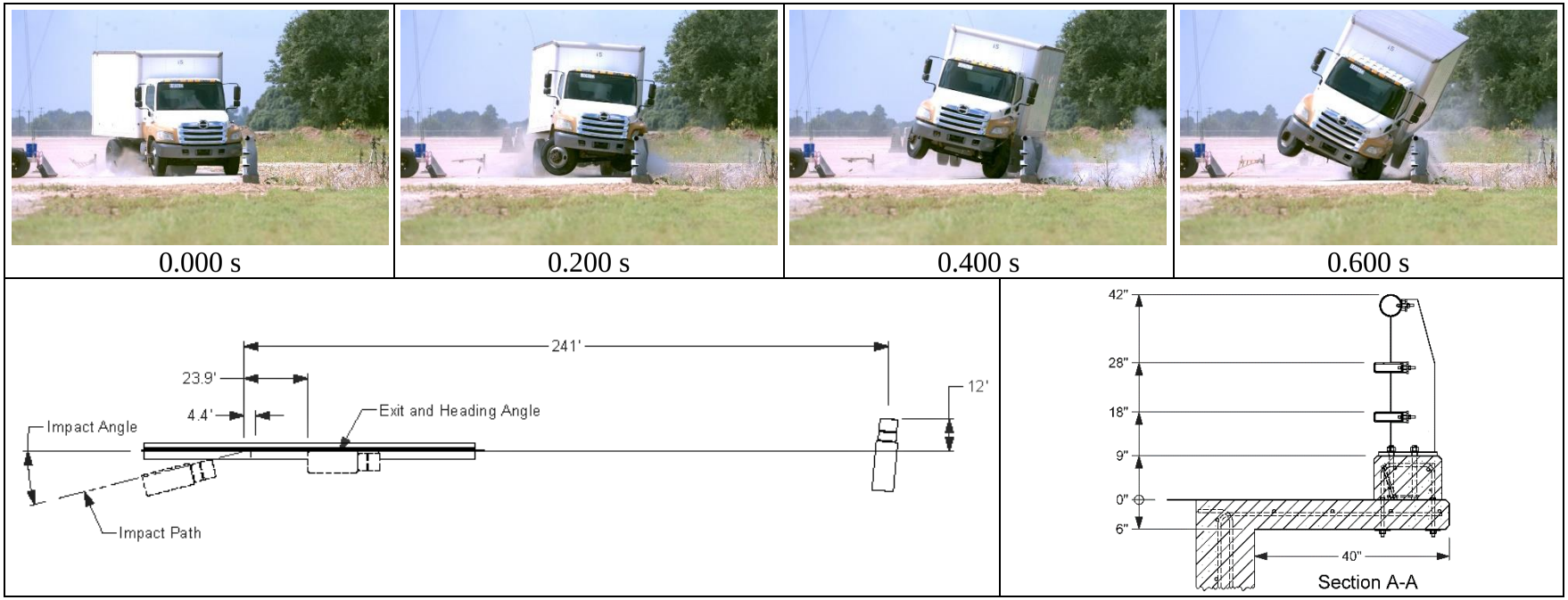
Post No.	Lean from Vertical
5	6°
6	11.5°
7	11°
8	4.5°

Figure 5.3. TxDOT T2P Retrofit Bridge Rail after Test No. 440861-2.

Figure 5.4. Field Side of TxDOT T2P Retrofit Bridge Rail after Test No. 440861-2.

Figure 5.5. Test Vehicle after Test No. 440861-2.

Figure 5.6. Interior of Test Vehicle after Test No. 440861-2.



General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ..... *MASH* Test 4-12
- TTI Test No. 440861-2
- Test Date 2021-07-23

Test Article
- Type ..... Longitudinal Barrier
- Name ..... TxDOT T2P Retrofit Bridge Rail
- Installation Length ..... 124 ft
- Material or Key Elements ... Cantilevered steel-reinforced deck, curb and HSS steel rail

Soil Type and Condition ..... Concrete Bridge Deck, Dry

Test Vehicle
- Type/Designation 10000S
- Make and Model ..... 2012 Hino 338 SUT
- Curb ..... 13,950 lb
- Test Inertial ..... 22,540 lb
- Dummy ..... No dummy
- Gross Static ..... 22,540 lb

Impact Conditions
- Speed ..... 56.3 mi/h
- Angle ..... 14.2°
- Location/Orientation ..... 4.4 ft upstream of post 6

Impact Severity ..... 144 kip-ft

Exit Conditions
- Speed ..... Rode off end
- Trajectory/Heading Angle ... Rode off end

Occupant Risk Values
- Longitudinal OIV ..... 5.4 ft/s
- Lateral OIV ..... 11.4 ft/s
- Longitudinal Ridedown ..... 2.1 g
- Lateral Ridedown ..... 3.9 g
- THIV ..... 3.9 m/s
- ASI 0.4

Max. 0.050-s Average
- Longitudinal ..... −1.6 g
- Lateral ..... 3.4 g
- Vertical ..... −1.7 g

Post-Impact Trajectory
- Stopping Distance ..... 241 ft downstream 12 ft twd field side

Vehicle Stability
- Maximum Roll Angle ..... 42°
- Maximum Pitch Angle ..... 12°
- Maximum Yaw Angle ..... 25°
- Vehicle Snagging ..... Yes
- Vehicle Pocketing ..... No

Test Article Deflections
- Dynamic ..... 14.9 inches
- Permanent ..... 9.0 inches
- Working Width ..... 64.4 inches
- Height of Working Width ..... 144.3 inches

Vehicle Damage
- VDS ..... NA
- CDC 11FLEW4
- Max. Exterior Deformation ..... 10.0 inches
- OCDI ..... NA
- Max. Occupant Compartment Deformation ..... None

Figure 5.7. Summary of Results for *MASH* Test 4-12 on TxDOT T2P Retrofit Bridge Rail.

Chapter 6. SUMMARY AND CONCLUSIONS

6.1. ASSESSMENT OF TEST RESULTS

The crash test reported herein was performed in accordance with *MASH* Test 4-12 on the TxDOT T2P retrofit bridge rail. Table 6.1 provides an assessment of the test based on the applicable safety evaluation criteria for *MASH* TL-4 longitudinal barriers.

6.2. CONCLUSIONS

The TxDOT T2P retrofit bridge rail met the performance criteria for *MASH* Test 4-12 for longitudinal barriers.

Table 6.1. Performance Evaluation Summary for *MASH* Test 4-12 on TxDOT T2P Retrofit Bridge Rail.

Test Agency: Texas A&M Transportation Institute Test No.: 440861-2 Test Date: 2021-07-23

MASH Test 4-12 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 T2P retrofit bridge rail contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 14.9 inches.	Pass
Occupant Risk		
D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	No detached elements, fragments, or other debris from the bridge rail were present to penetrate or 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 5.2.2 and Appendix E of MASH.	No deformation or intrusion of the occupant compartment occurred.	
G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	The 10000S vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 42 degrees and 12 degrees.	Pass

Chapter 7. IMPLEMENTATION*

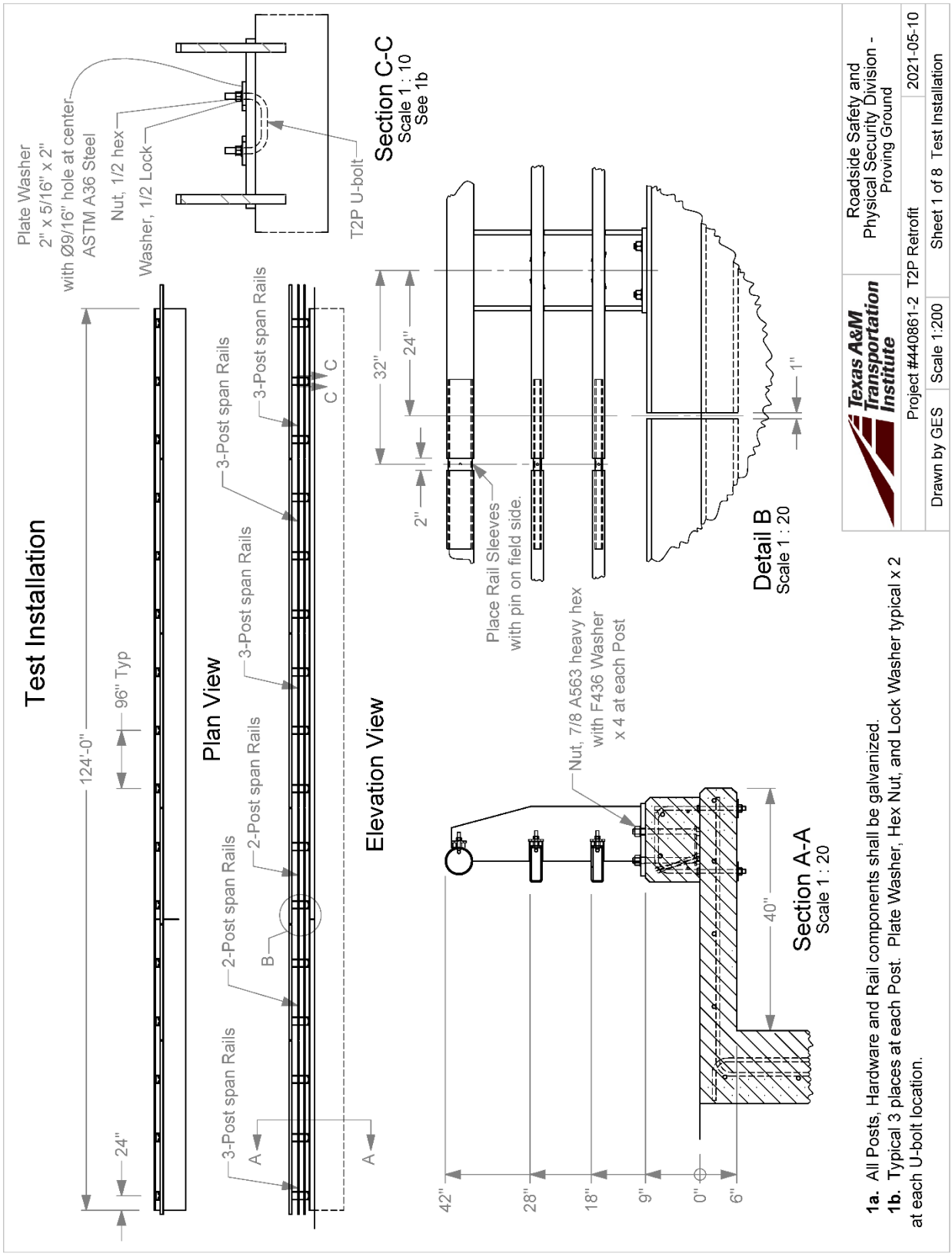
The TxDOT T2P bridge rail as tested in this project on a 6-inch-thick deck with a single layer of reinforcing steel (#5 bars; 40 ksi or greater) at 12 inches on the centers each way, as shown herein, is recommended for implementation for *MASH* TL-4. This retrofit design is recommended on all existing bridges with deck details that meet or exceed these as-tested conditions.

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

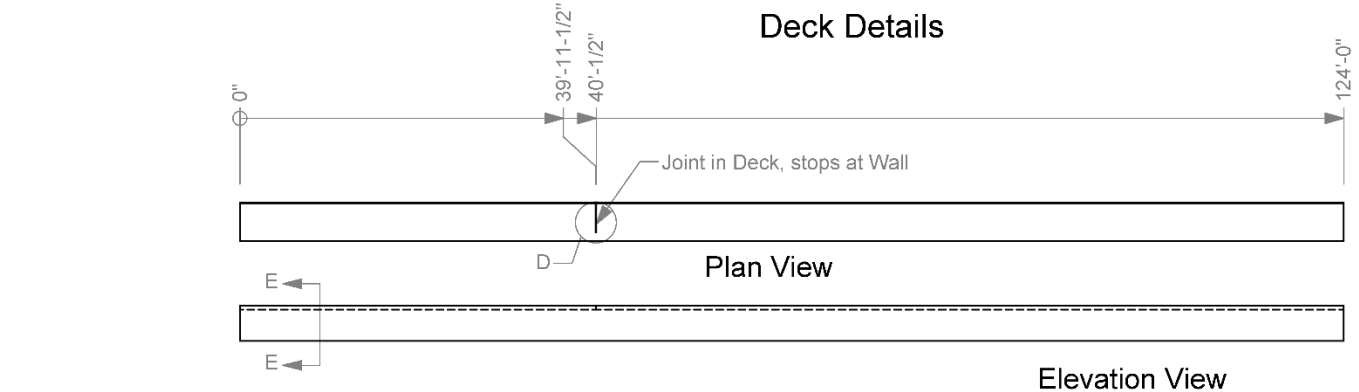
REFERENCES

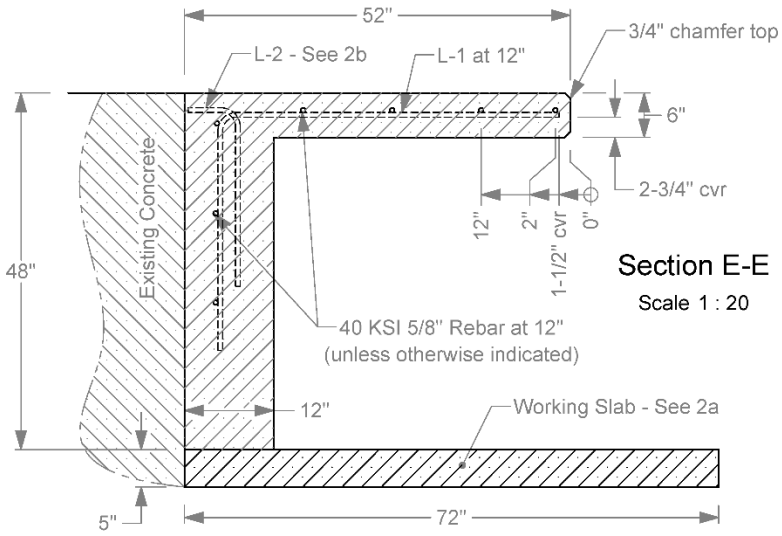
1. AASHTO. *Manual for Assessing Roadside Safety Hardware, Second Edition.* American Association of State Highway and Transportation Officials, Washington, DC, 2016.

APPENDIX A. DETAILS OF TXDOT T2P RETROFIT BRIDGE RAIL



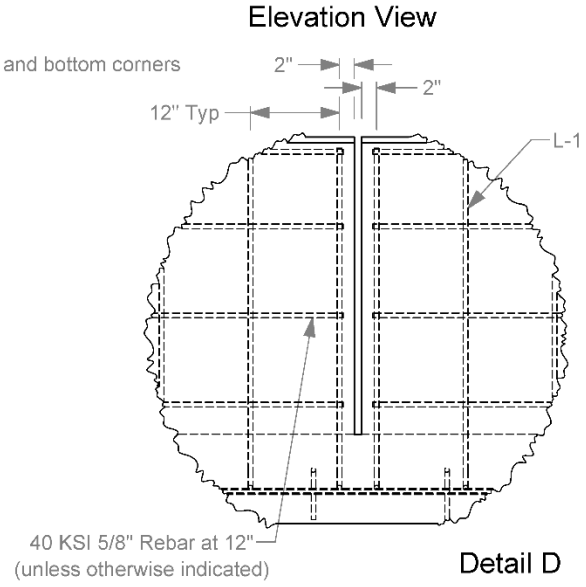
Deck Details





Section E-E

Scale 1 : 20



Detail D

Scale 1 : 20

2a. Working slab is 3,000 psi Concrete, with one mat of #4 grade 60 rebar at 12" each way, with 1-1/2" cover at top. Not shown in all views.

2b. Secure to existing rebar (not shown here) protruding from the runway with a minimum 3" weld. Maximum spacing is 18".

2c. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover). Lap length for 40 KSI #5 bars is 24".

2d. Concrete in Wall and Deck is 3,600 psi.

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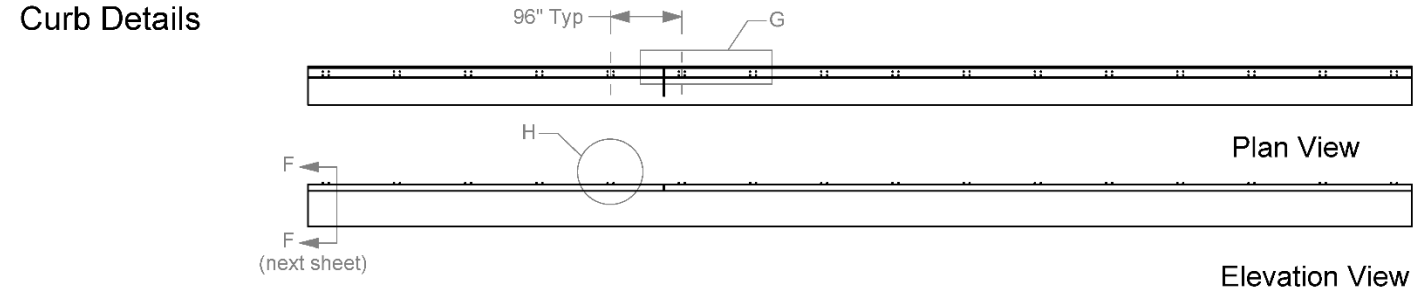
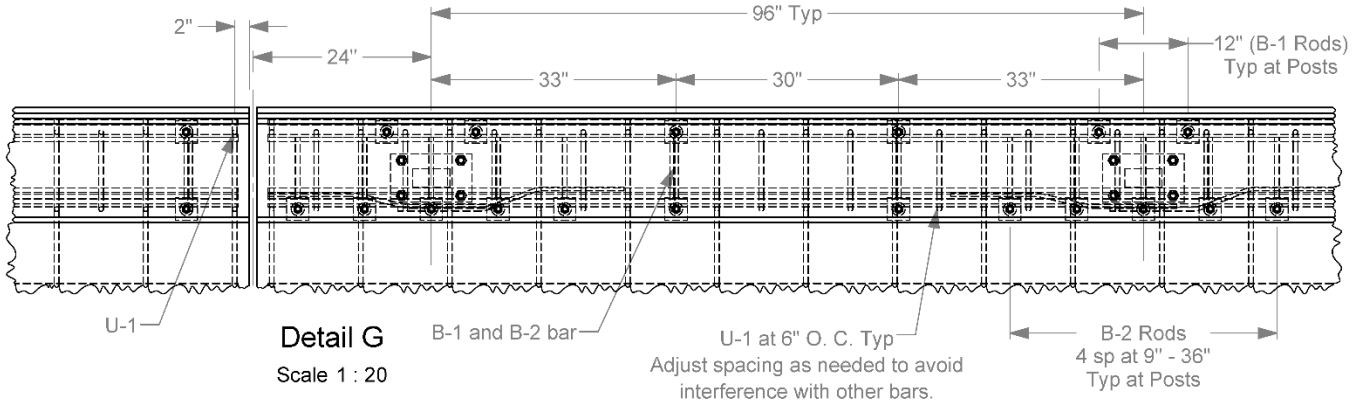
Project #440861-2 T2P Retrofit			2021-05-10
Drawn by GES	Scale 1:200	Sheet 2 of 8 Deck Details	

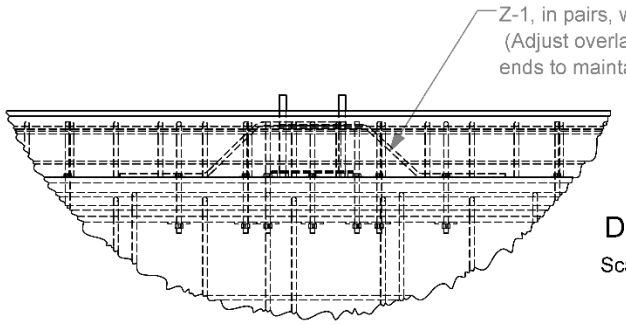
Q:\Accreditation-17025-2017\EIR-000 Project Files\440861 - TxDOT FY2021\440861-02 T2P Retrofit - Williams\Drafting, 440861-2\440861-2 Drawing

Curb Details





Detail G
Scale 1 : 20



Detail H
Scale 1 : 20

3a. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover).
3b. Concrete in Curb is 4,000 psi.

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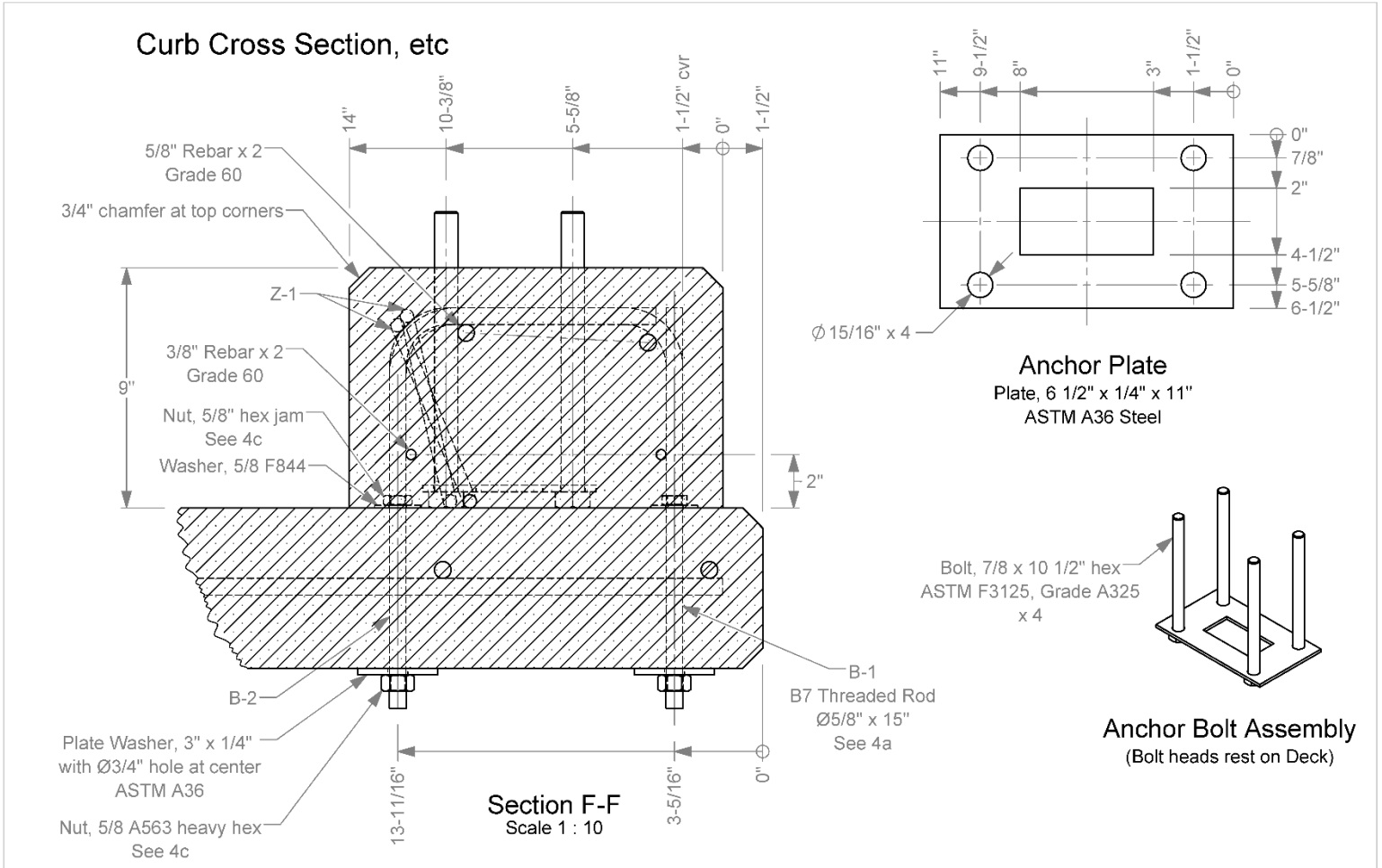

4a. Core Ø3/4" holes in Deck for B-1 and B-2 Rods. Percussion drilling is not permitted.

4b. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover). All rebar in the curb is grade 60. For longitudinal reinforcement in the curb, Lap length is 27" for #5 Bars and 18" for #3 bars.

4c. Hardware is typical at B-1 and B-2 Rods.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project #440861-2 T2P Retrofit		2021-05-10
Drawn by GES	Scale 1:5	Sheet 4 of 8 Curb Cross Section, etc

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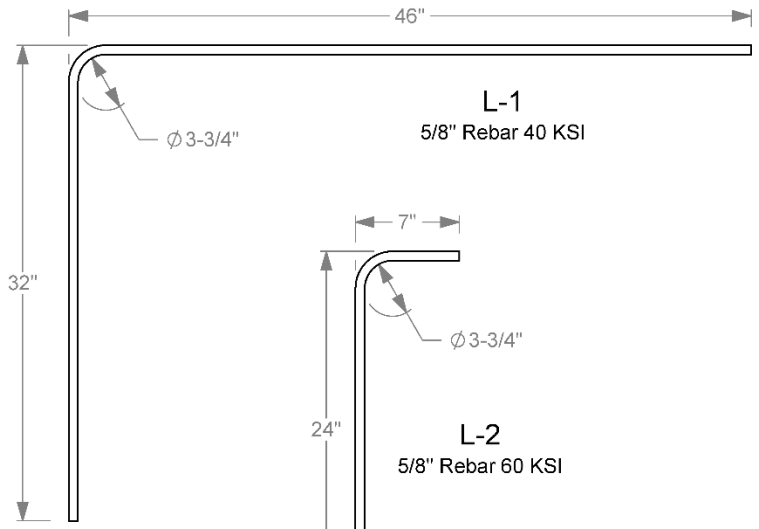
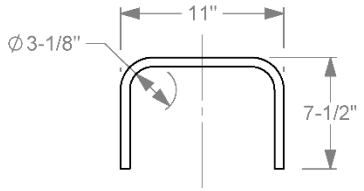
Bar Details

Threads not shown on threaded rods for clarity.

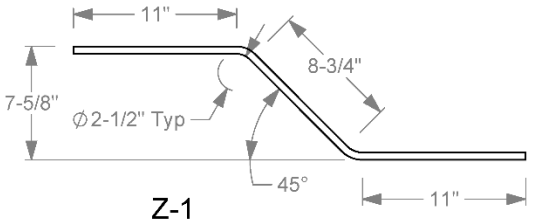


L-1
5/8" Rebar 40 KSI

L-2
5/8" Rebar 60 KSI

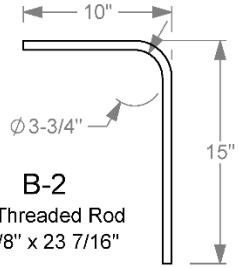


U-1
5/8" Rebar 60 KSI



Z-1
1/2" Rebar 60 KSI

B-1
B7 Threaded Rod
Ø5/8" x 15"



B-2
B7 Threaded Rod
Ø5/8" x 23 7/16"

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Project #440861-2 T2P Retrofit			2021-05-10
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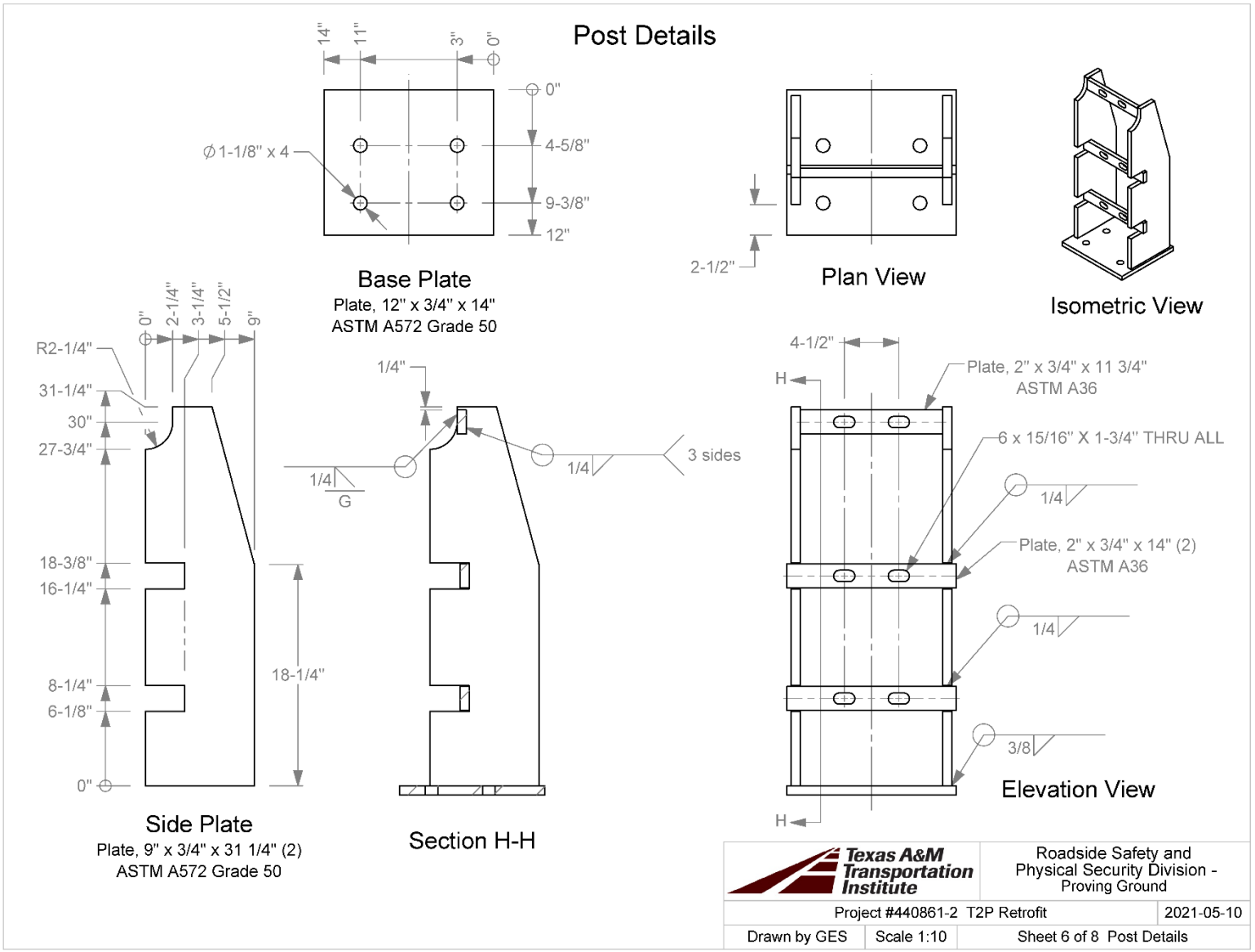
Post Details
14"
11"
3"
0"
0"
4-5/8"
9-3/8"
12"
∅1-1/8" x 4
Base Plate
Plate, 12" x 3/4" x 14"
ASTM A572 Grade 50
2-1/2"
Plan View
Isometric View
0"
2-1/4"
3-1/4"
5-1/2"
9"
R2-1/4"
31-1/4"
30"
27-3/4"
18-3/8"
16-1/4"
8-1/4"
6-1/8"
0"
18-1/4"
Side Plate
Plate, 9" x 3/4" x 31 1/4" (2)
ASTM A572 Grade 50
1/4"
1/4
G
1/4
3 sides
Section H-H
4-1/2"
H
Plate, 2" x 3/4" x 11 3/4"
ASTM A36
6 x 15/16" X 1-3/4" THRU ALL
1/4
Plate, 2" x 3/4" x 14" (2)
ASTM A36
1/4
3/8
H
Elevation View
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
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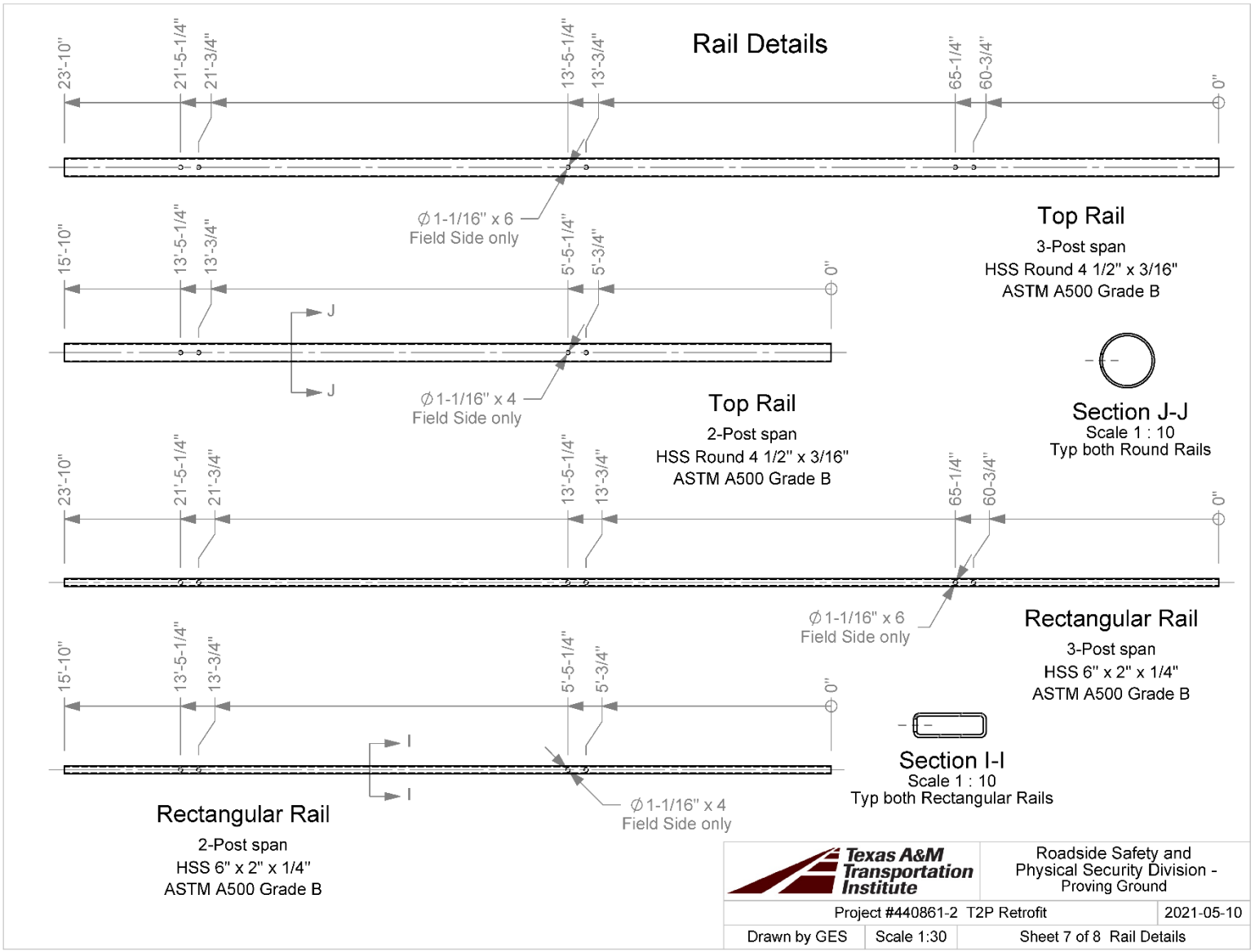
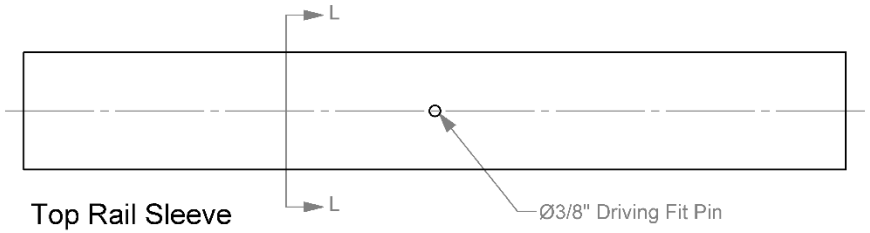
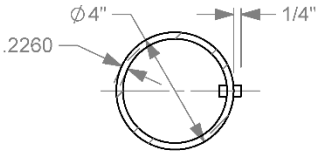
2021-05-10
Drawn by GES
Scale 1:10
Sheet 6 of 8 Post Details
Q:\Accreditation-17025-2017\EIR-000 Project Files\440861 - TxDOT FY2021\440861-02 T2P Retrofit - Williams\Drafting, 440861-2\440861-2 Drawing


Rail Details
23'-10"
21'-5-1/4"
21'-3/4"
13'-5-1/4"
13'-3/4"
65-1/4"
60-3/4"
0"
Ø1-1/16" x 6
Field Side only
Top Rail
3-Post span
HSS Round 4 1/2" x 3/16"
ASTM A500 Grade B
15'-10"
5'-5-1/4"
5'-3/4"
J
Ø1-1/16" x 4
Field Side only
Top Rail
2-Post span
HSS Round 4 1/2" x 3/16"
ASTM A500 Grade B
Section J-J
Scale 1 : 10
Typ both Round Rails
Ø1-1/16" x 6
Field Side only
Rectangular Rail
3-Post span
HSS 6" x 2" x 1/4"
ASTM A500 Grade B
I
Ø1-1/16" x 4
Field Side only
Rectangular Rail
2-Post span
HSS 6" x 2" x 1/4"
ASTM A500 Grade B
Section I-I
Scale 1 : 10
Typ both Rectangular Rails
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #440861-2 T2P Retrofit
2021-05-10
Drawn by GES
Scale 1:30
Sheet 7 of 8 Rail Details
Q:\Accreditation-17025-2017\EIR-000 Project Files\440861 - TxDOT FY2021\440861-02 T2P Retrofit - Williams\Drafting, 440861-2\440861-2 Drawing

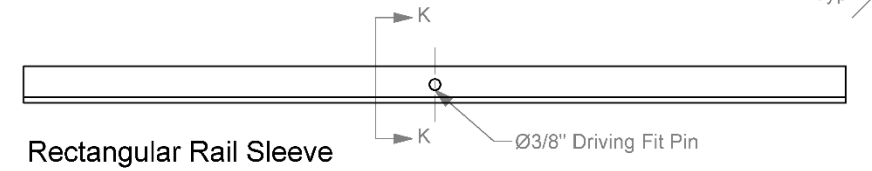
Joint Sleeves and U-bolt



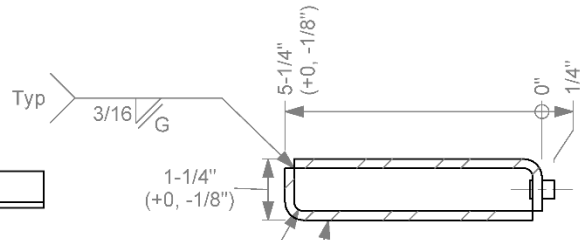
Top Rail Sleeve
Pipe, 3-1/2" sch. 40 x 28"
ASTM A500 Grade B



Section L-L

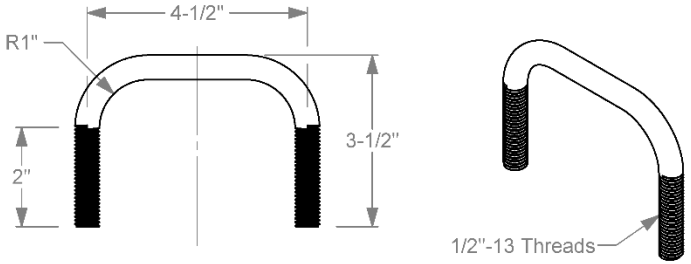


Rectangular Rail Sleeve



Section K-K
Scale 1 : 3

Plate, 28" x 3/16" x 5 13/16"
ASTM A36 Steel (x 2)



T2P U-bolt
Ø1/2" x 10"
ASTM A36 Steel

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #440861-2 T2P Retrofit		2021-05-10
Drawn by GES	Scale 1:5	Sheet 8 of 8 Joint Sleeves and U-bolt

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APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

madden

Certificate of Compliance

CUSTOMER: CMC
CUSTOMER PO #: 883800
MADDEN BOLT SO#: 122801

BOLTS: A193-B7
HEX NUTS:
FLAT WASHER:
LOCK WASHER:
COATING: A153
TEMPLATE:
OTHER:

NOTES:

Madden Bolt certifies that the above material is in compliance with the chemical and physical requirements of the ASTM or AISI specifications.

Thank you,

Authorized Signature: James Dagen

Date: June 7, 2021

13420 Hempstead HWY ● Houston, TX 77040 ● PH (713) 939-9999 ● FAX (713) 9397200

WWW.MADDENBOLT.COM

madden
Galvanizing, LLC

June 7, 2021
Madden Bolt Corporation
13420 Hempstead Hwy.
Houston, TX 77040

RE: Galvanization Certificate of Compliance
To Whom It May Concern:

We certify that our Hot Dip process meets the requirements of ASTM A123 Specification on the following order.

CUSTOMER #: CMC

SALES ORDER #: 122801 **PURCHASE ORDER #:** 883800

Approved By: _____
Roger Trejo

13420 Hempstead HWY ● Houston, TX 77040 ● PH (713) 939-9999 ● FAX (713) 9397200

WWW.MADDENBOLT.COM

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

JOB MATERIAL CERTIFICATION

Job No: 521519 **Job Information** **Certified Date:** 4/10/17

Containers: S12601892 S12601893 S12601894 S12601895 S12601896

Customer: The Lawless Group

Ship To: 2200 Alberta
Suite 130
Dallas, TX 75229

Vulcan Part No: ATR B7 5/8x12
Customer Part No: ATR B7 5/8x12
Customer PO No: Stock Transfer
Order No: 322035
Note:

Shipped Qty: 5 containers
Line No: 47

Applicable Specifications

Type	Specification	Rev	Amend	Option
-	ASTM F1554 Gd 105 S4	2015		
Heat Treat	ASME SA-193/SA-193M B7	2013		
	ASTM A193 B7	2016		

Test Results

See following pages for tests

Certified Chemical Analysis

Heat No: 10478270 Origin: USA

C	Mn	P	S	Si	Cr	Mo	Ni	V	Cu
0.420	0.89	0.010	0.025	0.28	0.92	0.21	0.05	0.003	0.08
Al	**Nb**	**Sn**	**Ti**	**N**	**B**	**DI**	**RR**	**G.S.**	**Macro S**
0.026	0.003	0.006	0.002	0.0070	0.0001	5.37	99:1	Fine	2
Macro R	**Macro C**	**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**J7**	**J8**
2	2	57	57	57	57	57	57	57	56
J9	**J10**	**J12**	**J14**	**J16**	**J18**	**J20**	**J24**	**J28**	**J32**
54	53	50	49	46	46	45	43	41	38

Notes

Material was manufactured, tested and inspected in accordance with Vulcan Threaded Products Inc. Quality Assurance Program and Manual Rev. A, dated 8/23/11. Processed material is Quenched and Tempered - Stress Free. No weld repair performed on the material. No Mercury used in the production of this material. Melted and Manufactured in the USA.
Document is in accordance with EN 10204 - 3.1B of 2004 (3.1).

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4/18/19

PE69664
10478270

ATR
1

Vulcan
5/8X12ATR

B7

Page 1 of 2

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

JOB MATERIAL CERTIFICATION

Job No: 521519 **Job Information** **Certified Date:** 4/10/17

Containers: S12601892 S12601893 S12601894 S12601895 S12601896

Test Results

Part No: BAR B7 .5626x288

Test No: 42225 **Test:** Quench & Temper Information (Lbs)

Description	Tempering Temp (F)	Run Speed (Ft/min)	Quench Water Temp (F)	Austenitizing Temp (F)	Note
Quench & Temper Information Results	1,337	36	85	1,627	

Test No. 42226 **Test:** A193 B7, F1554-105 Requirements

Description	Tensile (ksi)	Yield 0.2% Offset (ksi)	Elongation (%)	Elongation Gage Length	ROA (%)	Midradius Hardness	Surface Hardness	Center Hardness	Hardness Test Type	Note
	138	129	24	4D	62	30	29		HRC	
	139	131	23	4D	62	29	28		HRC	
	136	127	19	4D	61	30	29		HRC	
	137	128	24	4D	62	28	28		HRC	
	139	130	24	4D	65	30	28		HRC	

Test No 42227 **Test:** F1554-15 gd105 S4 Charpy ft/lbs Requirements

Description	Container	Test Temp (F)	Test1 (ft/lbs)	Test2 (ft/lbs)	Test3 (ft/lbs)	Results Avg (ft/lbs)	Note
		-20	157	147	125	143	

4/10/17

Griffin, Mitchell - Certification Engineer — Date

Plex 4/10/17 10:26 AM vulc.mgri Page 2 of 2

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

Rolando A Davila
Quality Assurance Manager

HEAT NO.:3104351 SECTION: REBAR 16MM (#5) 20'0" 300/40 GRADE: ASTM A615-20 Grade 300/40 ROLL DATE: 03/17/2021 MELT DATE: 03/17/2021 Cert. No.: 83406649 / 104351A138	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#: 83406649 BOL#: 74060369 CUST PO#: 879203 CUST P/N: DLVRY LBS / HEAT: 4006.000 LB DLVRY PCS / HEAT: 192 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.09%				
Mn	0.83%				
P	0.013%				
S	0.048%				
Si	0.18%				
Cu	0.38%				
Cr	0.17%				
Ni	0.12%				
Mo	0.034%				
V	0.000%				
Cb	0.001%				
Sn	0.013%				
Al	0.001%				
Yield Strength test 1	57.0ksi				
Tensile Strength test 1	93.7ksi				
Elongation test 1	15%				
Elongation Gage Lgth test 1	8IN				
Bend Test 1	Passed				
Bend Test Diameter	2.188IN				

The Following is true of the material represented by this MTR:
*Material is fully killed
*100% melted and rolled in the USA
*EN10204:2004 3.1 compliant
*Contains no weld repair
*Contains no Mercury contamination
*Manufactured in accordance with the latest version of the plant quality manual
*Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661
*Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov

REMARKS :

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

Rolando A Davila
Quality Assurance Manager

HEAT NO.:3104270 SECTION: REBAR 16MM (#5) 40'0" 420/60 GRADE: ASTM A615-20 Gr 420/60 ROLL DATE: 03/14/2021 MELT DATE: 03/14/2021 Cert. No.: 83411185 / 104270A765	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#: 83411185 BOL#: 74066972 CUST PO#: 879634 CUST P/N: DLVRY LBS / HEAT: 24030.000 LB DLVRY PCS / HEAT: 576 EA		

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.44%	Bend Test Diameter	2.188IN		
Mn	0.83%				
P	0.009%				
S	0.041%				
Si	0.18%				
Cu	0.29%				
Cr	0.14%				
Ni	0.26%				
Mo	0.087%				
V	0.000%				
Cb	0.004%				
Sn	0.012%				
Al	0.003%				
Yield Strength test 1	68.9ksi				
Tensile Strength test 1	107.9ksi				
Elongation test 1	15%				
Elongation Gage Lgth test 1	8IN				
Tensile to Yield ratio test1	1.57				
Bend Test 1	Passed				

The Following is true of the material represented by this MTR:

**Material is fully killed*
**100% melted and rolled in the USA*
**EN10204:2004 3.1 compliant*
**Contains no weld repair*
**Contains no Mercury contamination*
**Manufactured in accordance with the latest version of the plant quality manual*
**Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661*
**Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov*

REMARKS :

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

Rolando A Davila
Quality Assurance Manager

HEAT NO.:3102819 SECTION: REBAR 13MM (#4) 40'0" 420/60 GRADE: ASTM A615-20 Gr 420/60 ROLL DATE: 01/16/2021 MELT DATE: 01/05/2021 Cert. No.: 83346589 / 102819A371	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#: 83346589 BOL#: 73970947 CUST PO#: 874069 CUST P/N: DLVRY LBS / HEAT: 13254.000 LB DLVRY PCS / HEAT: 496 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.44%	Bend Test Diameter	1.750IN		
Mn	0.79%				
P	0.032%				
S	0.047%				
Si	0.17%				
Cu	0.34%				
Cr	0.09%				
Ni	0.11%				
Mo	0.040%				
V	0.000%				
Cb	0.001%				
Sn	0.011%				
Al	0.001%				
Yield Strength test 1	63.0ksi				
Tensile Strength test 1	101.3ksi				
Elongation test 1	13%				
Elongation Gage Lgth test 1	8IN				
Tensile to Yield ratio test1	1.61				
Bend Test 1	Passed				

The Following is true of the material represented by this MTR:

**Material is fully killed*
**100% melted and rolled in the USA*
**EN10204:2004 3.1 compliant*
**Contains no weld repair*
**Contains no Mercury contamination*
**Manufactured in accordance with the latest version of the plant quality manual*
**Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661*
**Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov*

REMARKS :

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155 7510

CERTIFIED MILL TEST REPORT
For additional copies call
830-372 3771

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

Rolando A Davila
Quality Assurance Manager

HEAT NO.:3104459
SECTION: REBAR 10MM (#3) 20'0" 420/60
GRADE: ASTM A615-20 Gr 420/60
ROLL DATE: 03/21/2021
MELT DATE: 03/21/2021
Cert. No.: [illegible]

SOLD TO: CMC Construction Svcs College Stati
13351 State Hwy 30
College Station TX
US 77845-7950

SHIP TO: CMC Construction Svcs College Stati
13351 State Hwy 30
College Station TX
US 77845 7950

Delivery#: 83409956
BOL#: 74065485
CUST PO#: [illegible]
CUST P/N:
DLVRY LBS / HEAT: [illegible]

Characteristic	Value
C	0.45%
Mn	0.68%
P	0.012%
S	0.040%
Si	0.16%
Cu	0.27%
Cr	0.11%
Ni	0.12%
Mo	0.041%
V	0.000%
Cb	0.001%
Sn	0.009%
Al	0.001%
Yield Strength test 1	72.7ksi
Tensile Strength test 1	112.8ksi
Elongation test 1	13%
Elongation Gage Lgth test 1	8IN
Tensile to Yield ratio test1	1.55
Bend Test 1	Passed

Characteristic	Value
Bend Test Diameter	1.313IN

The Following is true of the material represented by this MTR:

*Material is fully killed
*100% melted and rolled in the USA
*EN10204:2004 3.1 compliant
*Contains no weld repair
*Contains no Mercury contamination
*Manufactured in accordance with the latest version of the plant quality manual
*Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661
*Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov

REMARKS :

Page 1 OF 1 03/26/2021 09:36:32

CMC

1 ST

SEG

78155 7510

330 372 377

We hereby certify that the test results presented here

Rolando A Davila

Quality Assurance Manager

HEAT NO.:3104462

SECTION: REBAR 10MM (#3)

ROLL DATE: 03/21/2021

MELT DATE: 03/21/2021

S | CMC Construction Svcs College Stati

O

77845 7050

O | CMC Construction Svcs College Stati

Delivery#: 33

BOL#: 74065

LBS. HEAT: 2

	Value
C	0.45%
Mn	0.71%
P	0.010%
S	0.048%
Si	0.16%
Cu	0.28%
Cr	0.08%
Ni	0.11%
Mo	0.044%
V	0.000%
Cb	0.001%
Sn	0.010%
Al	0.002%
Yield Strength test 1	69.0ksi
Tensile Strength test 1	107.3ksi
Elongation test 1	13%
Elongation Gage Lgth test 1	8IN
Tensile to Yield ratio test1	1.56
Bend Test 1	Passed

Bend Test Diameter 1.313IN

The Following is true of the material represented by this MTR:

*Material is fully killed

*100% melted and rolled in the USA

*EN10204:2004 3.1 compliant

*Contains no weld repair

*Contains no Mercury contamination

*Manufactured in accordance with the latest version of the plant quality manual

*Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661

*Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov

REMARKS :

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

Rolando A Davila
Quality Assurance Manager

HEAT NO.:3104709 SECTION: REBAR 13MM (#4) 20'0" 420/60 GRADE: ASTM A615-20 Gr 420/60 ROLL DATE: 04/04/2021 MELT DATE: 03/31/2021 Cert. No.: 83418931 / 104709A130	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#: 83418931 BOL#: 74080324 CUST PO#: 880219 CUST P/N: DLVRY LBS / HEAT: 41629.000 LB DLVRY PCS / HEAT: 3116 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.45%	Bend Test Diameter	1.750IN		
Mn	0.77%				
P	0.031%				
S	0.049%				
Si	0.17%				
Cu	0.32%				
Cr	0.13%				
Ni	0.14%				
Mo	0.052%				
V	0.000%				
Cb	0.000%				
Sn	0.015%				
Al	0.001%				
Yield Strength test 1	66.1ksi				
Tensile Strength test 1	105.3ksi				
Elongation test 1	15%				
Elongation Gage Lgth test 1	8IN				
Tensile to Yield ratio test1	1.59				
Bend Test 1	Passed				

The Following is true of the material represented by this MTR:

*Material is fully killed
*100% melted and rolled in the USA
*EN10204:2004 3.1 compliant
*Contains no weld repair
*Contains no Mercury contamination
*Manufactured in accordance with the latest version of the plant quality manual
*Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661
*Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov

REMARKS :

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

Rolando A Davila
Quality Assurance Manager

HEAT NO.:3104707 SECTION: REBAR 13MM (#4) 20'0" 420/60 GRADE: ASTM A615-20 Gr 420/60 ROLL DATE: 04/04/2021 MELT DATE: 03/31/2021 Cert. No.: 83418931 / 104707A130	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#: 83418931 BOL#: 74080324 CUST PO#: 880219 CUST P/N: DLVRY LBS / HEAT: 6573.000 LB DLVRY PCS / HEAT: 492 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.44%	Bend Test Diameter	1.750IN		
Mn	0.69%				
P	0.028%				
S	0.042%				
Si	0.16%				
Cu	0.30%				
Cr	0.12%				
Ni	0.17%				
Mo	0.065%				
V	0.000%				
Cb	0.001%				
Sn	0.013%				
Al	0.001%				
Yield Strength test 1	66.6ksi				
Tensile Strength test 1	106.2ksi				
Elongation test 1	16%				
Elongation Gage Lgth test 1	8IN				
Tensile to Yield ratio test1	1.59				
Bend Test 1	Passed				

The Following is true of the material represented by this MTR:

*Material is fully killed
*100% melted and rolled in the USA
*EN10204:2004 3.1 compliant
*Contains no weld repair
*Contains no Mercury contamination
*Manufactured in accordance with the latest version of the plant quality manual
*Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661
*Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov

REMARKS :

TTI Rail Retrofit - TTI - J

QTY	SIZE	DESCRIPTION	BEND	TAG
		GRADE 60		
125	4	5'-6"		
34	4	11' x 10" x 11"	ZBAR	Z1
85	5	7" x 2'-0"	LBAR	L2
248	5	7½" x 11" x 7½"	UBAR	U1
15	**5**	**20'**		
51	**4**	**20'**		
15	**3**	**20'**		
		GRADE 40		
126	5	2'-8" x 3'-10"	LBAR	L1
67	5	20'		

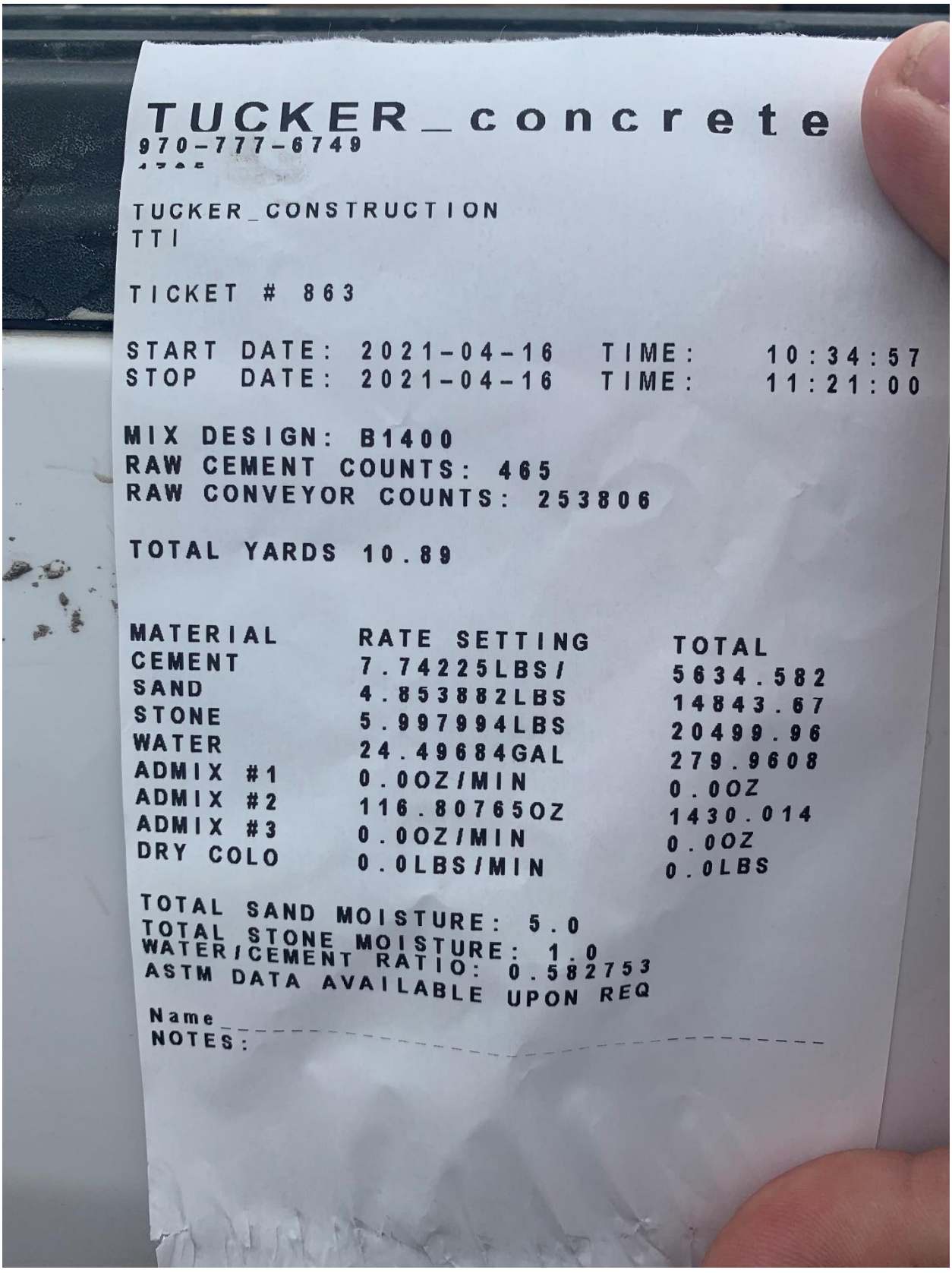
Texas A&M Transportation Institute	QF 7.3-01 Concrete Sampling	Doc. No. QF 7.3-01	Revision Date: 2020-07-29
Quality Form	Revised by: B.L. Griffith Approved by: D. L. Kuhn	Revision: 7	Page: 1 of 1

Project No: 440861-02 **Casting Date:** 4/16/2021 **Mix Design (psi):** 4000

Name of Technician Taking Sample	Terracon	Name of Technician Breaking Sample	Terracon
Signature of Technician Taking Sample	Terracon	Signature of Technician Breaking Sample	Terracon

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	Tucker	863	South half of the wall and deck
T2	Tucker	634	North half of the wall and deck

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average



TUCKER_concrete
970-777-6749

TUCKER_CONSTRUCTION
TTI

TICKET # 863

START DATE: 2021-04-16 TIME: 10:34:57
STOP DATE: 2021-04-16 TIME: 11:21:00

MIX DESIGN: B1400
RAW CEMENT COUNTS: 465
RAW CONVEYOR COUNTS: 253806

TOTAL YARDS 10.89

MATERIAL	RATE SETTING	TOTAL
CEMENT	7.74225LBS/	5634.582
SAND	4.853882LBS	14843.67
STONE	5.997994LBS	20499.96
WATER	24.49684GAL	279.9608
ADMIX #1	0.0OZ/MIN	0.0OZ
ADMIX #2	116.807650Z	1430.014
ADMIX #3	0.0OZ/MIN	0.0OZ
DRY COLO	0.0LBS/MIN	0.0LBS

TOTAL SAND MOISTURE: 5.0
TOTAL STONE MOISTURE: 1.0
WATER/CEMENT RATIO: 0.582753
ASTM DATA AVAILABLE UPON REQ

Name _____
NOTES: _____

TUCKER_concrete
979-777-6749
TRUCK_#4
TUCKER_CONSTRUCTION
TTI

TICKET # 634

START DATE: 2021-04-16 TIME: 10:59:33
STOP DATE: 2021-04-16 TIME: 11:49:32

MIX DESIGN: B1400

RAW CEMENT COUNTS: 6147
RAW CONVEYOR COUNTS: 209022
CONVEYOR SPEED: 50
TOTAL YARDS 9.747

MATERIAL	RATE SETTING	TOTAL
CEMENT	9.343309LBS	5039.31L
SAND	5.397386 GA	13277.23
ADJUSTED:		
STONE	7.101724 GA	18336.62
ADJUSTED:		
WATER	30.01423GAL	269.6036
ADMIX #1	0.0OZ/MIN	0.0OZ
ADMIX #2	0.0OZ/MIN	0.0OZ
ADMIX #3	0.0OZ/MIN	0.0OZ

TOTAL SAND MOISTURE: 0.0
TOTAL STONE MOISTURE: 0.0

Name _____
NOTES:

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0182
Service Date: 04/16/21
Report Date: 07/23/21 Revision 1 - Compressive Strength Test Date
Task: PO# 440861-02

Terracon
6198 Imperial Loop
College Station, TX 77845-5765
979-846-3767 Reg No: F-3272

Client

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

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information

Specified Strength: 4,000 psi @ 28 days

Mix ID: B1400
Supplier: Tucker Concrete
Batch Time: 1034 **Plant:** Bryan
Truck No.: 1705 **Ticket No.:** 863

Sample Information

Sample Date: 04/16/21 **Sample Time:** 1117
Sampled By: David Carpio
Weather Conditions: Cloudy, light wind
Accumulative Yards: 10.89 **Batch Size (cy):** 10.89
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: 18' north of south end
Placement Location: T2P

Field Test Data

Test	Result	Specification
Slump (in):	8	Not specified
Air Content (%):	1.9	Not specified
Concrete Temp. (F):	76	40 - 95
Ambient Temp. (F):	66	40 - 95
Plastic Unit Wt. (pcf):	144.7	Not specified
Yield (Cu. Yds.):		

Laboratory Test Data

Set No.	Specimen ID	Avg Diam. (in)	Area (sq in)	Date Received	Date Tested	Age at Test (days)	Maximum Load (lbs)	Compressive Strength (psi)	Fracture Type	Tested By
1	A	6.00	28.27		07/22/21	97 F	133,510	4,720	1	SLS
1	B	6.00	28.27		07/22/21	97 F	132,630	4,690	4	SLS
1	C	6.00	28.27		07/22/21	97 F	133,860	4,730	1	SLS
1	D					Hold				

Initial Cure: Outside Plastic Lids **Final Cure:** Field Cured

Comments: F = Field Cured
Note: Reported air content does not include Aggregate Correction Factor (ACF).

Samples Made By: Terracon
Services: Obtain samples of fresh concrete at the placement locations (ASTM C 172), perform required field tests and cast, cure, and test compressive strength samples (ASTM C 31, C 39, C 1231).
Terracon Rep.: David Carpio **Start/Stop:** 1015-1245
Reported To: Will
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Alex Dunigan, P.E.
(1) Texas Transportation Institute, Bill Griffith

Test Methods: ASTM C 31, ASTM C143, ASTM C231, ASTM C1064

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0182
Service Date: 04/16/21
Report Date: 07/23/21 Revision 1 - Compressive Strength Test Date
Task: PO# 440861-02

Terracon
6198 Imperial Loop
College Station, TX 77845-5765
979-846-3767 Reg No: F-3272

Client

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

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information

Specified Strength: 4,000 psi @ 28 days

Mix ID: B1400
Supplier: Tucker Concrete
Batch Time: 1059 **Plant:** Bryan
Truck No.: 4 **Ticket No.:** 634

Sample Information

Sample Date: 04/16/21 **Sample Time:** 1144
Sampled By: David Carpio
Weather Conditions: Cloudy, light wind
Accumulative Yards: 9.74 **Batch Size (cy):** 9.74
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: 57' North of south end
Placement Location: T2P

Field Test Data

Test	Result	Specification
Slump (in):	5 3/4	Not specified
Air Content (%):	2.4	Not specified
Concrete Temp. (F):	75	40 - 95
Ambient Temp. (F):	66	40 - 95
Plastic Unit Wt. (pcf):	145.5	Not specified
Yield (Cu. Yds.):		

Laboratory Test Data

Set No.	Specimen ID	Avg Diam. (in)	Area (sq in)	Date Received	Date Tested	Age at Test (days)	Maximum Load (lbs)	Compressive Strength (psi)	Fracture Type	Tested By
2	A	6.00	28.27		07/22/21	97 F	137,910	4,880	1	SLS
2	B	6.00	28.27		07/22/21	97 F	156,450	5,530	4	SLS
2	C	6.00	28.27		07/22/21	97 F	139,360	4,930	4	SLS
2	D					Hold				

Initial Cure: Outside Plastic Lids **Final Cure:** Field Cured

Comments: **F = Field Cured**
Note: Reported air content does not include Aggregate Correction Factor (ACF).

Samples Made By: Terracon
Services: Obtain samples of fresh concrete at the placement locations (ASTM C 172), perform required field tests and cast, cure, and test compressive strength samples (ASTM C 31, C 39, C 1231).

Terracon Rep.: David Carpio **Start/Stop:** 1015-1245
Reported To: Will
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Alex Dunigan, P.E.
(1) Texas Transportation Institute, Bill Griffith

Reviewed By: Alexander Dunigan
Project Manager

Test Methods: ASTM C 31, ASTM C143, ASTM C231, ASTM C1064

Texas A&M Transportation Institute	QF 7.3-01 Concrete Sampling	Doc. No. QF 7.3-01	Revision Date: 2020-07-29
Quality Form	Revised by: B.L. Griffith Approved by: D. L. Kuhn	Revision: 7	Page: 1 of 1

Project No: 440861-02 **Casting Date:** 4/16/2021 **Mix Design (psi):** 4000

Name of Technician Taking Sample	Terracon	Name of Technician Breaking Sample	Terracon
Signature of Technician Taking Sample	Terracon	Signature of Technician Breaking Sample	Terracon

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	Tucker	1094	100% of curb

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average

TUCKER Concrete

8930 LACY WELL RD
77845 979 777 6749

Job # TUCKER
TTI T2P

TICKET # 1094
START DATE: 06/14/2021 TIME: 07:46:26
STOP DATE: 06/14/2021 TIME: 08:33:52

MIX DESIGN B1500
RAW CEMENT COUNTS 6930
RAW CONVEYOR COUNTS 2584

TOTAL YARDS 4.24

MATERIAL	RATE SETTING	TOTAL
CAPTYPE1	448.3LBPM	2592.5LBS
LRMSAND	4.6 GATE	5611.5LBS
RGBLND	5.7 GATE	7749.9LBS
WATER	23.5GPM	133.4GAL
SIKA686	0.9GPM	5.1GAL

WATER / CEMENT RATIO 0.43
REQUEST ASTM INFORMATION

NAME
NOTES:

CONTINUED FROM 1093

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0200
Service Date: 06/14/21
Report Date: 07/23/21 Revision 2 - 38-day results
Task: PO# 440861-02

Terracon
6198 Imperial Loop
College Station, TX 77845-5765
979-846-3767 Reg No: F-3272

Client

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

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information

Specified Strength: 4,000 psi @ 28 days

Mix ID: B1500
Supplier: Tucker concrete
Batch Time: 0746 **Plant:** Onsite
Truck No.: VM1801 **Ticket No.:** From onsit

Sample Information

Sample Date: 06/14/21 **Sample Time:** 0800
Sampled By: Ethan Boultinghouse
Weather Conditions: Clear, no wind
Accumulative Yards: 2.0 **Batch Size (cy):** 4.24
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: 8th section of edge wall on north side of airfield
Placement Location: Curb T2P

Field Test Data

Test	Result	Specification
Slump (in):	5	
Air Content (%):	2.4	
Concrete Temp. (F):	82	
Ambient Temp. (F):	85	
Plastic Unit Wt. (pcf):	145.1	
Yield (Cu. Yds.):		

Laboratory Test Data

Set No.	Specimen ID	Avg Diam. (in)	Area (sq in)	Date Received	Date Tested	Age at Test (days)	Maximum Load (lbs)	Compressive Strength (psi)	Fracture Type	Tested By
1	A	6.01	28.37		06/18/21	4	95,630	3,370	1	SLS
1	B	6.00	28.27		07/22/21	38	125,440	4,440	3	SLS
1	C	6.00	28.27		07/22/21	38	128,520	4,550	3	SLS
1	D	6.00	28.27		07/22/21	38	126,320	4,470	1	SLS
						Average (38 days)		**4,480**		

Initial Cure: Outside Plastic Lids **Final Cure:** Field Cured

Comments: **Average compressive strength of 38 day cylinders complies with the specified strength.**
Note: Reported air content does not include Aggregate Correction Factor (ACF).

Samples Made By: Terracon
Services: Obtain samples of fresh concrete at the placement locations (ASTM C 172), perform required field tests and cast, cure, and test compressive strength samples (ASTM C 31, C 39, C 1231).
Terracon Rep.: Ethan Boultinghouse **Start/Stop:** 0645-0900
Reported To:
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Alex Dunigan, P.E.
(1) Texas Transportation Institute, Bill Griffith

Reviewed By: Alexander Dunigan
Project Manager

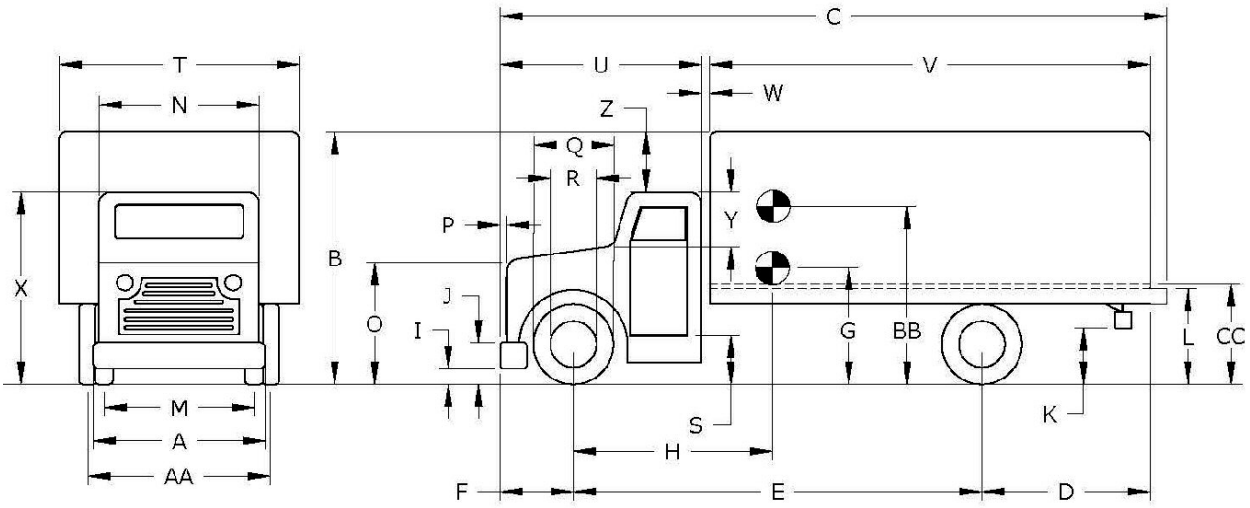
Test Methods: ASTM C 31, ASTM C143, ASTM C231, ASTM C1064

APPENDIX C. *MASH* TEST 4-12 (CRASH TEST NO. 440861-2)

C.1. VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 440861-2.

Date:	2021-07-23	Test No.:	440861-2	VIN No.:	5PVNV8JM5C4S50273
Year:	2012	Make:	HINO	Model:	338
Odometer:	212617	Tire Size Front:	275/80R22.5	Tire Size Rear:	275/80R22.5



Vehicle Geometry: ☑ inches or ☐ mm

A	Front Bumper Width:	92.50	K	Rear Bumper Bottom:		U	Cab Length:	107.00	
B	Overall Height:	135.00	L	Rear Frame Top:	39.00	V	Trailer/Box Length:	224.00	
C	Overall Length:	332.25	M	Front Track Width:	79.00	W	Gap Width:	1.50	
D	Rear Overhang:	86.50	N	Roof Width:	77.50	X	Overall Front Height:	104.75	
E	Wheel Base:	205.75	O	Hood Height:	60.00	Y	Roof-Hood Distance:	34.50	
F	Front Overhang:	40.00	P	Bumper Extension:	1.00	Z	Roof-Box Height Difference:	30.25	
G	C.G. Height:		Q	Front Tire Width:	39.50	AA	Rear Track Width:	73.00	
H	C.G. Horizontal Dist. w/Ballast:	131.62	R	Front Wheel Width:	23.25	BB	Ballast Center of Mass:	63.75	
I	Front Bumper Bottom:	18.75	S	Bottom Door Height:	38.25	CC	Cargo Bed Height:	50.75	
J	Front Bumper Top:	31.50	T	Overall Width:	97.00				

Allowable Range: C = 394 inches max.; E = 240 inches max.; CC = 49 ±2 inches; BB = 63 ±2 inches above ground;

Wheel Center Height Front	19.00	Wheel Well Clearance (Front)	13.25	Bottom Frame Height (Front)	24.75
Wheel Center Height Rear	19.00	Wheel Well Clearance (Rear)	4.00	Bottom Frame Height (Rear)	28.75

More information needed on next page

Table C.1. Vehicle Properties for Test No. 440861-2 (Continued).

Date: 2021-07-23 Test No.: 440861-2 VIN No.: 5PVNV8JM5C4S50273

Year: 2012 Make: HINO Model: 338

WEIGHTS (☑ lb or ☐ kg)	CURB	TEST INERTIAL
$W_{front\ axle}$	6850	8120
$W_{rear\ axle}$	7100	14420
W_{TOTAL}	13950	22540

Allowable Range for CURB = 13,200 ±2200 lb | Allowable Range for TIM = 22,046 ±660 lb

Ballast: 8590 (☑ lb or ☐ kg) (as-needed)
(See *MASH* Section 4.2.1.2 for recommended ballasting)

Mass Distribution (☑ lb or ☐ kg): **LF:** 4060 **RF:** 4060 **LR:** 7410 **RR:** 7010

Engine Type: T 260

Engine Size:

Transmission Type:

☑ Auto or ☐ Manual

☐ FWD ☑ RWD ☐ 4WD

Accelerometer Locations (☑ inches or ☐ mm)

	x[1]	y	z[2]
Front:			
Center:	131.50	0.00	50.00
Rear:	233.00	0.00	50.00

Describe any damage to the vehicle prior to test: None

Other notes to include ballast type, dimensions, mass, location, center of mass, and method of attachment:

Two concrete blocks 30 inches high x 60 inches wide x 30 inches long
Centered in middle of bed
63.75 inches from ground to center of block
Tied down with four 5/8-inch B7 rod and four 3/8-inch cables

Performed by: SCD Date: 2021-07-23

[1] Referenced to the front axle
[2] Above ground

C.2. SEQUENTIAL PHOTOGRAPHS

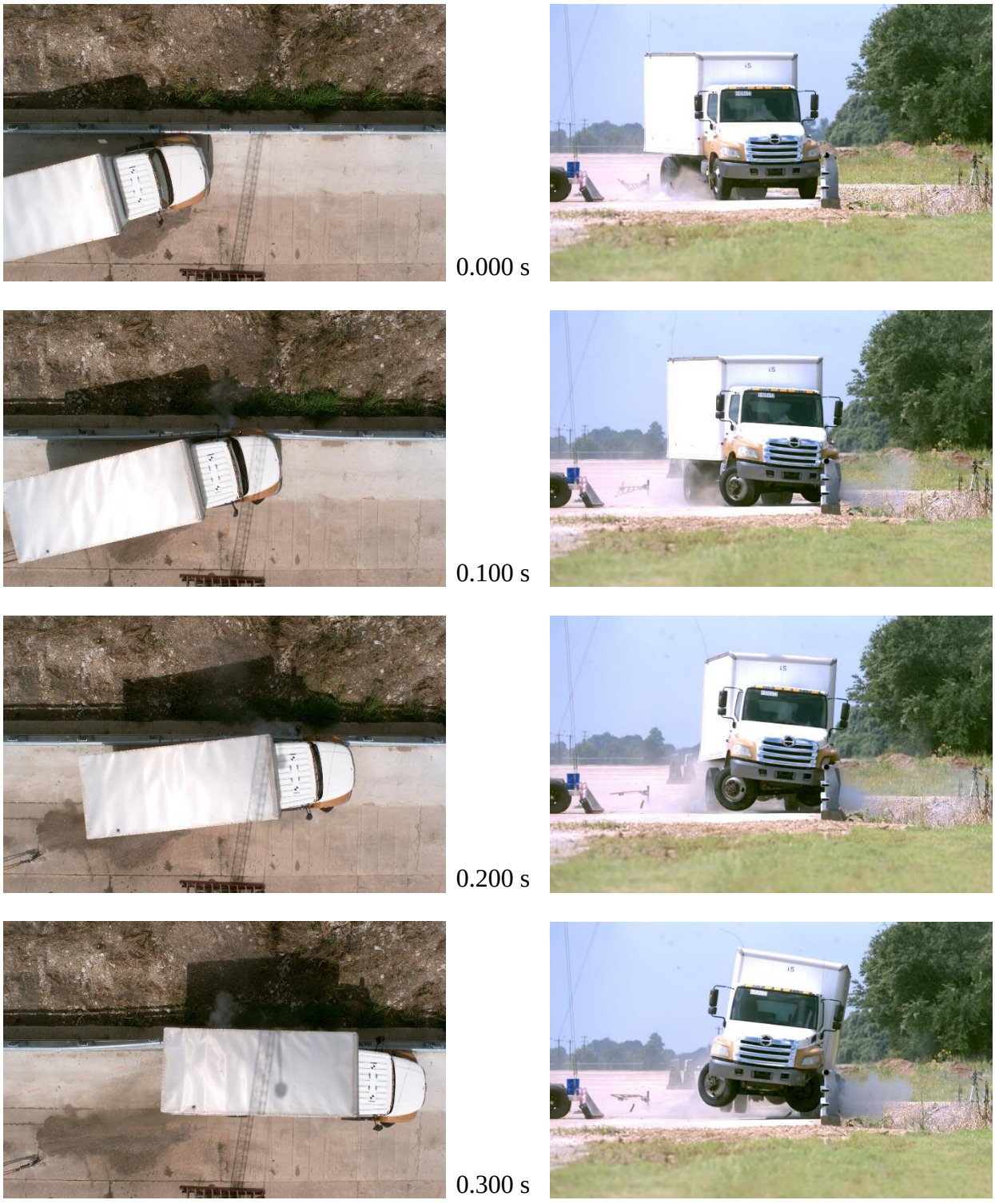


Figure C.1. Sequential Photographs for Test No. 440861-2 (Overhead and Frontal Views).


0.400 s


0.500 s


0.600 s


0.700 s

Figure C.1. Sequential Photographs for Test No. 440861-2 (Overhead and Frontal Views) (Continued).


0.000 s


0.400 s


0.100 s


0.500 s


0.200 s


0.600 s


0.300 s


0.700 s

Figure C.2. Sequential Photographs for Test No. 440861-2 (Rear View).

C.3. VEHICLE ANGULAR DISPLACEMENTS

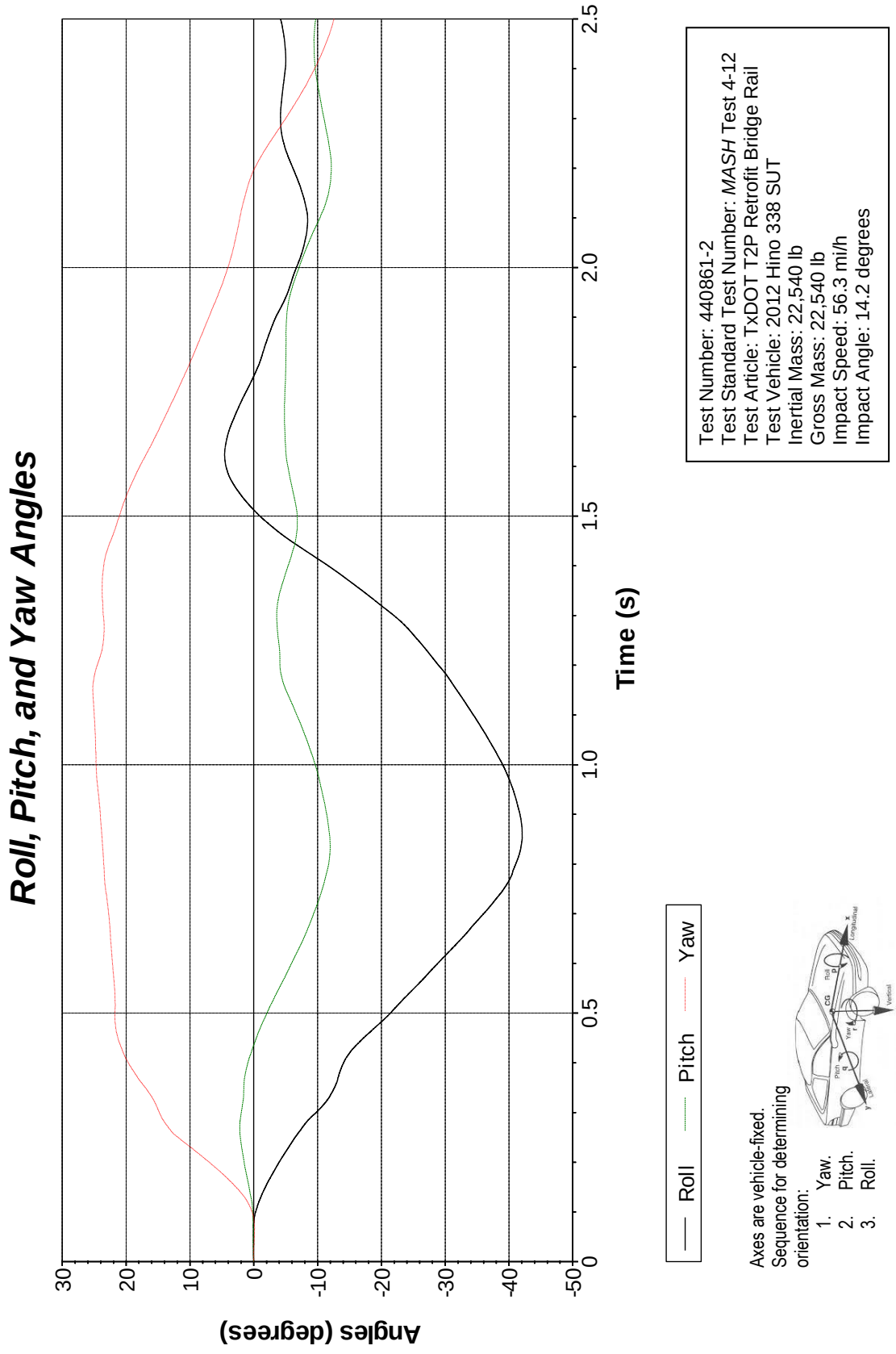


Figure C.3. Vehicle Angular Displacements for Test No. 440861-2.

C.4. VEHICLE ACCELERATIONS

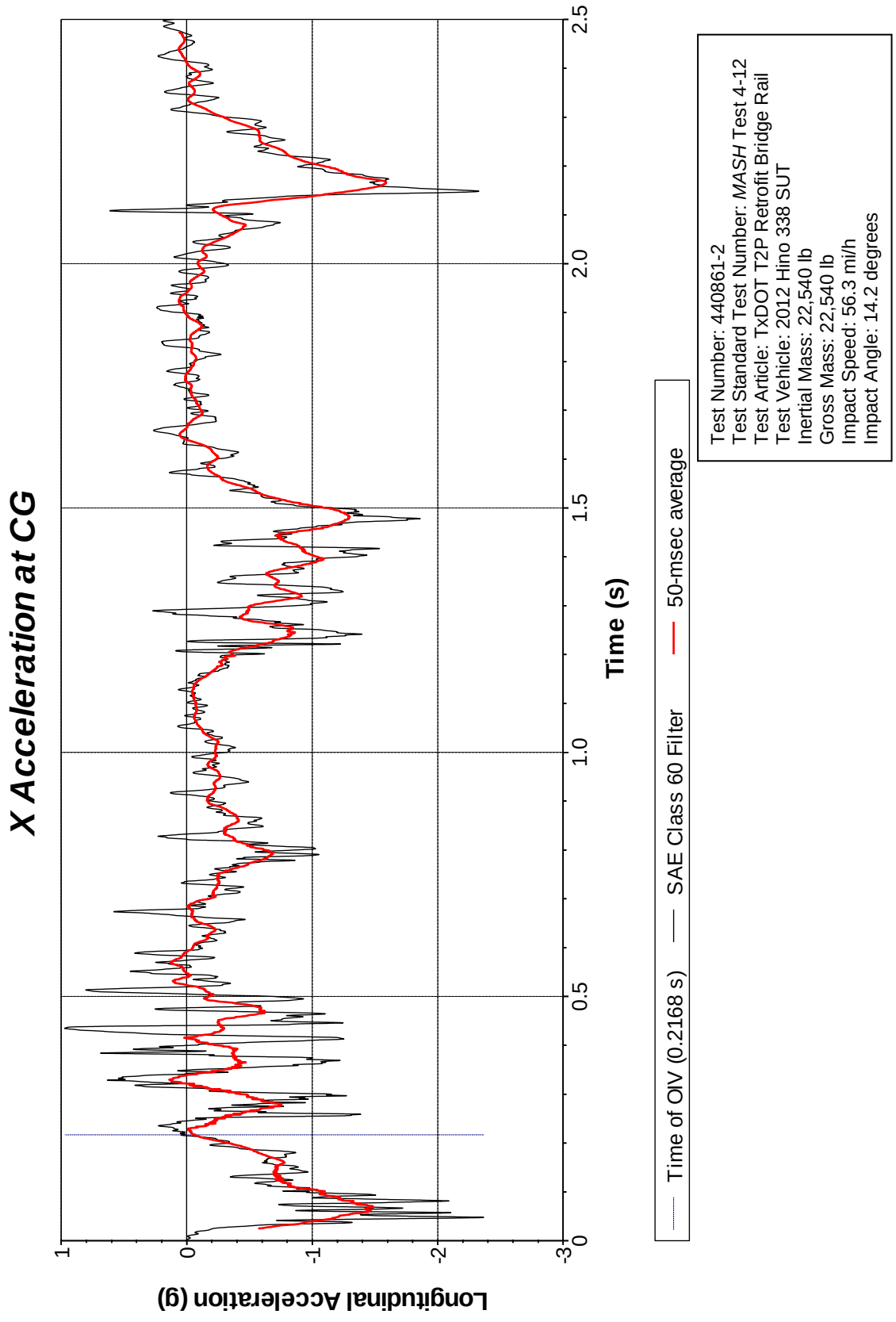


Figure C.4. Vehicle Longitudinal Accelerometer Trace for Test No. 440861-2 (Accelerometer Located at Center of Gravity).

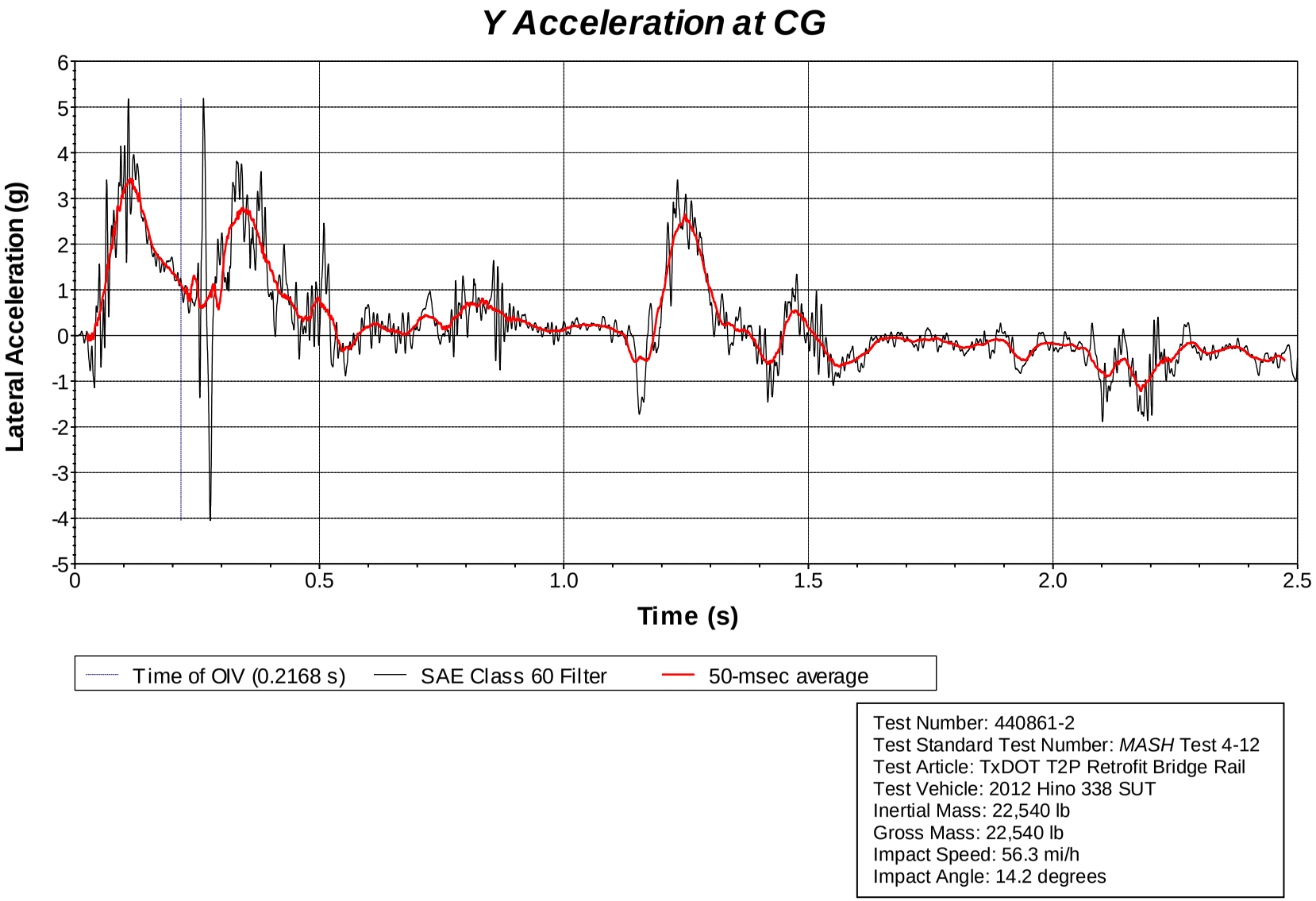


Figure C.5. Vehicle Lateral Accelerometer Trace for Test No. 440861-2 (Accelerometer Located at Center of Gravity).

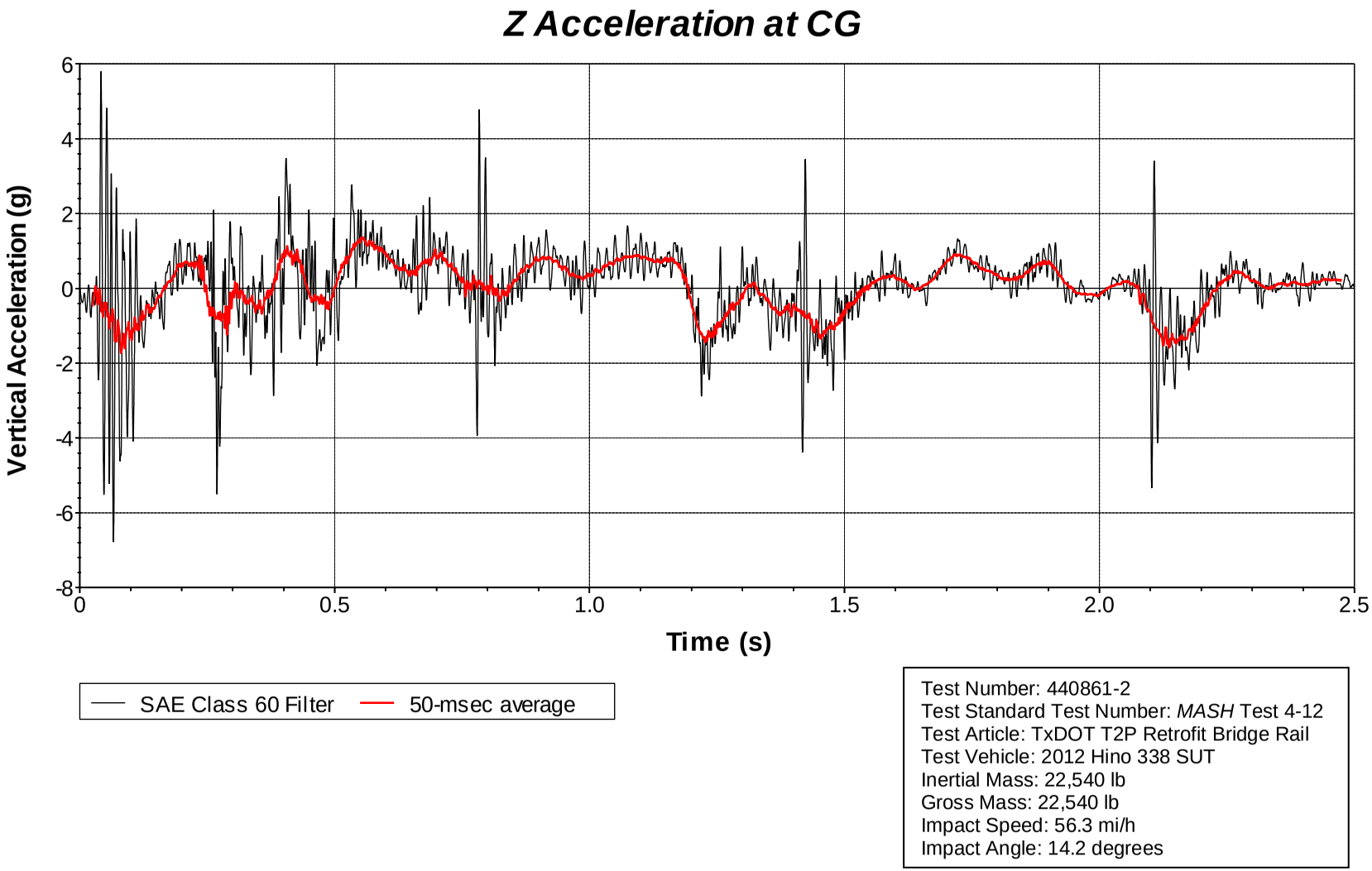


Figure C.6. Vehicle Vertical Accelerometer Trace for Test No. 440861-2 (Accelerometer Located at Center of Gravity).

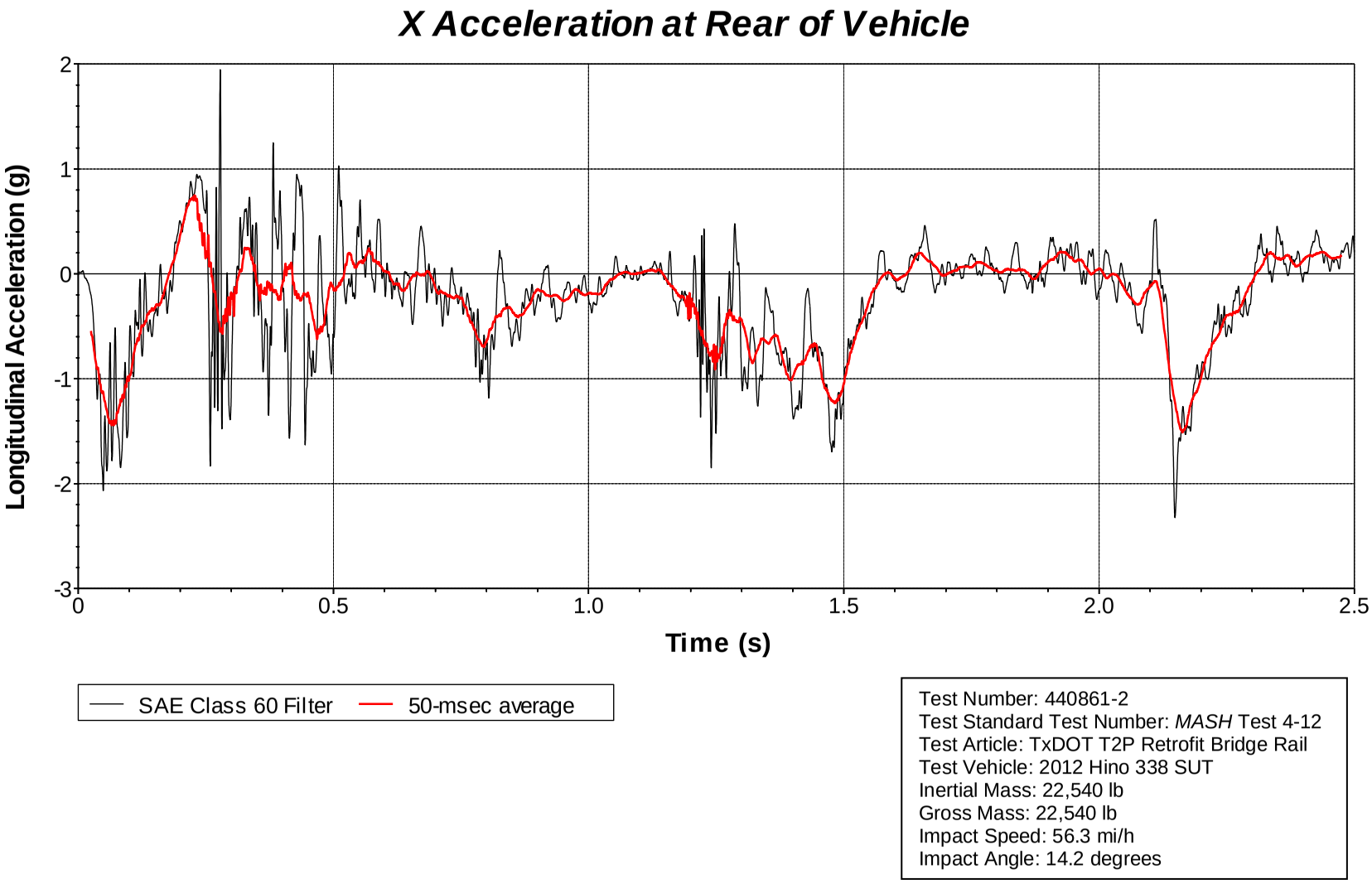


Figure C.7. Vehicle Longitudinal Accelerometer Trace for Test No. 440861-2 (Accelerometer Located at Rear of Vehicle).

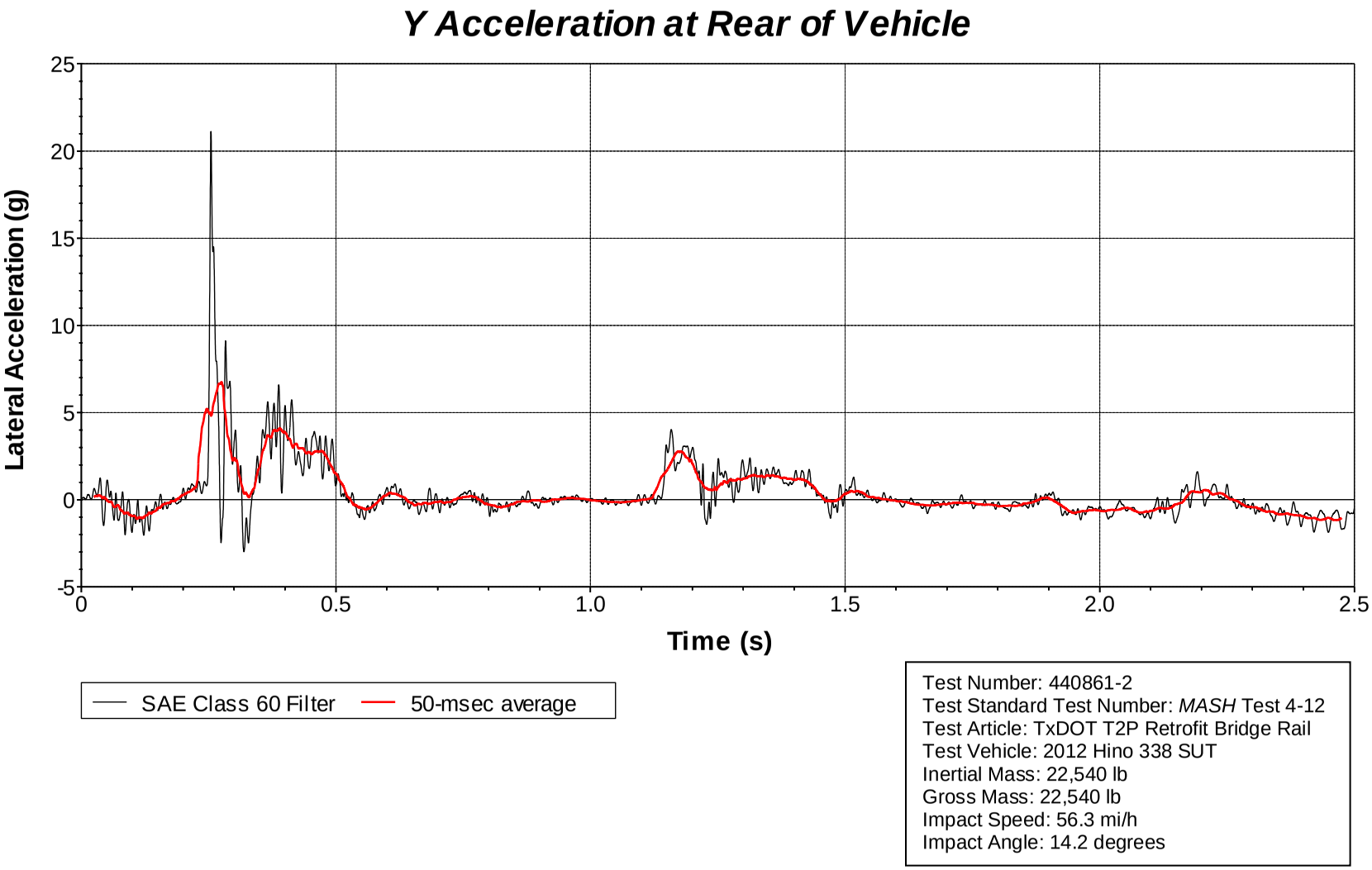


Figure C.8. Vehicle Lateral Accelerometer Trace for Test No. 440861-2 (Accelerometer Located at Rear of Vehicle).

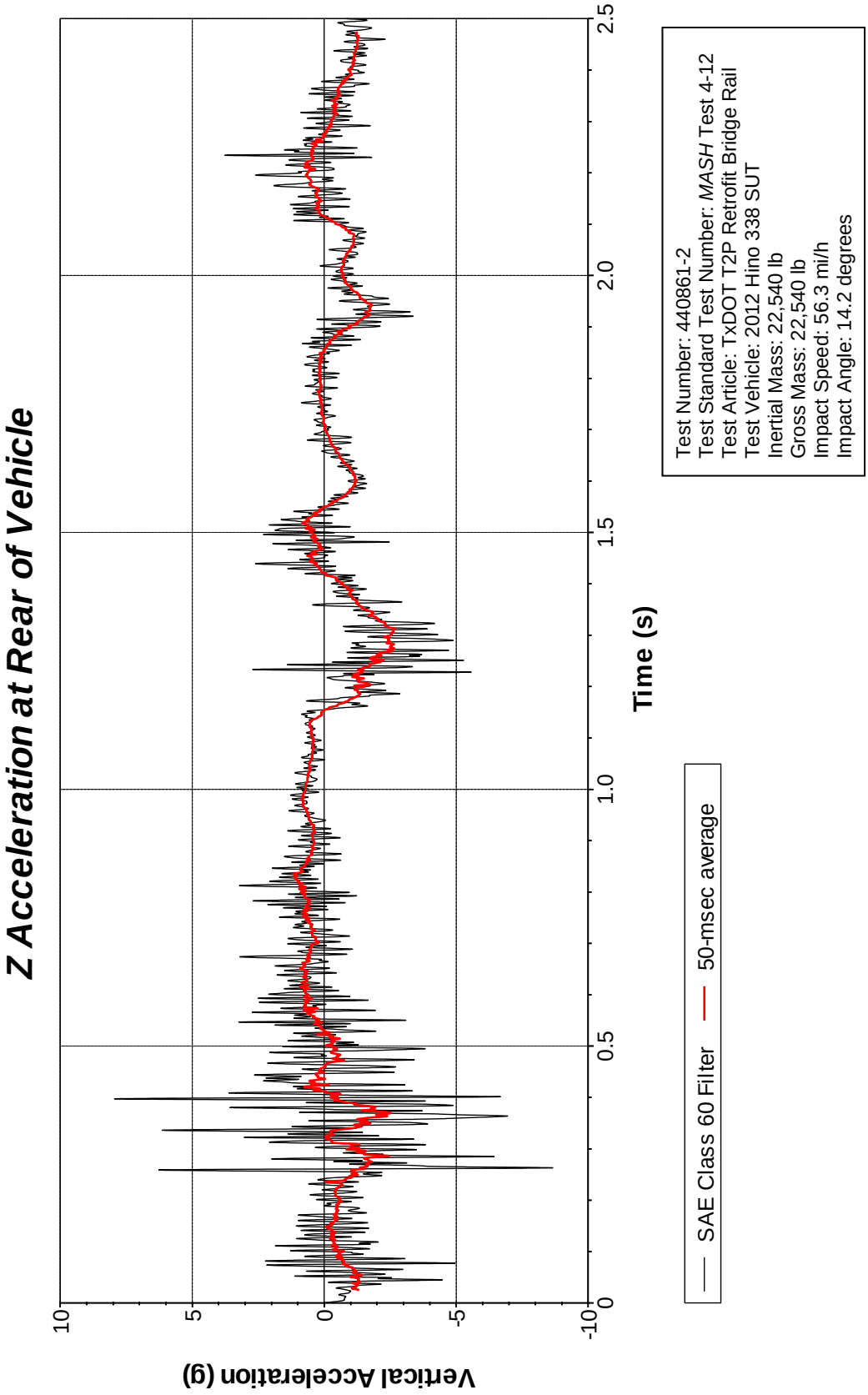


Figure C.9. Vehicle Vertical Accelerometer Trace for Test No. 440861-2 (Accelerometer Located at Rear of Vehicle).