TTI: 9-1002-15

CRASH TESTING AND EVALUATION OF THE TXDOT SHORT-SPAN SHORT-RADIUS GUARDRAIL SYSTEM

ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01

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

Test Report 9-1002-15-9

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/9-1002-15-9.pdf

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-17/9-1002-15-9		

4. Title and Subtitle	5. Report Date
CRASH TESTING AND EVALUATION OF THE TXDOT SHORT-SPAN SHORT-RADIUS GUARDRAIL SYSTEM	Published: January 2018
	6. Performing Organization Code
7. Author(s) Akram Y Abu-Odeh, Conor Mitchell, Roger P. Bligh, Wanda L. Menges, and Darrell L. Kuhn	8. Performing Organization Report No. Test Report No. 9-1002-15-9
9. Performing Organization Name and Address Texas A&M Transportation Institute Proving Ground 3135 TAMU College Station, Texas 77843-3135	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. 9-1002-15
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office 125 E. 11th Street Austin, Texas 78701-2483	13. Type of Report and Period Covered Technical Report: September 2015–August 2016
	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 Crash Testing Program

URL: http://tti.tamu.edu/documents/9-1002-15-9.pdf

16. Abstract

This research evaluated the impact performance of the TxDOT short-span short-radius guardrail system according to the safety-performance evaluation guidelines included in American Association of State Highway and Transportation Officials, entitled *Manual for Assessing Safety Hardware* (*MASH*) for Test Level Three (TL-3).

This report describes the TxDOT short-span short-radius guardrail system, documents the impact performance of the guardrail system according to *MASH* TL-3 evaluation criteria, and presents recommendations for implementation.

The short-span short-radius guardrail system performed acceptably according to *MASH* for modified tests 3-33 and 3-32.

17. Key Words	18. Distribution Statement
Short Radius, Guardrails, Crash Testing, Simulation, Roadside Safety	No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia 22312 http://www.ntis.gov

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	124	

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Report 9-1002-15-9
Project 9-1002-15
Project Title: Roadside Safety Device Crash Testing Program

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

Published: January 2018

TEXAS A&M TRANSPORTATION INSTITUTE
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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 results of the crash testing reported herein apply only to the article being tested.

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ISO 17025 Laboratory
Testing Certificate # 2821.01

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3100 SH 47, Building 7091
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ACKNOWLEDGMENTS

This research project was conducted under a cooperative program between the Texas A&M Transportation Institute, the Texas Department of Transportation, and the Federal Highway Administration. The TxDOT project manager for this research was Wade Odell, Research and Technology Implementation. Technical support and guidance were provided by Christopher Lindsey (Design Division). The authors acknowledge and appreciate their assistance. The authors acknowledge the computational support provided by the Texas A&M High Performance Research Computing (HPRC) (http://hprc.tamu.edu/). The authors appreciate the HPRC facility assistance.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

This project provides the Texas Department of Transportation (TxDOT) with a mechanism to quickly and effectively evaluate high-priority issues for roadside safety devices. Roadside safety devices shield motorists from roadside hazards such as non-traversable terrain and fixed objects. Some obstacles that cannot be moved out of the clear zone (e.g., mailboxes, sign supports) are designed to break away. To maintain the desired level of safety for the motoring public, these safety devices must be designed to accommodate various site conditions and 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. Under this project, roadside safety issues are identified and prioritized for investigation. Each roadside safety issue is addressed with a separate work plan, and the results are summarized in an individual test report.

1.2 RESEARCH PROBLEM STATEMENT

TxDOT requested assistance with the development of short-span short-radius guardrail system suitable for use on roadways with perpendicular intersection such as driveway. The device is intended to meet the evaluation criteria recommended in the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) (*1*).

1.3 RESEARCH OBJECTIVES

This research task developed short-span short-radius guardrail system for use under *MASH* TL-3 testing environments. The TxDOT short-span short-radius guardrail system is intended to meet *MASH* Test Level 3 (TL-3) evaluation criteria.

Reported herein are details of the short-span short-radius guardrail system, descriptions of the tests performed, assessment of test results, and implementation recommendations.

CHAPTER 2: PREDICTIVE SIMULATIONS

2.1 INTRODUCTION

The model of the short-radius guardrail system consists of a steel thrie-beam representing the short radius system and four 700-lb sand barrels placed on the inner side of the short radius. The rail is supported by a rigid rotating anchor post on one end, and it is attached to a rigid concrete parapet at the other end. Figure 2.1 shows an isometric view of the model. The model includes a representation of ditch placed 5 ft offset from the thrie-beam on each side. The ditched is sloped at 3H:1V starting at the 5-ft offset.

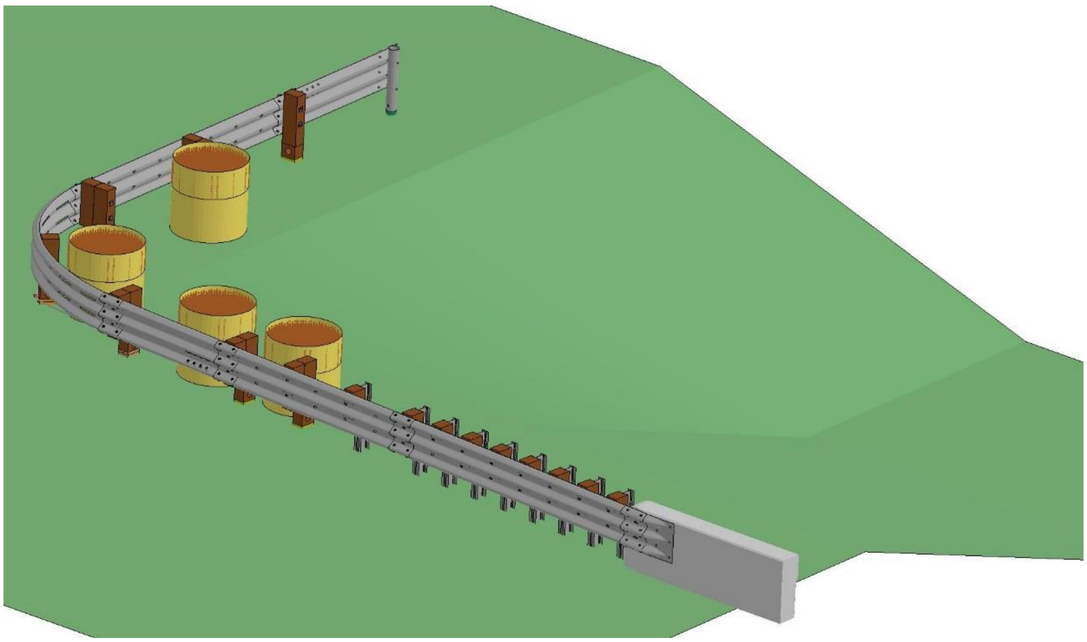


Figure 2.1. Isometric View of Short Radius Guardrail.

2.2 SIMULATION CASE #1: SMALL CAR—IMPACT ANGLE OF 15° WITH FOUR SAND BARRELS

This simulation was meant to evaluate the tested short radius system under TxDOT project 0-6711 but with a ditch on the field side as mentioned earlier. The impact angle was 15° from the face of the parapet and, similar to the previous test, the impact point was at the nose of the radius.

Figures 2.2 and 2.3 show that the short radius successfully contained the vehicle. The hood sustained damage as shown in Figure 2.4, but the vehicle did not underride the rail.

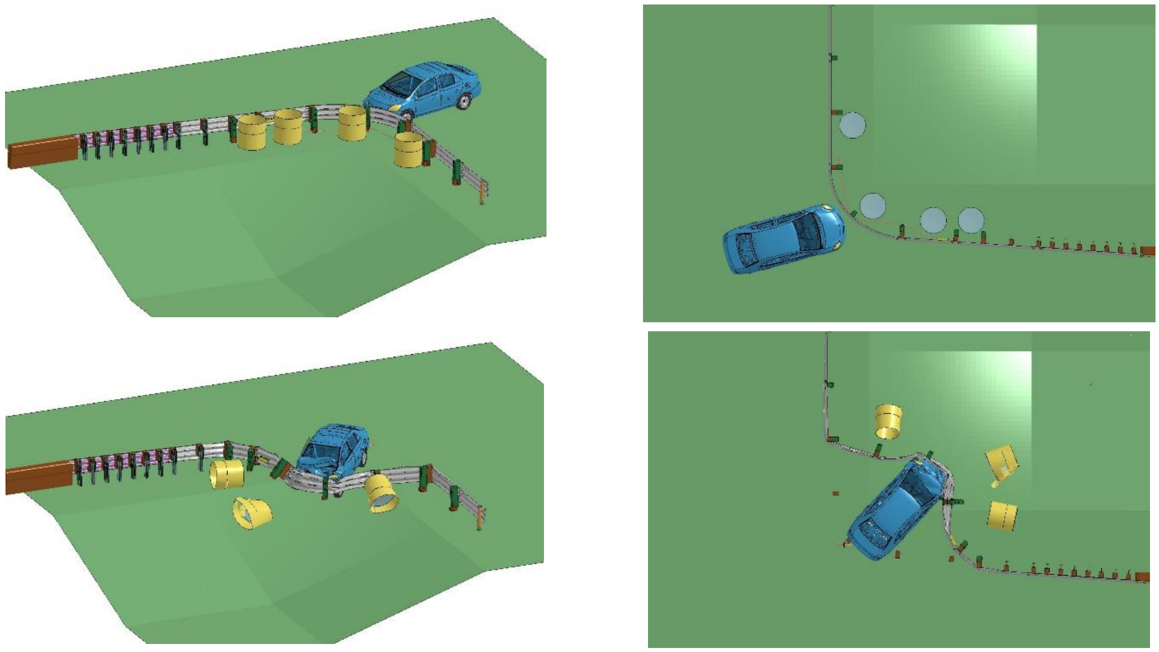


Figure 2.2. Small Car Impact with Four Barrel System Short Radius (Case #1).

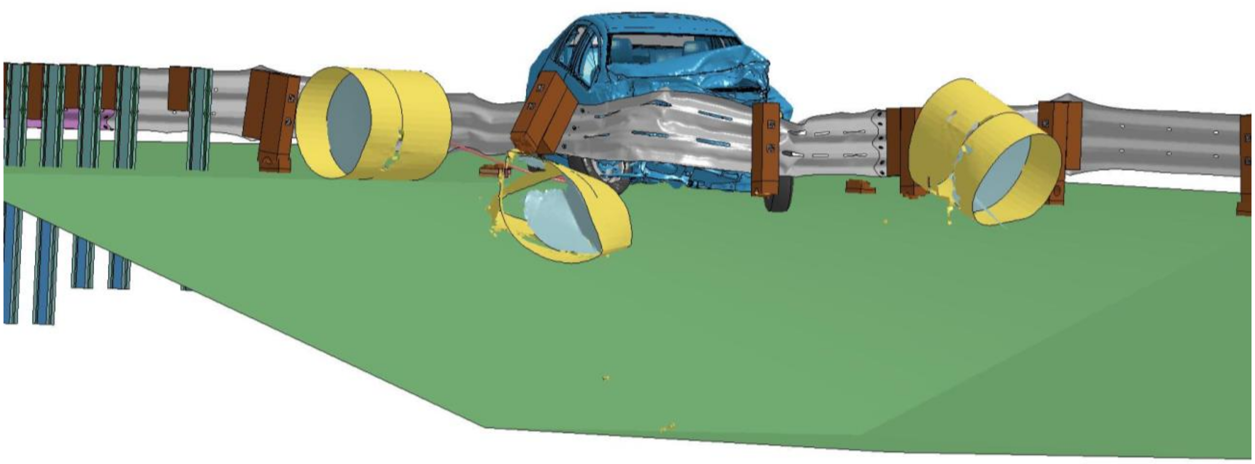


Figure 2.3. Small Car Interaction with Short Radius during Impact (Case #1).

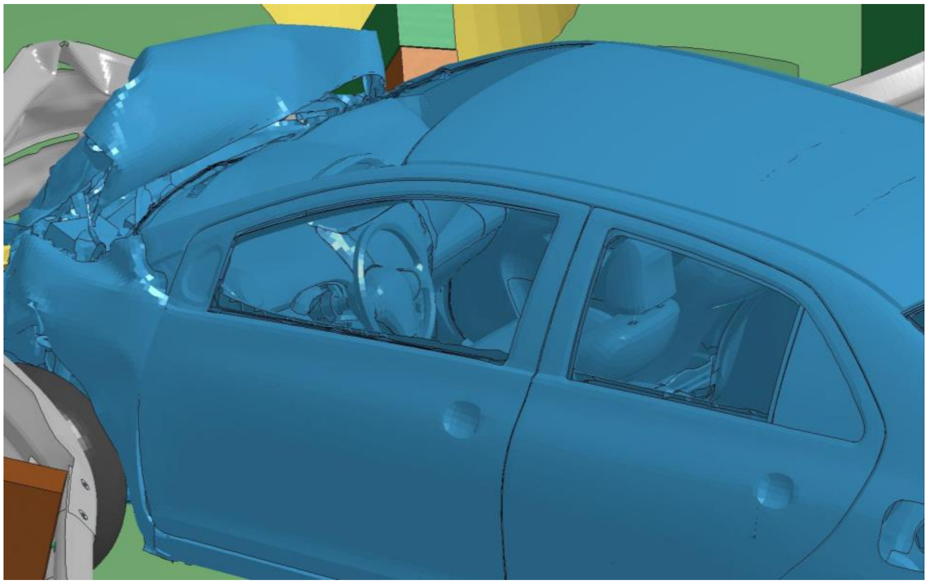


Figure 2.4. Side View of Small Car after Collision (Case #1).

2.3 SIMULATION CASE #2: SMALL CAR—IMPACT ANGLE OF 25° WITH FOUR SAND BARRELS

The impact angle for this simulation was 25° from the face of the parapet, and the impact point was at the nose of the radius. This impact angle was chosen to check the system adequacy to this impact angle that is used for redirecting impacts. Figure 2.5 shows that the short radius with four barrels successfully contained the vehicle. However, Figures 2.6 and 2.7 indicate that the there is a greater potential for the vehicle to under ride as compared the 15° impact angle simulation in Case #1. Hence, an impact angle of 25° seems to be more critical for the short radius with 3H:1V ditch than an impact angle of 15°.

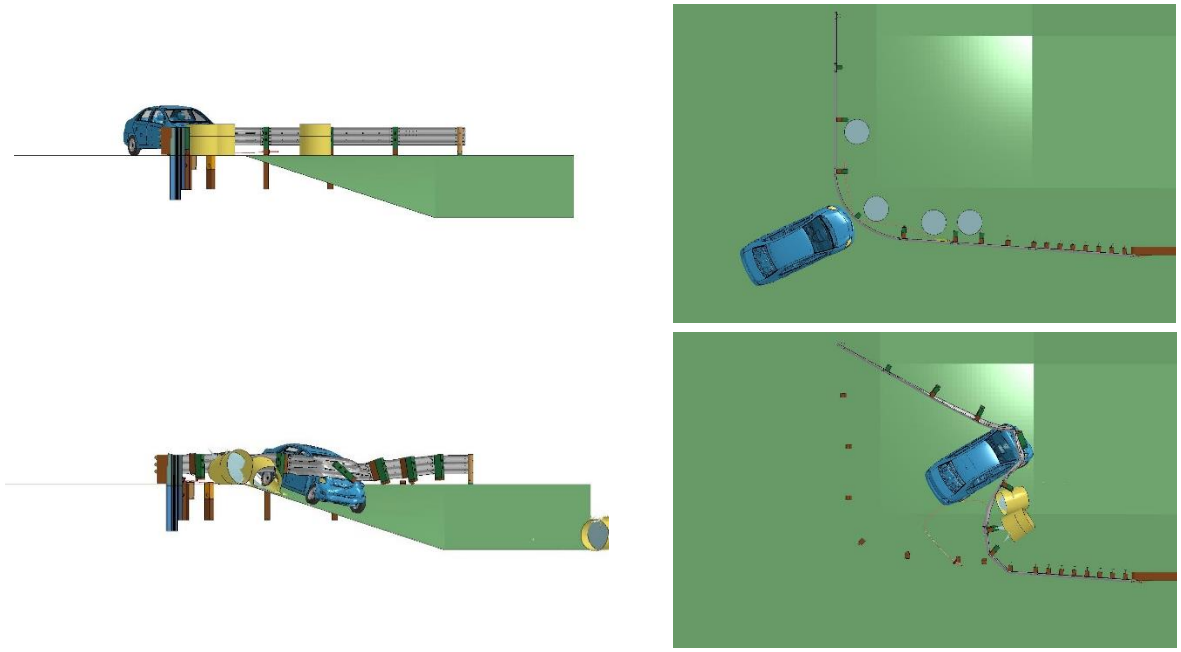


Figure 2.5. Photos from Simulation before and after Collision (Case #2).

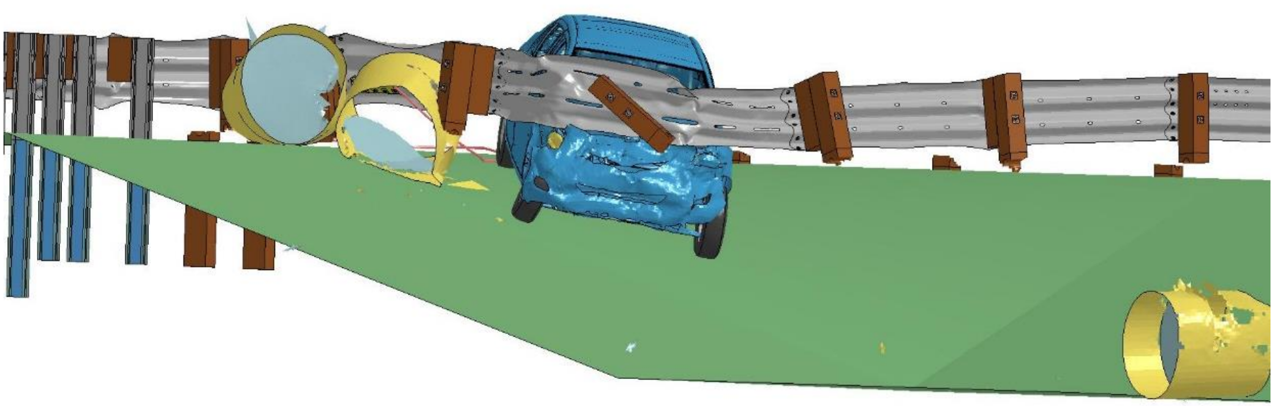


Figure 2.6. Front View of Vehicle after Collision (Case #2).

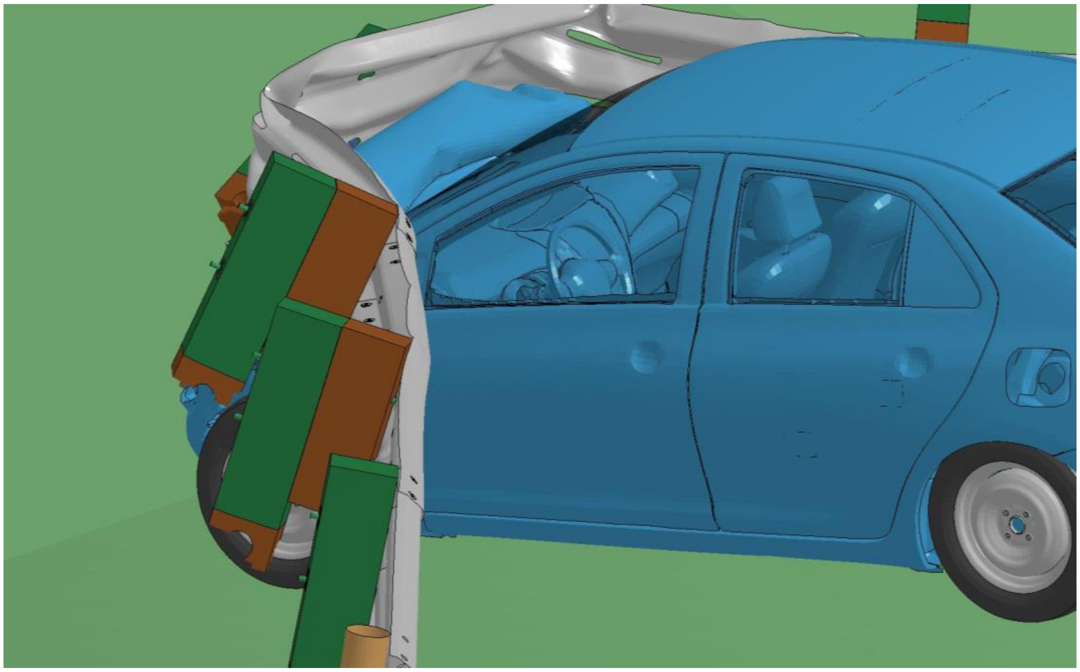


Figure 2.7. Side View of Vehicle after Collision (Case #2).

2.4 SIMULATION CASE #3: SMALL CAR—IMPACT ANGLE OF 25° WITH SIX SAND BARRELS

This simulation represents a design solution to reduce the under-ride potential observed in Case #2. The impact angle is 25° from the face of the parapet, but the number of barrels was increased to six as a design change that is simple to implement since structural components of the system were not changed.

Figure 2.8 shows the short radius with six sand barrels successfully contain the vehicle. The increased number of sand barrels reduced the potential of underride of the rail as shown in Figure 2.9. The hood buckled inward but did not interact with the windshield of the car as shown in Figure 2.10.

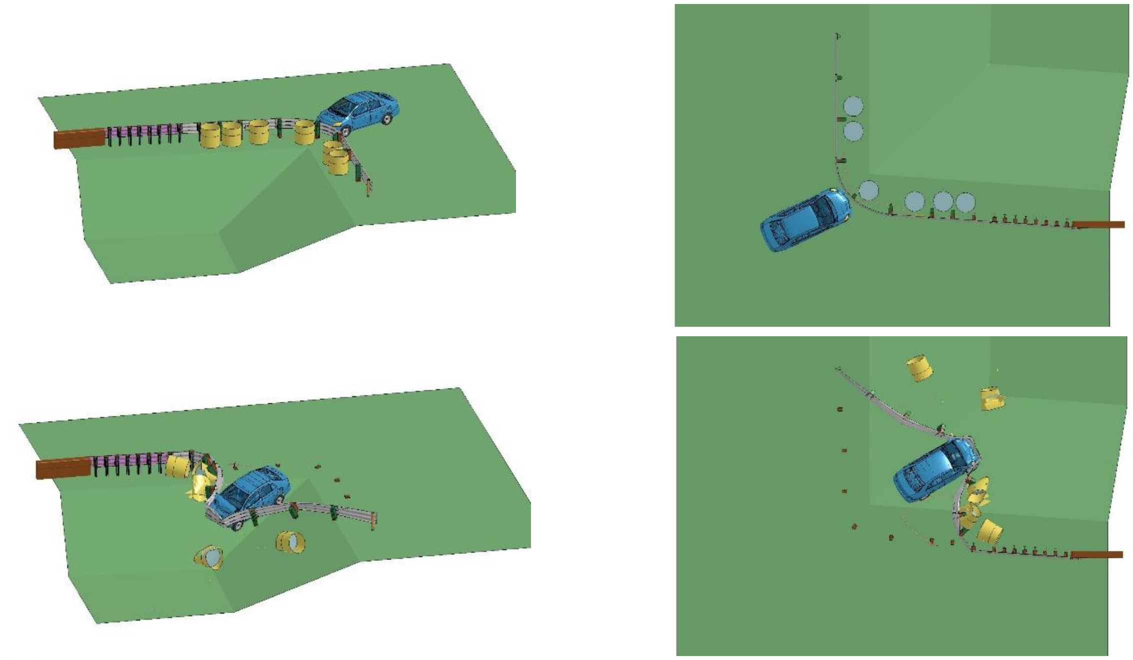


Figure 2.8. Photos from Simulation before and after Collision with Short Radius (Case #3).

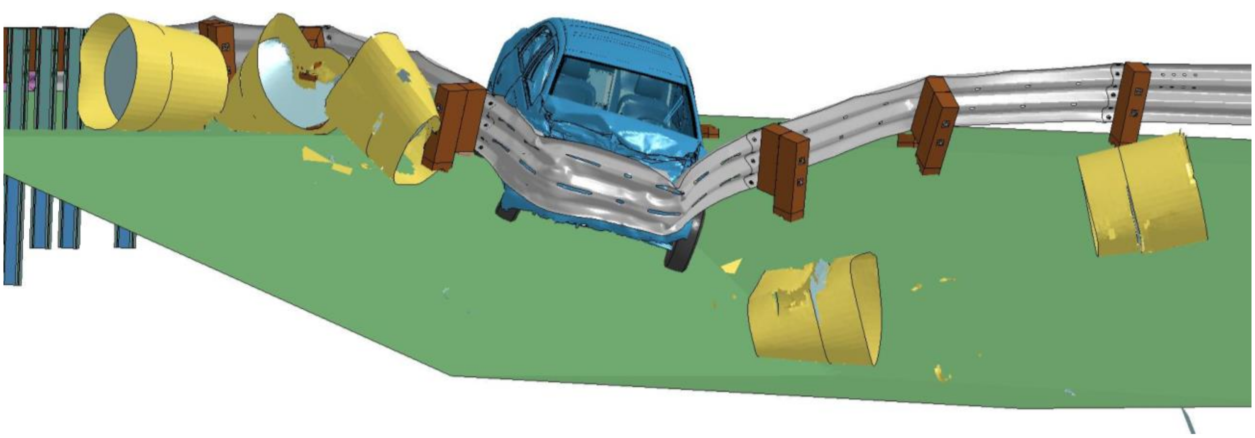


Figure 2.9. Front View of Vehicle after Collision (Case #3).

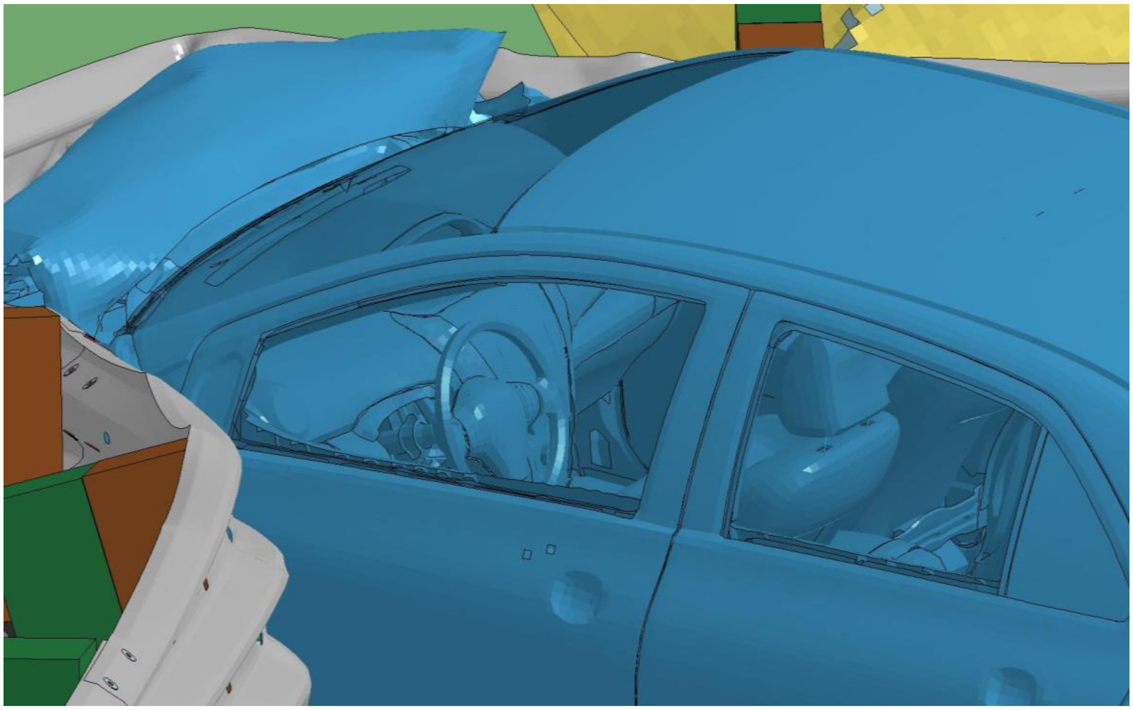


Figure 2.101. Side View of Vehicle after Collision (Case #3).

2.5 SIMULATION CASE #4: LARGE TRUCK—IMPACT ANGLE OF 15° WITH FOUR SAND BARRELS

This test was similar to Case #1 for the small car; the impact angle was 15° from the face of the parapet and four sand barrels were used in the simulation.

Figure 2.11 shows that the short radius with four sand barrels successfully contained the truck with no over-riding issues.

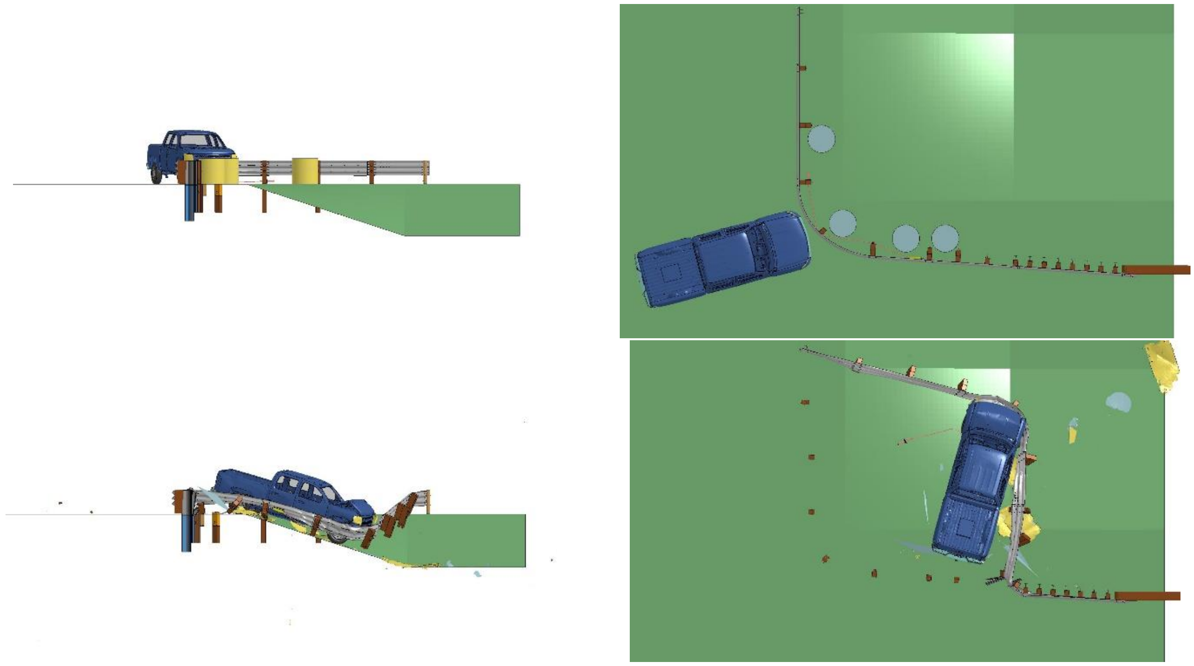


Figure 2.11. Photos from Simulation before and after Collision (Case #4).

2.6 SIMULATION CASE #5: LARGE TRUCK—IMPACT ANGLE OF 25° WITH FOUR SAND BARRELS

The impact angle for this simulation was 25° from the face of the parapet, and the impact point was at the nose of the radius. Just like Case #2 for the small car, this impact angle was chosen to check the system adequacy to this impact angle that is used for length of need or redirecting type of impacts. Figure 2.12 shows that the short radius with four barrels successfully contained the truck. It is worth noting from Figure 2.12 that there is a potential for the rear right wheel of the truck to straddle the rail. This is not considered an adverse outcome since the truck was safely contained and stable on the sloped terrain.

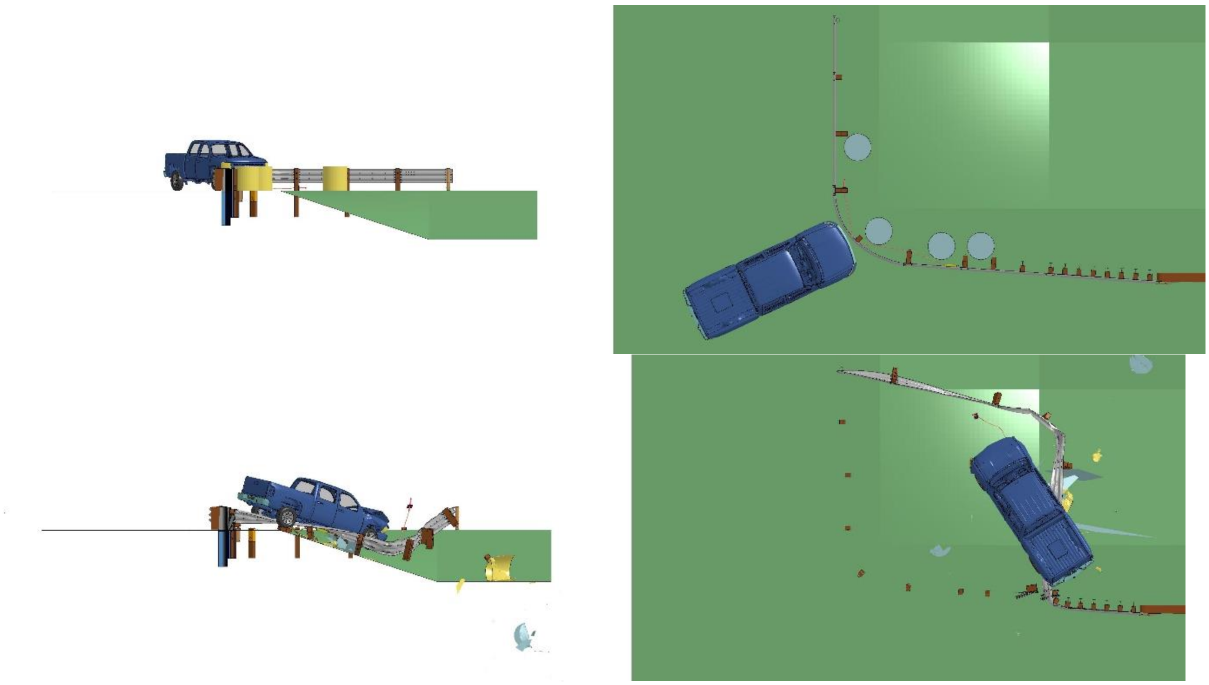


Figure 2.12. Photos from Simulation before and after Collision with Short Radius (Case #5).

2.7 SIMULATION CASE #6: LARGE TRUCK—IMPACT ANGLE OF 25° WITH SIX SAND BARRELS

The impact angle for this simulation was 25° from the face of the parapet, and the impact point was at the nose of the radius. Just like Case #3 for the small car, this simulation was conducted to evaluation the effect of the additional barrels on the system performance. Figure 2.13 shows that the short radius with six barrels successfully contained the truck. It is worth noting from Figure 2.13 that there is a potential for the rear right wheel of the truck to straddle the rail just like the simulation with four barrels in Case #5. This is not considered an adverse outcome since the truck was safely contained and stable on the sloped terrain.

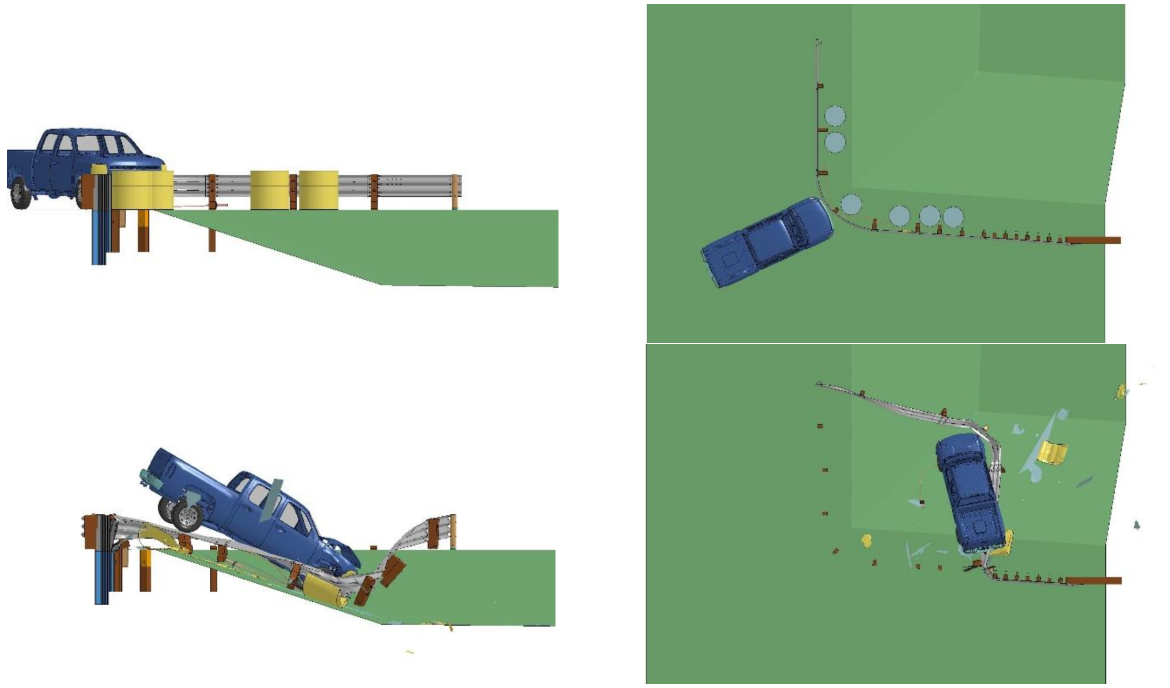


Figure 2.13. Photos from Simulation before and after Collision (Case #6).

2.8 RECOMMENDATION FOR TESTING

The simulations conducted indicate that using 25° as an impact angle is more critical for the small car than using 15°. The design was modified to address potential vehicle under ride by adding two more barrels. The truck simulations indicated no sensitivity to the change in impact angle. However, the rear wheel straddling the system was observed in cases where six barrels were used in the design.

Hence, the recommendation for testing is to use the impact angle of 25° and change the design to include six sand barrels instead of four.

CHAPTER 3: DETAILS OF THE SHORT-SPAN SHORT-RADIUS GUARDRAIL SYSTEM

3.1 TEST ARTICLE DESIGN AND CONSTRUCTION

3.1.1 General Details

Each test installation consisted of a 31-inch tall, thrie-beam short-radius guardrail system constructed with the 27-ft-7½-inch long primary-road leg (as measured along the guardrail) that transitioned to a section of bridge parapet, and an 18-ft-9-inch long secondary-road leg that terminated with a rounded thrie-beam end section (RTE02a) that is attached a stiff pipe that can rotate around the vertical axis. The curved 12-ft-6-inch (post-to-post) arc length thrie-beam section (RTM02a) was rolled to an 8-ft-4½-inch inside radius. The primary-road side thrie-beam of the system was flared to the field side 4¼° from the tangent line of the parapet face, and the secondary-road side thrie-beam was perpendicular to the parapet face tangent. Six sand barrels were strategically placed on the inboard, field side of the installation. A pit was constructed on the field side of the installation. The upper edge of the pit was located 5 ft behind and parallel to the inside of the guardrail. The pit was 18 ft wide × 6 ft deep with a 3:1 slope on the face. The end anchor on the secondary roadway and the modified Breakaway Cable Terminal (BCT) foundation tube were analyzed and designed to withstand expected loads due to vehicular impact. The simulated parapet section was not designed for direct impact by a vehicle. Details of the analysis process are shown in Appendix A. See Appendix B, Sheets 1, 2, and 3 for overall installation details.

3.1.2 Guardrail

The spacing for posts 1 through 4 was 6 ft-3 inches. The spacing for posts 4 through 6 was 6 ft-3 inches as measured along the arc of the curved thrie-beam. The spacing for posts 6 to 7 was 6 ft-3 inches, and posts 7 to 10 were each spaced at 3 ft-1½ inches. Posts 10 to 17 were equally spaced at 1 ft-6¾ inches. Post 17 to the end face of the concrete parapet was approximately 12½ inches. See Appendix B, Sheet 3 for details.

Several sections comprised the guardrail. Beginning with a rounded thrie-beam end section (RTE02a) attached to post 1, a 75-inch long thrie-beam anchor rail connected post 1 to post 2. A standard thrie-beam, 8-space, 12 ft-6 inch span (RTM08) connected posts 2, 3, and 4. Posts 4, 5, and 6 supported the aforementioned curved 12 ft-6 inch (post-to-post) arc length curved thrie-beam section (RTM02a). Another 75-inch long thrie-beam anchor rail spanned between posts 6 and 7. A 9 ft-4½ inch long thrie-beam section spanned between post 7 and post 10, and a doubled 12 ft-6 inch long thrie-beam section spanned between post 10 and post 17 and the parapet (i.e., two sections of thrie-beam were nested one within the other). At post 10, the upstream thrie-beam section was sandwiched between the nested double thrie-beams on the traffic side, and all three layers were bolted to post 10. Finally, a thrie-beam terminal connector (RTE01b) completed the transition from the guardrail to the parapet. All guardrail sections were galvanized standard 12-gauge material.

Post 1 at the thrie-beam end section was comprised of an 8-inch schedule 80 pipe (8⅝-inch OD, ½-inch wall) installed in a 10-inch square tube socket (hollow structural shape

[HSS] 10×10×½-inch wall A500 Grade B) embedded in a concrete foundation. The post was 80 inches tall with a 10-inch × 10-inch × ½-inch thick ASTM A36 square support collar welded to it at 21¾ inches below the top. The post was inserted into the 72-inch long square tube, and its support collar rested on top of the square tube, which was 9¾ inches above grade. Thus, the top of the post was 31½ inches above grade. The square tube was void of concrete and included a 9¼-inch square plate on the bottom. See Appendix B, Sheets 8, 15, and 16 for post 1 details.

Post 1's square tube socket was embedded 62¼ inches deep into a 96-inch deep × 30-inch diameter steel reinforced concrete foundation. The foundation contained a concentric 24-inch diameter reinforcing bar cage. The rebar cage was fabricated using eight 24-inch diameter #3 (⅜-inch) rings vertically spaced at 12 inches, and eight 91-inch long #5 (⅝-inch) vertical bars. The vertical bars were equally spaced circumferentially inside the rings. Concrete cover over rebar at the top of the foundation was 2 inches, and the top of the foundation was at grade level. See Attachment B, Sheet 8 of 22 for details.

Post 1 was connected to the thrie-beam anchor rail with two sets of BCT anchor cable assemblies (FCA01), guardrail anchor brackets (FPA01), and eight associated ⅝-inch diameter × 2-inch long A307 grade 5 hex bolts, washers, and recessed guardrail nuts. Each of the two ¾-inch (6×19) galvanized wire rope anchor cables was 6 ft-6¾ inches end to end, inclusive of terminal fittings. Each termination consisted of a standard swaged fitting with a 1-inch diameter threaded stud, washer, and nut; the swage was specified to exceed the breaking strength of the wire rope. The upstream ends of the anchor cables were inserted through post 1 via two sets of holes on 7⅝-inch vertical centerlines in the post: two 1¾-inch diameter holes on the downstream or swage side, and two 1¼-inch diameter holes on the upstream or threaded side. The swage stud nuts were tightened such that all slack was removed from the cable. See Appendix B, Sheets 7 and 15 for details.

Post 2 was a modified BCT timber post (PDF01) 5½ inches × 7½ inches × 48¼ inches long. A 2½-inch diameter weakening hole was located 30¾-inches from the top near grade. A ⅞-inch diameter hole was located 33¼-inches from the top through which to install a strut bolt as described below. Post 2's foundation tube was a 6-inch × 8-inch × $^{3}/_{16}$-inch thick ASTM A500 grade B steel HSS structural tube (PTE05), 72 inches long and embedded approximately 70 inches deep into drilled holes with compacted standard soil as per *MASH*. Two $^{13}/_{16}$-inch diameter holes were located 1-inch below the top of the tube (centered in the lateral direction) to secure the timber post in the tube and accommodate the strut bolt.

The tube socket of post 1 and the foundation tube of post 2 were joined at grade level with two C4×7.25 ASTM A36 channel struts (1 field side, 1 traffic side; legs outward), each 71½ inches long. A strut bracket made of C8×11.5 ASTM A36 channel, 4 inches long, was bolted with two ½ × 1½-inch A307 grade 5 hex bolts and nuts to the downstream face of the tube socket. The ends of the struts were bolted to the strut bracket and the foundation tube and post with one ⅝ × 10-inch A307 grade 5 hex bolt and nut on each end. See Appendix B, Sheets 7 and 20 for details.

Post 3 was a modified CRT timber post (PDE09) 6 inches × 8 inches × 72 inches long. Two 3½-inch diameter weakening holes were located at 32 inches (grade level) and 44½ inches below the top. The guardrail was attached to post 3 via a 6-inch × 8-inch × 22-inch tall thrie-beam timber blockout (PDB02a) and two ⅝ × 18-inch guardrail bolts (FBB04) and recessed guardrail nuts. Post 3 was installed 40 inches deep into a drilled hole with compacted standard soil as per *MASH* without a foundation tube.

Post 4 was a modified BCT timber post (PDF01) 5½ inches × 7½ inches × 48¼ inches long. A 2½-inch diameter weakening hole was located 30¾ inches from the top near grade. A ⅞-inch diameter hole was located 33¼ inches from the top through which to install a ⅝-inch × 10-inch A307 Grade 5 hex bolt, flat washer, and recessed guardrail nut that secured the post in the foundation tube. Post 4's foundation tube was a 6-inch × 8-inch × $^{3}/_{16}$-inch thick ASTM A500 grade B steel HSS structural tube (PTE05), 72 inches long and embedded approximately 70 inches deep into a drilled hole with compacted strong soil as per *MASH*. Two $^{13}/_{16}$-inch diameter holes were located 1-inch below the top of the tube (centered in the lateral direction) to secure the timber post in the tube as described above. The guardrail was attached to post 4 via a thrie-beam timber blockout (PDB02a) and two ⅝ × 18-inch guardrail bolts (FBB04) and recessed guardrail nuts.

Post 5 was also a modified BCT timber post (PDF01). The guardrail was attached directly to post 5 (i.e., no blockout) with two ⅝-inch × 10-inch guardrail bolts (FBB03) and recessed guardrail nuts. Post 5's foundation tube was similar to that of post 4, but was fitted with an anchor cable bearing saddle made from half of a 4-inch schedule 40 pipe (4½ inches OD × 0.2375 inch wall thickness). This saddle was welded (U-side up) to, and protruded 2 inches from, the external traffic side of the foundation tube. See Appendix B, Sheet 21 for details.

Post 6 was also a modified BCT timber post (PDF01). Like post 4, the guardrail was attached to post 6 via a thrie-beam timber blockout (PDB02a) and two ⅝-inch × 18-inch guardrail bolts (FBB04) and recessed guardrail nuts. Post 6's foundation tube was similar to that of post 5, but the anchor cable bearing saddle was located on the field side of the tube. See Appendix B, Sheet 21 for details.

Posts 7 and 8 (like post 3) were modified CRT timber posts (PDE09) 6 inches × 8 inches × 72 inches long. Two 3½-inch diameter weakening holes were located at 32 inches (grade level) and 44½ inches from the top. The guardrail was attached to each of posts 7 and 8 via a 6-inch × 8-inch × 22-inch tall thrie-beam timber blockout (PDB02a) and two ⅝ × 18-inch guardrail bolts (FBB04) and recessed guardrail nuts. Posts 7 and 8 were installed 40 inches deep into a drilled hole with compacted strong soil as per *MASH* without a foundation tube.

Posts 9, 10, and 11 were W6×8.5 wide flange guardrail posts (PWE01), 72 inches long. The guardrail was attached to each of these posts via a W-beam timber routered blockout (6 inches × 8 inches × 14 inches tall; with a 4½-inch wide × ⅜-inch deep relief, PDB01b) and two ⅝-inch × 10-inch guardrail bolts (FBB03) and recessed guardrail nuts. Posts 9, 10, and 11 were installed 40 inches into a drilled hole with compacted strong soil as per *MASH.* See Appendix B, Sheets 5 and 19 for details.

Posts 12 through 17 were W6×8.5 wide flange guardrail posts (PWE07), 84 inches long. The guardrail was attached to each of posts 12 through 17 via a thrie-beam timber routered blockout (6 inches × 8 inches × 18 inches tall; with a 4½-inch wide × ⅜-inch deep relief, similar to a PDB02) and two ⅝-inch × 10-inch guardrail bolts (FBB03) and recessed guardrail nuts.

Posts 12 through 17 were installed 52 inches deep into a drilled hole with compacted strong soil as per *MASH*. Of special note is that the thrie-beam guardrail was intentionally not bolted to posts 12 and 13 and their blockouts. The blockouts were, however, bolted to their respective posts. See Appendix B, Sheets 5 and 19 for details.

A thrie-beam terminal connector (RTE01b) was used to connect and transition the thrie-beam to the parapet. Five A325 ⅞-inch diameter hex bolts, nuts, and 1¾-inch OD hardened flat washers secured the connector to the parapet: three 14-inch long bolts in the upper, wider part of the parapet, and two 12-inch long bolts in the lower, narrower part of the parapet. The terminal connector and doubled thrie beam were joined with 12 sets of ⅝-inch diameter × 2-inch long guardrail bolts (FBB02), rectangular washers (FWR03), and recessed guardrail nuts. See Appendix B, Sheet 4 for details.

An anchor cable attached at post 4, wove around post 5 on the traffic side and around post 6 on the field side using the anchor cable U-shaped bearing saddles installed near grade on the foundation tubes, and terminated on the thrie-beam near post 7. The ¾-inch (6×19; or IWRC; AASHTO M-30; 46 kips min.) galvanized wire rope measured 18 ft-5 inches end to end, inclusive of terminal fittings. Each termination consisted of a standard swaged fitting with a 1-inch diameter threaded stud, washer, and nut; the swage was specified to exceed the breaking strength of the wire rope. The post 4 weakening hole at grade contained a 2-inch schedule 40 (0.1535-inch wall thickness) BCT post sleeve (FMM02a) through which one terminal end of the anchor cable was secured via a 8-inch × 8-inch × ⅝-inch thick BCT bearing plate (FPB01), flat washer, and nut. The opposite end of the anchor cable was secured to the lower field side involute of the thrie-beam with a guardrail anchor bracket (FPA01). The swage stud nuts were tightened such that all slack was removed from the cable. See Appendix B, Sheets 4, 6, and 22 for details.

3.1.3 Concrete Parapet

For previous short-radius guardrail tests, a reinforced concrete bridge parapet was constructed by adding on to the existing concrete runway apron, and was used for these tests. The parapet base tapered from 60 to 56⅝ inches wide at the guardrail attachment end (yielding a 2° offset angle) and was 8 ft long, 18 inches thick, and constructed of steel reinforced TxDOT Class C concrete with a minimum specified strength of 3600 psi. All reinforcing steel was ASTM Grade 60, and unions of longitudinal, traverse, and vertical rebar were wire-tied on site. See Appendix B, Sheets 9 through 14 for details.

The parapet itself was 32 inches tall with a smooth vertical traffic side face and a stepped field side face. Its profile was 10½ inches wide at the base and transitioned with a 1½-inch chamfer to a 12-inch wide top portion beginning 18½ inches above grade. Exposed edges were chamfered ¾ inch. The traffic side face conformed to the 2° offset and was 24 inches from the edge of the runway on the upstream end, and 20⅝ inches from the edge of the runway on the guardrail end. On the traffic side, the width of the parapet tapered from 12 inches to 10 inches over the final 12 inches on the guardrail attachment end. Five 1-inch diameter holes were cast into the parapet at the time of the concrete pour to accommodate the thrie-beam terminal connector. See Appendix B, Sheet 9 for details.

Reinforcement in the parapet consisted of sixteen ½-inch nominal diameter reinforcing steel (#4 rebar) S-bars longitudinally spaced on 6-inch longitudinal centers and four 82-inch long #4 bent bars vertically spaced on 8-inch centers on the traffic side, and four 93-inch long #4 straight bars vertically spaced on 8-inch centers on the field side. The parapet was tied to the base with fifteen ½-inch nominal diameter reinforcing steel (#4 rebar) U-bars longitudinally spaced on 6-inch centers. Each 25½-inch tall U-bar extended from the bottom base mat to 10 inches into the lower portion of the parapet.

The base was secured to the runway apron with six ⅝-inch diameter (#5 rebar) × 24-inch long tie bars located on 16-inch horizontal centers. The tie bars were approximately 3 inches below the top surface, embedded 6 inches deep into holes drilled horizontally into the edge of the apron, and secured with Hilti RE200-A epoxy. See Appendix B, Sheet 11 for details.

Reinforcement in the base consisted of two mats of ⅝-inch nominal diameter reinforcing steel (#5 rebar) located approximately 1½ inches and 15 inches below the upper surface of the base. The upper mat rested on the new tie bars installed in the edge of the apron. The fifteen 53-inch long upper transverse bars were spaced on 6-inch centers and joined with seven 90-inch long longitudinal bars on 8-inch centers. The eight 53-inch lower transverse bars were spaced on 12-inch centers and joined with five 90-inch longitudinal bars on 12-inch centers. Five U-shaped support bars spaced on 18-inch centers provided structure and continuity between the upper and lower mats on the field side of the base.

3.1.4 Sand Barrels

Six sand barrels (Energy Absorption Systems, Inc. "ENERGITE III" Model 640 barrel and 320 cone with lid) weighing 700 lb each were strategically placed on the field side of the thrie-beam. The distances from each barrel's outer shell to the back side of the rail at posts 3, 5, 7, 8, and 9 were approximately 13, 13, 8½, 10, 13½, and 16½-inches, respectively. See Attachment B, Sheet 3 of 22 for placement geometry.

Figure 3.1 shows details of the test installation. Figure 3.2 presents photographs of the completed test installation. Further details may be found in Appendix A.

3.2 MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to install/construct the short-span short-radius guardrail system.

3.3 SOIL CONDITIONS

The test installation was installed in standard soil meeting AASHTO standard specifications for "Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses," designated M147-65(2004), grading B.

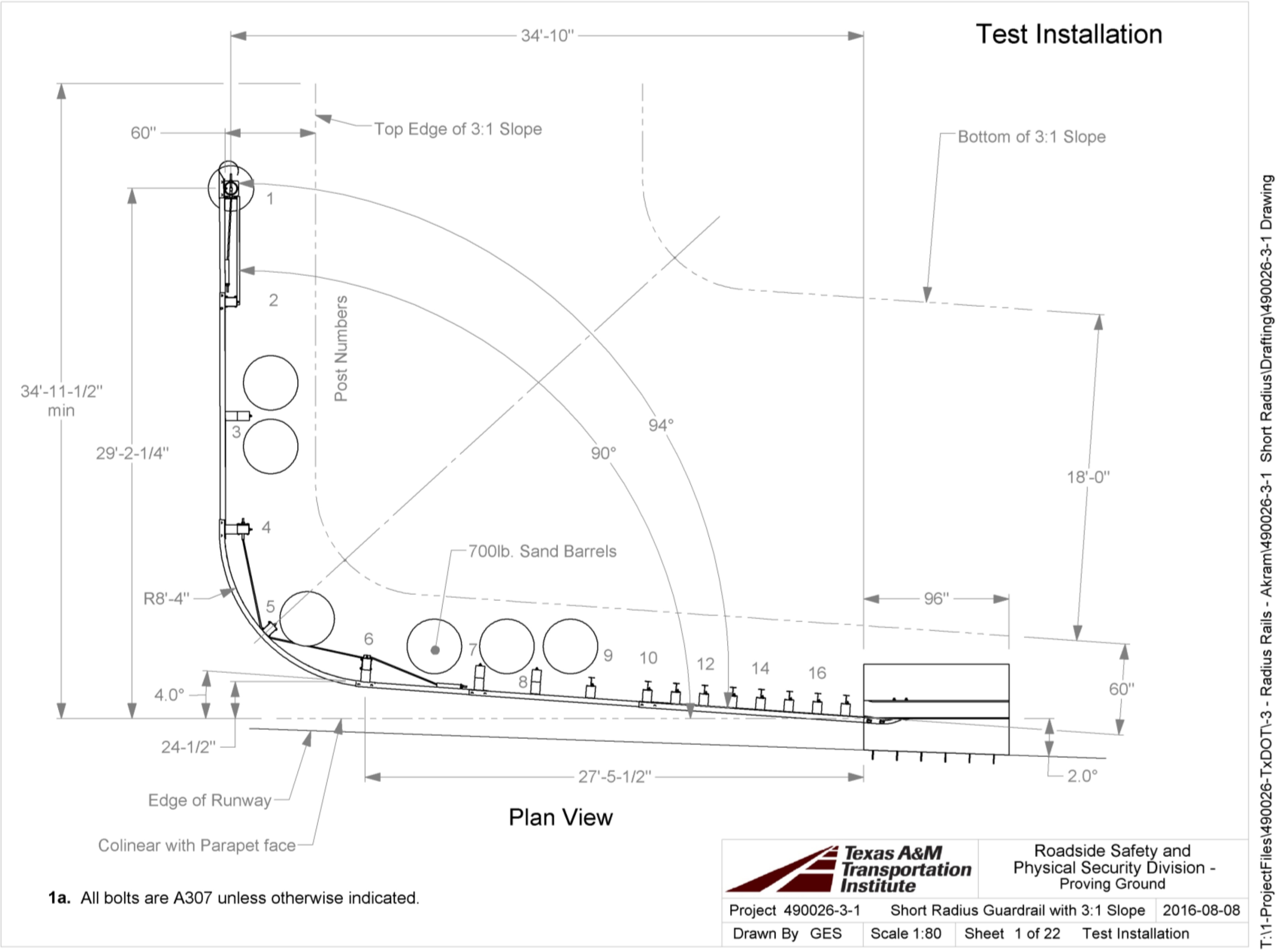


Figure 3.1. Overall Setup of the Short-Span Short-Radius Guardrail System Installation.

Figure 3.2. TxDOT Short-Span Short-Radius Guardrail System before Test No. 490026-3-1.

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the short-span short-radius guardrail system for full-scale crash testing, two standard W6×16 posts were installed in the immediate vicinity of the TxDOT short-span short-radius guardrail systems, using the same fill materials and installation procedures used in the standard dynamic test was performed (see Table C.1 in Appendix C for establishment minimum soil strength properties in the dynamic test performed in accordance with *MASH* Appendix B). As determined in the tests shown in Appendix C, Table C.1, the minimum post load required for deflections at 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 standard installation).

On the day of Test No. 490026-3-1, August 9, 2016, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 10,404 lbf, 11,515 lbf, and 12,727 lbf, respectively. Table C.2 in Appendix C shows the strength of the backfill material in which the TxDOT short-span short-radius guardrail system was installed met minimum requirements.

On the day of Test No. 490026-3-2, August 11, 2016, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 10,151 lbf, 11,060 lbf, and 11,969 lbf, respectively. Table C.3 in Appendix C shows the strength of the backfill material in which the TxDOT short-span short-radius guardrail system was installed met minimum requirements.

CHAPTER 4: TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1 CRASH TEST MATRIX

Table 4.1 shows the test conditions and evaluation criteria for terminals and redirective crash cushions under *MASH* Test Level 3. The impact performance of the short-radius guardrail system was evaluated using modified *MASH* Tests 3-32 and 3-33 for non-gating terminals. Researchers believe a 25° impact angle (measured tangent with the traffic face of the concrete parapet) would be more critical in determining the performance of the short radius guardrail system, so the target critical impact angle (CIA) was selected to be 25°. The target CIP for each test was determined according to the information provided in *MASH* and is shown in Figures 4.1 and 4.2.

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

Table 4.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-3 Terminals.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria	
			Speed (mi/h)	Angle (degrees)	Gating	Non-Gating
Terminals and Redirective Crash Cushions	3-30	1100C	62	0	C,D,F,H,I,N	A,D,F,H,I
	3-31	2270P	62	0	C,D,F,H,I,N	A,D,F,H,I
	3-32	1100C	62	CIA 5-15	C,D,F,H,I,N	A,D,F,H,I
	3-33	2270P	62	CIA 5-15	C,D,F,H,I,N	A,D,F,H,I
	3-34	1100C	62	15	C,D,F,H,I,N	A,D,F,H,I
	3-35	2270P	62	25	C,D,F,H,I,N	A,D,F,H,I
	3-36	2270P	62	25	C,D,F,H,I,N	A,D,F,H,I
	3-37a	2270P	62	25	C,D,F,H,I,N	A,D,F,H,I
	3-37b	1100C				
	3-38	1500A	62	0	C,D,F,H,I,N	A,D,F,H,I

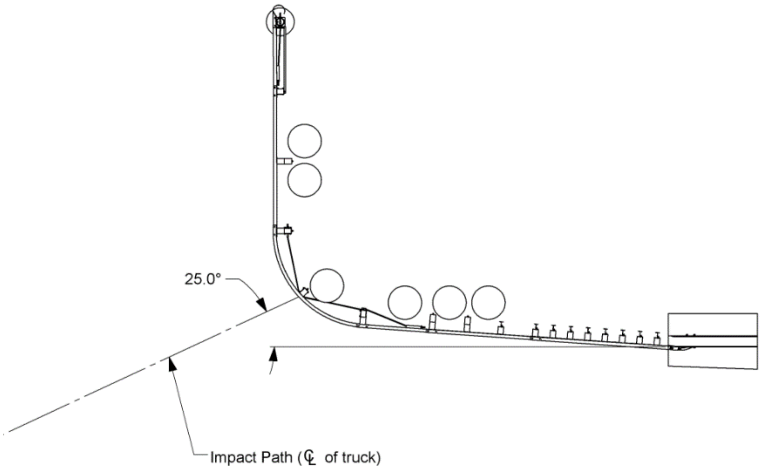


Figure 4.1. Target CIP for Modified *MASH* Test 3-33 on the Short-Radius Guardrail System.

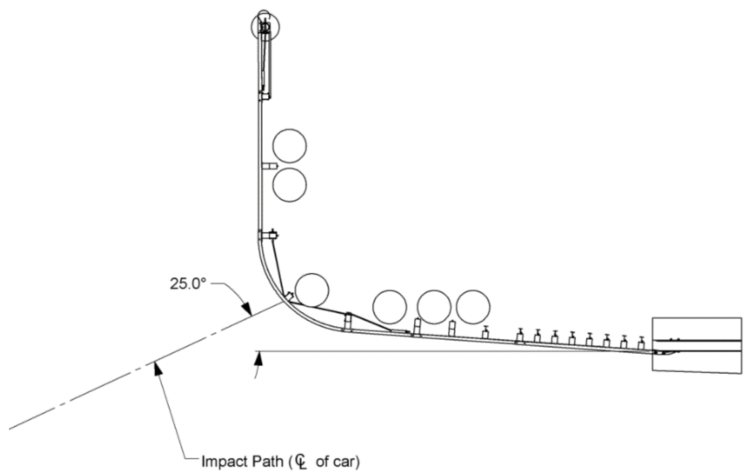


Figure 4.2. Target CIP for Modified *MASH* Test 3-32 on the TxDOT Short-Radius Guardrail System.

4.2 EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-3 and 5-1A through 5-1C of *MASH* were used to evaluate the crash tests reported herein. The test conditions and evaluation criteria required for *MASH* Tests 3-32 and 3-33 are listed in Table 4.1, and the substance of the evaluation criteria in Table 4.2. An evaluation of the crash test results is presented in detail under the section Assessment of Test Results.

Table 4.2. Evaluation Criteria Required for *MASH* TL-3 Non-Gating Terminals.

Evaluation Factors	Evaluation Criteria
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.*
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.*
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75°.
	H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.
	I. The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.

CHAPTER 5: TEST CONDITIONS

5.1 TEST FACILITY

The full-scale crash tests reported herein were performed at the Texas A&M Transportation Institute (TTI) Proving Ground, an International Standards Organization (ISO) 17025-accredited laboratory with American Association for Laboratory Accreditation 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 TTI Proving Ground is located on the Texas A&M University System RELLIS Campus, a 2000-acre complex of research and training facilities, located 10 miles 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 that are 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 short-span short-radius guardrail system 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.

5.2 VEHICLE TOW AND GUIDANCE SYSTEM

The test vehicles were 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 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 (no sooner than 2 s after impact), after which the brakes were activated, if needed, to bring the test vehicle to a safe and controlled stop.

5.3 DATA ACQUISITION SYSTEMS

5.3.1 Vehicle Instrumentation and Data Processing

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

5.3.2 Anthropomorphic Dummy Instrumentation

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

According to *MASH*, use of a dummy in the 2270P vehicle is optional. No dummy was used in the 2270P vehicle.

5.3.3 Photographic Instrumentation and Data Processing

Photographic coverage of each test included three high-speed cameras:

- One placed overhead with a field of view perpendicular to the ground and directly over the impact point.
- One placed behind the installation at an angle.
- One placed to have 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 short-span short-radius guardrail system. The flashbulb was visible from each camera. The videos from these high-speed cameras were analyzed 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 each test vehicle and the installation before and after the test.

CHAPTER 6: CRASH TEST NO. 490026-3-1 ON THE SHORT-SPAN SHORT-RADIUS GUARDRAIL

6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-33 involves a 2270P vehicle weighing 5000 lb ±110 lb and impacting the short radius guardrail system at an impact speed of 62 mi/h ±2.5 mi/h and a CIA of 5–15° ±1.5°. Researchers believe a 25° impact angle (measured tangent with the traffic face of the concrete parapet) would be more critical in determining the performance of the short radius guardrail system, so the target CIA was selected to be 25°. The target CIP was the vehicle centerline aligned with the centerline of the nose of the radius.

The 2010 Dodge RAM 1500 pickup truck used in the test weighed 5036 lb. The actual impact speed and angle were 62.4 mi/h and 25.0°, respectively. The actual impact point was vehicle centerline with the centerline of the nose of the radius. Minimum kinetic energy (KE) allowed for *MASH* Test 3-33 is 594 kip-ft, and actual KE was 656 kip-ft.

6.2 TEST VEHICLE

Figures 6.1 and 6.2 show the 2012 Dodge RAM 1500 pickup truck used for the crash test. Test inertia weight of the vehicle was 5036 lb, and its gross static weight was 5036 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and the height to the upper edge of the bumper was 26.0 inches. The height to the center of gravity of the vehicle was 28.6 inches. Tables D.1 and D.2 in Appendix D.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 6.1. TxDOT Short-Span Short-Radius Guardrail System/Test Vehicle Geometrics for Test No. 490026-3-1.

Figure 6.2. Test Vehicle before Test No. 490026-3-1.

6.3 WEATHER CONDITIONS

The test was performed on the morning of August 9, 2016. Weather conditions at the time of testing were as follows: (a) wind speed: 6 mi/h; (b) wind direction: 209° with respect to the vehicle (vehicle was traveling in a northwesterly direction); (c) temperature: 90°F; (d) relative humidity: 64 percent.

6.4 TEST DESCRIPTION

As the 2010 Dodge RAM 1500 pickup truck was traveling at an impact speed of 62.4 mi/h, the centerline of the vehicle contacted the centerline of the nose at an impact angle of 25.0°. Table 6.1 lists times and significant events that occurred during Test No. 490026-3-1. Brakes on the vehicle were not applied. At 2.270 s, the vehicle came to rest on the field side of the concrete parapet 13 ft upstream of the concrete parapet. Figures D.1 and D.2 in Appendix D.2 show sequential photographs of the test period.

6.5 DAMAGE TO TEST INSTALLATION

Figures 6.3 shows the damage to the short-span short-radius guardrail system. The guardrail element rotated approximately 70° at post 1, and posts 2 through 8 ruptured at the weakening holes at grade. Posts 9, 10, 11, and 12 were leaning downstream and toward the field side 45°, 80°, 10°, and 8°, respectively. Post 13 displaced 0.25 inch toward the field side.

6.6 DAMAGE TO TEST VEHICLE

Figure 6.4 shows damage to the exterior of the vehicle, and Figure 6.5 shows the interior of the vehicle after the test. The front bumper, hood, grill, radiator and fan, radiator support, right and left front fenders, and the right front tire and rim were damaged. Maximum exterior crush to the vehicle was 12.25 inches in the front plane just to the right of centerline of the vehicle at bumper height. No occupant compartment deformation or intrusion occurred. Tables D.2 and D.3 in Appendix D.1 provide exterior crush and occupant compartment measurements, respectively.

Table 6.1. Events during Test No. 490027-3-1.

TIME (s)	EVENT
0.003	Post 5 begins to deflect toward the field side
0.011	Post 5 ruptures at the weakening holes at grade
0.012	Post 4 begins to deflect to the left and towards the field side
0.017	Thrie-beam guardrail element begins to deform around post 4
0.020	Vehicle contacts barrel 3
0.022	Post 5 completes rupture at the weakening holes at grade
0.042	Guardrail element begins to deform around post 3 and post 4 begins to rupture at the cable bolt hole near grade
0.045	Vehicle begins to yaw counterclockwise
0.067	Post 4 completes rupture
0.082	Guardrail element contacts barrel 2
0.104	Post 3 begins to deflect toward the field side and the guardrail element begins to deform around post 7
0.108	Post 2 begins to deflect toward the field side
0.128	Guardrail element contacts barrels 4
0.167	Guardrail element contacts barrel 1
0.190	Post 3 ruptures at grade
0.200	Guardrail element deforms around post 8
0.208	Guardrail element and barrel 4 contacts barrel 5
0.244	Post 2 begins to rupture immediately above the ground strut
0.272	Guardrail element develops a bend between post 9 and 10
0.273	Barrel 5 contacts barrel 6
0.289	Post 2 completes rupture
0.426	Guardrail deforms around posts 10
0.507	Guardrail deforms around posts 11
0.575	Guardrail deforms around posts 12

Figure 6.3. TxDOT Short-Span Short-Radius Guardrail System after Test No. 490026-3-1.

Damage to roof occurred when pulling vehicle out of system

Figure 6.4. Vehicle after Test No. 490026-3-1.

Damage to roof occurred when pulling vehicle out of system

Figure 6.5. Interior of Vehicle after Test No. 490026-3-1.

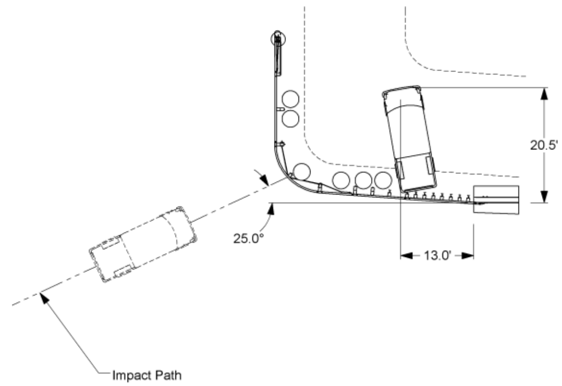
6.7 OCCUPANT RISK FACTORS

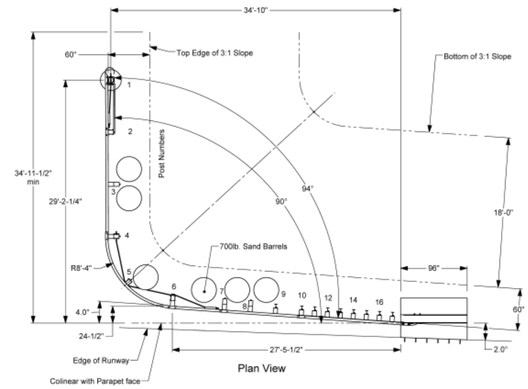
Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and are shown in Table 6.2. Figure 6.6 summarizes these data and other pertinent information from the test. Figure D.2 in Appendix D.3 shows the vehicle angular displacements, and Figures D.3 through D.8 in Appendix D.4 show accelerations versus time traces.

Table 6.2. Occupant Risk Factors for Test No. 490027-3-1.

Occupant Risk Factor	Value	Time
Impact Velocity		
Longitudinal	**23.6 ft/s**	at 0.1368 s on front of interior
Lateral	**6.9 ft/s**	
Ridedown Accelerations		
Longitudinal	**6.3 g**	0.1378–0.1478 s
Lateral	**5.0 g**	0.5547–0.5647 s
THIV	**27.8 km/h** **7.7 m/s**	at 0.1374 s on front of interior
PHD	**7.5 g**	0.1374–0.1474 s
ASI	**0.83**	0.0376–0.0876 s
Maximum 50-ms Moving Average		
Longitudinal	**-9.2 g**	0.0152–0.0652 s
Lateral	**-4.2 g**	0.0996–0.1496 s
Vertical	**2.5 g**	0.1408–0.1908 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**28.5°**	0.9893 s
Pitch	**25.3°**	1.0633 s
Yaw	**84.8°**	2.0000 s

0.000 s	0.200 s	0.600 s	1.200 s





General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	Modified MASH Test 3-33
TTI Test No.	490026-3-1
Test Date	2016-08-09
Test Article	
Type	Short-Radius Terminal
Name	Short-Span Short-Radius Guardrail
Installation Length	42.8 ft x 29.2 ft
Material or Key Elements	31-inch tall, 58-ft-10-inch long thrie-beam short-radius guardrail
Soil Type and Condition	AASHTO M147-65(2004), grading B Soil (crushed limestone), dry
Test Vehicle	
Type/Designation	2270P
Make and Model	2010 Dodge RAM 1500
Curb	4848 kb
Test Inertial	5036 lb
Dummy	No dummy
Gross Static	5036 lb

Impact Conditions	
Speed	62.4 mi/h
Angle	25.0 degrees
Location/Orientation	Centerline radius
Kinetic Energy	
Exit Conditions	
Speed	Stopped
Angle	NA
Occupant Risk Values	
Longitudinal OIV	23.6 ft/s
Lateral	6.9 ft/s
Longitudinal Ridedown	6.3 g
Lateral Ridedown	5.0 g
THIV	27.8 km/h
PHD	7.5 g
ASI	0.83
Max. 0.050-s Average	
Longitudinal	−9.2 g
Lateral	−4.2 g
Vertical	2.5 g

Post-Impact Trajectory	
Stopping Distance	20.5 ft behind concrete parapet
Vehicle Stability	
Maximum Yaw Angle	85 degrees
Maximum Pitch Angle	25 degrees
Maximum Roll Angle	28 degrees
Vehicle Snagging	NA
Vehicle Pocketing	NA
Test Article Deflections	
Dynamic	25.3 ft
Permanent	25.3 ft
Working Width	27.3 ft
Vehicle Damage	
VDS	12FD4
CDC	12FDEW4
Max. Exterior Deformation	12.25 inches
OCDI	RF0000000
Max. Occupant Compartment Deformation	None

Figure 6.6. Summary of Results for Modified *MASH* Test 3-33 at 25° on the Short-Span Short-Radius Guardrail.

CHAPTER 7: CRASH TEST NO. 490026-3-2 ON THE SHORT-SPAN SHORT-RADIUS GUARDRAIL

7.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-32 involves an 1100C passenger car weighing 2420 lb ±55 lb impacting the support structure at an impact speed of 62 mi/h ±2.5 mi/h and a CIA of 5–15° ±1.5°. The researchers believe a 25° impact angle (measured tangent with the traffic face of the concrete parapet) would be more critical in determining the performance of the short radius guardrail system; therefore, the target CIA was selected to be 25°. The target impact point was the vehicle centerline aligned with the centerline of the radius of the system.

The 2011 Kia Rio used in the test weighed 2453 lb, and the actual impact speed and angle were 63.8 mi/h and 24.9°. The actual impact point was centerline of the vehicle aligned with the centerline of the radius. Minimum KE allowed for *MASH* Test 3-32 is 288 kip-ft, and actual KE was 334 kip-ft.

7.2 TEST VEHICLE

Figures 7.1 and 7.2 show the 2011 Kia Rio used for the crash test. Test inertia weight of the vehicle was 2453 lb, and its gross static weight was 2618 lb. The height to the lower edge of the vehicle bumper was 8.0 inches, and the height to the upper edge of the bumper was 21.25 inches. Table E.1 in Appendix E.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 7.1. TxDOT Short-Span Short-Radius Guardrail System/Test Vehicle Geometrics for Test No. 490026-3-2.


Figure 7.2. Test Vehicle before Test No. 490026-3-2.

7.3 WEATHER CONDITIONS

The test was performed on the afternoon of August 11, 2016. Weather conditions at the time of testing were as follows: (a) wind speed: 4 mi/h; (b) wind direction: 183° (vehicle was traveling in a southerly direction); (c) temperature: 100°F; (d) relative humidity: 46 percent.

7.4 TEST DESCRIPTION

The 2011 Kia Rio, traveling at an impact speed of 63.8 mi/h, impacted the short-span short-radius at 24.9° with the centerline of the vehicle aligned with the centerline of the radius. Table 7.1 lists times and significant events that occurred during Test No. 490026-3-2. Brakes on the vehicle were not applied. At 1.700 s, the vehicle came to rest 21 ft upstream of the parapet and 18 ft toward the field side. Figure E.1 in Appendix E.2 shows sequential photographs of the test period.

7.5 DAMAGE TO TEST INSTALLATION

Figure 7.3 shows the damage to the short-span short-radius guardrail. Post 2 was leaning toward the field side 5°, but did not rupture. Posts 3 through 8 ruptured at the weakening holes at grade, and post 9 rotated counterclockwise 5°.

7.6 VEHICLE DAMAGE

Figure 7.4 shows damage to the exterior of the vehicle, and Figure 7.5 shows the interior of the vehicle after the test. The front bumper, hood, radiator and support, right and left front doors, right and left front fenders, and left and right front doors were damaged. The windshield had stress cracks radiating from the lower right corner along the A-pillar. Maximum exterior crush was 10.0 inches just left of the centerline of the front of the vehicle at bumper height. No occupant compartment deformation or intrusion occurred. Tables E.2 and E.3 in Appendix E.1 provide exterior crush and occupant compartment measurements, respectively.

Table 7.1. Events during Test No. 490027-3-2.

TIME (s)	EVENT
0.004	Post 5 began to deflect toward the field side
0.006	Thrie-beam guardrail element began to deform around post 4
0.017	Post 4 began to displace to the left and deflect toward the field side
0.022	Vehicle contacts barrel 3 and post 5 ruptures at weakening holes at grade
0.033	Vehicle began to yaw counterclockwise
0.038	Post 4 began to rupture at the cable bolt hole near grade
0.041	Post 3 begins to rise upward from ground and deflect toward field side
0.054	Guardrail element develops a bend at post 3 and begins to deform around post
0.070	Post 4 ruptured through
0.100	Guardrail element contacted barrel 2
0.103	Post 4 contacted the ground surface
0.112	Guardrail element began to wrap around post 7 and barrel 4
0.113	Ground cable and bearing plate separated from post 4
0.120	Post 6 ruptured through at the weakening holes at grade
0.123	Guardrail element contacted barrel 4
0.125	Post 2 began to deflect toward the field side
0.160	Ground cable and bearing plate from post 4 contacted the driver side door of the vehicle
0.240	Guardrail element developed a bend between post 2 and 3
0.258	Guardrail element contacted barrel 1
0.268	Guardrail element developed a kink at the bolt holes at post 8
0.314	Barrel 5 contacted barrel 6
0.405	Post 8 ruptured at the weakening holes at grade and the vehicle and guardrail began to drag it toward the field side
0.413	Guardrail element began to deform around post 9
0.445	Guardrail developed a kink at the bolt holes at post 9

Figure 7.3. TxDOT Short-Span Short-Radius Guardrail System after Test No. 490026-3-2.

Figure 7.4. Test Vehicle after Test No. 490026-3-2.

Figure 7.5. Interior of Vehicle after Test No. 490026-3-2.

7.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and are shown in Table 7.2. Figure 7.6 summarizes these data and other pertinent information from the test. Figure C.2 in Appendix C.3 shows the vehicle angular displacements, and Figures C.3 through C.8 in Appendix C.4 show accelerations versus time traces.

Table 7.2. Occupant Risk Factors for Test No. 490026-3-2.

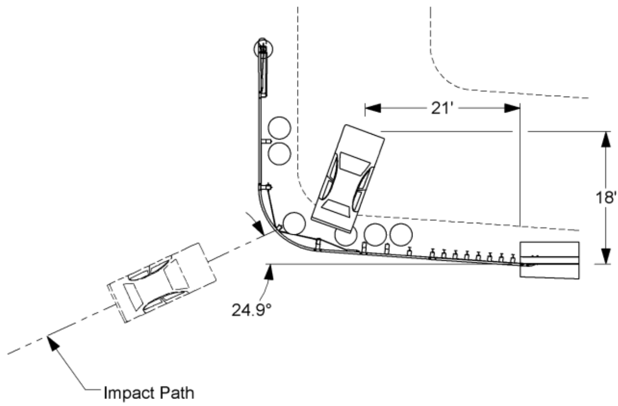
Occupant Risk Factor	Value	Time
Impact Velocity		
Longitudinal	**34.4 ft/s**	at 0.1017 s on front of interior
Lateral	**4.3 ft/s**	
Ridedown Accelerations		
Longitudinal	**6.6 g**	0.1132–0.1232 s
Lateral	**10.1 g**	0.1375–0.1475 s
THIV	**38.1 km/h** **10.6 m/s**	at 0.1022 s on front of interior
PHD	**11.2 g**	0.1373–0.1473 s
ASI	**1.26**	0.0424–0.0924 s
Maximum 50-ms Moving Average		
Longitudinal	**-14.4 g**	0.0149–0.0649 s
Lateral	**-6.4 g**	0.1274–0.1774 s
Vertical	**-3.4 g**	0.0555–0.1055 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**8.5°**	0.8052 s
Pitch	**17.7°**	0.8022 s
Yaw	**40.4°**	0.8646 s

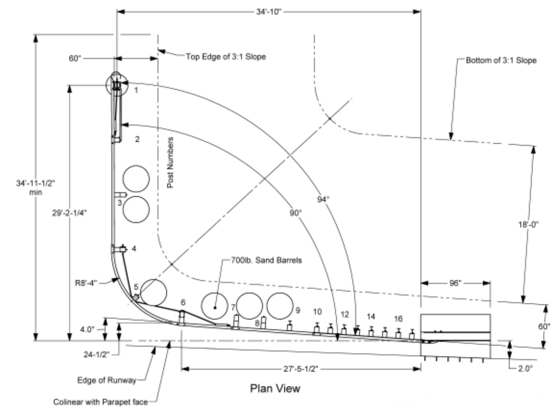
0.000 s

0.200 s

0.400 s

0.600 s





General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	Modified MASH Test 3-32
TTI Test No.	490026-3-2
Test Date	2016-08-11
Test Article	
Type	Short-Radius Terminal
Name	Short-Span Short-Radius Guardrail
Installation Length	42.8 ft x 29.2 ft
Material or Key Elements	31-inch tall, 58-ft-10-inch long thrie-beam short-radius guardrail
Soil Type and Condition	AASHTO M147-65(2004), grading B Soil (crushed limestone), dry
Test Vehicle	
Type/Designation	1100C
Make and Model	2011 Kia Rio
Curb	2474 lb
Test Inertial	2453 lb
Dummy	165 lb
Gross Static	2618 lb

Impact Conditions	
Speed	63.8 mi/h
Angle	24.9 degrees
Location/Orientation	Centerline radius
Kinetic Energy	334 kip-ft
Exit Conditions	
Speed	Stopped
Angle	NA
Occupant Risk Values	
Longitudinal OIV	34.4 ft/s
Lateral	4.3 ft/s
Longitudinal Ridedown	6.6 g
Lateral Ridedown	10.1 g
THIV	38.1 km/h
PHD	11.2 g
ASI	1.26
Max. 0.050-s Average	
Longitudinal	−14.4 g
Lateral	−6.4 g
Vertical	−3.4 g

Post-Impact Trajectory	
Stopping Distance	Behind concrete parapet
Vehicle Stability	
Maximum Yaw Angle	40 degrees
Maximum Pitch Angle	18 degrees
Maximum Roll Angle	8 degrees
Vehicle Snagging	NA
Vehicle Pocketing	NA
Test Article Deflections	
Dynamic	19.4 ft
Permanent	19.4 ft
Working Width	19.4 ft
Vehicle Damage	
VDS	12FD4
CDC	12FDEW4
Max. Exterior Deformation	10.0 inches
OCDI	FR0000000
Max. Occupant Compartment Deformation	None

Figure 7.6. Summary of Results for Modified *MASH* Test 3-32 at 25° on the Short-Span Short-Radius Guardrail.

CHAPTER 8: SUMMARY AND CONCLUSIONS

Under this project, crash tests were performed following *MASH* guidelines and procedures to assess the impact performance of short-span short-radius guardrail system. A summary of the results is presented below.

8.1 SUMMARY OF RESULTS

8.1.1 Modified *MASH* Test 3-33 – Crash Test No. 490026-3-1

The Short-Span Short-Radius Guardrail System contained the 2270P vehicle that came to a controlled stop on the field side of the installation. Maximum dynamic deflection of the curved guardrail element during the test was 25.3 ft. Several posts fractured at ground level, however, none of these penetrated or showed potential for penetrating the occupant compartment. The posts rode along with the vehicle and did not present hazard to others in the area. No occupant compartment deformation or intrusion occurred. The rear right wheel straddled the deformed rail section. However, the 2270P vehicle remained upright and stable on the slope after the collision event. Maximum roll and pitch angles were 28° and 25°, respectively. Occupant risk factors were within the limits specified in *MASH*. The 2270P vehicle came to rest behind the concrete parapet.

8.1.2 Modified *MASH* Test 3-32 – Crash Test No. 490026-3-2

The Short-Span Short-Radius Guardrail System contained the 1100C vehicle, which came to a complete stop on the field side of the installation. Maximum dynamic deflection of the curved guardrail element was 19.4 ft. Several posts fractured at ground level, however, none of these penetrated or showed potential for penetrating the occupant compartment. The posts rode along with the vehicle and did not present hazard to others in the area. No occupant compartment deformation or intrusion occurred. The 1100C vehicle remained upright and stable on the slope after the collision event. Maximum roll and pitch angles were 8° and 18°, respectively. Occupant risk factors were within the limits specified in *MASH*. The 1100C vehicle came to rest behind the concrete parapet.

8.2 CONCLUSIONS

Tables 8.1 and 8.2 show that the Short-Span Short-Radius Guardrail System performed acceptably according to *MASH* evaluation criteria using the modified test conditions for *MASH* 3-33 and 3-32.

Table 8.1. Performance Evaluation Summary for Modified *MASH* Test 3-33 on the TxDOT Short-Span Short-Radius Guardrail System.

Test Agency: Texas A&M Transportation Institute | Test No.: 490026-3-1 | Test Date: 2016-08-09

MASH Test 3-33 Evaluation Criteria	Test Results	Assessment
<u>*Structural Adequacy*</u> *A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The Short-Span Short-Radius Guardrail System contained the 2270P vehicle, which came to a controlled stop on the field side of the installation. Maximum dynamic deflection of the guardrail element during the test was 25.3 ft.	Pass
<u>*Occupant Risk*</u> *D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	Several posts fractured at ground level, however, none of these penetrated or showed potential for penetrating the occupant compartment. The posts rode along with the vehicle and did not present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No occupant compartment deformation or intrusion 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 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 28° and 25°, 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 OIV was 23.6 ft/s, and lateral OIV was 6.9 ft/s.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.	Longitudinal ridedown acceleration was 6.3 g, and lateral ridedown acceleration was 5.0 g.	Pass
<u>*Vehicle Trajectory*</u> *N. Vehicle trajectory behind the test article is acceptable.*	The 2270P vehicle came to rest behind the concrete parapet.	Pass

Table 8.2. Performance Evaluation Summary for Modified *MASH* Test 3-32 on the TxDOT Short-Span Short-Radius Guardrail System.

Test Agency: Texas A&M Transportation Institute | Test No.: 490026-3-2 | Test Date: 2016-08-11

MASH Test 3-32 Evaluation Criteria	Test Results	Assessment
<u>*Structural Adequacy*</u> *A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The Short-Span Short-Radius Guardrail System contained the 1100C vehicle, which came to a complete stop on the field side of the installation. Maximum dynamic deflection of the curved guardrail element was 19.4 ft.	Pass
<u>*Occupant Risk*</u> *D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	Several posts fractured at ground level, however, none of these penetrated or showed potential for penetrating the occupant compartment. The posts rode along with the vehicle and did not present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No occupant compartment deformation or intrusion 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 8° and 18°, 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 OIV was 34.4 ft/s, and lateral OIV was 4.3 ft/s.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.	Longitudinal ridedown acceleration was 6.6 g, and lateral ridedown acceleration was 10.1 g.	Pass
<u>*Vehicle Trajectory*</u> *N. Vehicle trajectory behind the test article is acceptable.*	The 1100C vehicle came to rest behind the concrete parapet.	Pass

CHAPTER 9: IMPLEMENTATION STATEMENT*

A 31-inch tall short radius system was developed and tested per *MASH* TL-3 modified conditions and is considered *MASH* complaint per the evaluation criteria. Hence, this system is recommended for implementation on primary roads where TL-3 (or lower) safety features are recommended.

This new short radius system requires a placement footprint of 34 ft-10 inches along the primary road and 29 ft-3 inches along the driveway. It is critical that the primary rail portion of this system maintains a 4 percent flare with the primary roadway. The secondary rail with the rigid rotating anchor is designed for driveways or roadways with speeds less than 30 mph. The impact performance of the short-span and short-radius guardrail system with the 3H:1V slope was evaluated using modified *MASH* Tests 3-32 and 3-33 as recommended from the simulation effort of this study. *MASH* Tests 3-31 and 3-35 were conducted successfully on the same system design but without the field side ditch and with four sand barrels under TxDOT project 0-6711. *MASH* Tests 3-31 and 3-35 are not considered affected by the presence of the sloped ditch behind the installation since the vehicle was redirected by the structural elements of the system and not being captured by the system.

The system requires a minimum of 5 ft of flat ground behind it at a slope of 10H:1V or flatter to accommodate the placement of the six 700-lb sand barrels positioned per the supplied drawings. A slope of 3H:1V or flatter can be placed after the 5-ft flat area to accommodate ditches in the field side.

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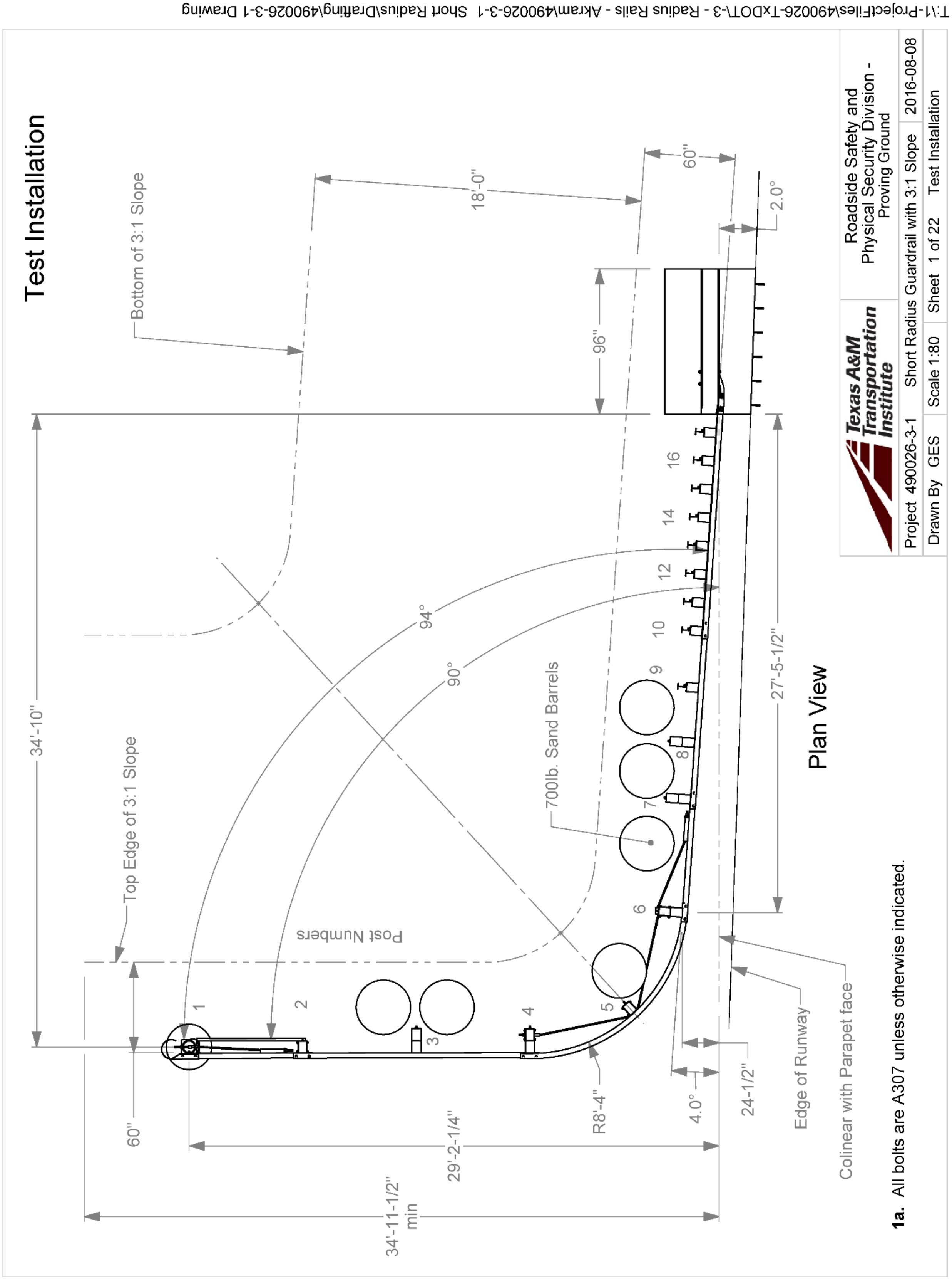
* The opinions/interpretations identified/expressed in this section are outside the scope of TTI Proving Ground's A2LA Accreditation.

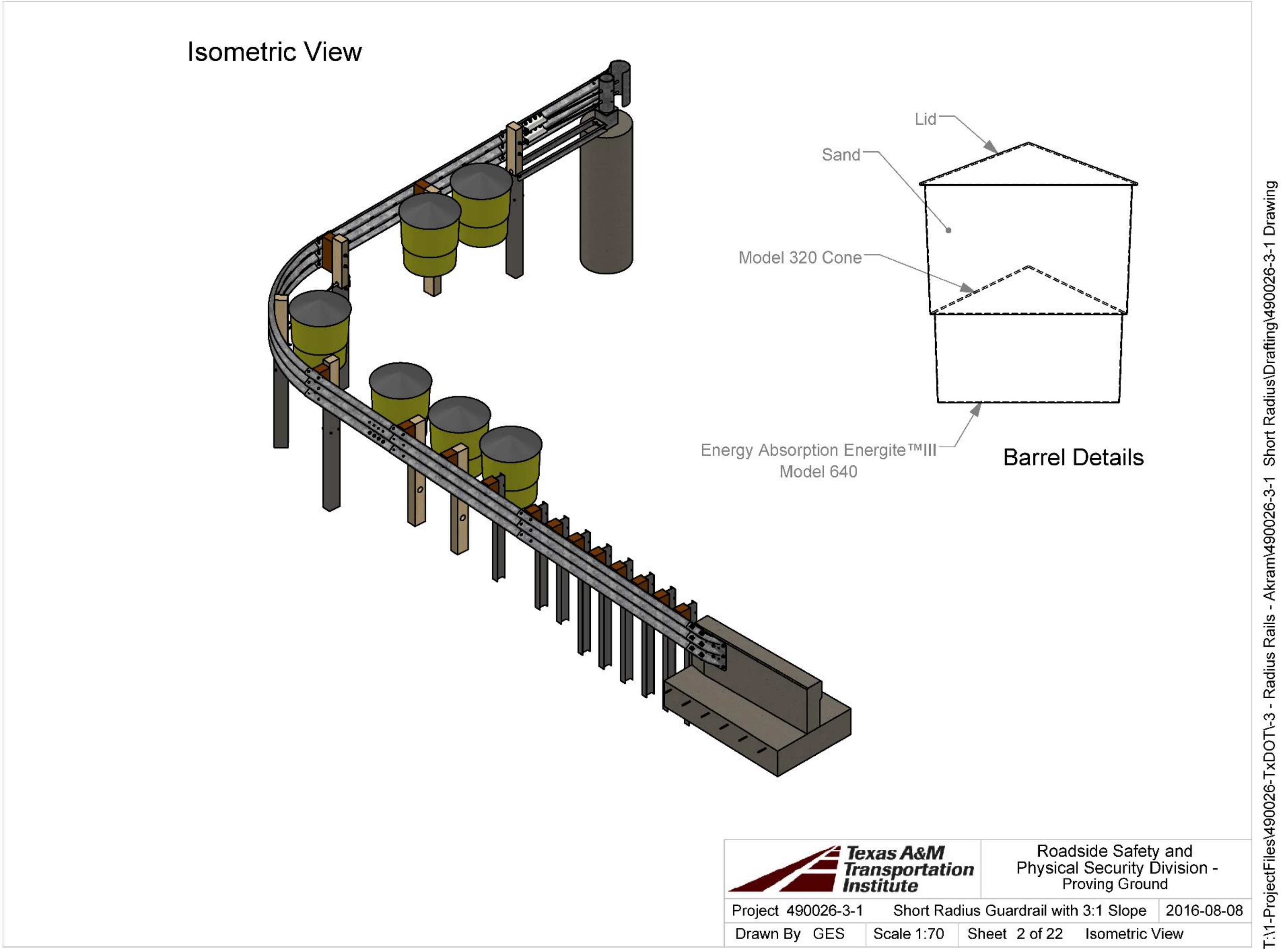
REFERENCES

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

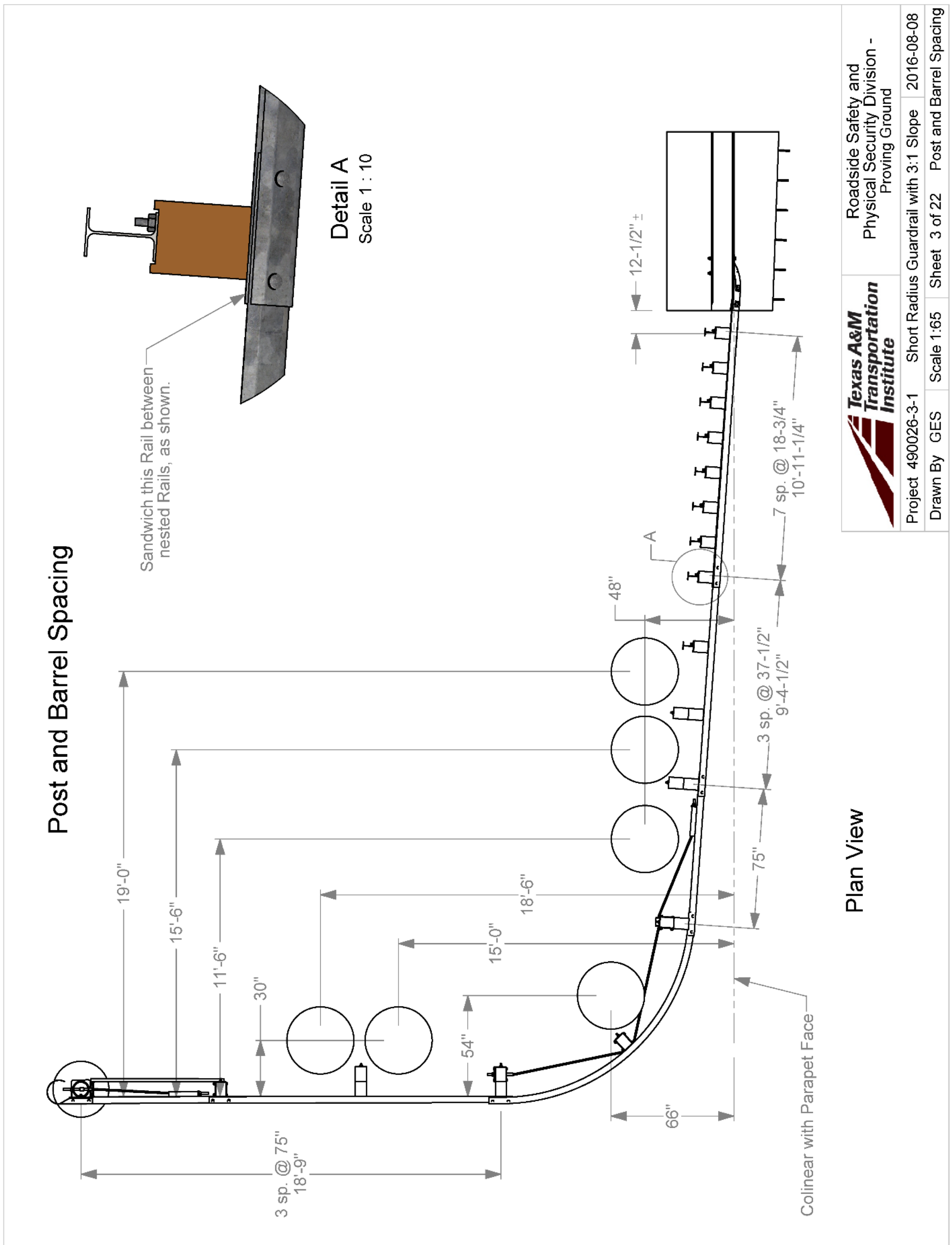
2. H.E. Ross, Jr., D.L. Sicking, R.A. Zimmer, and J.D. Michie. *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.

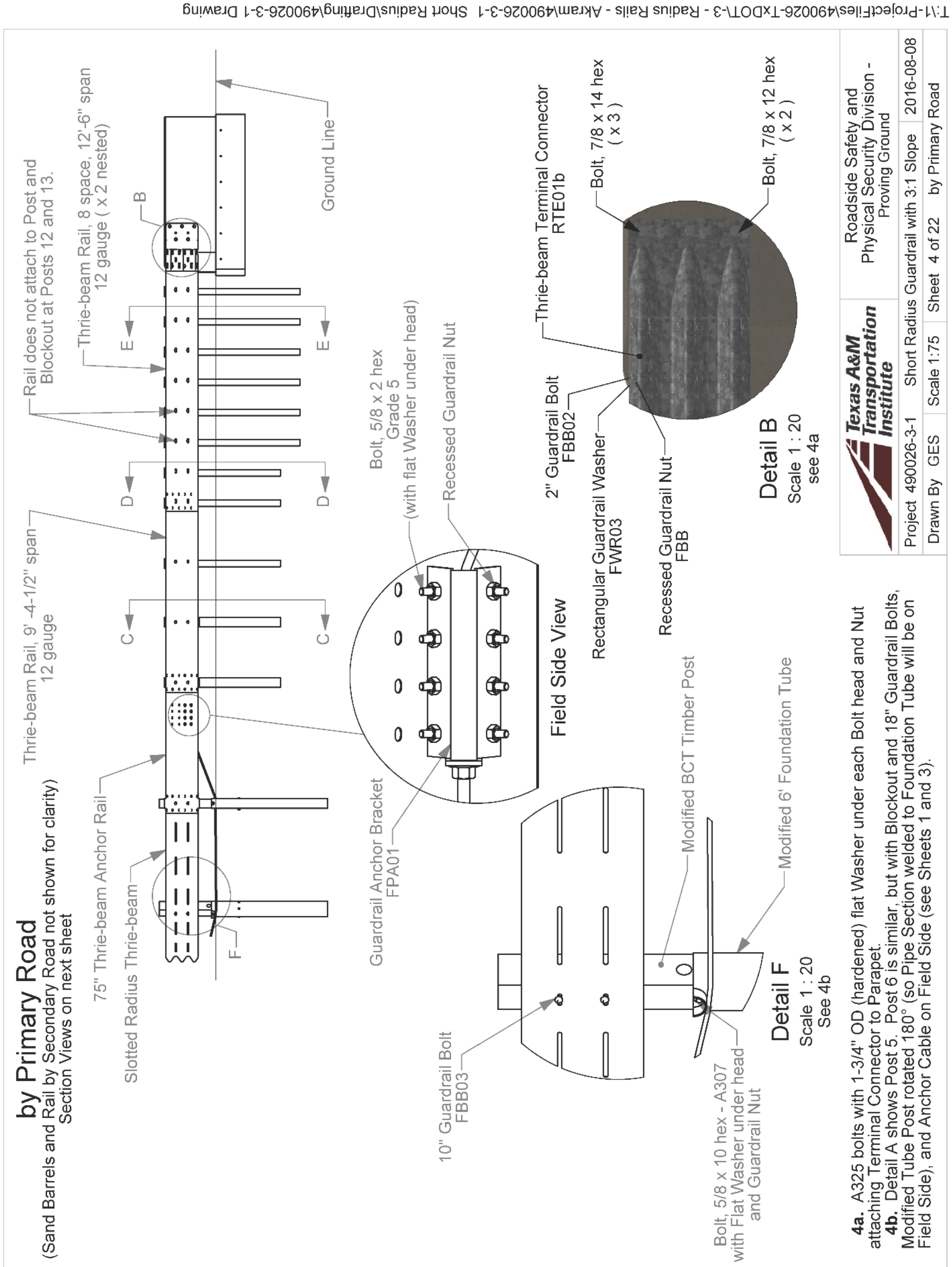
APPENDIX A: TXDOT SHORT-SPAN SHORT-RADIUS GUARDRAIL




Isometric View
Lid
Sand
Model 320 Cone
Energy Absorption Energite™III Model 640
Barrel Details
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project 490026-3-1
Short Radius Guardrail with 3:1 Slope
2016-08-08
Drawn By GES
Scale 1:70
Sheet 2 of 22
Isometric View
T:\1-ProjectFiles\490026-TxDOT\-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing

T:\1-ProjectFiles\490026-TxDOT-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing




by Primary Road
(Sand Barrels and Rail by Secondary Road not shown for clarity)
Section Views on next sheet
Slotted Radius Thrie-beam
75" Thrie-beam Anchor Rail
Thrie-beam Rail, 9' -4-1/2" span
12 gauge
Rail does not attach to Post and
Blockout at Posts 12 and 13.
Thrie-beam Rail, 8 space, 12'-6" span
12 gauge (x 2 nested)
B
F
C
D
E
Ground Line
Guardrail Anchor Bracket
FPA01
Bolt, 5/8 x 2 hex
Grade 5
(with flat Washer under head)
Recessed Guardrail Nut
Field Side View
10" Guardrail Bolt
FBB03
Modified BCT Timber Post
Modified 6' Foundation Tube
Bolt, 5/8 x 10 hex - A307
with Flat Washer under head
and Guardrail Nut
Detail F
Scale 1 : 20
See 4b
Thrie-beam Terminal Connector
RTE01b
Bolt, 7/8 x 14 hex
(x 3)
Bolt, 7/8 x 12 hex
(x 2)
2" Guardrail Bolt
FBB02
Rectangular Guardrail Washer
FWR03
Recessed Guardrail Nut
FBB
Detail B
Scale 1 : 20
see 4a
4a. A325 bolts with 1-3/4" OD (hardened) flat Washer under each Bolt head and Nut attaching Terminal Connector to Parapet.
4b. Detail A shows Post 5. Post 6 is similar, but with Blockout and 18" Guardrail Bolts, Modified Tube Post rotated 180° (so Pipe Section welded to Foundation Tube will be on Field Side), and Anchor Cable on Field Side (see Sheets 1 and 3).
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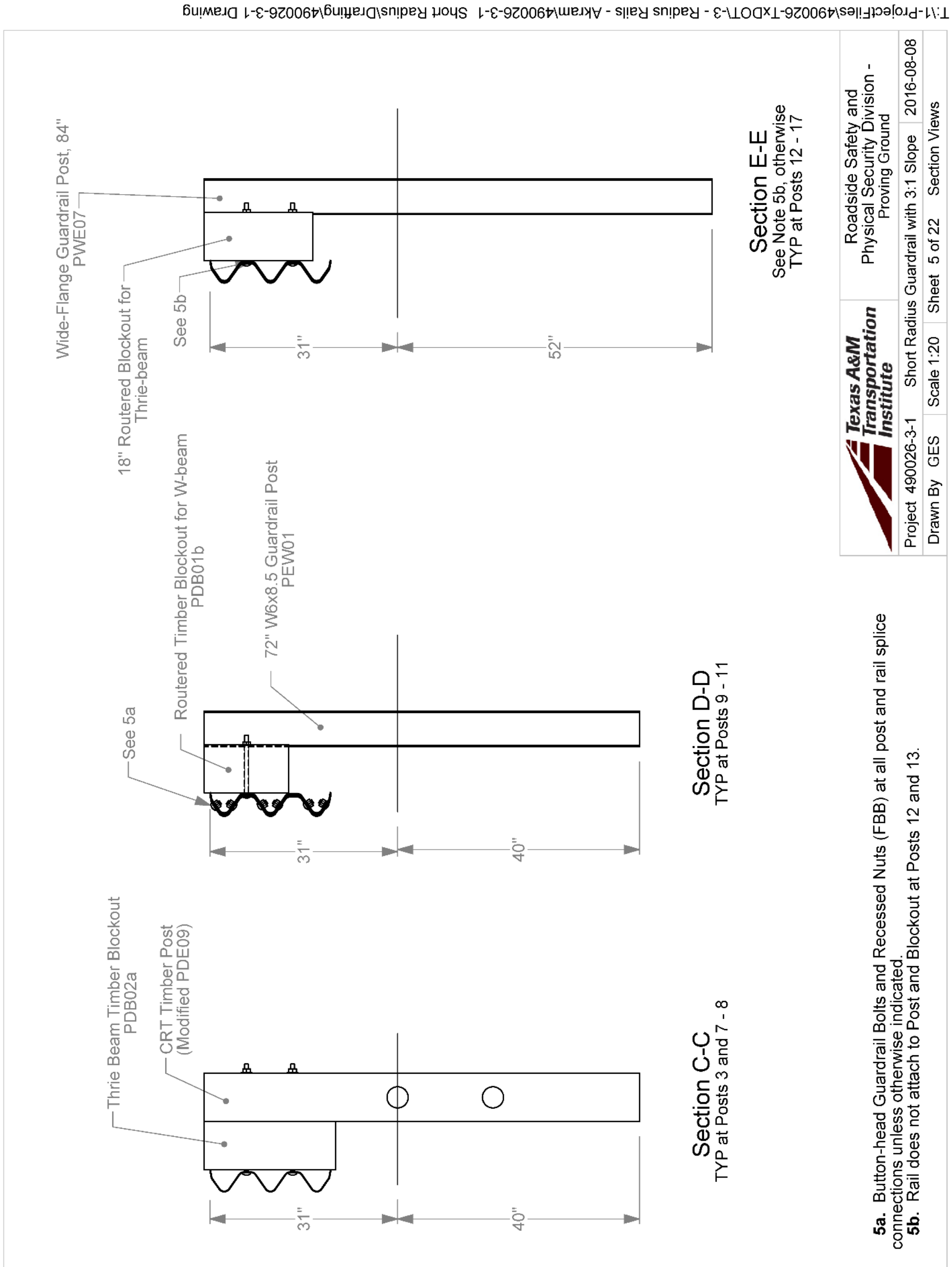
Short Radius Guardrail with 3:1 Slope
Sheet 4 of 22
by Primary Road
2016-08-08
T:\1-ProjectFiles\490026-TxDOT-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing


T:\1-ProjectFiles\490026-TxDOT-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing
Thrie Beam Timber Blockout
PDB02a
CRT Timber Post
(Modified PDE09)
31"
40"
Section C-C
TYP at Posts 3 and 7 - 8
See 5a
Routered Timber Blockout for W-beam
PDB01b
72" W6x8.5 Guardrail Post
PEW01
31"
40"
Section D-D
TYP at Posts 9 - 11
Wide-Flange Guardrail Post, 84"
PWE07
18" Routered Blockout for
Thrie-beam
See 5b
31"
52"
Section E-E
See Note 5b, otherwise
TYP at Posts 12 - 17
5a. Button-head Guardrail Bolts and Recessed Nuts (FBB) at all post and rail splice connections unless otherwise indicated.
5b. Rail does not attach to Post and Blockout at Posts 12 and 13.
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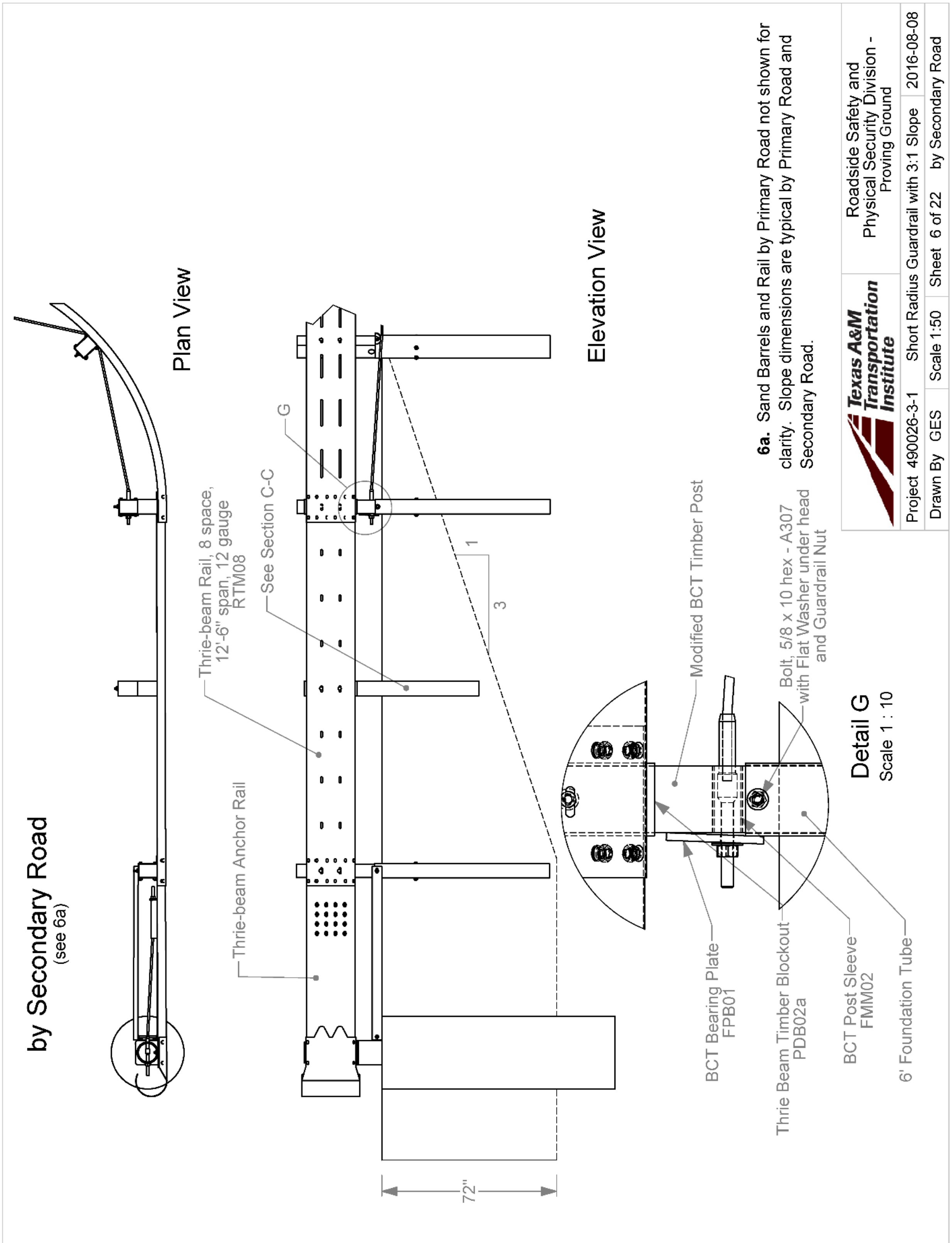
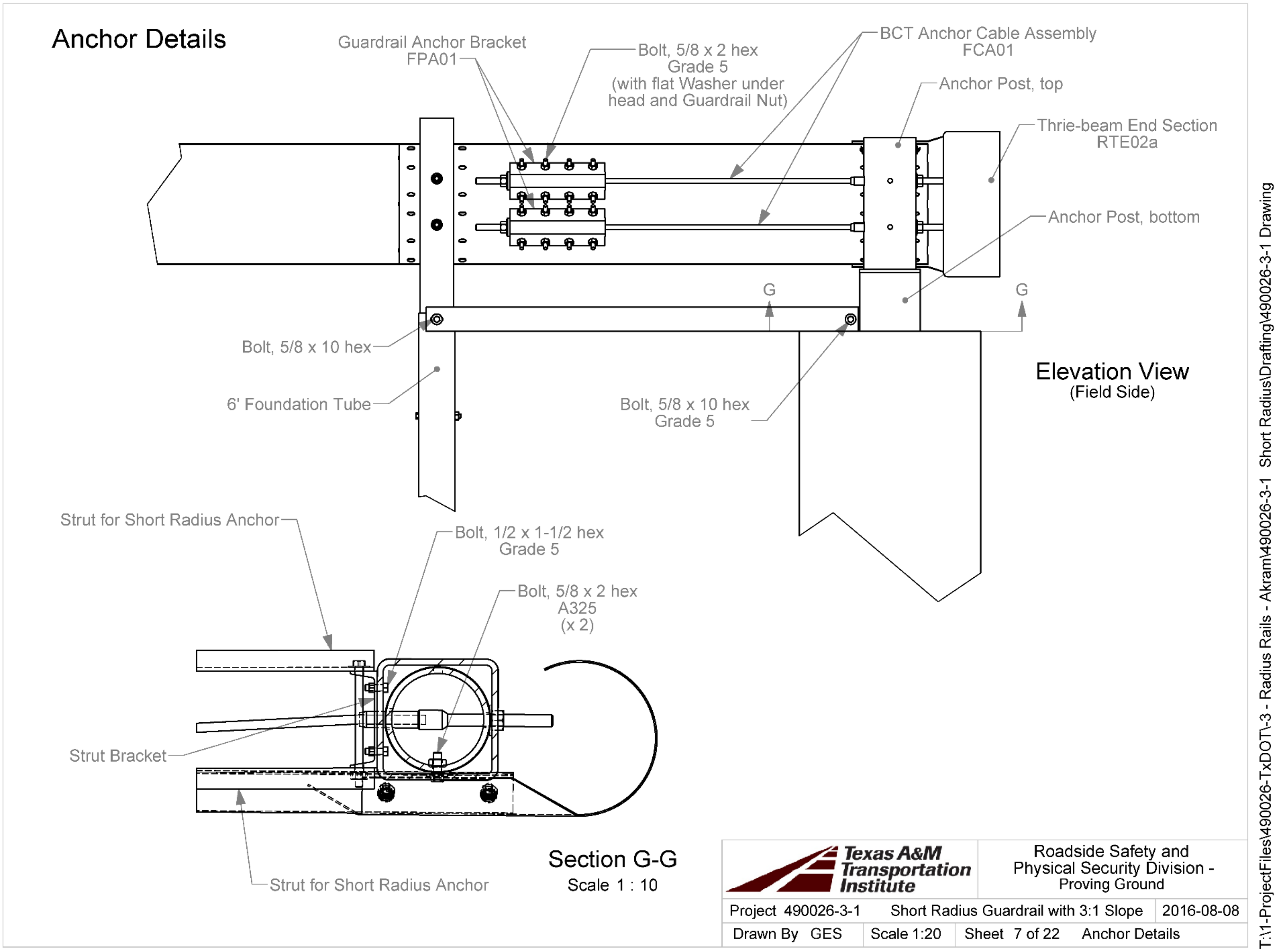
Sheet 5 of 22
Section Views

T:\1-ProjectFiles\490026-TxDOT-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing





Anchor Details
Guardrail Anchor Bracket FPA01
Bolt, 5/8 x 2 hex Grade 5 (with flat Washer under head and Guardrail Nut)
BCT Anchor Cable Assembly FCA01
Anchor Post, top
Thrie-beam End Section RTE02a
Anchor Post, bottom
G
G
Bolt, 5/8 x 10 hex
6' Foundation Tube
Bolt, 5/8 x 10 hex Grade 5
Elevation View
(Field Side)
Strut for Short Radius Anchor
Bolt, 1/2 x 1-1/2 hex Grade 5
Bolt, 5/8 x 2 hex A325 (x 2)
Strut Bracket
Strut for Short Radius Anchor
Section G-G
Scale 1 : 10
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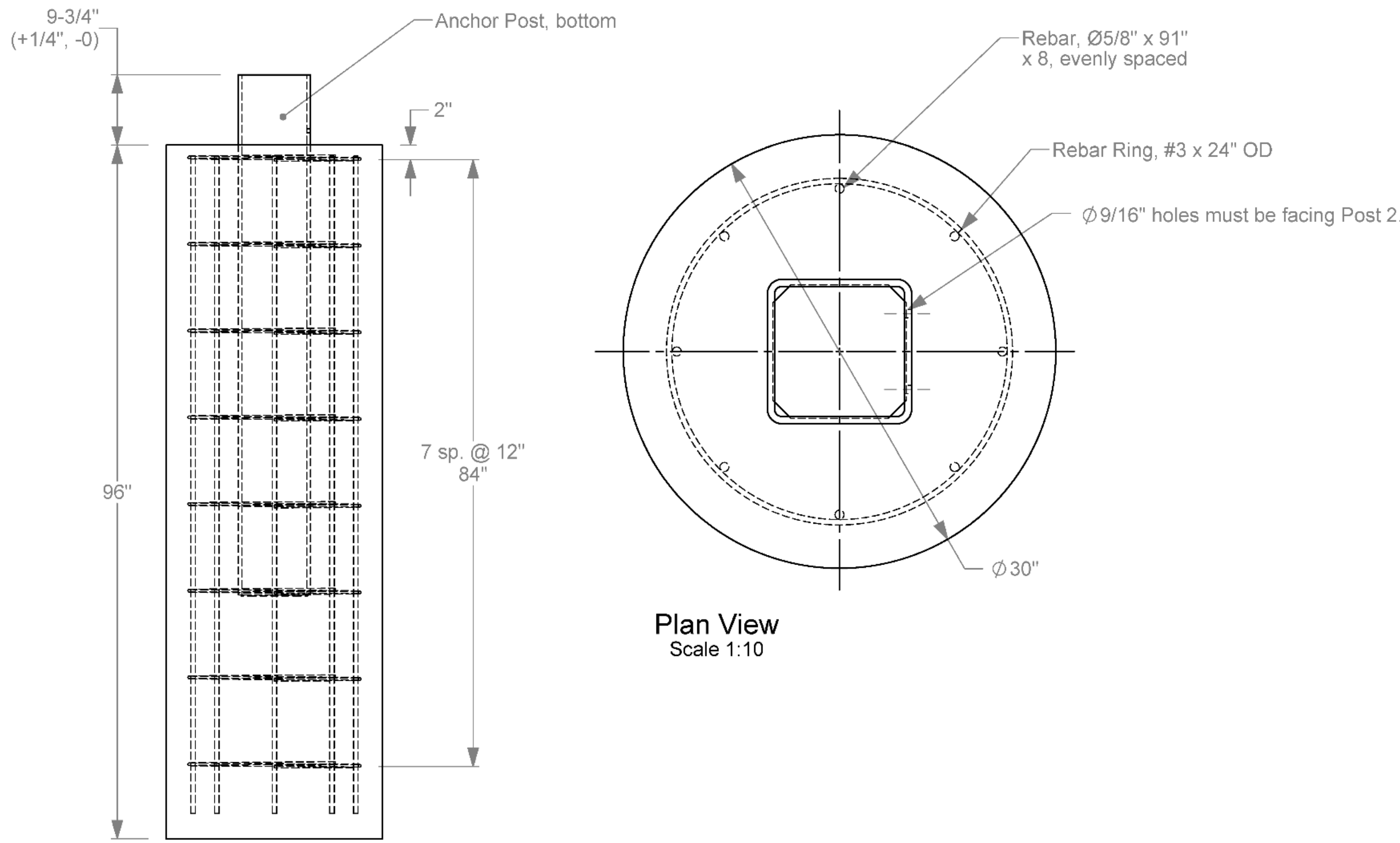
Anchor Details
T:\1-ProjectFiles\490026-TxDOT\-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing

Post 1 Foundation



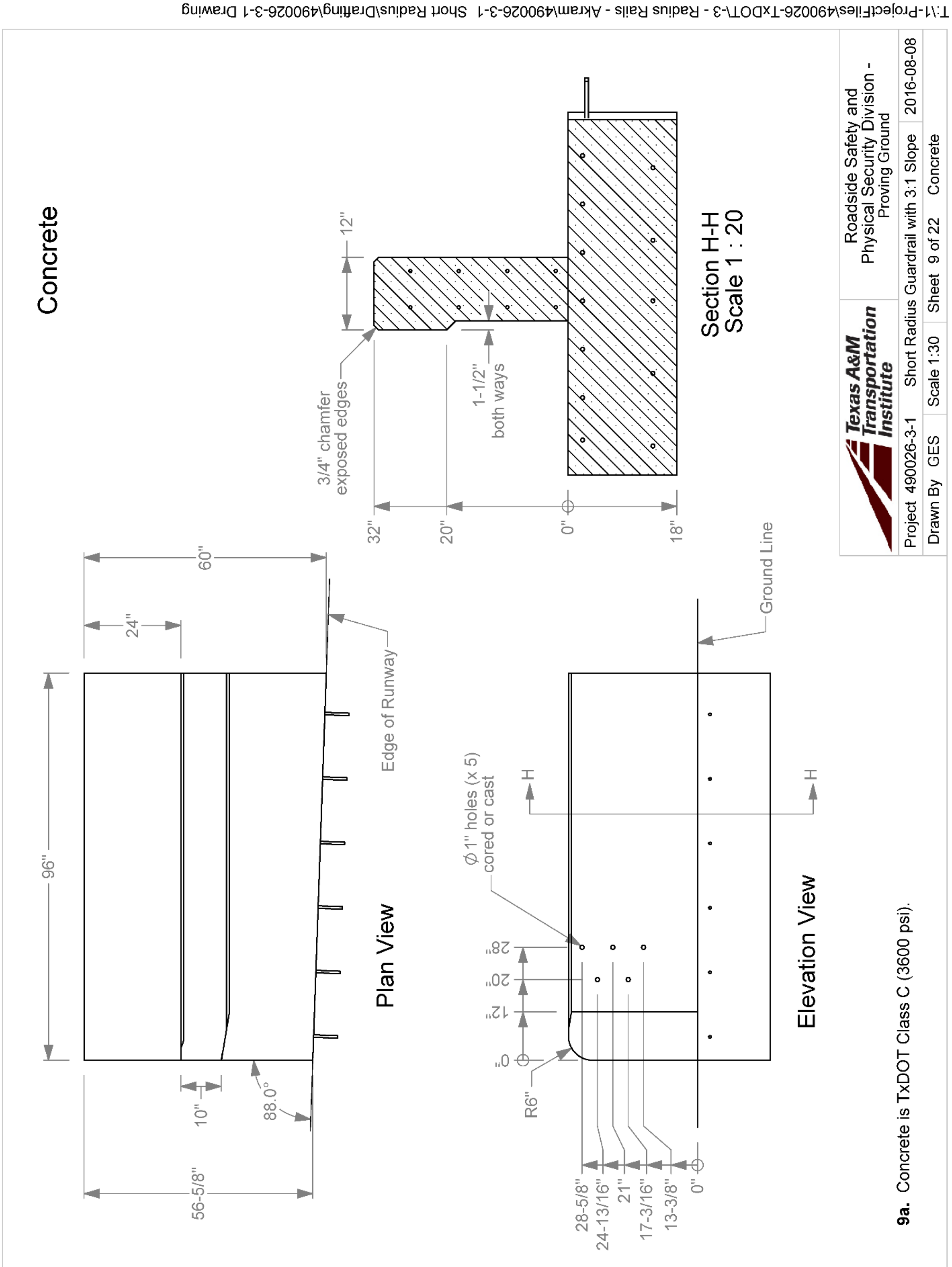
Elevation View

Plan View
Scale 1:10

8a. Concrete is TxDOT Class C (3600 psi).

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
Project 490026-3-1	Short Radius Guardrail with 3:1 Slope		2016-08-08
Drawn By GES	Scale 1:20	Sheet 8 of 22	Post 1 Foundation

T:\1-ProjectFiles\490026-TxDOT\-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing


Concrete
Plan View
96"
24"
60"
10"
88.0°
56-5/8"
Edge of Runway
Elevation View
Ø 1" holes (x 5)
cored or cast
R6"
0"
12"
20"
28"
28-5/8"
24-13/16"
21"
17-3/16"
13-3/8"
H
Ground Line
Section H-H
Scale 1 : 20
3/4" chamfer
exposed edges
1-1/2"
both ways
12"
32"
20"
18"
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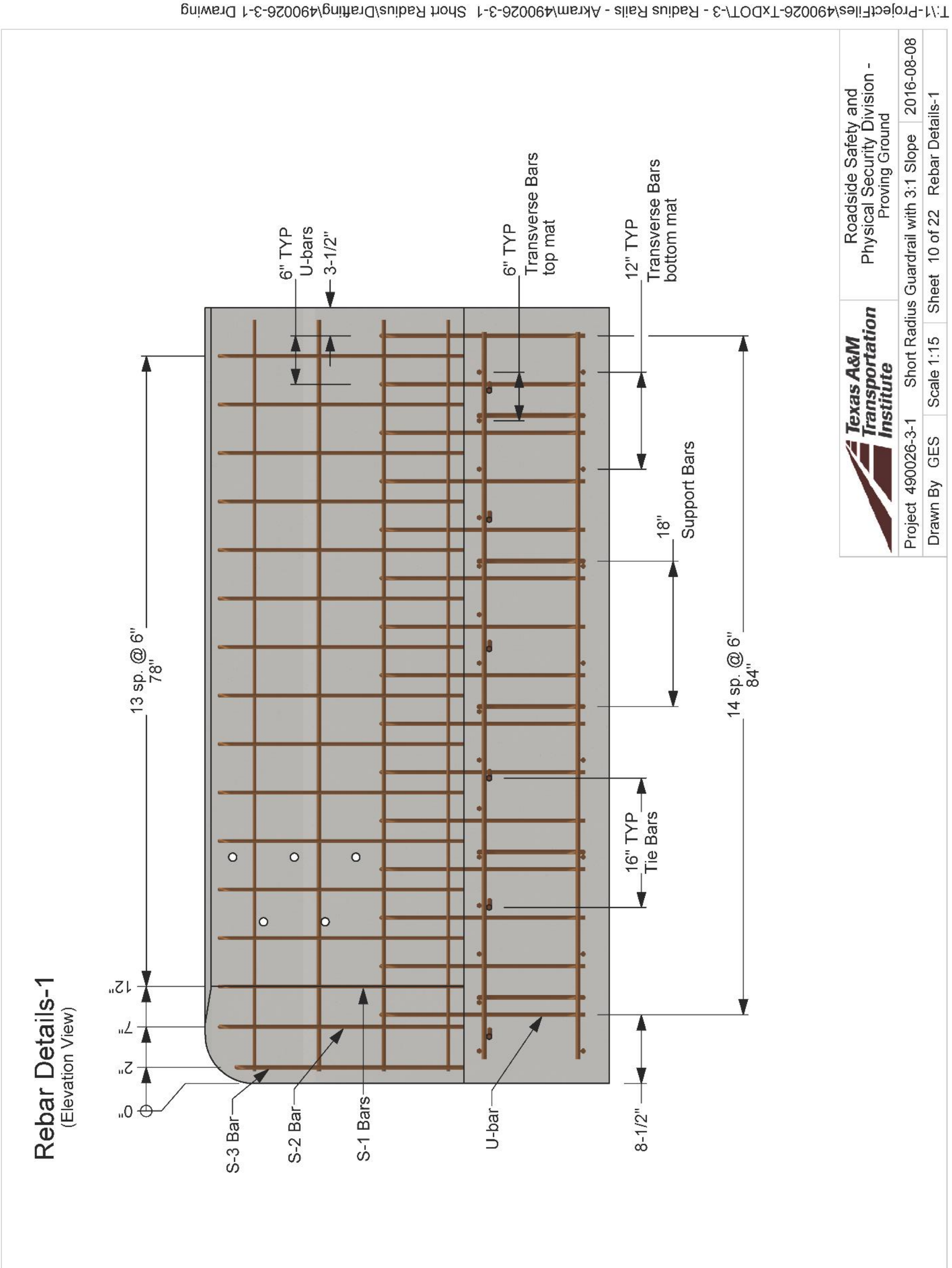
Concrete
T:\1-ProjectFiles\490026-TxDOT-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing
9a. Concrete is TxDOT Class C (3600 psi).


T:\1-ProjectFiles\490026-TxDOT-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing
Rebar Details-1
(Elevation View)
13 sp. @ 6"
78"
14 sp. @ 6"
84"
6" TYP
U-bars
3-1/2"
6" TYP
Transverse Bars
top mat
12" TYP
Transverse Bars
bottom mat
18"
Support Bars
16" TYP
Tie Bars
0"
2"
7"
12"
S-3 Bar
S-2 Bar
S-1 Bars
U-bar
8-1/2"
Texas A&M Transportation Institute
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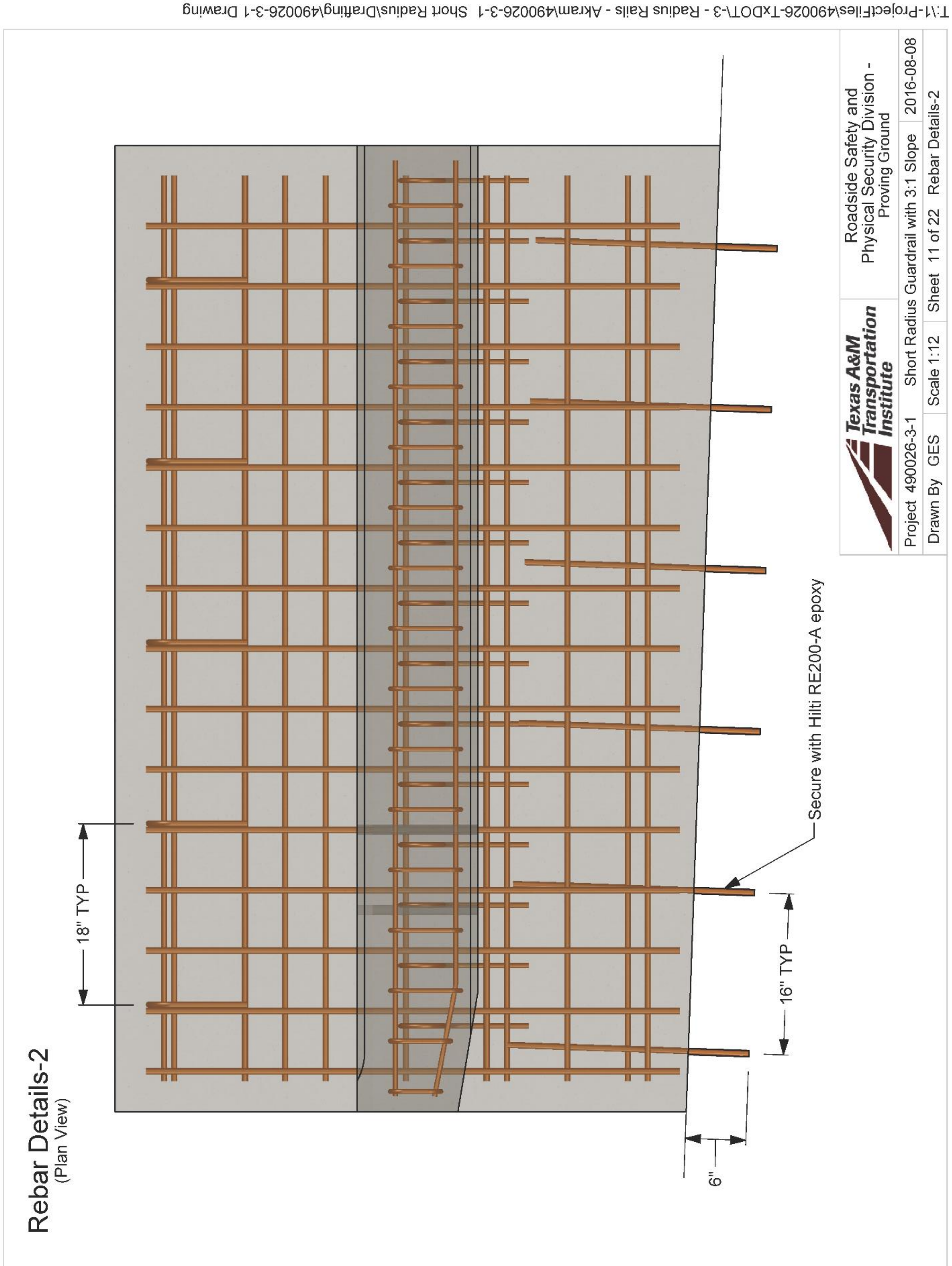
Sheet 10 of 22
Rebar Details-1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Rebar Details-2
(Plan View)
18" TYP
16" TYP
6"
Secure with Hilti RE200-A epoxy
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Scale 1:12
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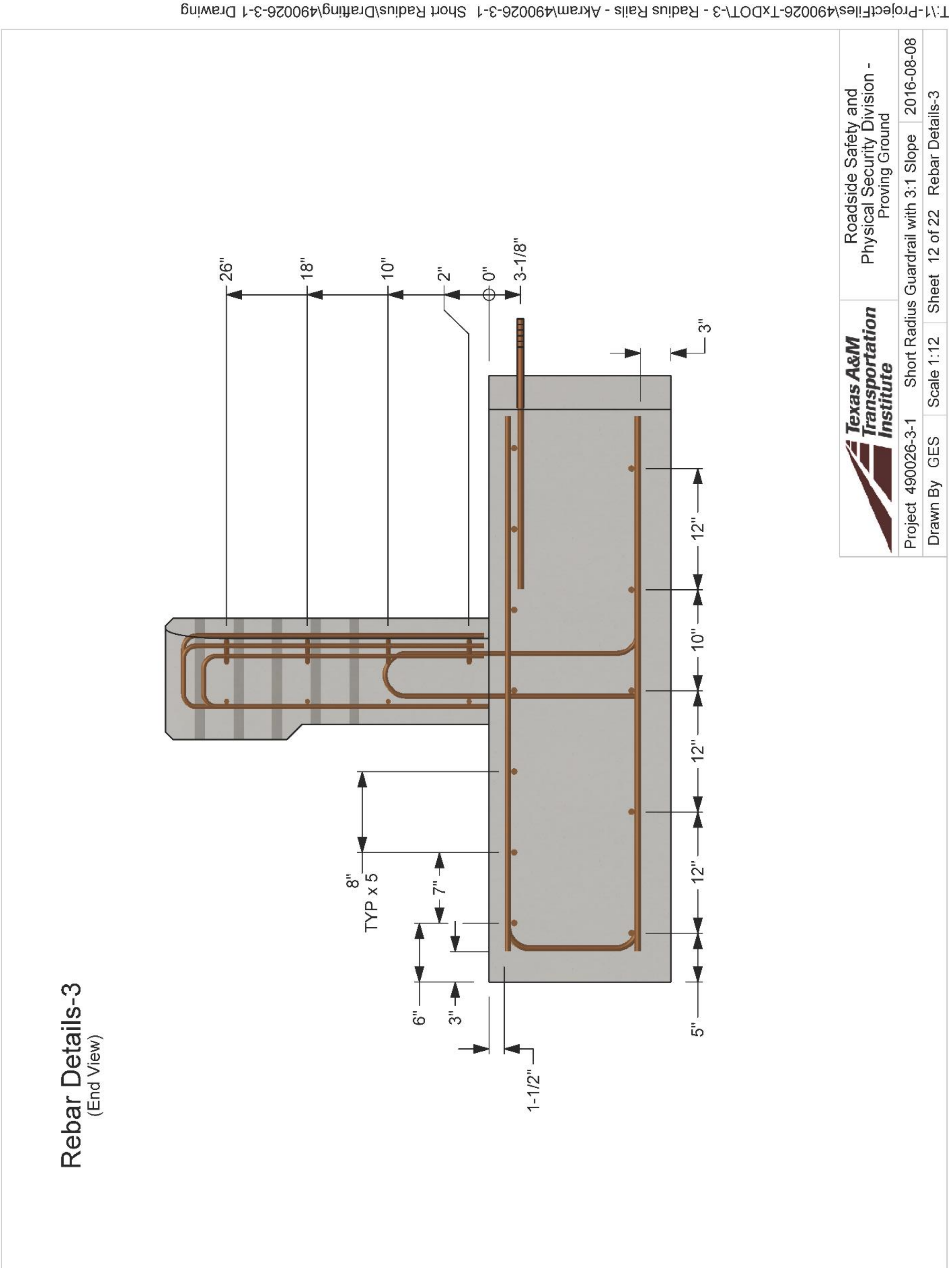
Rebar Details-2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Rebar Details-3
(End View)
26"
18"
10"
2"
0"
3-1/8"
3"
12"
10"
12"
12"
5"
8"
TYP x 5
7"
6"
3"
1-1/2"
Texas A&M Transportation Institute
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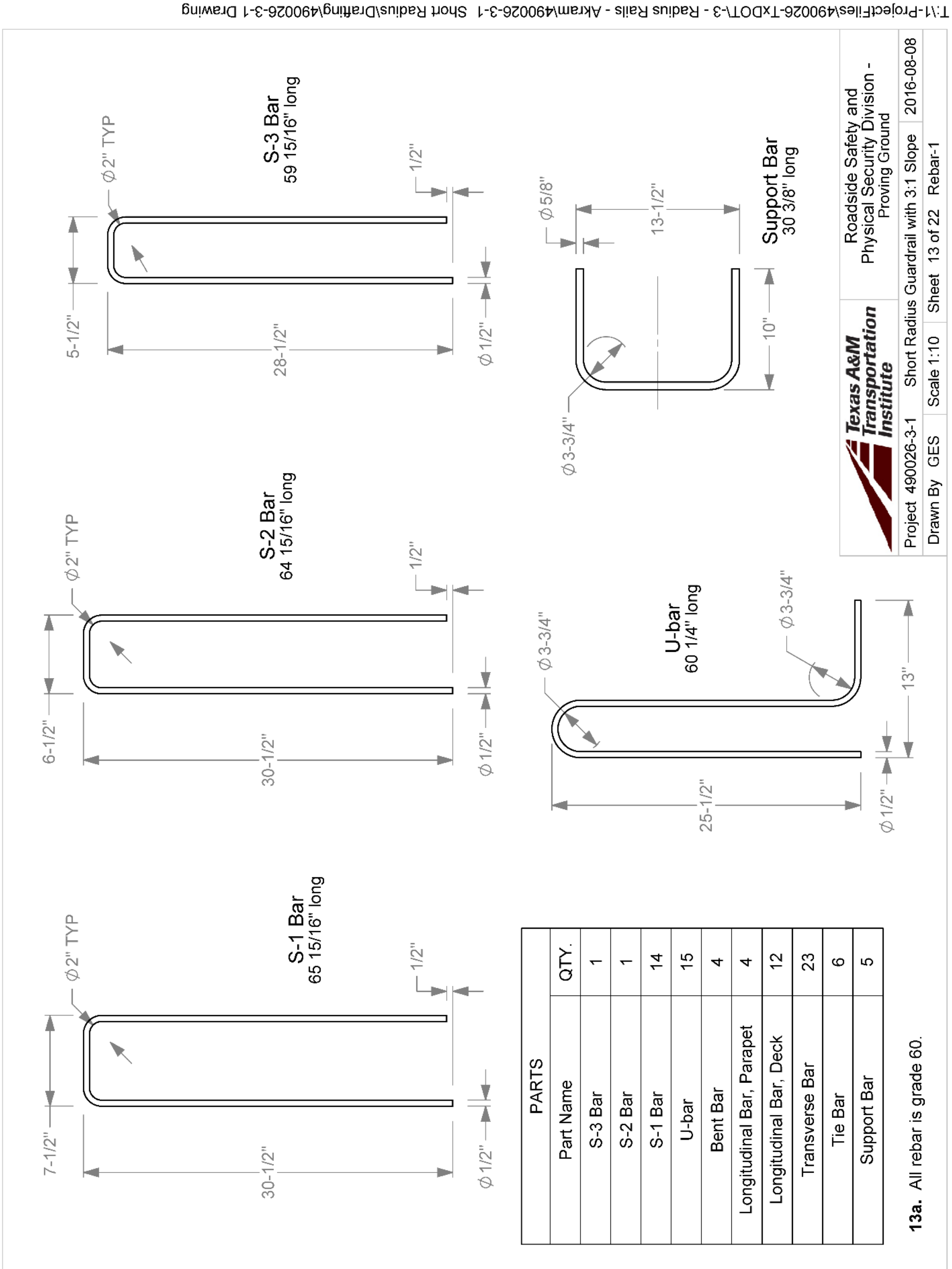
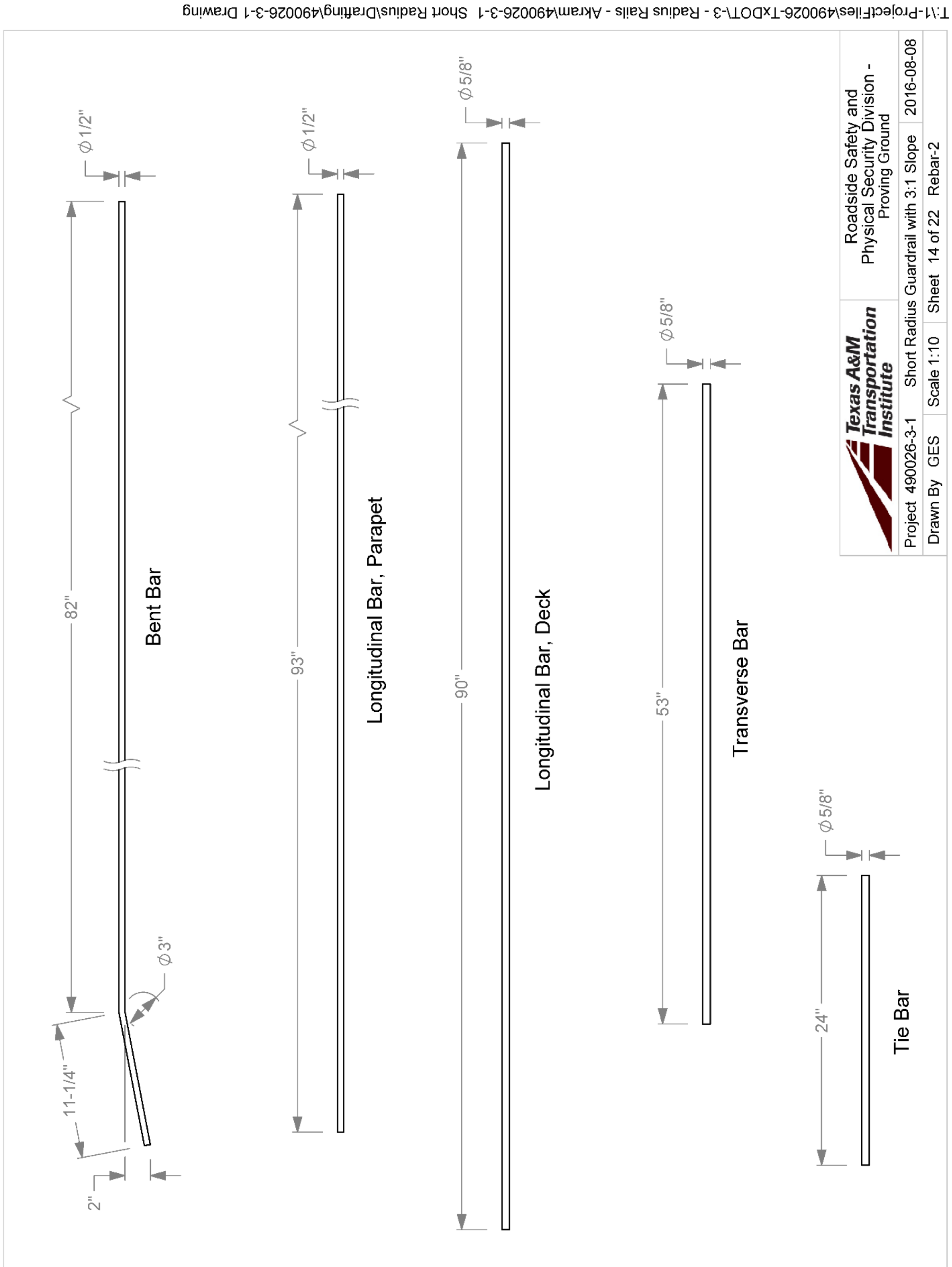
Rebar Details-3



PARTS	
Part Name	QTY.
S-3 Bar	1
S-2 Bar	1
S-1 Bar	14
U-bar	15
Bent Bar	4
Longitudinal Bar, Parapet	4
Longitudinal Bar, Deck	12
Transverse Bar	23
Tie Bar	6
Support Bar	5

13a. All rebar is grade 60.


T:\1-ProjectFiles\490026-TxDOT-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing
Bent Bar
82"
Ø 1/2"
Ø 3"
11-1/4"
2"
Longitudinal Bar, Parapet
93"
Ø 1/2"
Longitudinal Bar, Deck
90"
Ø 5/8"
Transverse Bar
53"
Ø 5/8"
Tie Bar
24"
Ø 5/8"
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
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Short Radius Guardrail with 3:1 Slope
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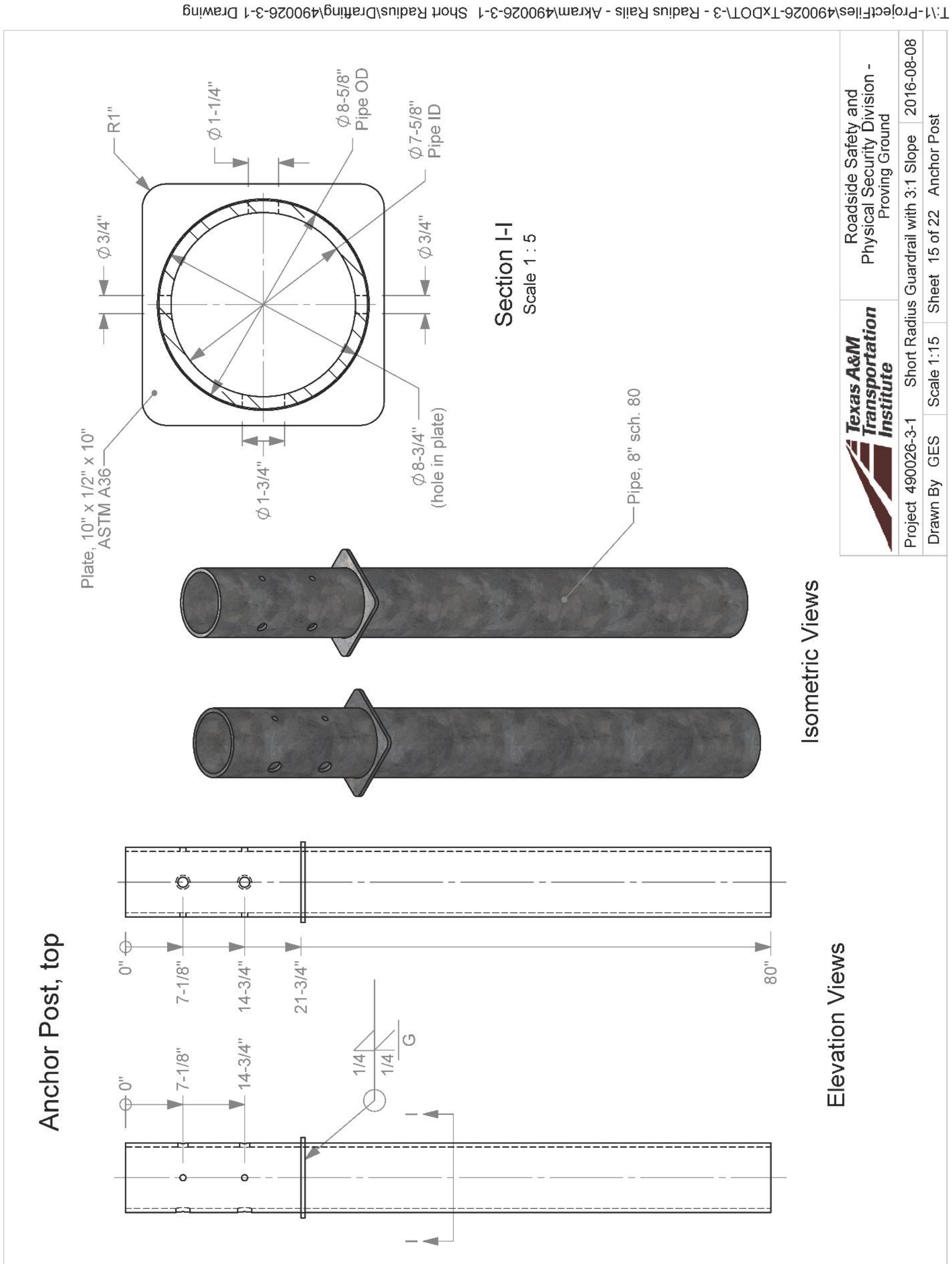
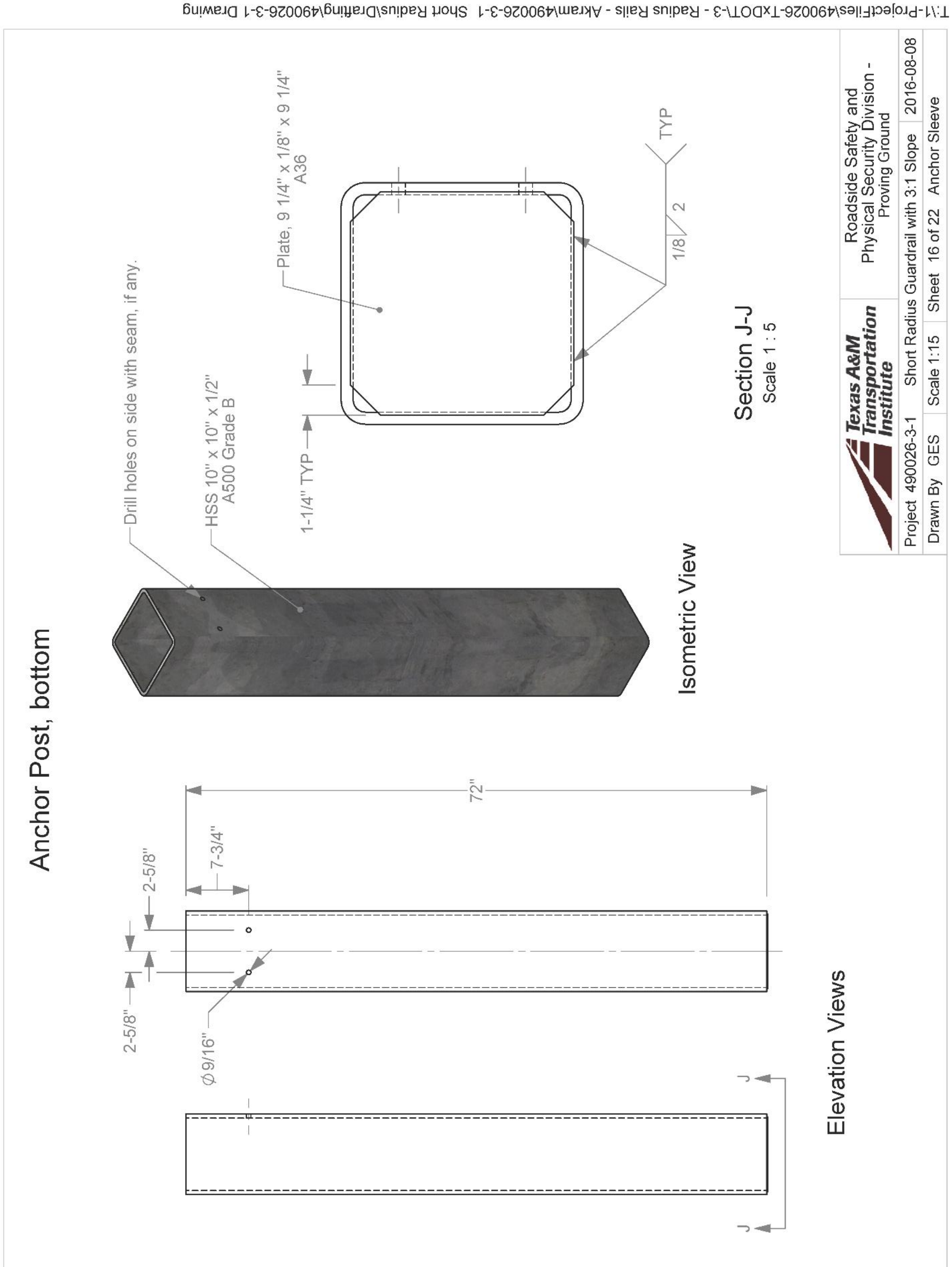
Drawn By GES
Scale 1:10
Sheet 14 of 22
Rebar-2


T:\1-ProjectFiles\490026-TxDOT\-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing
Anchor Post, top
Elevation Views
Isometric Views
Section I-I
Scale 1 : 5
R1"
Ø 1-1/4"
Ø 8-5/8"
Pipe OD
Ø 7-5/8"
Pipe ID
Ø 3/4"
Ø 3/4"
Ø 1-3/4"
Ø 8-3/4"
(hole in plate)
Plate, 10" x 1/2" x 10"
ASTM A36
Pipe, 8" sch. 80
0"
7-1/8"
14-3/4"
21-3/4"
80"
1/4
1/4
G
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project 490026-3-1
Short Radius Guardrail with 3:1 Slope
2016-08-08
Drawn By GES
Scale 1:15
Sheet 15 of 22
Anchor Post


T:\1-ProjectFiles\490026-TxDOT\-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing
Anchor Post, bottom
2-5/8"
7-3/4"
72"
2-5/8"
Ø9/16"
J
J
Elevation Views
Drill holes on side with seam, if any.
HSS 10" x 10" x 1/2"
A500 Grade B
Isometric View
1-1/4" TYP
Plate, 9 1/4" x 1/8" x 9 1/4"
A36
1/8
2
TYP
Section J-J
Scale 1 : 5
Texas A&M Transportation Institute
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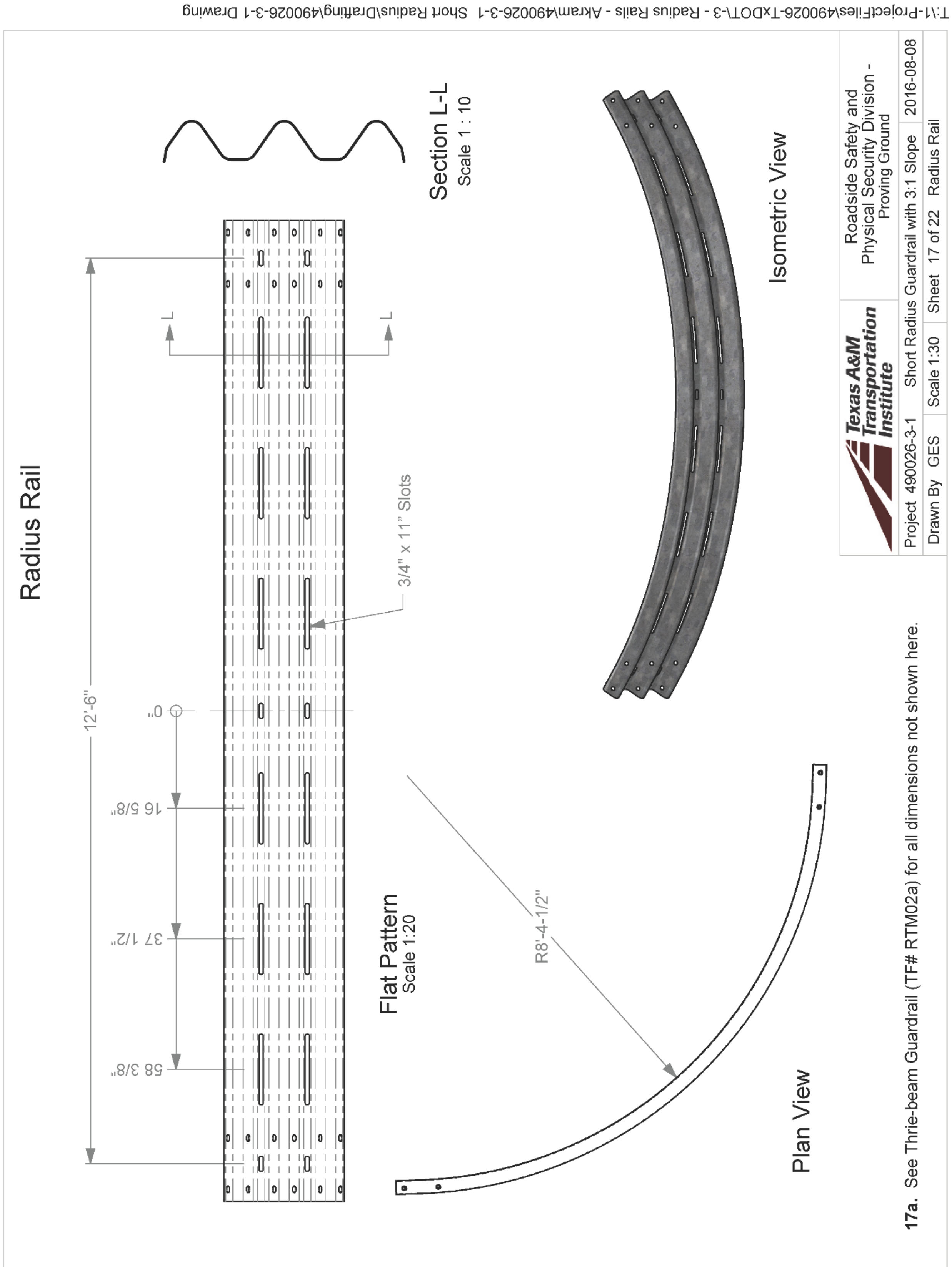
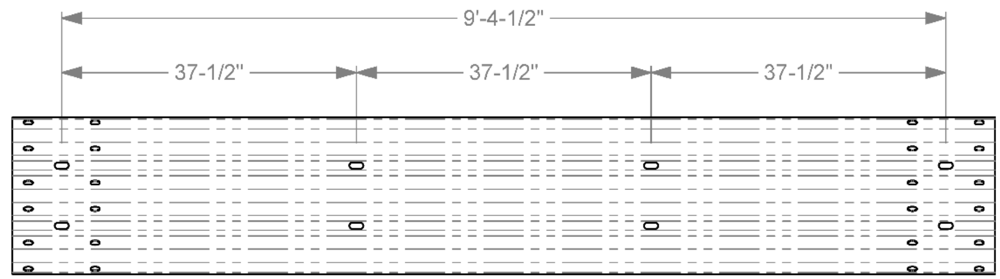
Short Radius Guardrail with 3:1 Slope
2016-08-08
Drawn By GES
Scale 1:15
Sheet 16 of 22
Anchor Sleeve

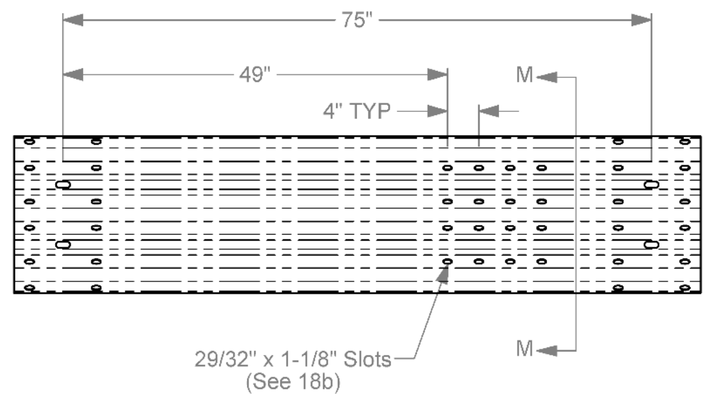


17a. See Thrie-beam Guardrail (TF# RTM02a) for all dimensions not shown here.

9'-4-1/2" Thrie-beam, 37-1/2" spacing



75" Thrie-beam Anchor Rail

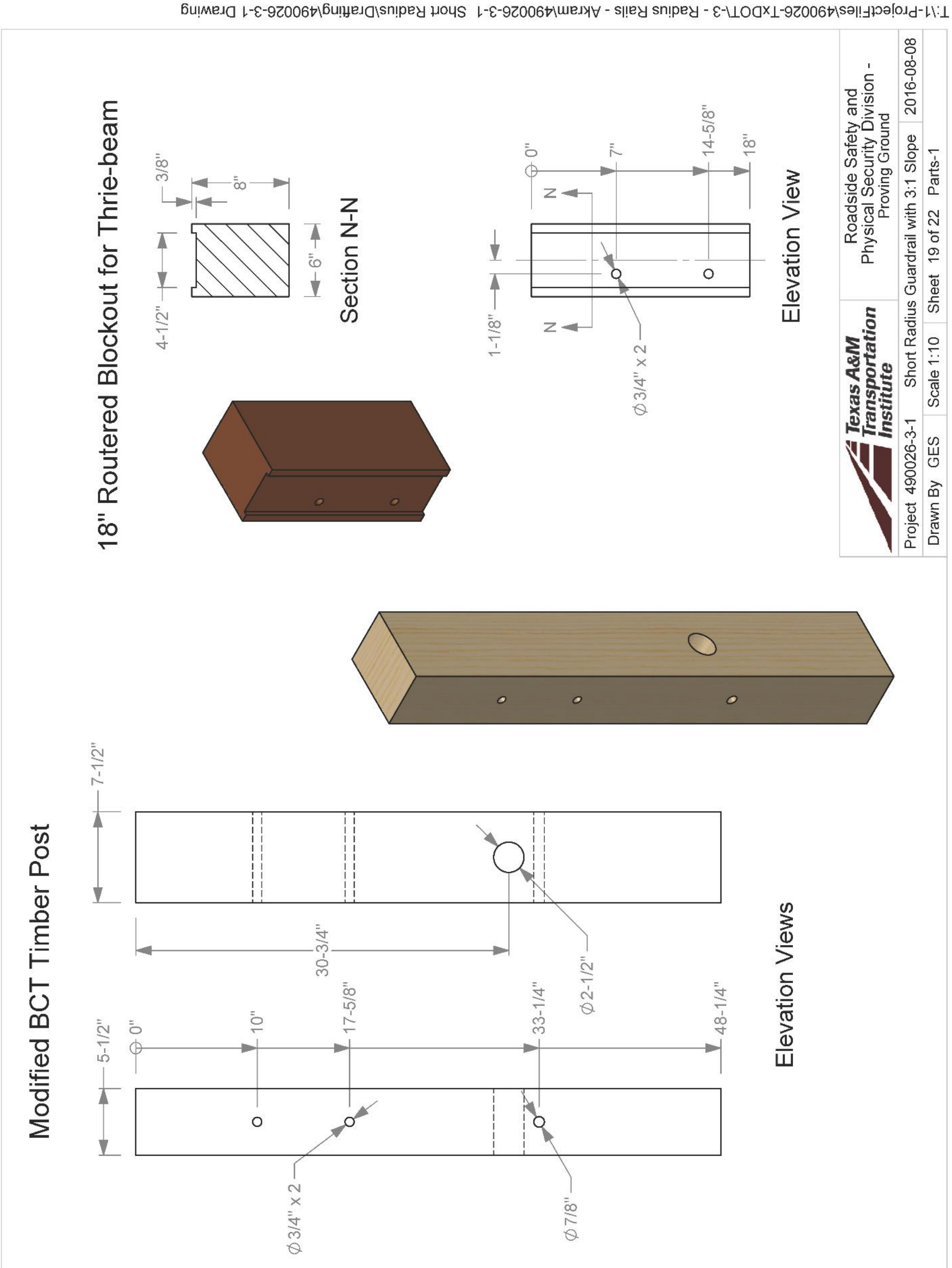


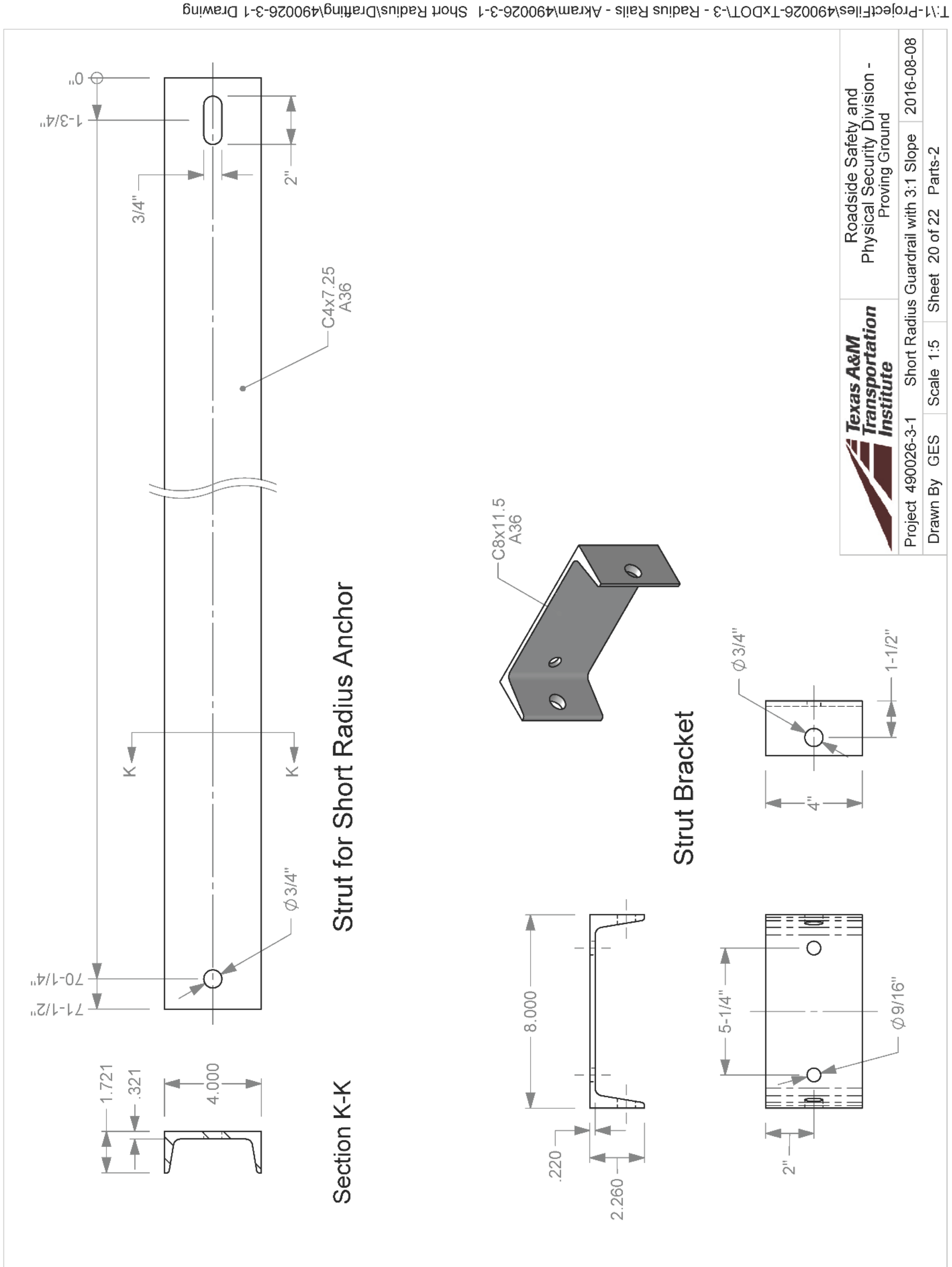
Section M-M
Scale 1 : 10

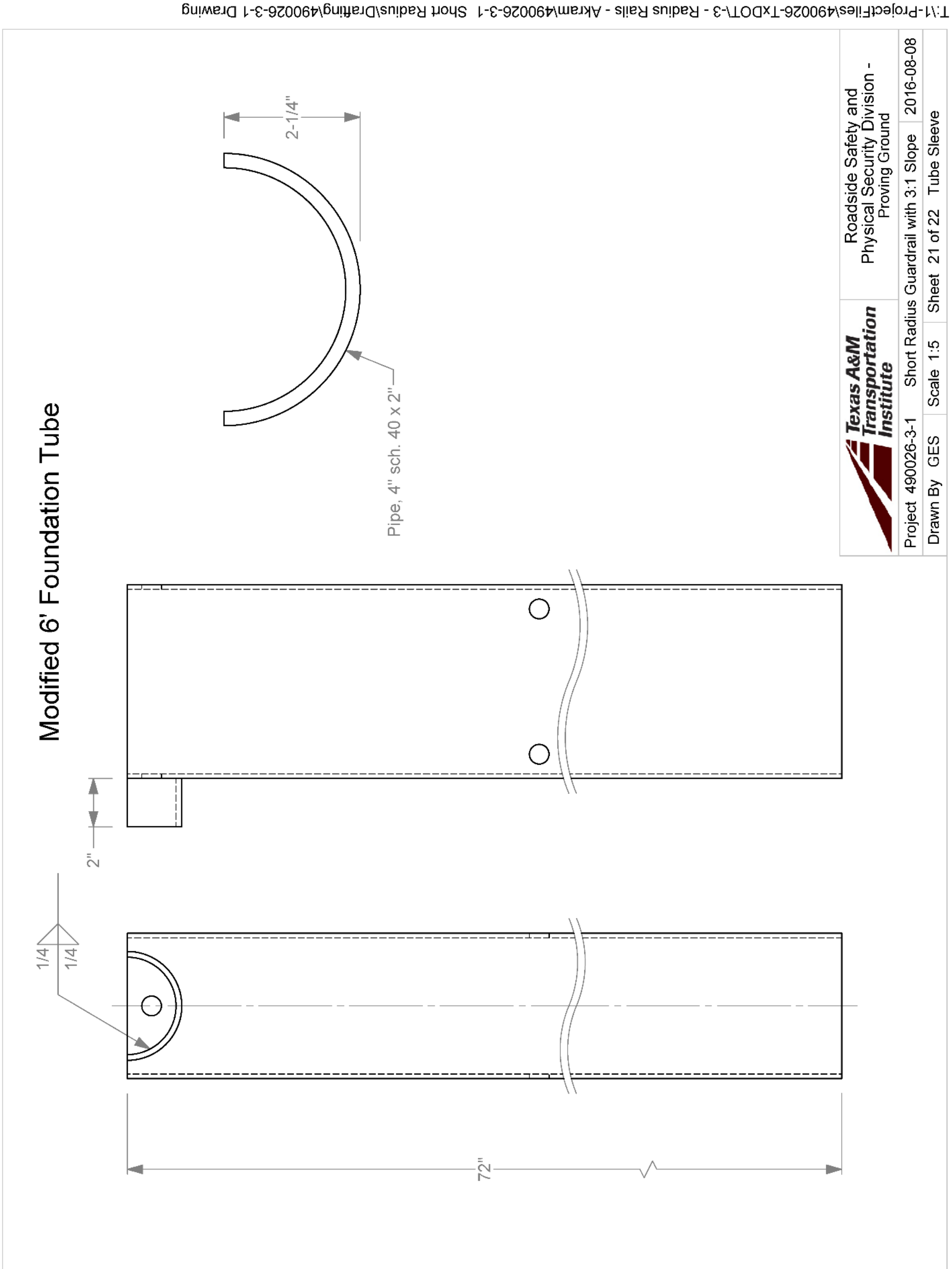
18a. See Thrie-beam Guardrail (TF 13 # RTM02a) for all dimensions not shown here.
18b. Anchor Bracket slots in line with, and same size as, Splice Bolt slots. See BCT Terminal Rail Section (TF 13 # RWM14a).

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project 490026-3-1	Short Radius Guardrail with 3:1 Slope		2016-08-08
Drawn By GES	Scale 1:20	Sheet 18 of 22	Thrie-beam Rails

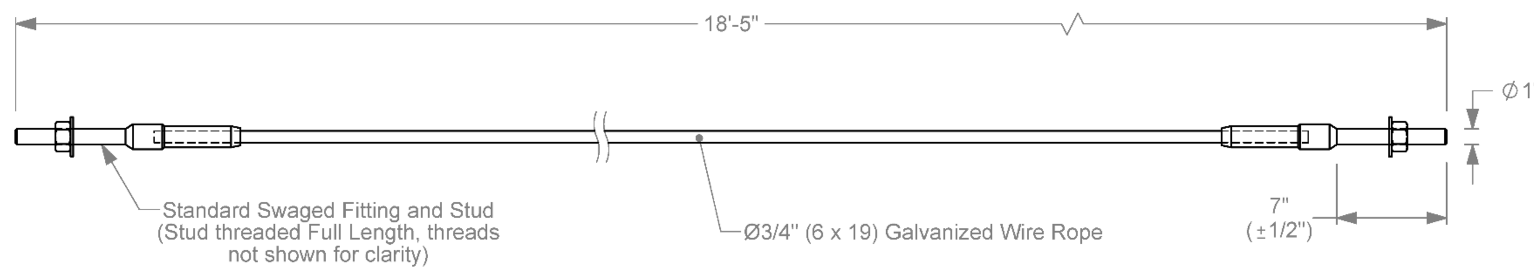
T:\1-ProjectFiles\490026-TxDOT\-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing


T:\1-ProjectFiles\490026-TxDOT-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing
Modified BCT Timber Post
5-1/2"
0"
10"
17-5/8"
33-1/4"
48-1/4"
7-1/2"
30-3/4"
⌀2-1/2"
⌀3/4" x 2
⌀7/8"
Elevation Views
18" Routered Blockout for Thrie-beam
3/8"
8"
4-1/2"
6"
Section N-N
0"
7"
14-5/8"
18"
1-1/8"
N
N
⌀3/4" x 2
Elevation View
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project 490026-3-1
Short Radius Guardrail with 3:1 Slope
2016-08-08
Drawn By GES
Scale 1:10
Sheet 19 of 22
Parts-1


T:\1-ProjectFiles\490026-TxDOT\-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing
Strut for Short Radius Anchor
C4x7.25
A36
0"
1-3/4"
3/4"
2"
K
K
Ø3/4"
70-1/4"
71-1/2"
Section K-K
1.721
.321
4.000
Strut Bracket
C8x11.5
A36
Ø3/4"
1-1/2"
4"
8.000
.220
2.260
5-1/4"
Ø9/16"
2"
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project 490026-3-1
Short Radius Guardrail with 3:1 Slope
2016-08-08
Drawn By GES
Scale 1:5
Sheet 20 of 22
Parts-2


T:\1-ProjectFiles\490026-TxDOT\-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing
Modified 6' Foundation Tube
2-1/4"
Pipe, 4" sch. 40 x 2"
2"
1/4
1/4
72"
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project 490026-3-1
Short Radius Guardrail with 3:1 Slope
2016-08-08
Drawn By GES
Scale 1:5
Sheet 21 of 22
Tube Sleeve

Anchor Cable for Short Radius Rail



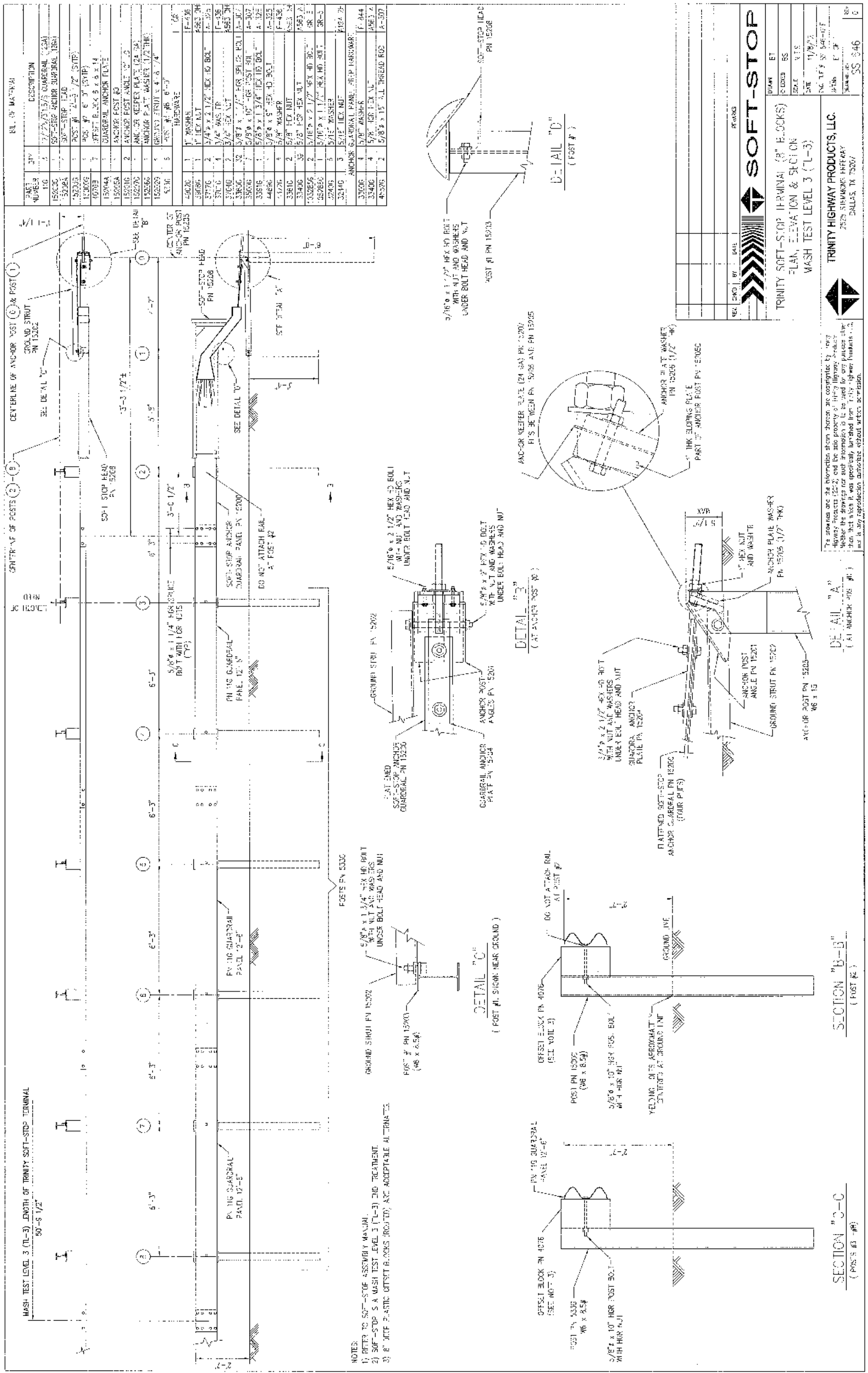
22a. The Stud shall conform to the requirements of ASTM A449 and shall be galvanized in accordance with ASTM A153. The threads shall have a Class 2A fit before galvanizing.

22b. The Wire Rope shall conform to the requirements of AASHTO M-30 and shall be Ø3/4" pre-formed, 6 x 19, wire strand core or independent wire rope core (IWRC), galvanized, right regular lay,manufactured of improved plow steel with a minimum breaking strength of 46,000 lbs.

22c. The swaged fitting, stud, and nut shall develop the breaking strength of the wire rope.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project 490026-3-1	Short Radius Guardrail with 3:1 Slope	2016-08-08
Drawn By GES	Scale 1:10	Sheet 22 of 22 Anchor Cable

T:\1-ProjectFiles\490026-TxDOT\-3 - Radius Rails - Akram\490026-3-1 Short Radius\Drafting\490026-3-1 Drawing


SOFT-STOP
TRINITY SOFT-STOP TERMINAL (8" BLOCKS)
PLAN, ELEVATION & SECTION
MASH TEST LEVEL 3 (TL-3)
TRINITY HIGHWAY PRODUCTS, LLC.
BILL OF MATERIAL
DETAIL "A"
DETAIL "B"
DETAIL "C"
DETAIL "D"
SECTION "B-B"
SECTION "C-C"
SS 846

APPENDIX B: SUMMARY OF SUPPORTING CERTIFICATION DOCUMENTS

MATERIAL USED

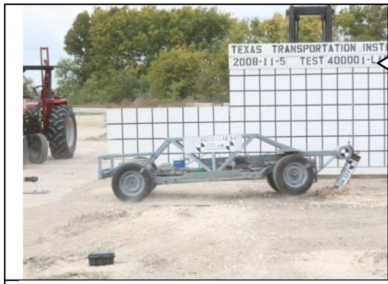
TEST NUMBER	490026-3
TEST NAME	Radius Guardrail
DATE	2016-08

#	DATE RECEIVED	DESCRIPTION	GRADE	YIELD	TENSILE	SUPPLIER
13-147	2014-05-13	Rebar Ring, #3 x 24"	grade 60	65.6	102.4	CMC Steel
13-148	2014-05-13	Rebar, #5	grade 60	65.2	100.4	CMC Steel
13-149	2014-05-13	Rebar, #4	grade 60	64.5	97.0	CMC Steel
13-151	2014-05-16	HSS 10 x 10 x 5/8	A500 grade B	53840	65790	Mack Bolt & Steel
13-152	2014-05-16	Pipe, 8" sch 80	x	42100	60200	Mack Bolt & Steel
13-153	2014-05-16	C8x11.5	A36/A529 gr.50	57.0-57.9	80.0-81.1	Mack Bolt & Steel
13-154	2014-05-16	C4x7.25	?	53.2-54.7	72.3-73.5	Mack Bolt & Steel
13-155	2014-05-16	Guardrail Parts		see paperwork		Trinity Industries
13-170	2014-06-25	Special Thrie-beams		53960, 59920	70650, 79090	Trinity Industries
13-172	2014-07-08	Tubing, 10 x 10 x 1/2	A500 Grade B/C	62,500	73,400	Mack Bolt & Steel
15-064	2016-08-19	Guardrail Parts		see attached		Trinity Industries
15-059	2016-07-26	Guardrail Parts		see attached		Trinity Industries

All detailed certification documents are on file at TTI Proving Ground.

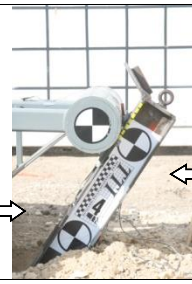
APPENDIX C: SOIL PROPERTIES

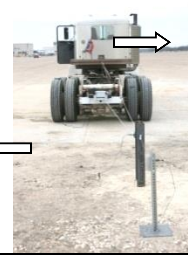
Table C.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.



Dynamic Setup

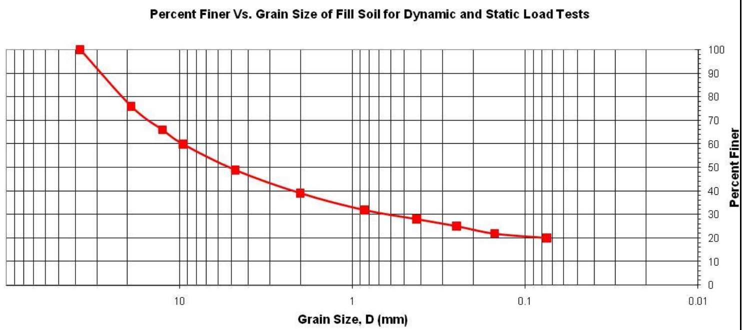
Post-Test Photo of post



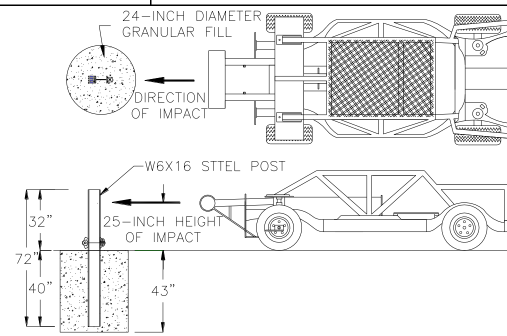


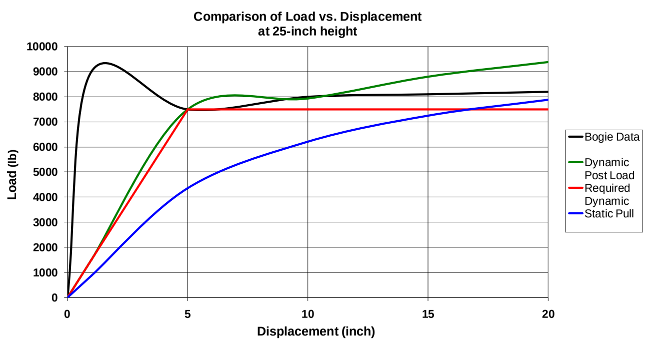
Post-Test Photo

Static Load Test

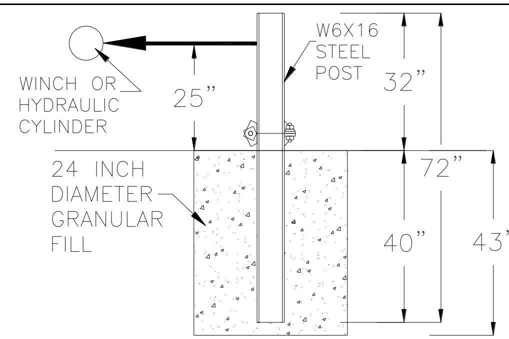


Dynamic Test Installation Details



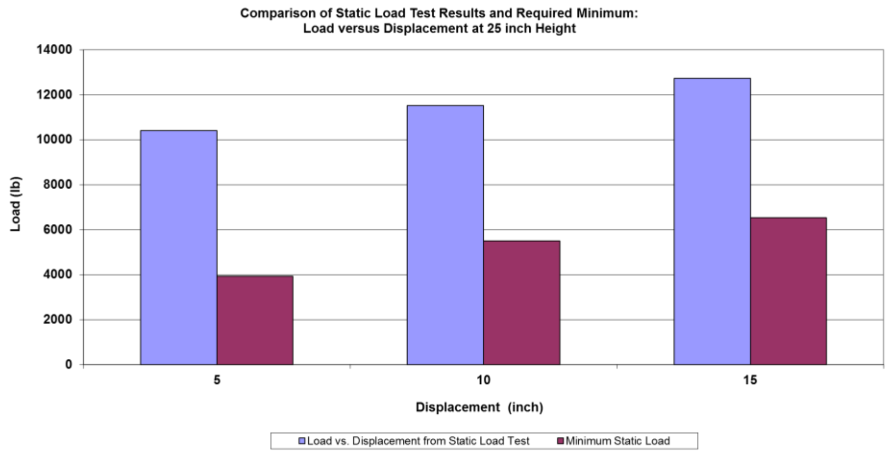


Static Load Test Installation Details

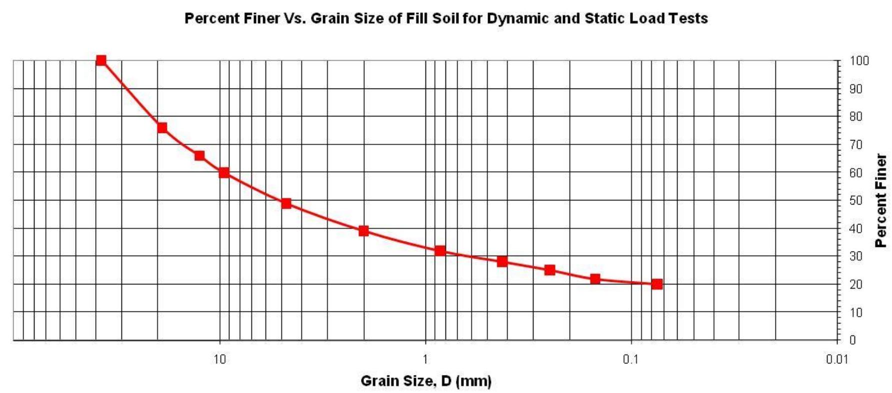


Date	2008-11-05
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis above)
Description of Fill Placement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

Table C.2. Test Day Static Soil Strength Documentation for Test No. 490026-3-1.



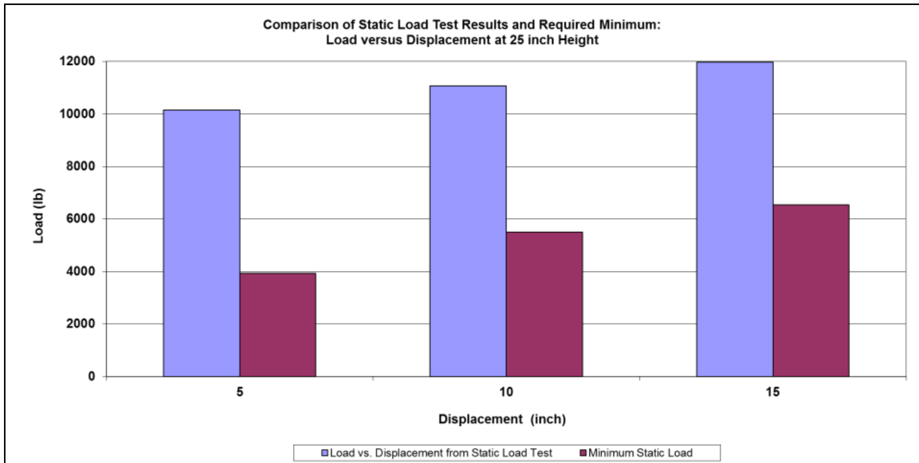
Static Load Setup



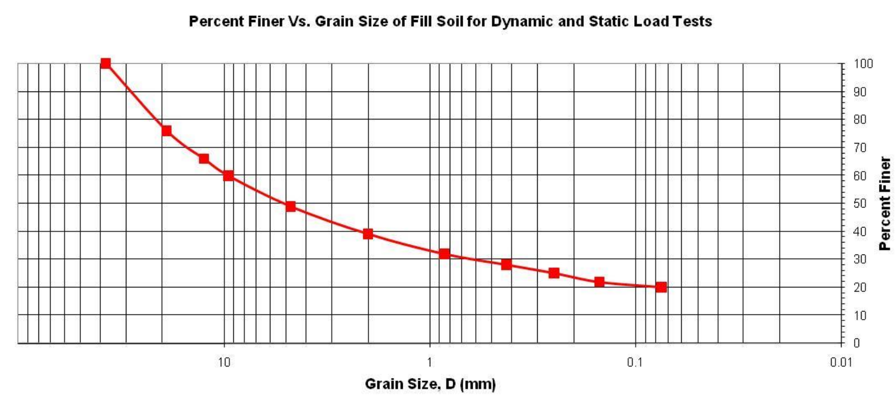
Post-Test Photo of Post

Date...	2016-08-09
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

Table C.3. Test Day Static Soil Strength Documentation for Test No. 490026-3-2.



Static Load Setup



Post-Test Photo of Post

Date...	2016-08-11
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

APPENDIX D: MODIFIED *MASH* TEST 3-33 (CRASH TEST NO. 490026-3-1)

D.1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 490026-3-1.

Date: 2016-08-22 Test No.: 490026-3-1 VIN No.: 1D7RB1G2A5133459

Year: 2010 Make: Dodge Model: RAM 1500

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

Tread Type: Highway Odometer: 142022

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

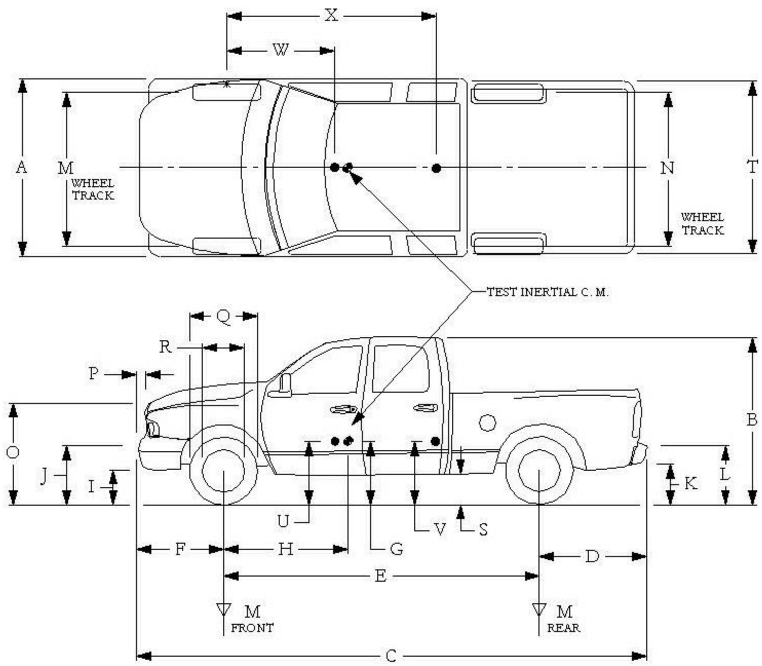
NOTES: None

Engine Type: V-8
Engine CID: 4.7 liter

Transmission Type:
x Auto or ___ Manual
___ FWD x RWD ___ 4WD

Optional Equipment:
None

Dummy Data:
Type: None
Mass: NA
Seat Position: NA



Geometry: inches

A	78.50	F	41.50	K	20.00	P	3.00	U	27.00
B	75.00	G	28.62	L	29.25	Q	30.50	V	29.75
C	231.00	H	64.66	M	68.50	R	18.00	W	62.60
D	49.50	I	11.75	N	68.00	S	13.00	X	78.10
E	140.50	J	26.00	O	45.50	T	77.00		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	17.50
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	25.50

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2840	2790	
Back	3900	M_{rear}	2008	2246	
Total	6700	M_{Total}	4848	5036	

Mass Distribution:
lb LF: 1406 RF: 1384 LR: 1132 RR: 1114

Table D.2. Measurements of Vehicle Vertical CG for Test No. 490026-3-1.

Date: 2016-08-22 Test No.: 490026-3-1 VIN: 1D7RB1G2A5133459

Year: 2010 Make: Dodge Model: RAM 1500

Body Style: Quad Cab Mileage: 142022

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 195 lb (440 lb max)

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

Measured Vehicle Weights: (lb)									
LF:	1406		RF:	1384			Front Axle:	2790	
LR:	1132		RR:	1114			Rear Axle:	2246	
Left:	2538		Right:	2498			Total:	5036	
							5000 ±110 lb allowed		
Wheel Base:		140.5	inches	Track: F:	68.5	inches	R:	68	inches
	148 ±12 inches allowed				Track = (F+R)/2 = 67 ±1.5 inches allowed				
Center of Gravity, SAE J874 Suspension Method									
X:	62.66	inches	Rear of Front Axle		(63 ±4 inches allowed)				
Y:	-0.27	inches	Left -	Right +	of Vehicle Centerline				
Z:	28.625	inches	Above Ground		(minumum 28.0 inches allowed)				

Hood Height: 45.50 inches Front Bumper Height: 26.00 inches

43 ±4 inches allowed

Front Overhang: 41.50 inches Rear Bumper Height: 29.25 inches

39 ±3 inches allowed

Overall Length: 231 inches

237 ±13 inches allowed

Table D.3. Exterior Crush Measurements of Vehicle for Test No. 490026-3-1.

Date:	2016-08-22	Test No.:	490026-3-1	VIN No.:	1D7RB1G2A5133459
Year:	2010	Make:	Dodge	Model:	RAM 1500

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	72	12.25	72	10	7	11.5	12.25	9	11	0
	Measurements recorded										
	in inches										

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

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline) 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).

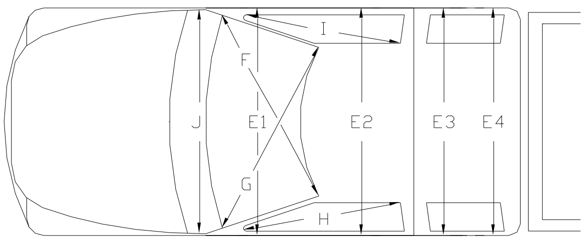
***Measure and document on the vehicle diagram the location of the maximum crush.

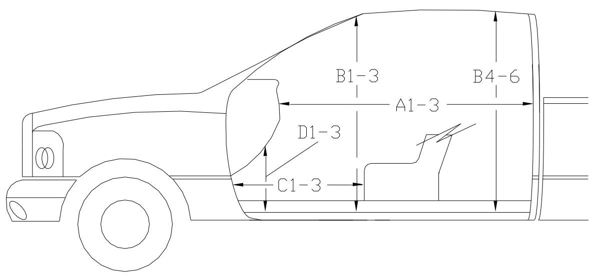
Note: Use as many lines/columns as necessary to describe each damage profile.

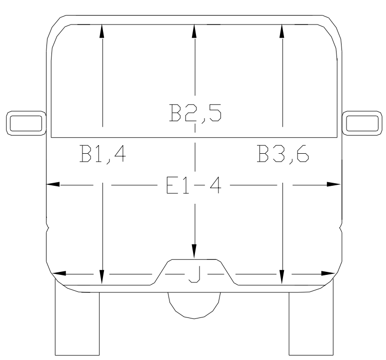
Table D.4. Occupant Compartment Measurements of Vehicle for Test No. 490026-3-1.

Date: 2016-08-22 Test No.: 490026-3-1 VIN No.: 1D7RB1G2A5133459

Year: 2010 Make: Dodge Model: RAM 1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	**After** (inches)
A1	65.25	65.25
A2	63.50	63.50
A3	65.50	65.50
B1	44.75	44.75
B2	38.00	38.00
B3	44.75	44.75
B4	39.25	39.25
B5	43.00	43.00
B6	39.25	39.25
C1	26.00	26.00
C2	-----	-----
C3	25.00	25.00
D1	11.50	11.50
D2	-----	-----
D3	11.25	11.25
E1	58.75	58.75
E2	63.75	63.75
E3	63.75	63.75
E4	63.25	63.25
F	59.00	59.00
G	59.00	59.00
H	37.50	37.50
I	37.50	37.50
J*	22.75	22.75

D.2 SEQUENTIAL PHOTOGRAPHS

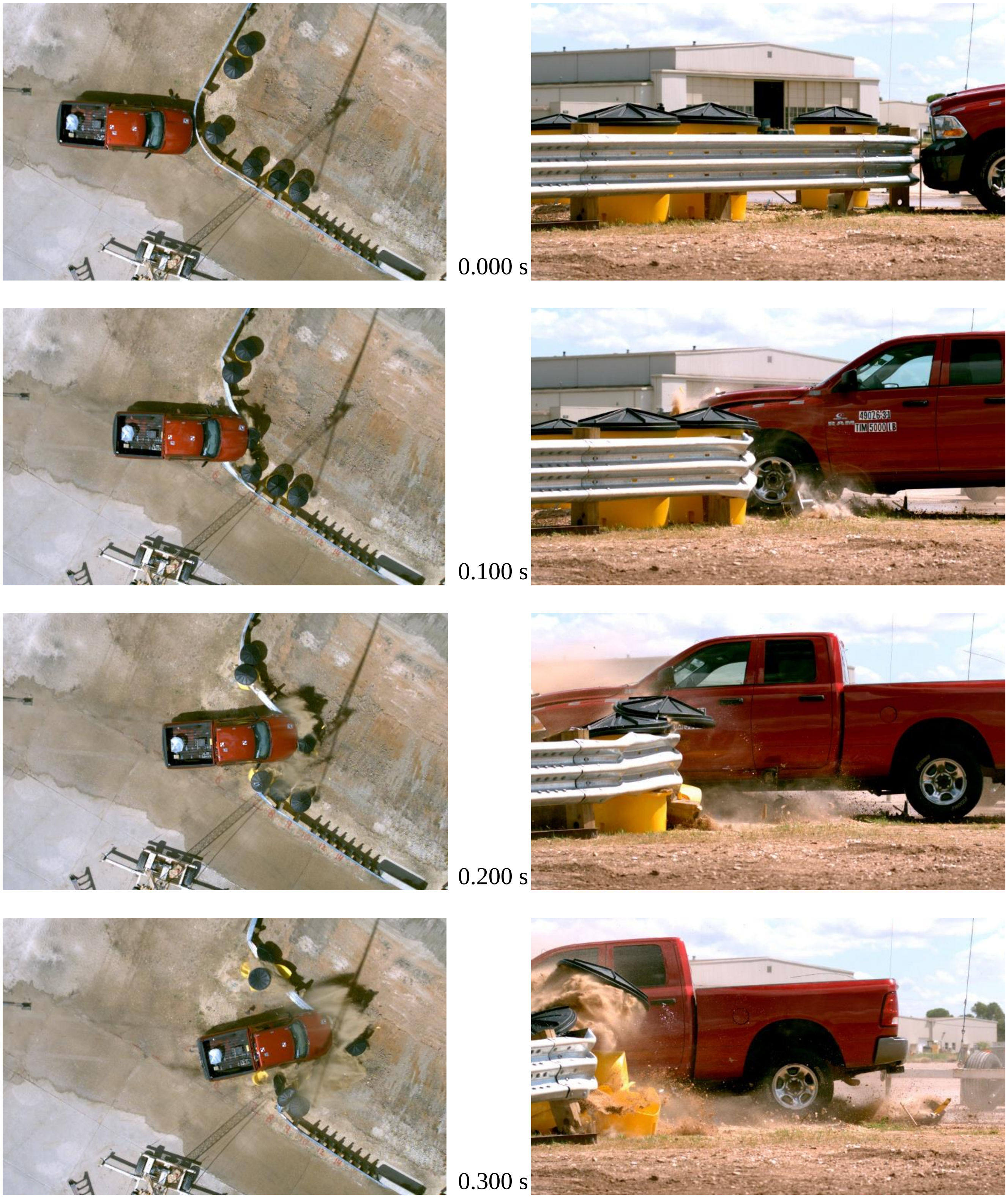


Figure D.1. Sequential Photographs for Test No. 490026-3-1 (Overhead and Perpendicular Views).


0.400 s



0.500 s



0.600 s

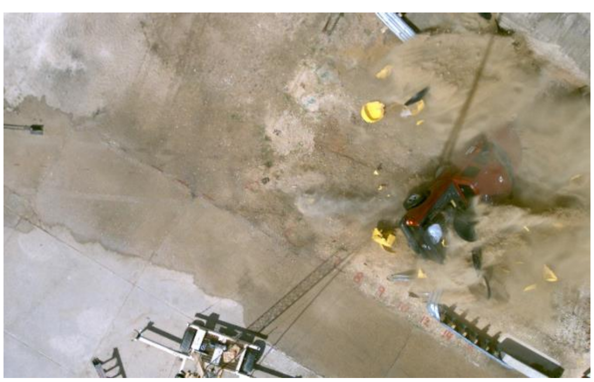
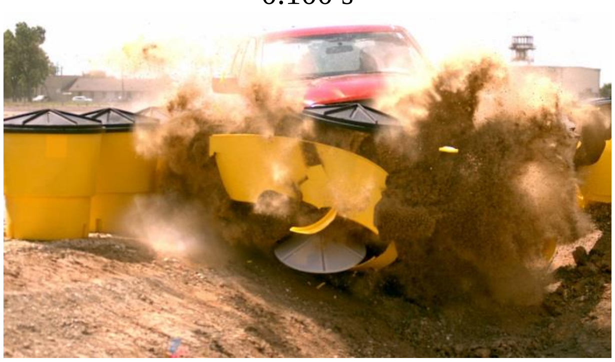


0.700 s


Figure D.1. Sequential Photographs for Test No. 490026-3-1 (Overhead and Perpendicular Views) (Continued).

0.000 s

0.100 s



0.200 s

0.300 s

0.400 s

0.500 s

0.600 s

0.700 s

Figure D.2. Sequential Photographs for Test No. 490026-3-1 (Frontal View).

D.3 VEHICLE ANGULAR DISPLACEMENT

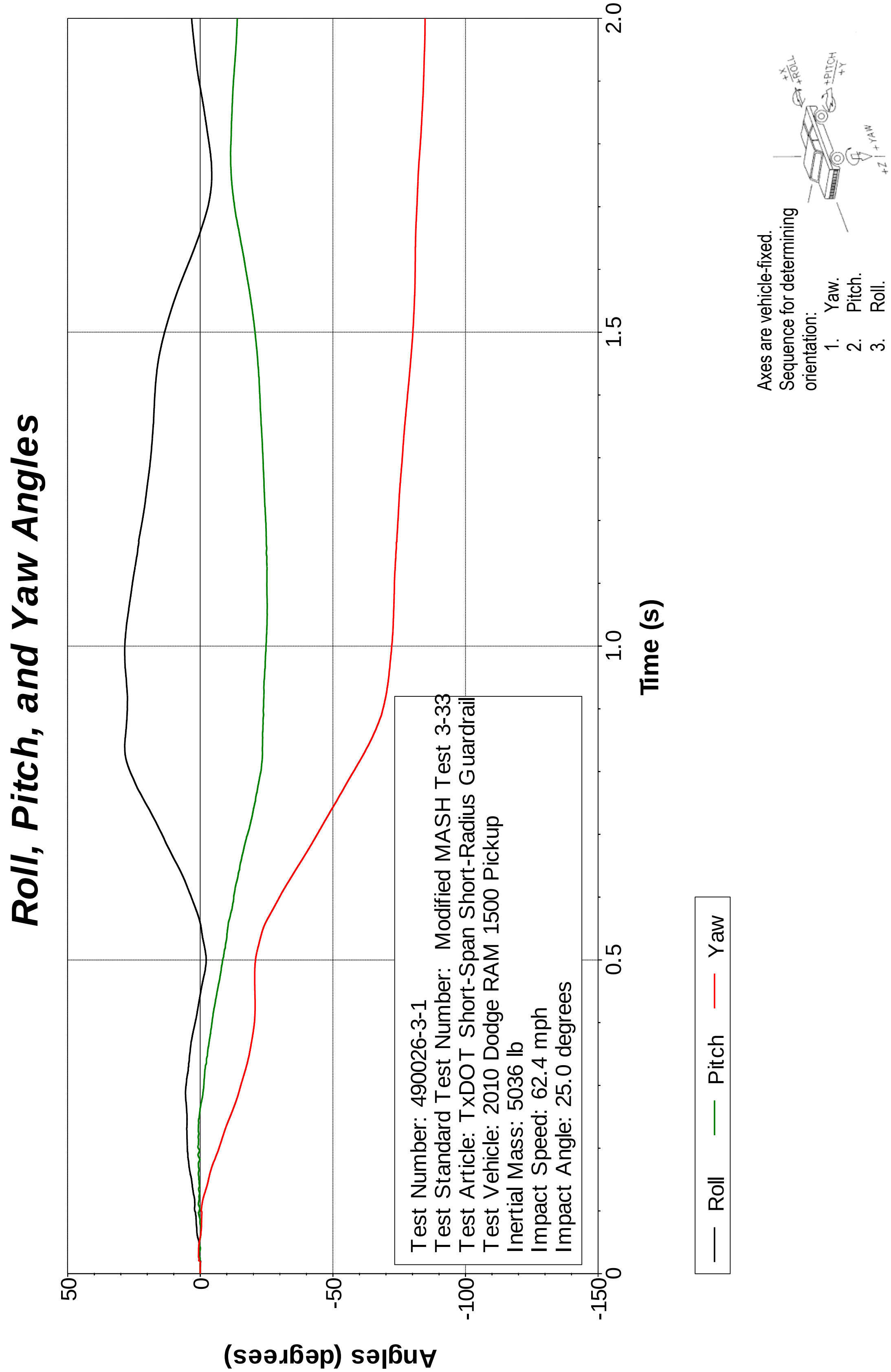


Figure D.3. Vehicle Angular Displacements for Test No. 490026-3-1.

D.4 VEHICLE ACCELERATIONS

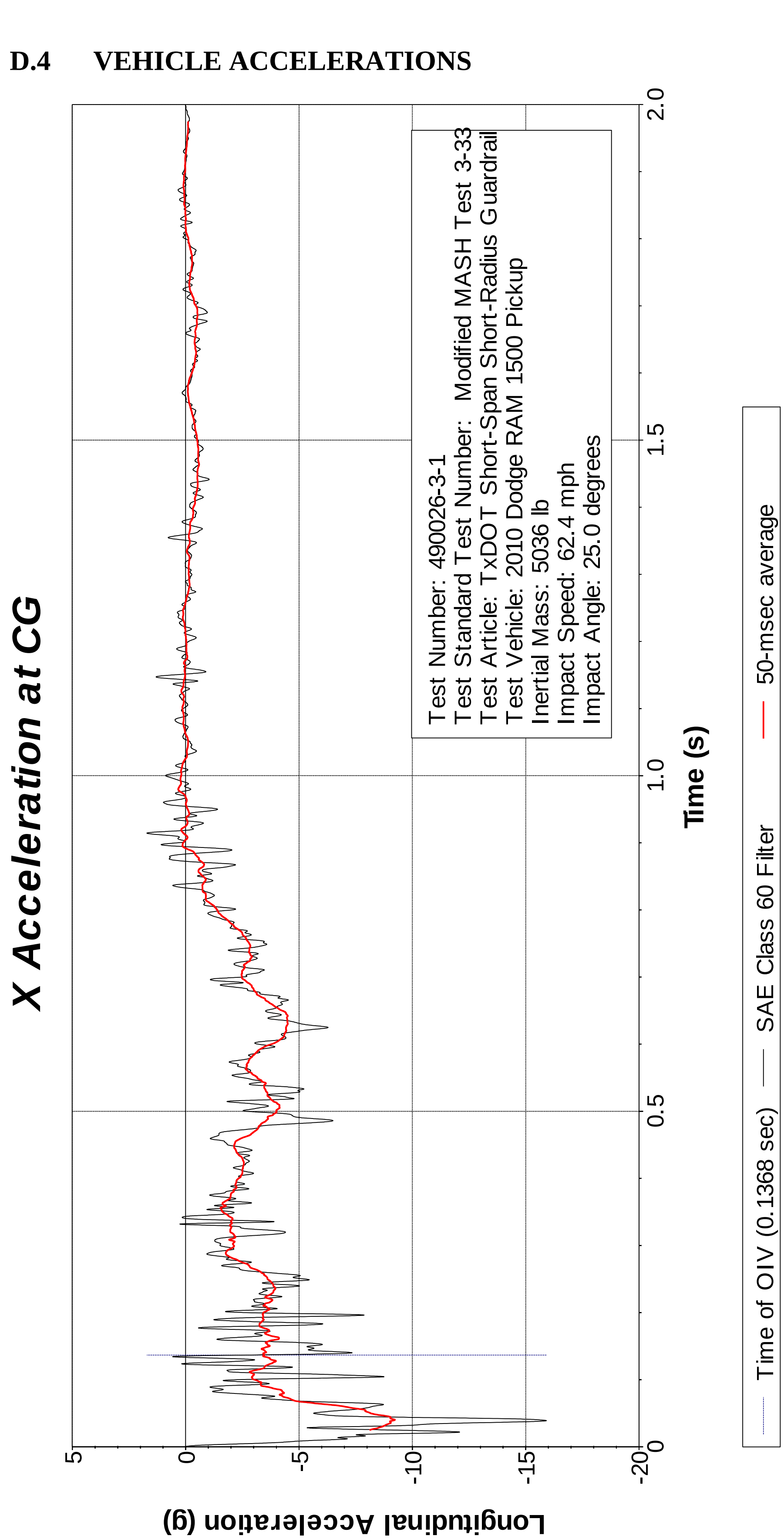


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 490026-3-1 (Accelerometer Located at Center of Gravity).

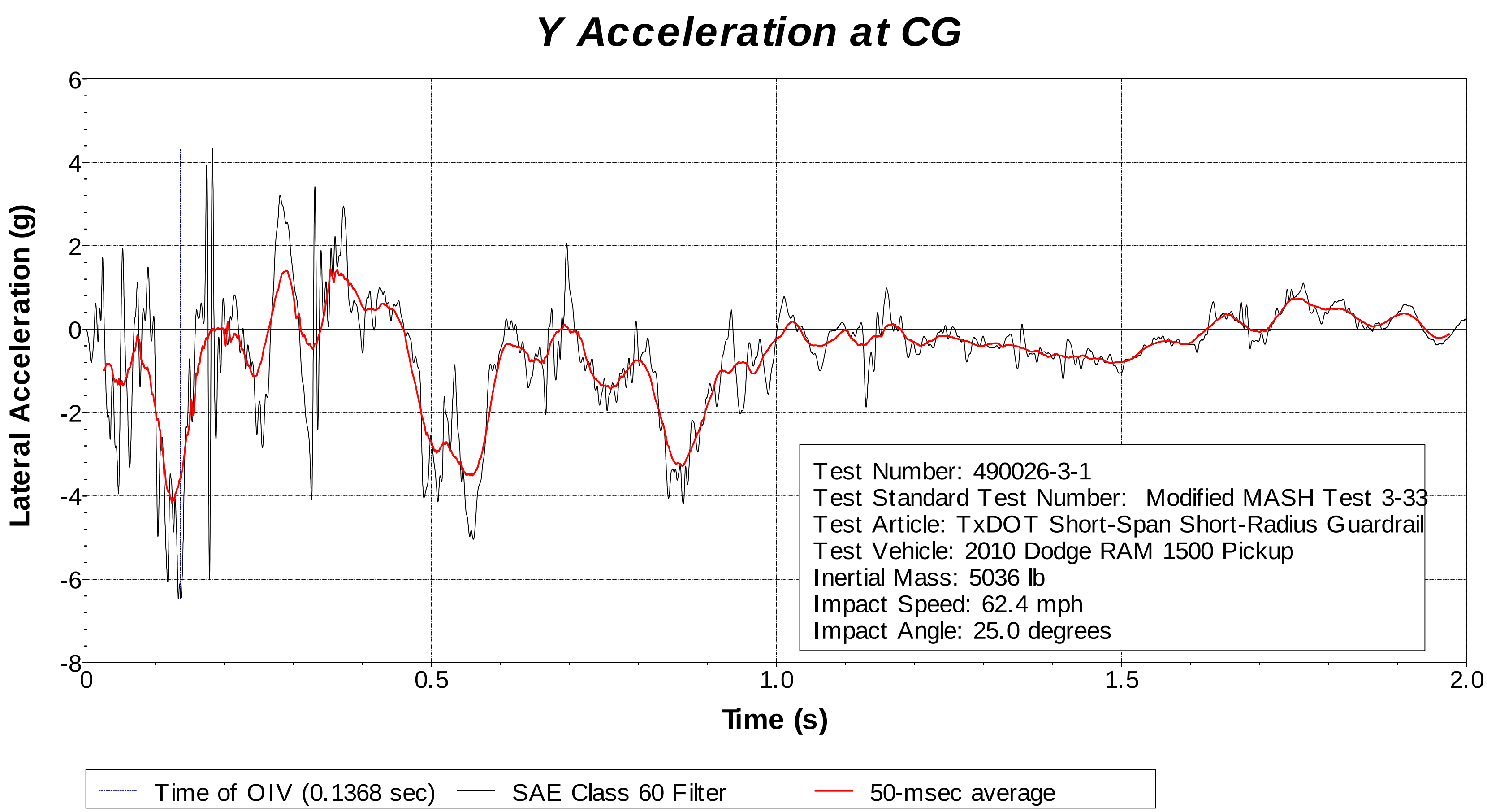


Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 490026-3-1 (Accelerometer Located at Center of Gravity).

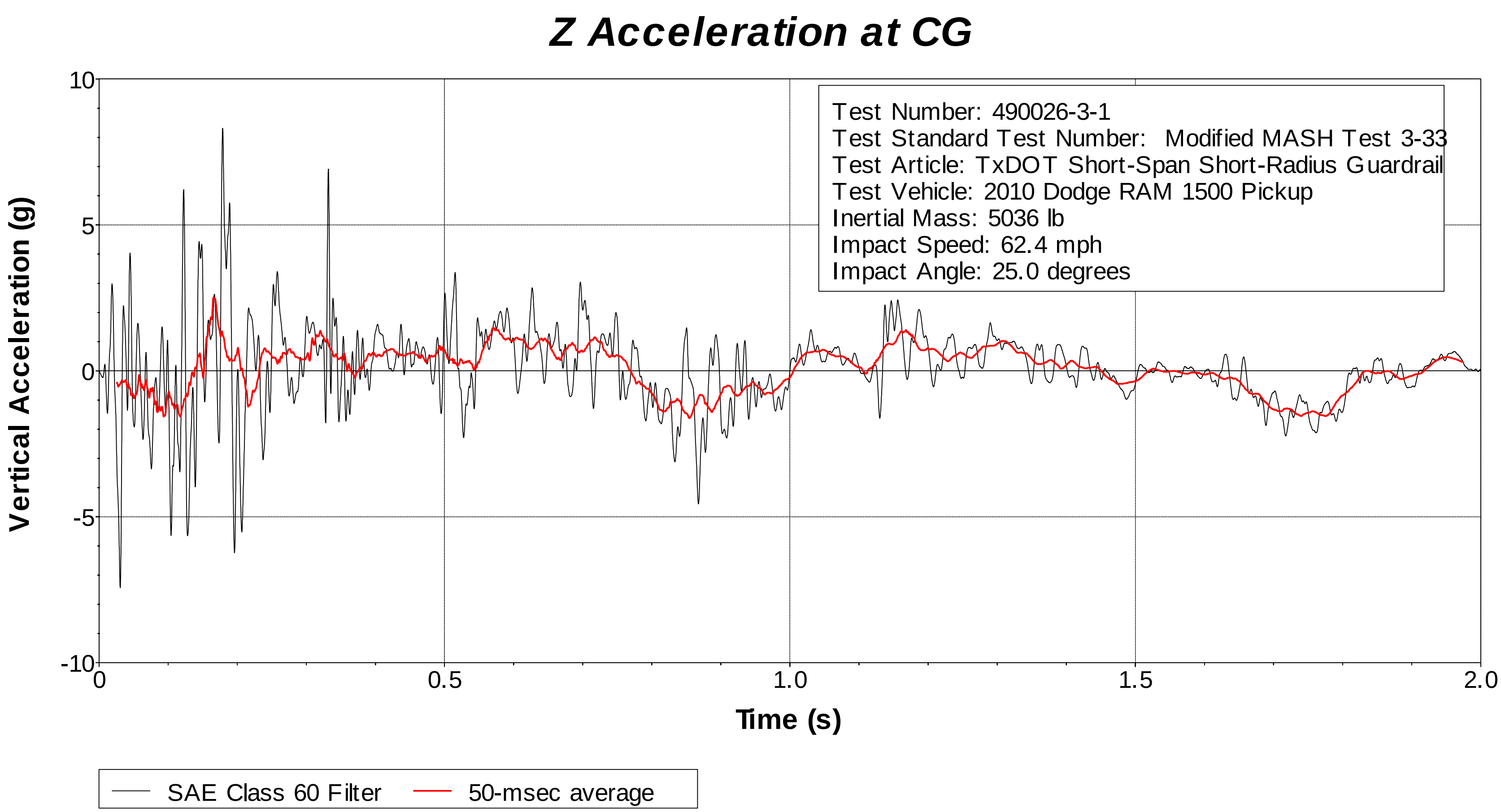


Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 490026-3-1 (Accelerometer Located at Center of Gravity).

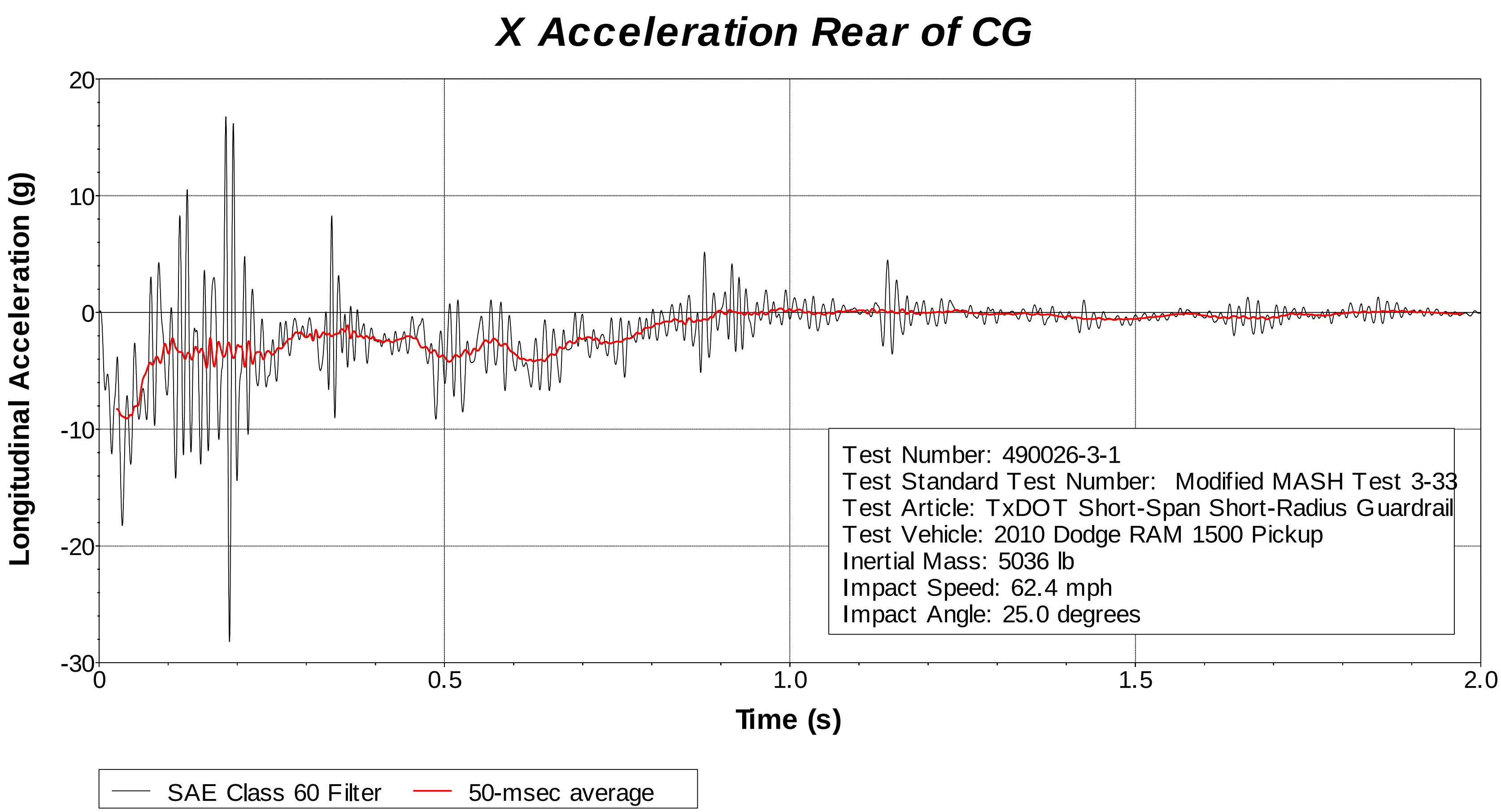


Figure D.7. Vehicle Longitudinal Accelerometer Trace for Test No. 490026-3-1 (Accelerometer Located Rear of Center of Gravity).

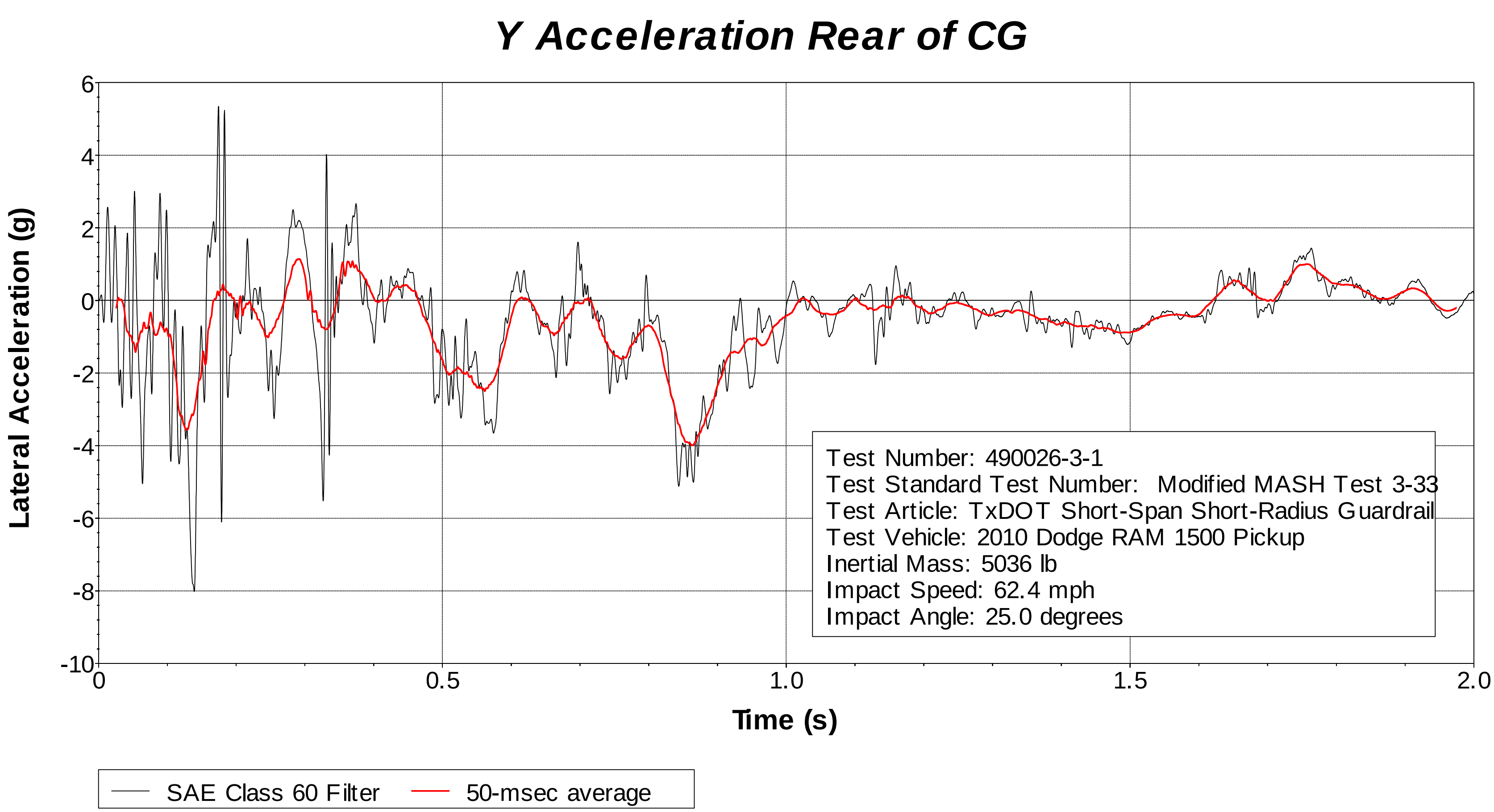


Figure D.8. Vehicle Lateral Accelerometer Trace for Test No. 490026-3-1 (Accelerometer Located Rear of Center of Gravity).

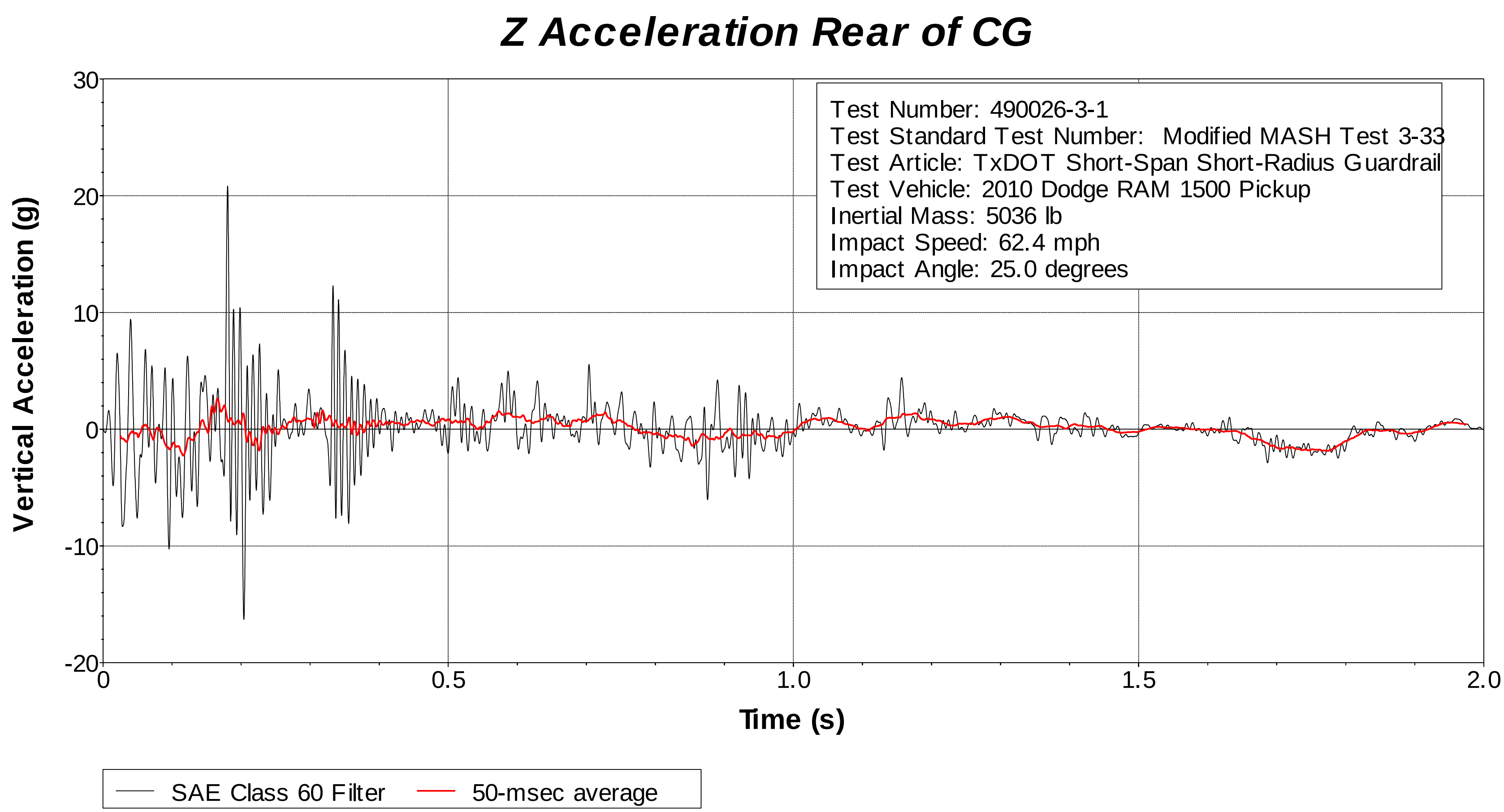


Figure D.9. Vehicle Vertical Accelerometer Trace for Test No. 490026-3-1 (Accelerometer Located Rear of Center of Gravity).

APPENDIX E: MODIFIED *MASH* TEST 3-32
(CRASH TEST NO. 490026-3-2)

E.1 VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 490026-3-2.

Date: 2016-08-11 Test No.: 490026-3-2 VIN No.: KNADHYA388691819

Year: 2011 Make: Kia Model: Rio

Tire Inflation Pressure: 32 psi Odometer: 101224 Tire Size: 185/65R14

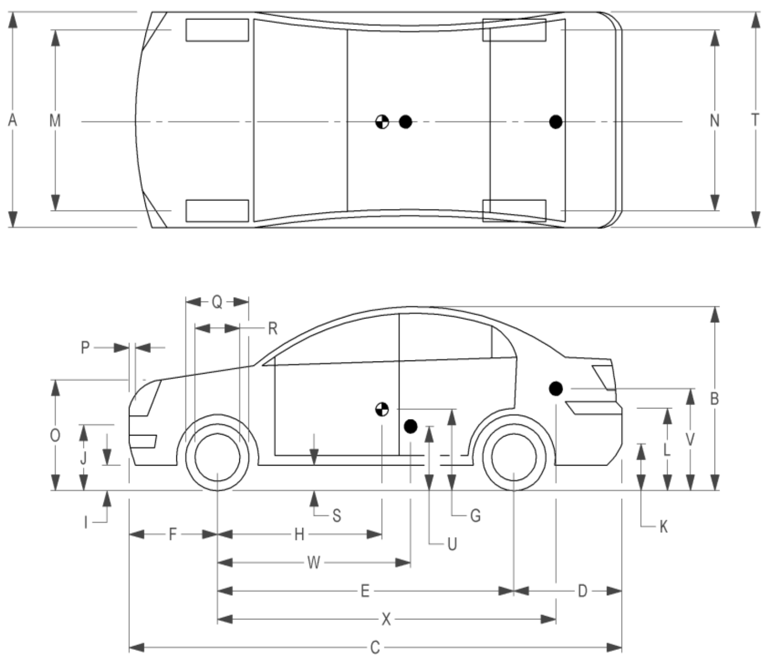
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None

Engine Type: 4 cylinder
Engine CID: 1.6 liter
Transmission Type:
x Auto or ____ Manual
x FWD ____ RWD ____ 4WD
Optional Equipment:
None

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



Geometry: inches

A	66.38	F	33.00	K	11.75	P	4.10	U	14.25
B	57.25	G	----	L	25.50	Q	22.50	V	21.25
C	165.75	H	35.67	M	57.75	R	15.50	W	35.40
D	34.00	I	8.00	N	57.10	S	7.50	X	105.90
E	98.75	J	21.25	O	28.25	T	66.20		
Wheel Center Ht Front			11.00	Wheel Center Ht Rear			11.00	W-H	0

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1918	M_{front}	1586	1567	1652
Back	1874	M_{rear}	888	886	966
Total	3638	M_{Total}	2474	2453	2618

Allowable TIM = 2420 lb ±55 lb | Allowable GSM = 2585 lb ± 55 lb

Mass Distribution:
lb LF: 775 RF: 792 LR: 435 RR: 451

Table E.2. Exterior Crush Measurements of Vehicle for Test No. 490026-3-2.

Date: 2016-08-11 Test No.: 490026-3-2 VIN No.: KNADHYA388691819

Year: 2011 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 Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bumper ht	48	10	48	7	8.5	10	8	7	6.5	0
	Measurements recorded										
	in inches										

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

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline) 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).

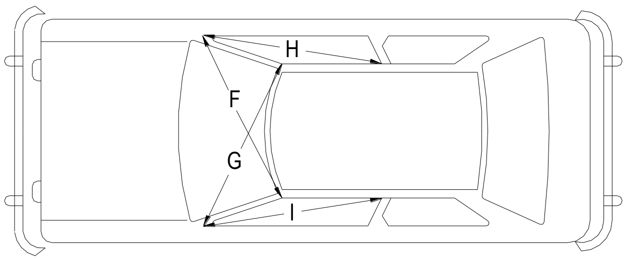
***Measure and document on the vehicle diagram the location of the maximum crush.

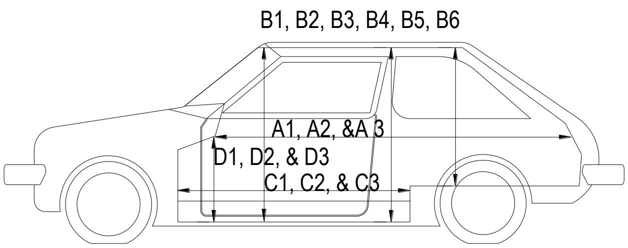
Note: Use as many lines/columns as necessary to describe each damage profile.

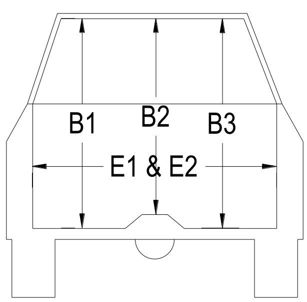
Table E.3. Occupant Compartment Measurements of Vehicle for Test No. 490026-3-2.

Date: 2016-08-11 Test No.: 490026-3-2 VIN No.: KNADHYA388691819

Year: 2011 Make: Kia Model: Rio





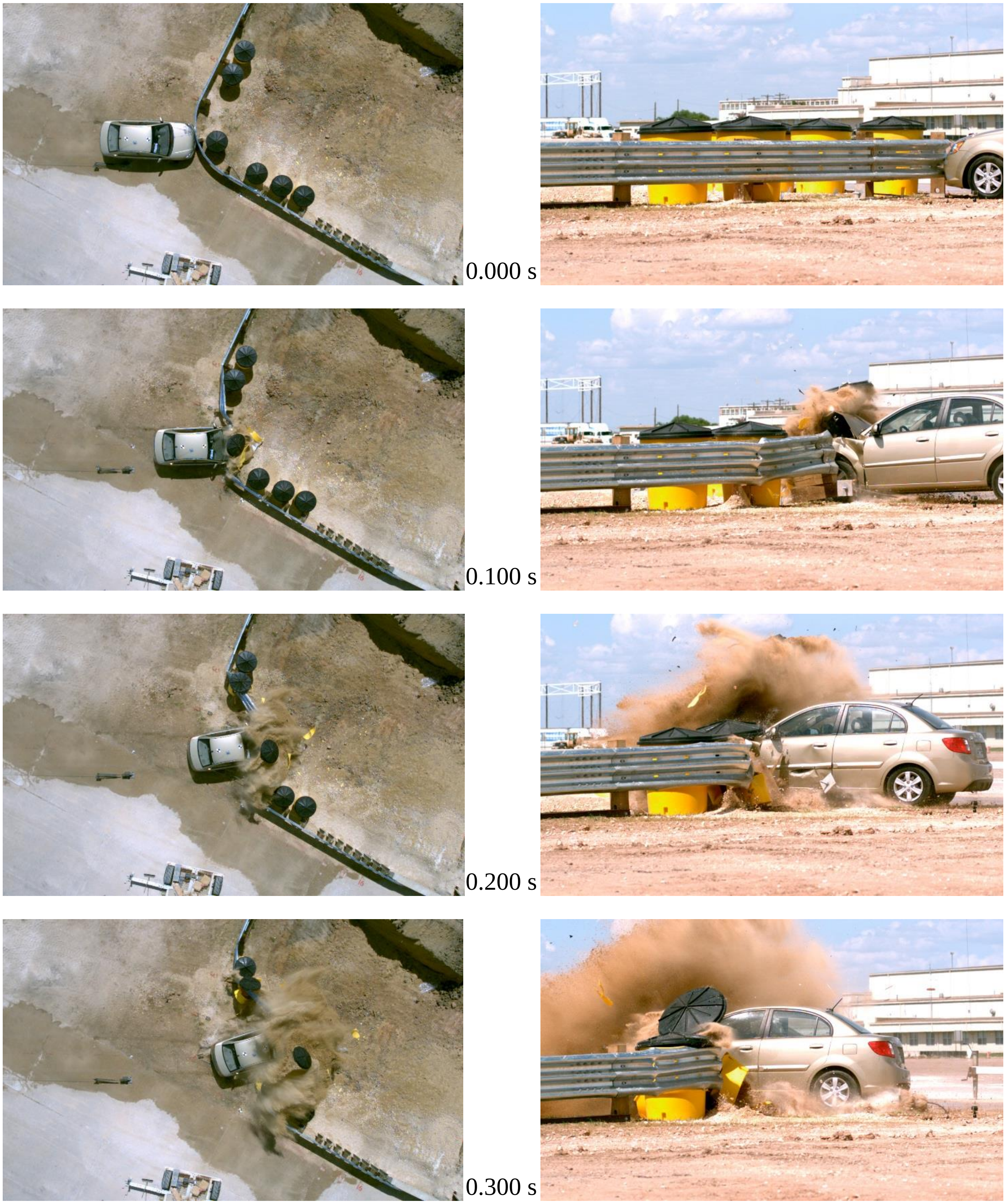


OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	**After** (inches)
A1	67.50	67.50
A2	67.00	67.00
A3	67.50	67.50
B1	40.25	40.25
B2	36.50	36.50
B3	40.25	40.25
B4	36.00	36.00
B5	35.75	35.75
B6	36.00	36.00
C1	25.50	25.50
C2	-----	-----
C3	25.50	25.50
D1	25.50	25.50
D2	-----	-----
D3	9.50	9.50
E1	51.50	51.50
E2	51.10	51.10
F	51.00	51.00
G	51.00	51.00
H	36.75	36.75
I	36.75	36.75
J*	51.00	51.00

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

E.2 SEQUENTIAL PHOTOGRAPHS



0.000 s

0.100 s

0.200 s

0.300 s

Figure E.1. Sequential Photographs for Test No. 490026-3-2 (Overhead and Left Perpendicular Views).

0.400 s

0.500 s

0.600 s

0.700 s

Figure E.1. Sequential Photographs for Test No. 490026-3-2 (Overhead and Left Perpendicular Views) (Continued).

0.000 s

0.100 s

0.200 s

0.300 s

0.400 s

0.500 s

0.600 s

0.700 s

Figure E.2. Sequential Photographs for Test No. 490026-3-2 (Right Perpendicular View).

E.3 VEHICLE ANGULAR DISPLACEMENT

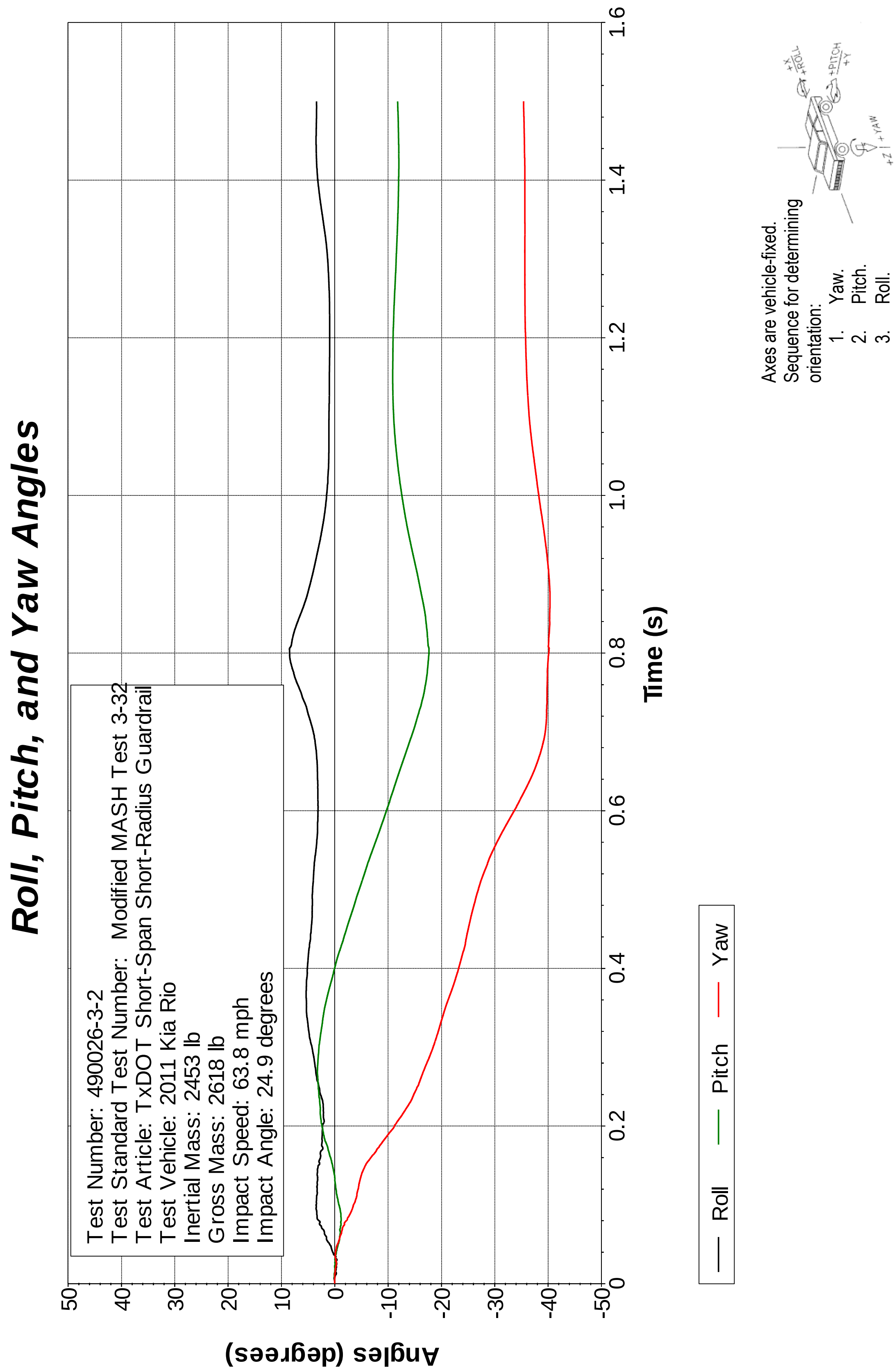


Figure E.3. Vehicle Angular Displacements for Test No. 490026-3-2.

E.4 VEHICLE ACCELERATIONS

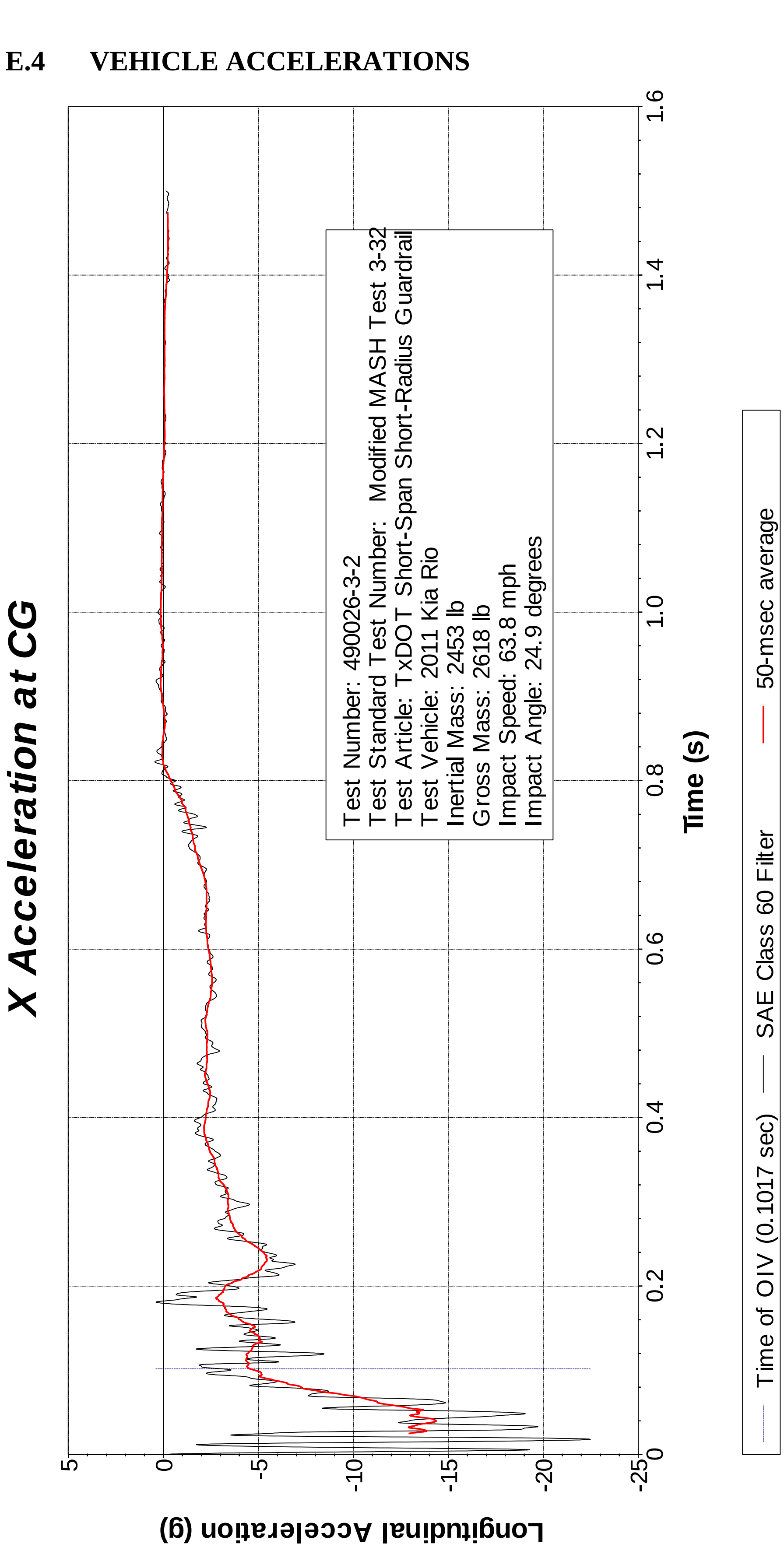


Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 490026-3-2 (Accelerometer Located at Center of Gravity).

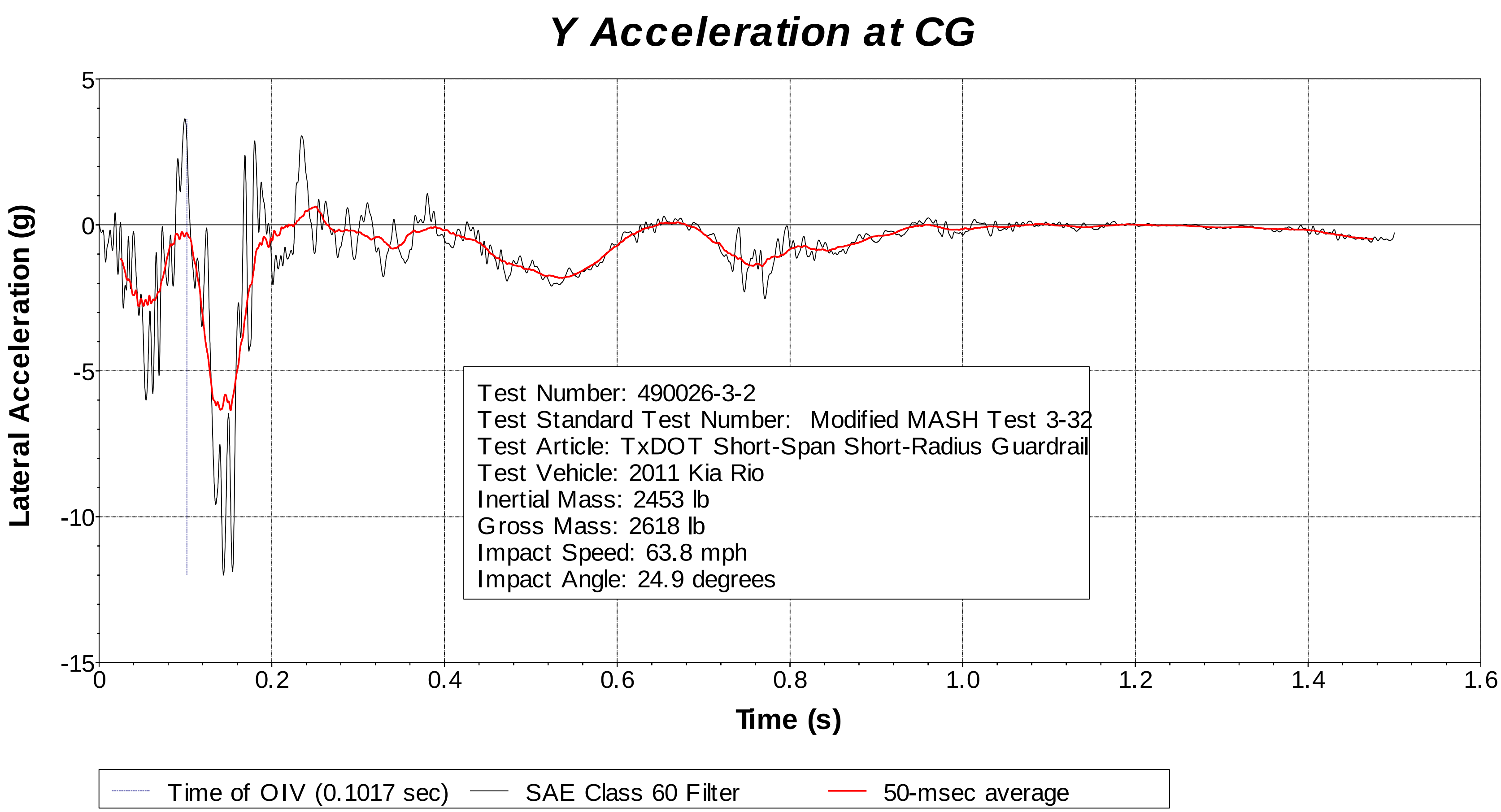


Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 490026-3-2 (Accelerometer Located at Center of Gravity).

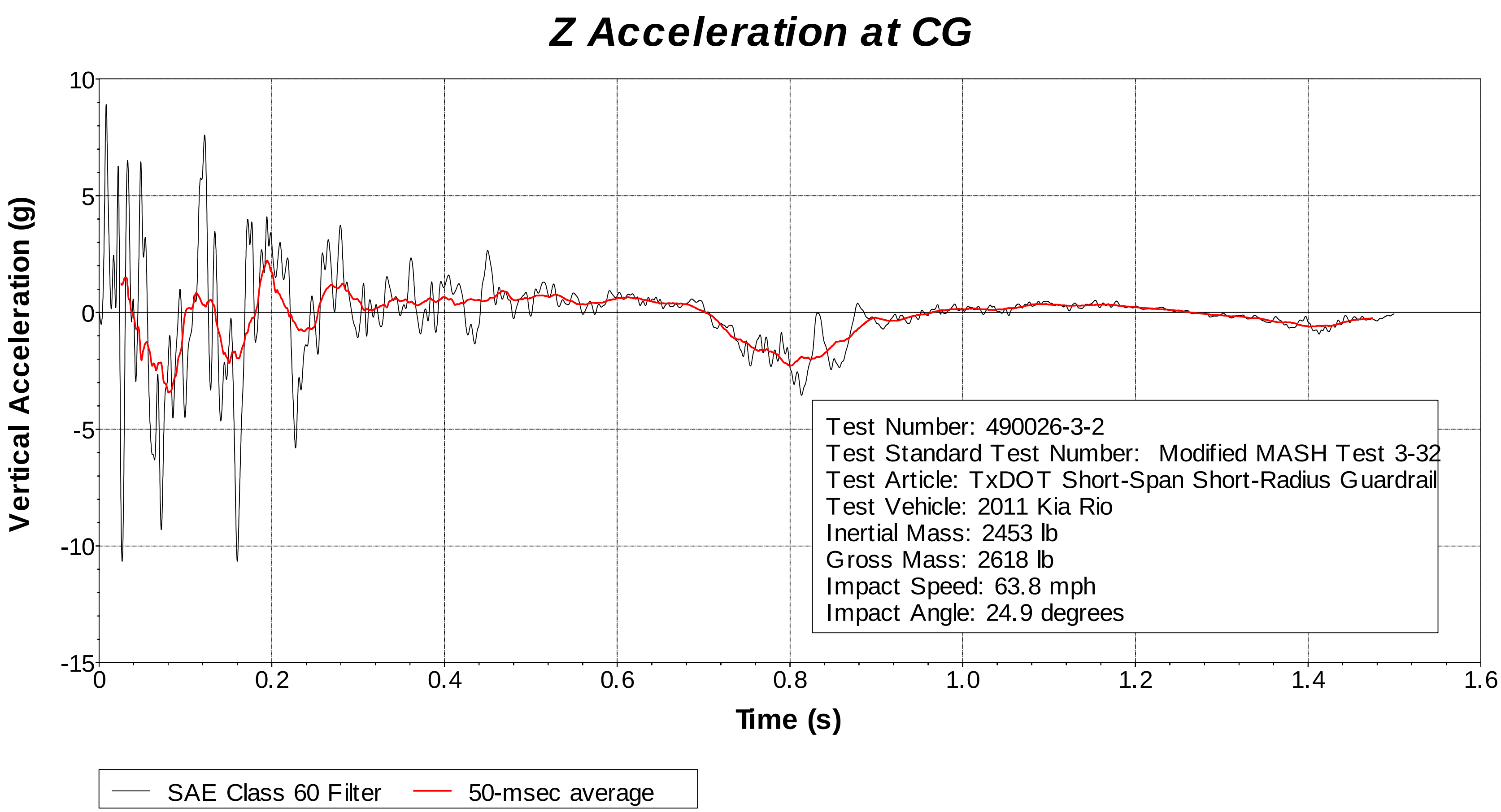


Figure E.6. Vehicle Vertical Accelerometer Trace for Test No. 490026-3-2 (Accelerometer Located at Center of Gravity).

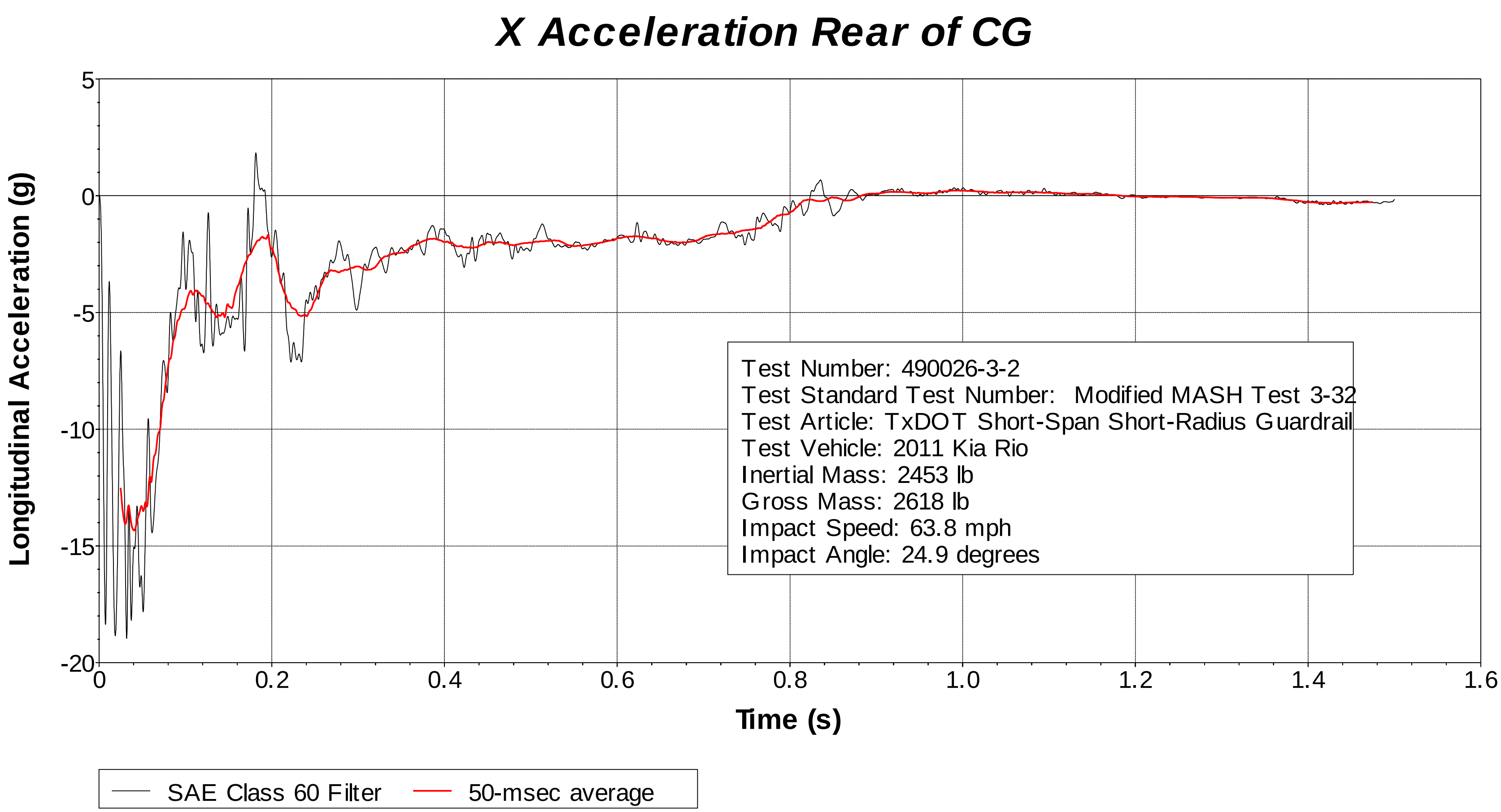


Figure E.7. Vehicle Longitudinal Accelerometer Trace for Test No. 490026-3-2 (Accelerometer Located Rear of Center of Gravity).

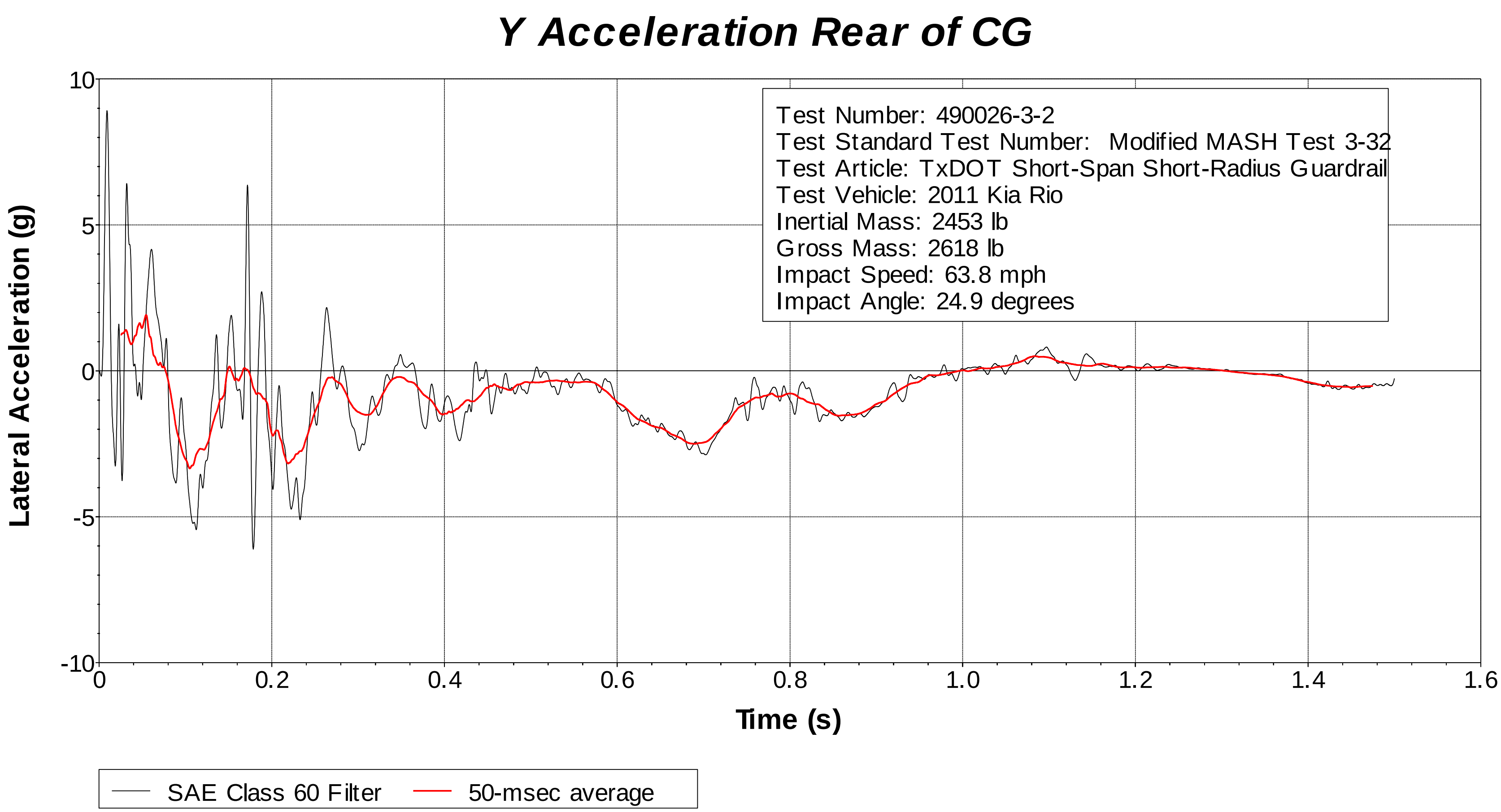


Figure E.8. Vehicle Lateral Accelerometer Trace for Test No. 490026-3-2 (Accelerometer Located Rear of Center of Gravity).

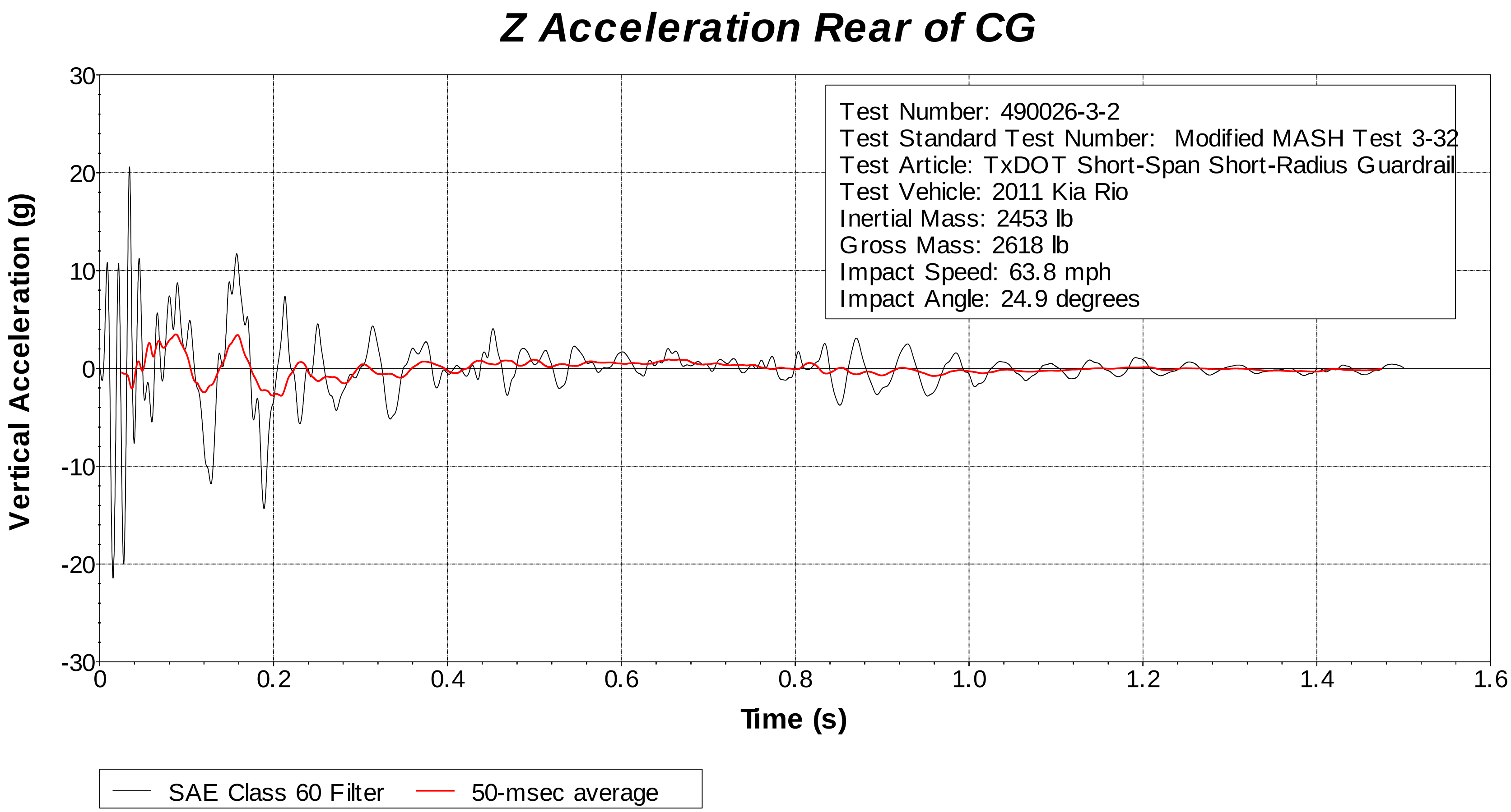


Figure E.9. Vehicle Vertical Accelerometer Trace for Test No. 490026-3-2 (Accelerometer Located Rear of Center of Gravity).