CRASH TEST AND *MASH* TL-3 EVALUATION OF THE TxDOT SHORT RADIUS GUARDRAIL

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3100 SH 47, Building 7091
Bryan, TX 77807

Test Report No. 0-6711-1

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16. Abstract

When a roadway intersects a highway with restrictive features such as a bridge rail and canal, it becomes difficult to fit a guardrail with the proper length, transitions, and end treatment along the highway. Possible solutions include relocating the constraint blocking the placement of the guardrail, shortening the designed guardrail length, or designing a curved guardrail.

Curved, or short radius, guardrails typically present the most viable solution for these areas. However, no previously designed short radius guardrails meet National Cooperative Highway Research Program (NCHRP) *Report 350* Test Level 3 (TL-3) guidelines. Now, the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) has updated crash testing criteria. The new guidelines supersede *NCHRP Report 350* and increased the size of test vehicles and changed the test matrices to include more impact conditions. Therefore, meeting new impact standards for short radius guardrails has become more challenging.

TTI researchers investigated, modeled, and simulated an optimized short radius design under this project. Subsequently, TTI researchers crash tested this system successfully to *MASH* 3-33, 3-32, 3-31, and 3-35 test conditions. This innovative design utilizes an energy dissipation component plus a cable anchor that provides tension capacity to the rail section on the primary roadway, though an anchor BCT post on the secondary road portion of the system. These new innovative design details made the system very effective in capturing the vehicles in short distances while using readily available components.

17. Key Words
Short Radius, Crash Testing, Roadside Safety. T-Intersections, Curved Rail, Guardrails, Simulation, Finite Element, Longitudinal Barrier, Bridge Rail, Canal, Crash Testing, Roadside Safety.

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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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CHAPTER 1. INTRODUCTION

1.1. INTRODUCTION

When a roadway intersects a highway with restrictive features such as a bridge rail and canal, it becomes difficult to fit a guardrail with the proper length, transitions, and end treatment along the highway. Possible solutions include relocating the constraint, blocking the placement of the guardrail, shortening the designed guardrail length, or designing a curved guardrail.

Curved or short radius, guardrails typically present the most viable solution for these areas. However, no previously designed short radius guardrails meet National Cooperative Highway Research Program (NCHRP) *Report 350* Test Level 3 (TL-3) guidelines (*1*). Now, the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) has updated crash testing criteria (*2*). The new guidelines supersede *NCHRP Report 350* by increasing the size of test vehicles and changing the test matrices to include more impact conditions. Therefore, meeting new impact standards for short radius guardrails will be more challenging.

1.2. OBJECTIVES/SCOPE OF RESEARCH

The literature review sought to aid researchers in developing new design concepts for short radius guardrails. The review outlines challenges encountered by previous designs, promising design features of previous designs, the *MASH* TL-3 impact criteria, and short radius guardrail concepts.

1.3. LITERATURE REVIEW

1.3.1. Summary of Previous Crash Tests

Southwest Research Institute (SwRI) performed the first documented full-scale crash tests on short radius systems in 1989 (*3*). SwRI designed and tested a system in Yuma County, Arizona, which met the requirements of *NCHRP Report 230* service level PL1 (*4*). In 1992, Texas A&M Transportation Institute (TTI) tested a W-beam system (*5*) followed by a thrie beam system in 1994 (*6*). From 2000 to 2008, Midwest Roadside Safety Facility (MwRSF) tested several prototype short radius guardrails (*7, 8, 9*) according to *NCHRP Report No. 350* TL-3 guidelines. A summary of documented crash tests on short radius guardrails is given below.

1.3.1.1. Southwest Research Institute for Yuma County, Arizona: 1989

1.3.1.1.1. Design Considerations

The short radius guardrail used for these tests consists of an 8-ft radius curved section connected to an 18-ft straight section on the primary road and a 12.5-ft straight section on the secondary road. The primary side connects to a bridge rail while the secondary side ends with a modified breakaway cable terminal (BCT). The primary side consists of six control release terminal (CRT) posts, while the secondary side has one CRT post and one BCT post. The curved section has one CRT post at the centerline to support it and two freestanding CRT posts behind it. At the end of the bridge curb, a tapered curb was installed to minimize wheel snag. The guardrail's performance was evaluated according to *NCHRP Report Number 230,* and the tests were conducted based on *AASHTO Guide Specifications for Bridge Railings* (*10*).

1.3.1.1.2. Test YC-1

The purpose of Test YC-1 was to test for vehicle spearing or vaulting caused by the guardrail when a pickup truck impacts the system in line with the bridge rail. The 5376-lb pickup impacted the system at a speed of 45 mph and an angle of 1.4° (refer to Figure 1.1). Figure 1.2 shows that the barrier successfully redirected the vehicle without any contact to the bridge rail. Post 5 was fractured, and posts 6 through 8 were deflected during impact. Only the first post on the primary side was fractured while the second, third, and fourth were displaced. The vehicle was deflected with minimal damage and acceptable values for occupant risk and ridedown acceleration. Therefore, the system was acceptable according to *NCHRP Report 230* guidelines.

1.3.1.1.3. Test YC-2

The purpose of Test YC-2 was to test for vehicle spearing or vaulting caused by the guardrail when a small car impacts the system in line with the bridge rail. The 1978-lb car impacted the system at an impact speed of 50.3 mph and an impact angle of −0.7° (refer to Figure 1.3). Figure 1.4 shows the barrier successfully redirected the vehicle without any contact to the bridge rail. Both the barrier and vehicle experienced minimal damage, and values for occupant risk and ridedown acceleration remained within limits that *NCHRP Report 230* specified. Therefore, the system was acceptable according to *NCHRP Report 230* guidelines.

1.3.1.1.4. Test YC-3

The purpose of Test YC-3 was to determine whether a pickup truck would be contained if it strikes the system at the curved section, which was 12 ft from the edge of the roadway. The 5380-lb truck impacted the rail at an impact speed of 44.8 mph and an impact angle of 19.7° (refer to Figure 1.5). Figure 1.6 shows sequential photographs of the crash test. The centerline post immediately fractured, and the rail deformed inward. The guardrail wrapped around the front and sides of the vehicle as it continued through the system. The end anchorage holding the rail in place fractured, which allowed the vehicle to continue without capture. The test was not successful according to *NCHRP Report 230* because the system failed to contain the vehicle.

1.3.1.1.5. Test YC-4

After analyzing the results of Test YC-3, the guardrail on the secondary side was lengthened by 12.5 ft. This would increase the amount of energy the system could use to stop the vehicle. The purpose of Test YC-4 was to determine whether a pickup truck would be contained if it struck the modified system at the curved section, which was 12 ft from the edge of the roadway. The 5381-lb truck impacted the curved section of the rail at an impact speed of 44.9 mph and an impact angle of 20.1° (refer to Figure 1.7). Figure 1.8 shows sequential photographs of the crash test. The centerline post immediately fractured, and the rail deformed inward. The guardrail wrapped around the front and right side of the vehicle as it continued through the system. The uneven loading caused the vehicle to yaw counterclockwise. The vehicle turned toward the secondary side and stopped without making contact with the bridge railing. The occupant risk factors and decelerations were within the guidelines of *NCHRP Report 230* and the vehicle was successfully contained. Therefore, the system was considered acceptable.

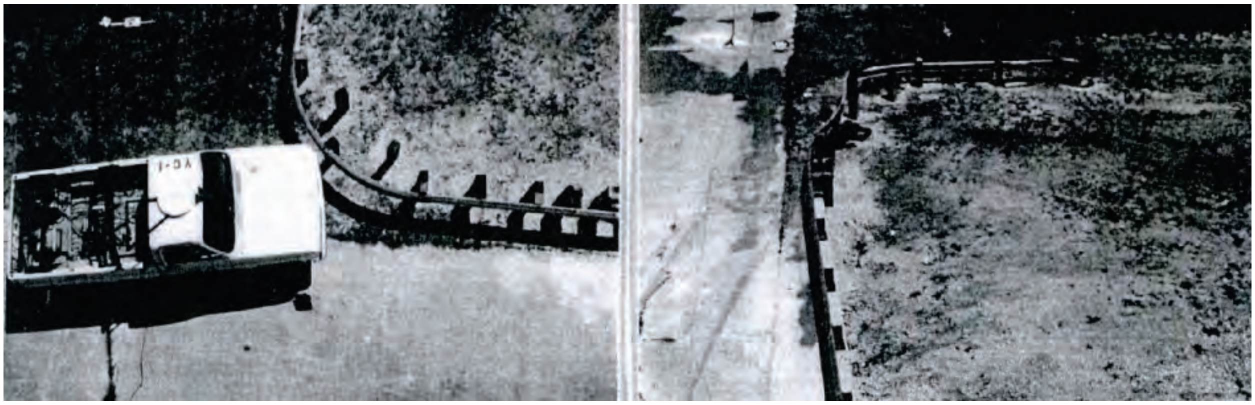

Figure 1.1. Impact Conditions and System Damage for YC-1 (3).

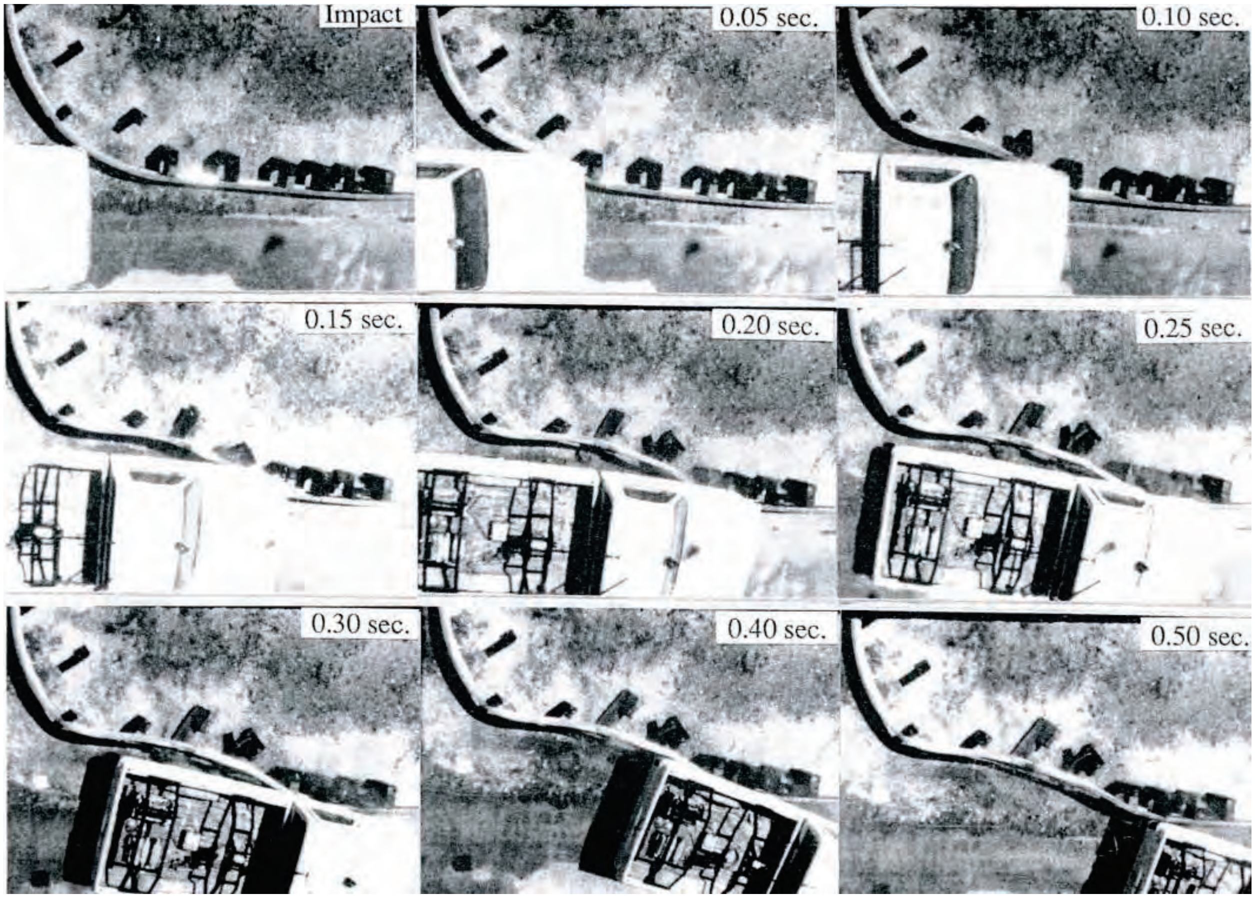

Figure 1.2. Sequential Photographs for YC-1 (3).

Figure 1.3. Impact Conditions and System Damage for YC-2 (*3*).

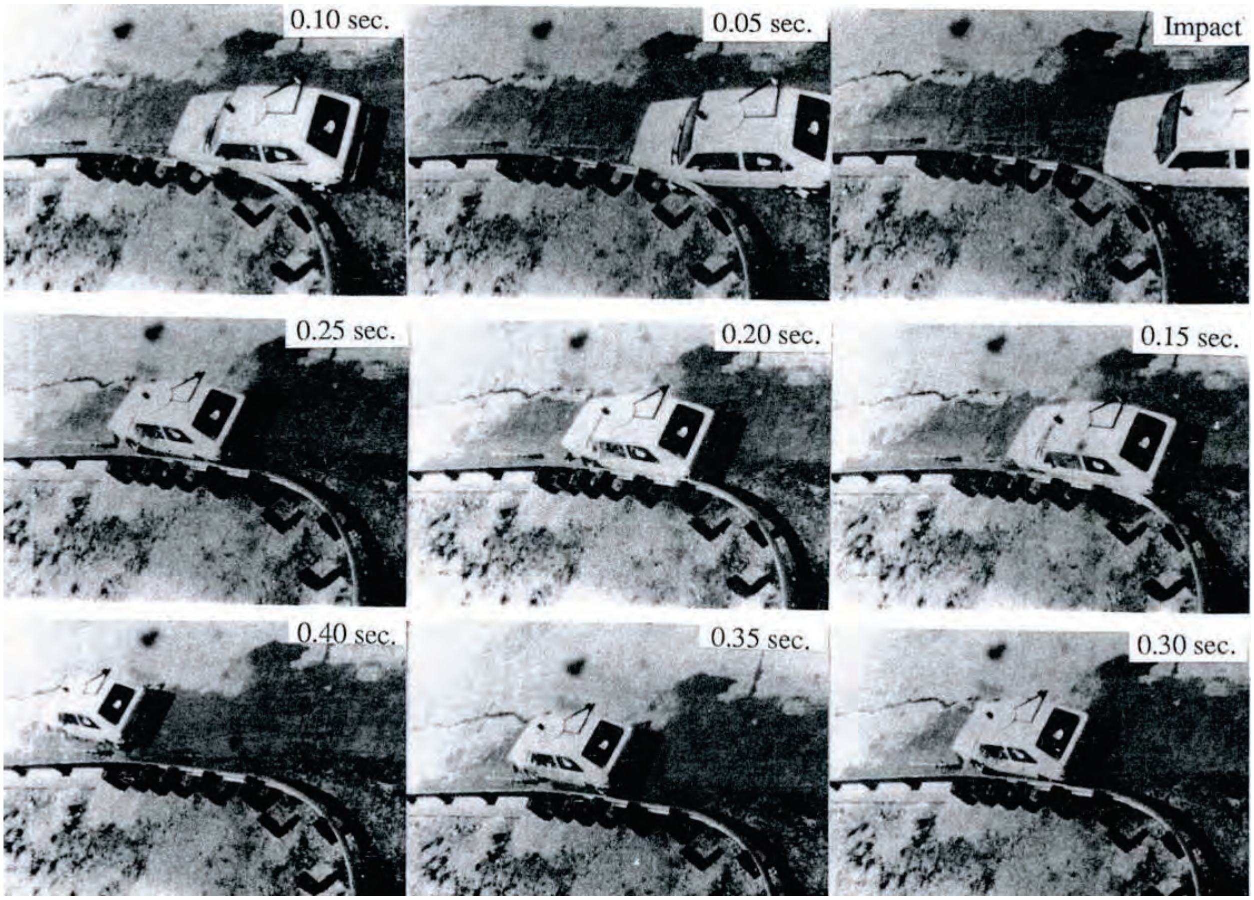

Figure 1.4. Sequential Photographs for YC-2 (*3*).

Figure 1.5. Impact Conditions and System Damage for YC-3 (3).

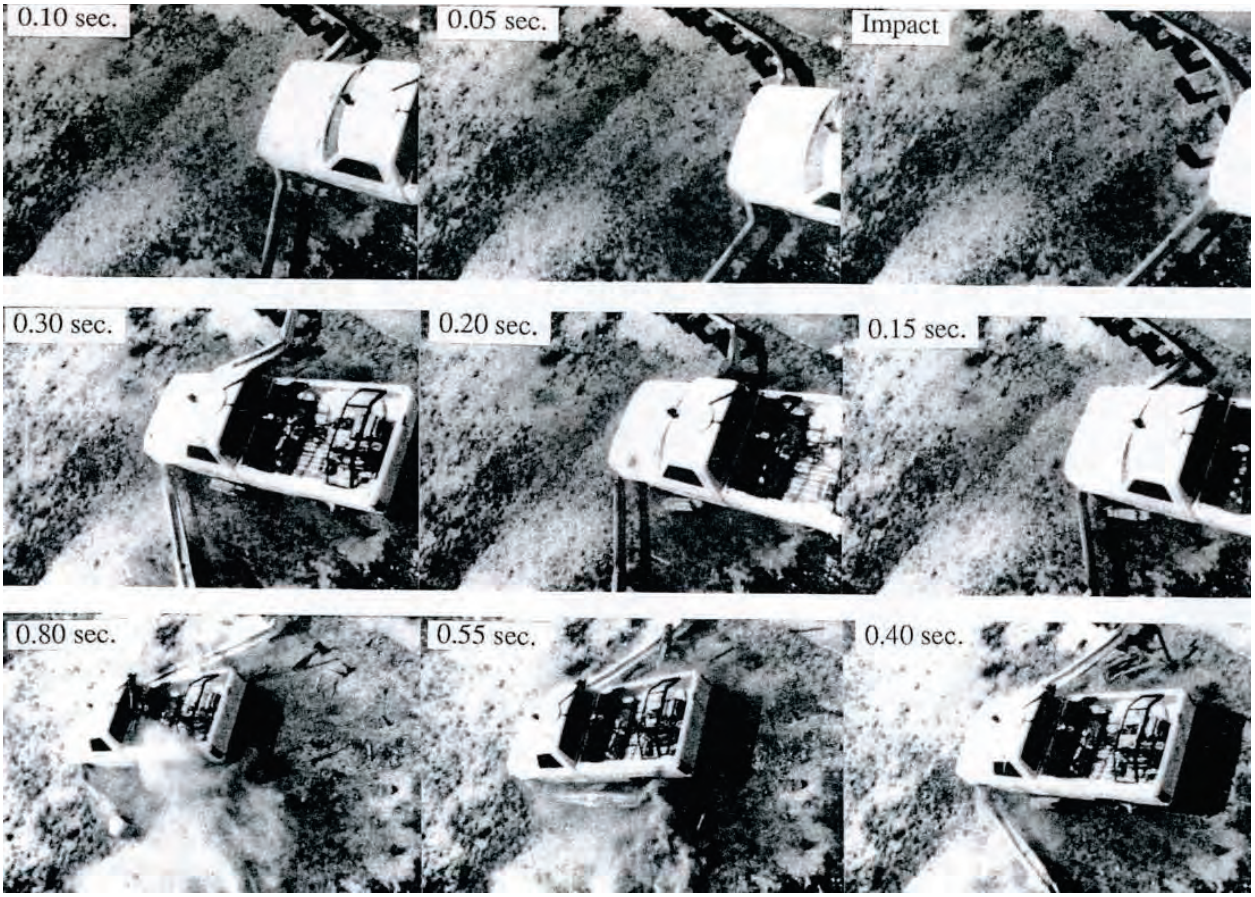

Figure 1.6. Sequential Photographs for YC-3 (3).

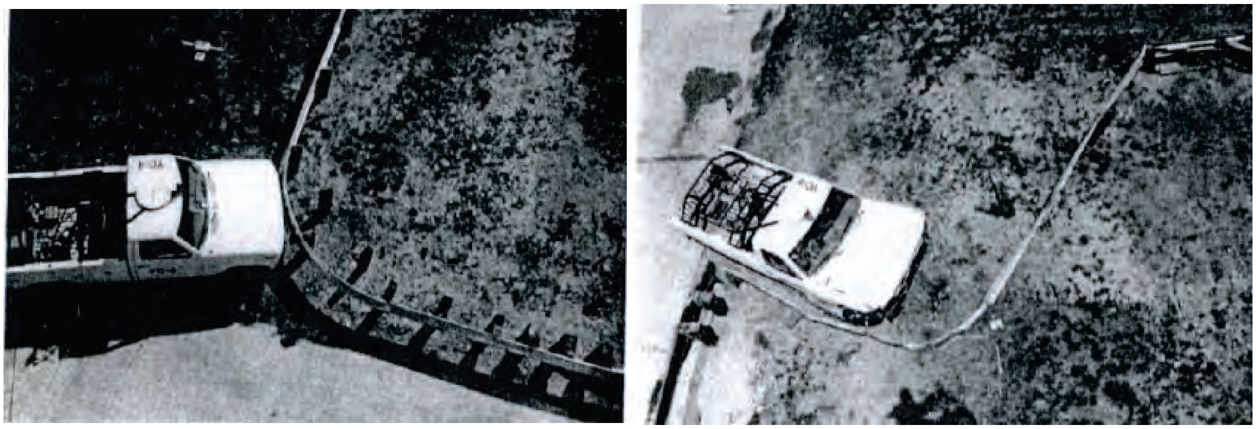

Figure 1.7. Impact Conditions and System Damage for YC-4 (*3*).

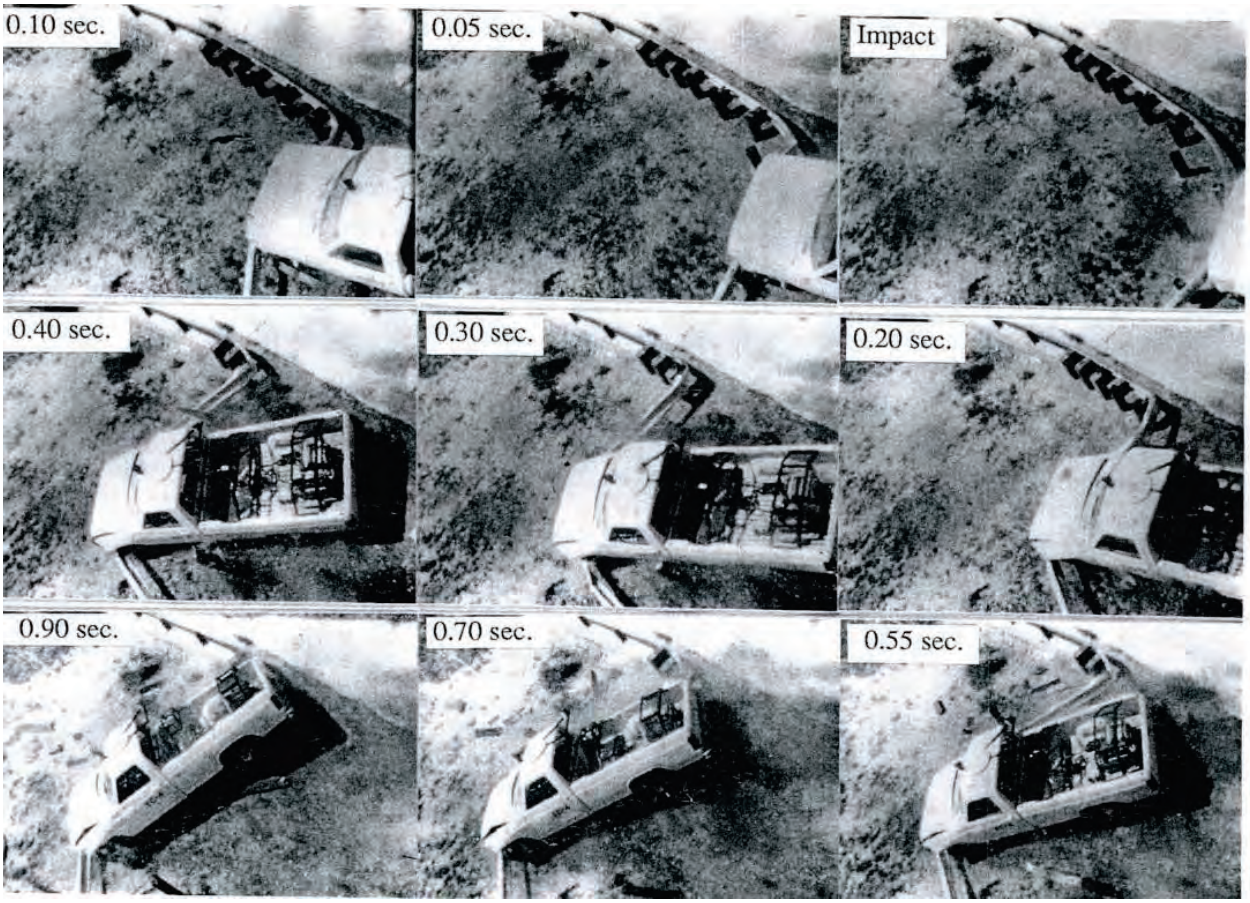

Figure 1.8. Sequential Photographs for YC-4 (*3*).

1.3.1.1.6. Test YC-5

The purpose of Test YC-5 was to determine whether a small car would be contained if it strikes the modified system at the curved section that was 12 ft from the roadway. The 1980-lb vehicle impacted the curved section of the rail at an impact speed of 44.2 mph and an impact angle of 20° (refer to Figure 1.9). Figure 1.10 shows the guardrail deformed, fracturing four posts on the primary side along with the centerline post and both freestanding posts. The vehicle maintained a constant trajectory, and stopped 12 ft past the impact position. The test was successful according to *NCHRP Report 230* because the vehicle was contained with safe values for occupant impact velocities (OIV) and ridedown accelerations (RDA).

1.3.1.1.7. Test YC-6

The purpose of Test YC-6 was to check for wheel snag when a car impacts the system at the transition between the guardrail and bridge rail. The car impacted the system just before the transition from the guardrail to the bridge rail (refer to Figure 1.11). Figure 1.12 shows sequential photos of the crash test. It maintained contact with the system for 13 ft, then was redirected. After the test, tire marks were found on the tapered curb, which indicates that wheel snag occurred. The vehicle was redirected, but the lateral value for OIV was above the recommended limit specified in *NCHRP Report 230*. Therefore, the test indicated marginal performance according to *NCHRP Report 230*.

1.3.1.1.8. Test YC-7

The purpose of Test YC-7 was to check for wheel snag when the pickup truck impacts the system at the transition between the guardrail and bridge rail. The 5424-lb truck impacted the system just before the bridge rail at an impact speed of 45.2 mph and an impact angle of 20.7° (refer to Figure 1.13). Figure 1.14 shows sequential photographs of the crash test. The vehicle maintained contact with the system for 12 ft before being redirected. No evidence of wheel snag was found, no posts were fractured, and the values for OIV and RDA were within acceptable limits. Therefore, Test YC-7 was successful according to *NCHRP Report 230* guidelines.

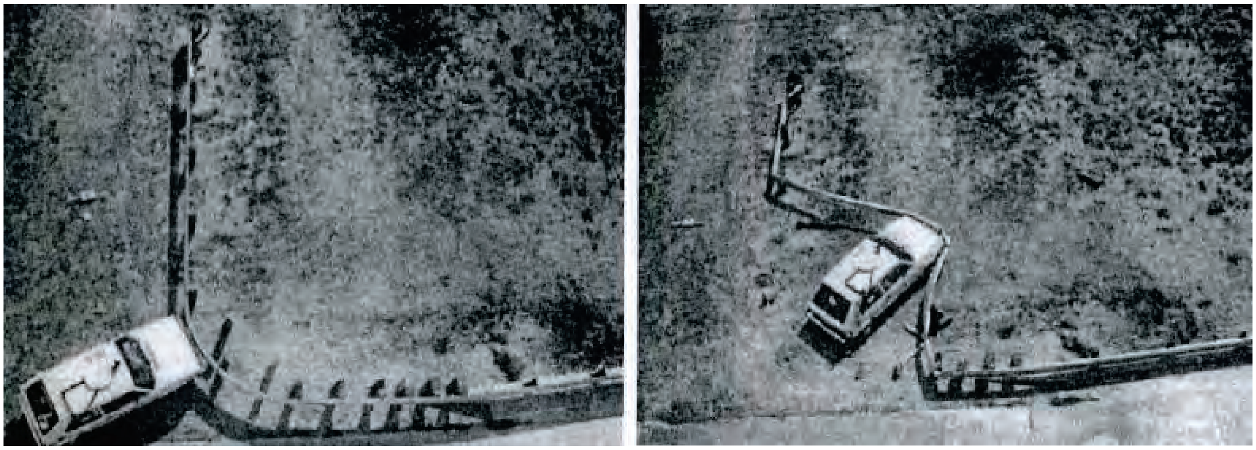

Figure 1.9. Impact Conditions and System Damage for YC-5 (*3*).

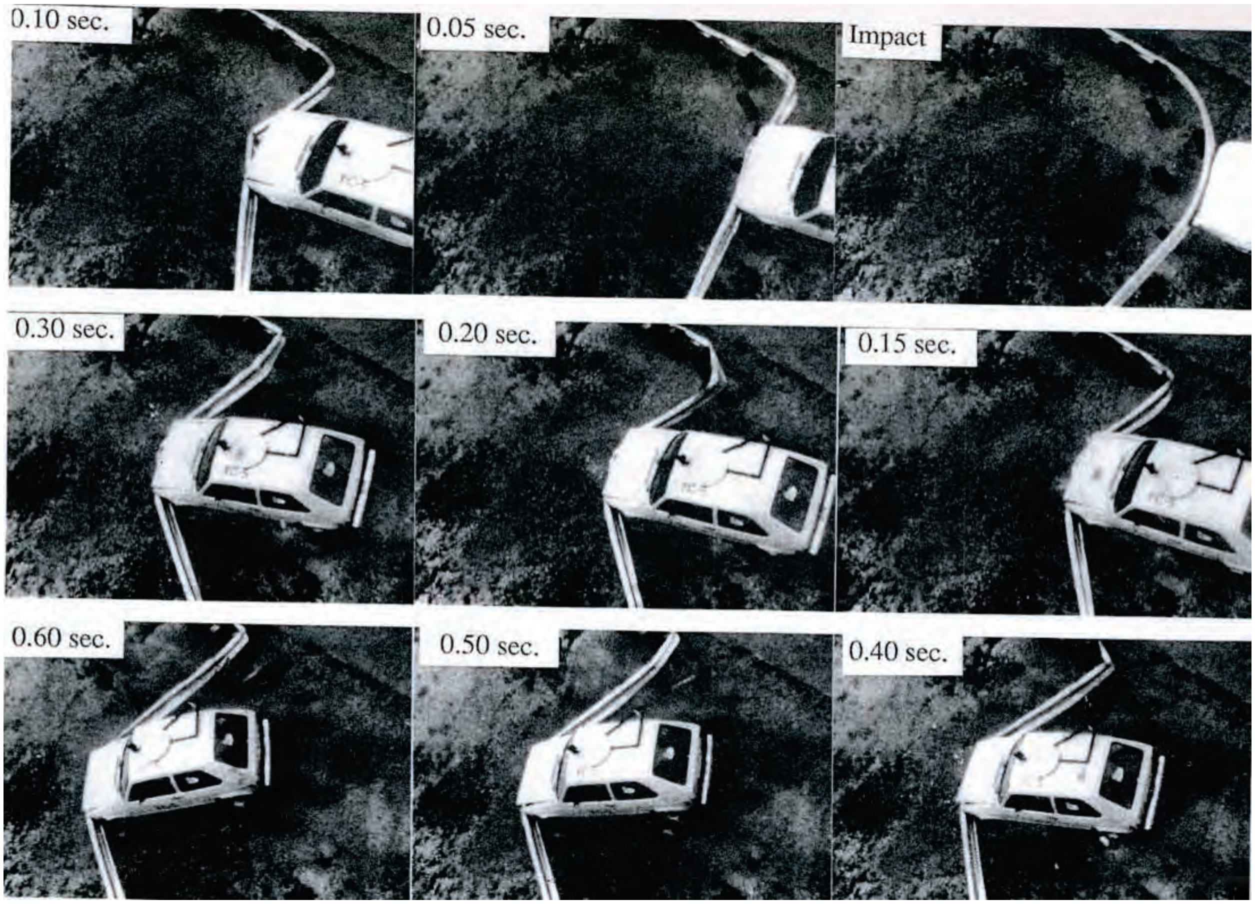

Figure 1.10. Sequential Photographs for YC-5 (*3*).

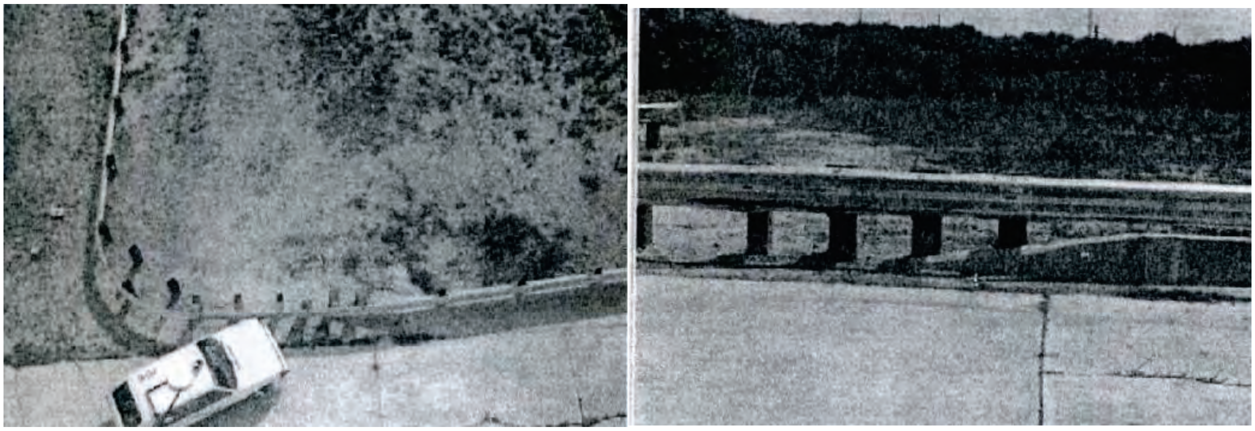

Figure 1.11. Impact Conditions and System Damage for YC-6 (*3*).

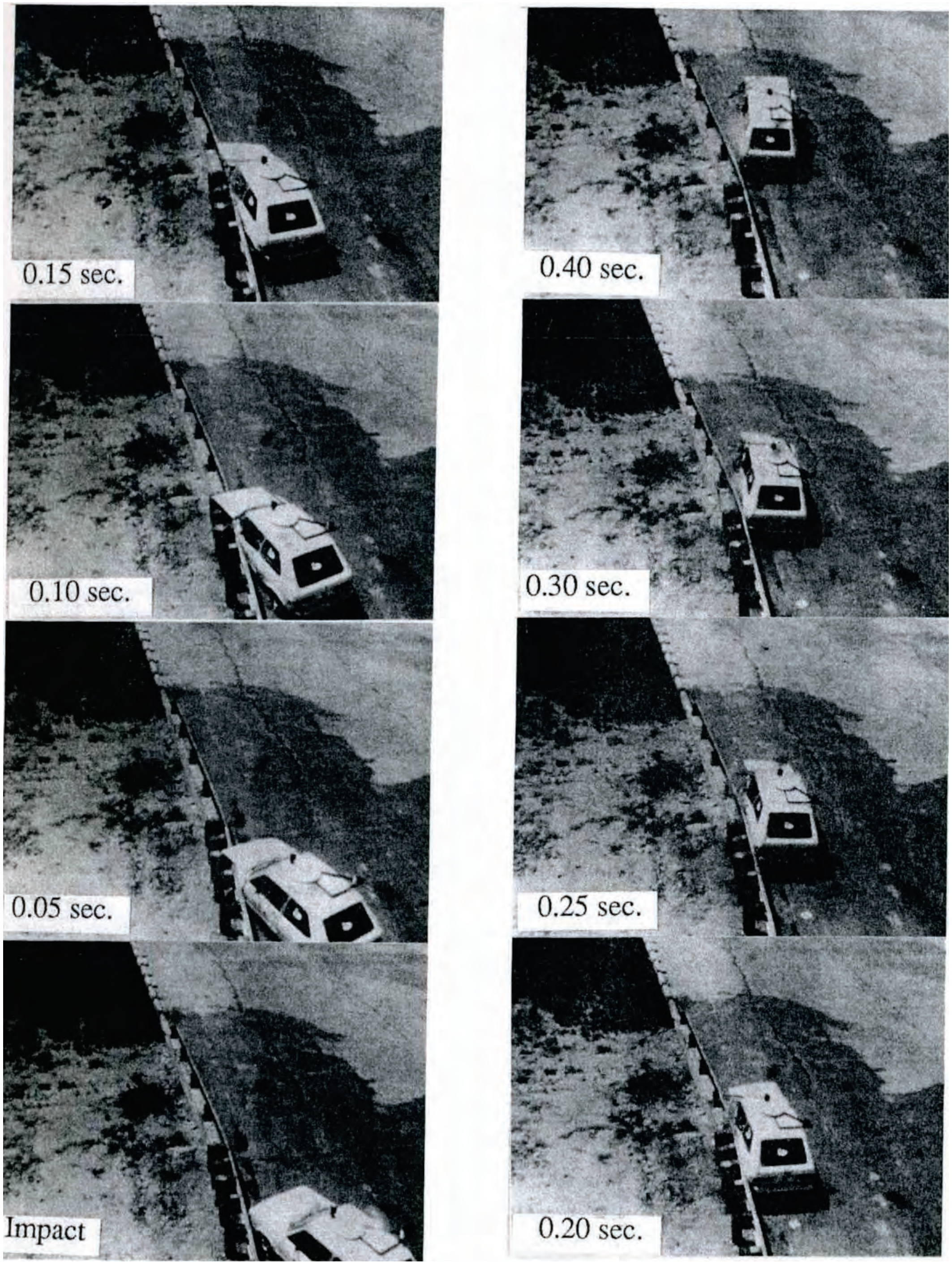

Figure 1.12. Sequential Photographs for YC-6 (*3*).

Figure 1.13. Impact Conditions and System Damage for YC-7 (*3*).

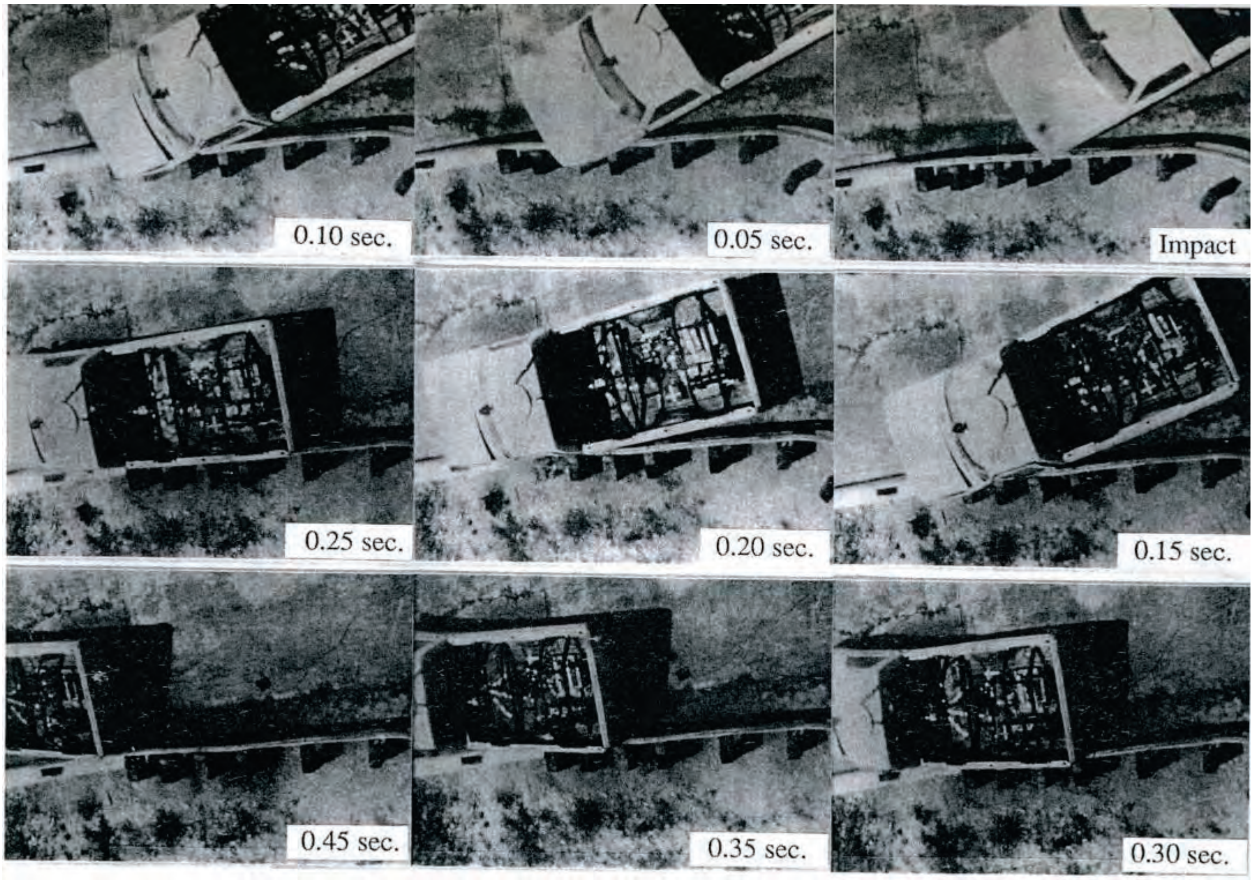

Figure 1.14. Sequential Photographs for YC-7 (*3*).

1.3.1.1.9. Primary Findings

Table 1.1 presents a summary of the pertinent test results for the Yuma County testing. The freestanding posts behind the curved section of the rail performed well. They slowed the vehicle down without causing too much damage. After test YC-3 failed because of a lack of tension in the system, the secondary side was lengthened. Researchers have determined that a minimum length of 25 ft was necessary to maintain tension in the guardrail. This greatly improved the performance of the system by increasing the amount of energy the guardrail could absorb to slow the vehicle. Testing was done to ensure that wheel snag does not occur when a vehicle impacts the transition between the guardrail and bridge rail. These tests showed no indication of significant wheel snag occurring for this design. However, lateral velocity change was too high according to *NCHRP Report 230*. The researchers asserted that the design of the tapered curb, which started the bridge rail, needs improvement. Overall, this design satisfied the requirements of *NCHRP Report 230* service level PL1.

Table 1.1. Summary of Crash Test Data for Yuma County (*3*).

Organization and Test Number	Guardrail Description	Test Vehicle (lb)	Impact Speed (mph)	Impact Angle (degrees)	OIV (ft/s) Longitudinal Lateral	RDA (Gs) Longitudinal Lateral	Vehicle Safely Redirected
SWRI: YC-1	8 ft radius, W-beam	5376 pickup	45	1.4	14.4 7.8	2.7 7.1	Yes
SWRI: YC-2	YC-1	1978 car	50.3	0.7	9.4 16.0	0.7 4.7	Yes
SWRI: YC-3	YC-2	5380 pickup	44.8	19.7	14.5 8.3	6.5 4	No
SWRI: YC-4	YC-3, lengthened secondary side by 12.5 ft	5381 pickup	44.9	20.1	20.1 11.0	5.6 2.9	Yes
SWRI: YC-5	YC-4	1980 car	44.2	20.0	27.8 7.3	10.5 3.3	Yes
SWRI: YC-6	YC-4	1980 Car	51.1	19.4	6.8 22.7	0.1 6.8	Yes
SWRI: YC-7	YC-4	5424 pickup	45.2	20.7	2.2 18.7	2.8 8.9	Yes

1.3.1.2. TTI W-Beam System: 1992 (5)

1.3.1.2.1. Design Considerations

The short radius guardrail consisted of a 14-ft 3-inch radius curved section with a 31-ft 5-inch straight segment parallel to the primary road and a 60-ft 8-inch section parallel to the secondary roadway. A TxDOT turndown terminated the secondary straight section. The guardrail was a 12-gauge W-beam supported by 7-inch diameter weakened wooden posts. The system contained two BCT anchors: one was located in the curved region and the other was located upstream of the transition. The transition section was a tubular W-beam, which is made from two pieces of W-beam welded back to back.

1.3.1.2.2. Test 1263-1

The purpose of this test was to evaluate the ability of the system to capture small vehicles impacting the curved section of the rail. The 1970-lb car impacted the system near the center of its curved section at an impact speed of 58.4 mph and an impact angle of 20.5° (refer to Figure 1.15). Instead of fracturing, the CRT posts in the curved section of the guardrail were pulled from the ground. The BCT post also did not fracture as expected, so the cable anchor did not release properly. Each of these occurrences contributed to higher tension in the rail than anticipated and caused the vehicle to be stopped too quickly. The impact lifted the back end of the vehicle completely off the ground. This system was not adequate because the longitudinal impact velocity of 41.8 ft/s exceeded the limit according to *NCHRP Report 230*.

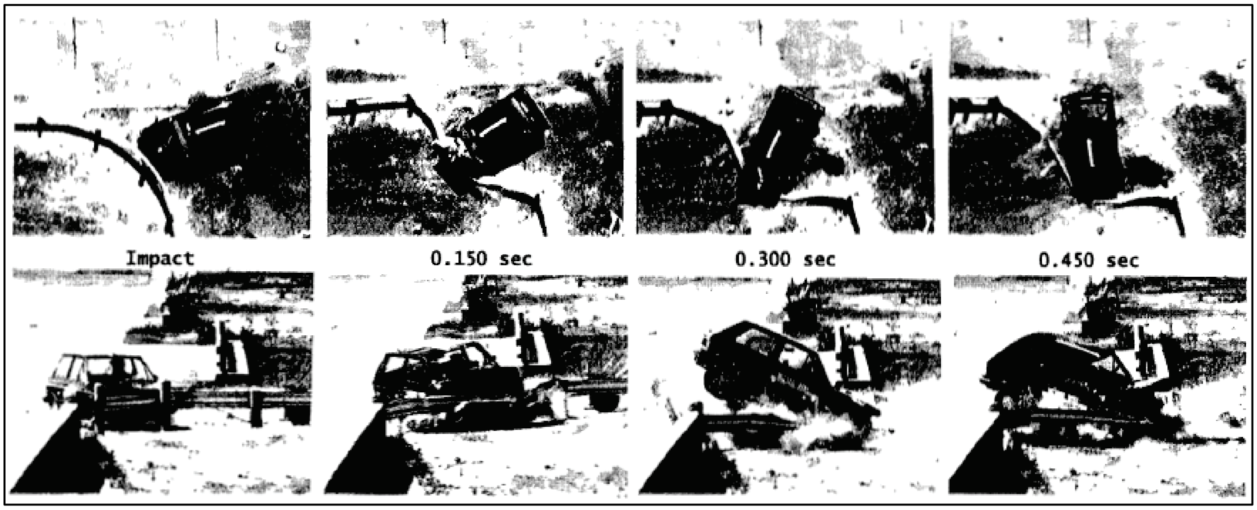

Figure 1.15. Sequential Photographs for Test 1263-1 (5).

1.3.1.2.3. Test 1263-2

After analyzing the results of Test 1263-1, changes were made to decrease the stiffness of the system. The downstream BCT assembly was replaced with a weakened CRT post in order to ensure the cable anchoring system properly releases. Also, the depth of all CRT posts was increased from 38 inches to 44 inches to raise the chance of fracturing instead of pulling out of the ground. The impact conditions for Test 1263-2 were the same as the impact conditions for Test 1263-1 (refer to Figure 1.16). The 1970-lb car impacted the curved section of the system at an impact speed of 59.0 mph and an impact angle of 20.4°. The CRT posts in the curved section of the guardrail fractured as expected. However, as the vehicle traveled through the system, a splice in the rail fractured. This caused the vehicle to travel much farther than the allowable stopping distance. Because the vehicle was not stopped within the intended distance, the system was considered inadequate according to *NCHRP Report 230*.

1.3.1.2.4. Test 1263-3

After analyzing the results of Test 1263-2, researchers made changes to increase the strength of the W-beam. To do this, two W-beams were placed one behind the other for the entire length of the system except for the transition and turndown section. The impact conditions for Test 1263-3 were the same as the impact conditions for Test 1263-2 (refer to Figure 1.17). The 1970-lb car impacted the system at an impact speed of 60.2 mph and an impact angle of 20.7°. The guardrail functioned as intended. The posts in the curved section fractured properly and the anchoring system released cleanly. The vehicle was stopped after traveling 14 ft, and the values for OIV and RDA were within acceptable limits. Therefore, the system was considered adequate according to *NCHRP Report 230*.

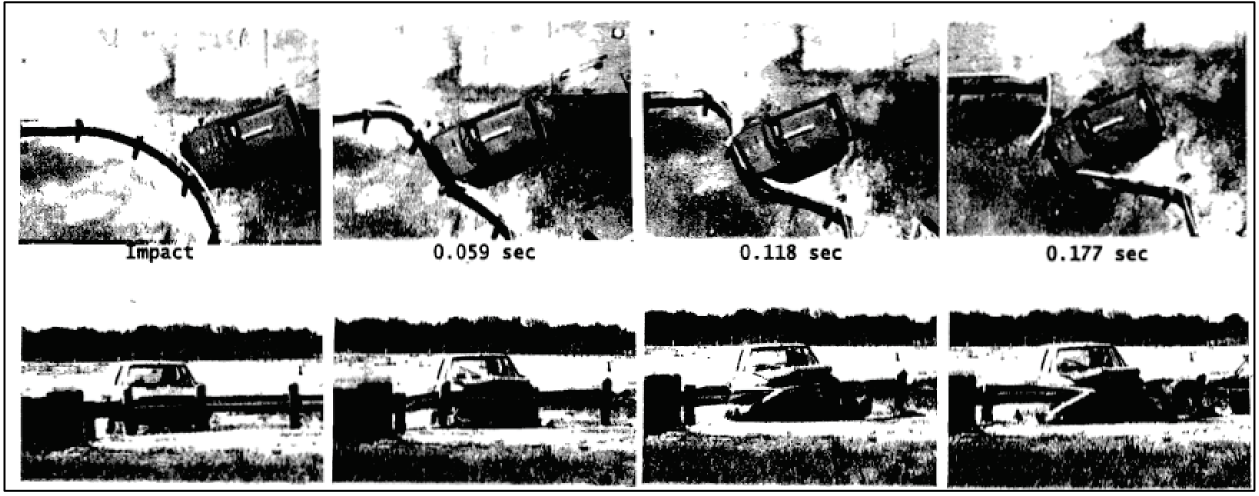

Figure 1.16. Sequential Photographs for Test 1263-2 (*5*).

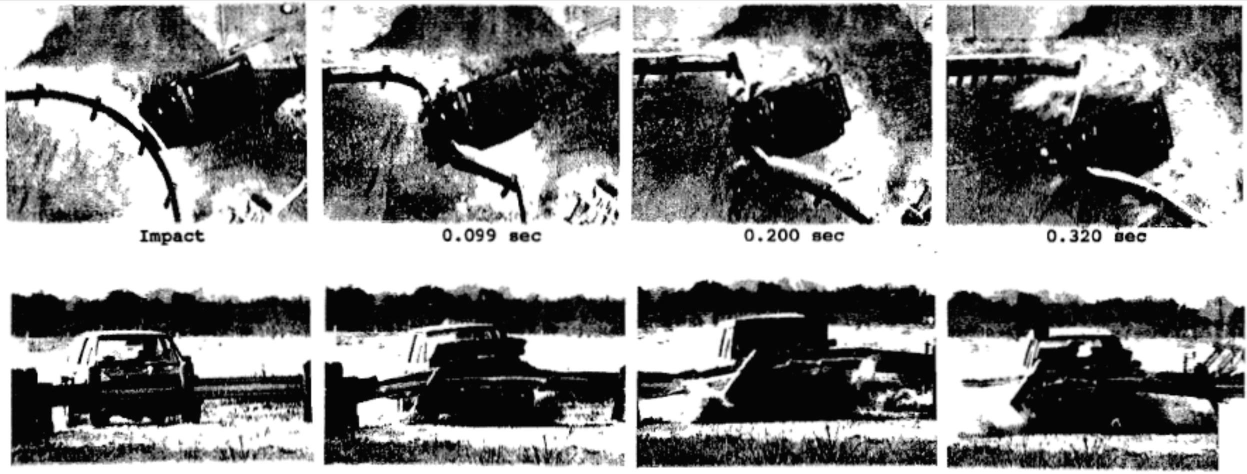

Figure 1.17. Sequential Photographs for Test 1263-3 (*5*).

1.3.1.2.5. Test 1263-4

For this test, the radius of the curved portion was increased from 14 ft 3 inches to 16 ft. This change was made to simplify installation of the system. The purpose of this test was to evaluate the redirective performance of the system's transition region. The 4500-lb sedan impacted the straight section of the system 75 inches from the bridge rail at an impact speed of 57.1 mph and an impact angle of 24.7° (refer to Figure 1.18). Minimal wheel snagging occurred at the transition region and the vehicle was safely redirected. The system was considered adequate according to *NCHRP Report 230*.

1.3.1.2.6. Test 1263-5

The purpose of this test was to evaluate the ability of the system to capture large vehicles impacting the curved section of the rail. No modifications to the system we made between Tests 1263-4 and 1263-5. The 4500-lb sedan impacted the centerline of the guardrail at an impact speed of 58.5 mph and an impact angle of 26.8° (refer to Figure 1.19). The posts in the curved section of the rail fractured as intended and the guardrail deformed properly. However, after deflecting 16 ft, the guardrail slipped above the vehicle's bumper. It traveled over the hood of the vehicle and caused significant damage to the passenger compartment. Because the system did not capture the vehicle and the passenger compartment had an unacceptable amount of damage, it was considered inadequate according to *NCHRP Report 230*.

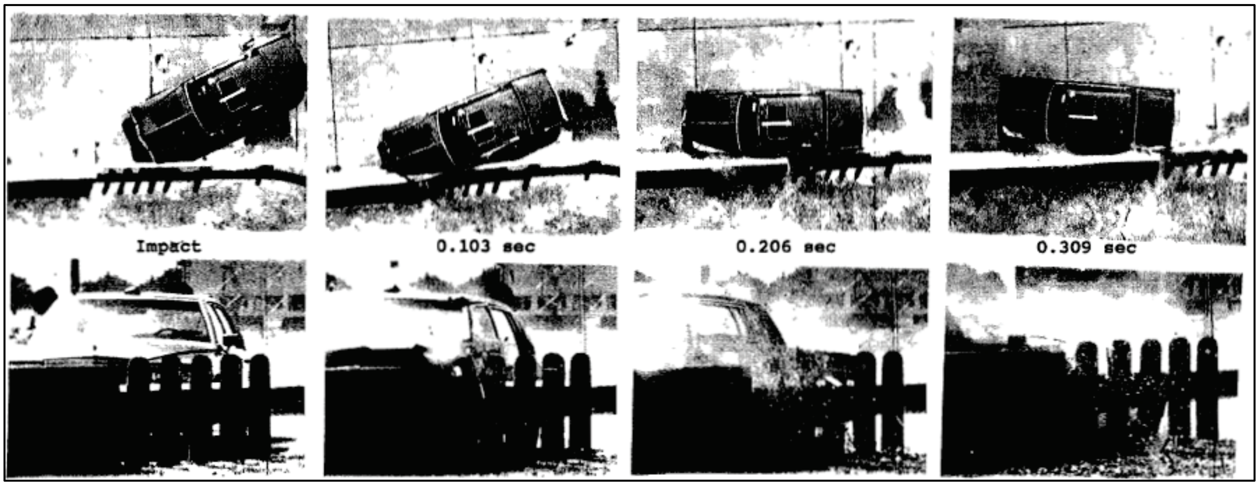

Figure 1.18. Sequential Photographs for Test 1263-4 (5).

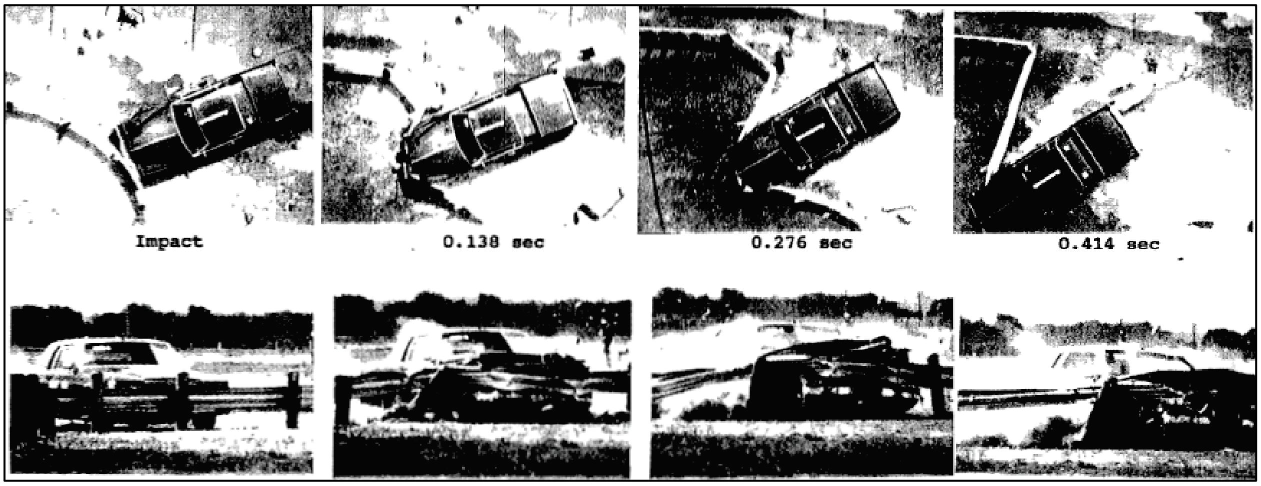

Figure 1.19. Sequential Photographs for Test 1263-5 (5).

1.3.1.2.7. Test 1263-6

After analyzing the results of Test 1263-5, researchers made changes to prevent vehicle underride. The post at the beginning of the turndown was weakened. This would cause the post to fracture before the rail can ride up on the vehicle. The purpose of this test was to evaluate the redirective performance of the system when a vehicle impacts the curved section at a shallow angle. The centerline of the 4500-lb sedan impacted the centerline of system's primary side at an impact speed of 58.3 mph and an impact angle of 2.0° (refer to Figure 1.20). The vehicle was redirected without snagging. Little damage was done to the vehicle, and the system and values for OIV and RDA were within recommended limits. Therefore, the system was considered adequate according to *NCHRP Report 230*.

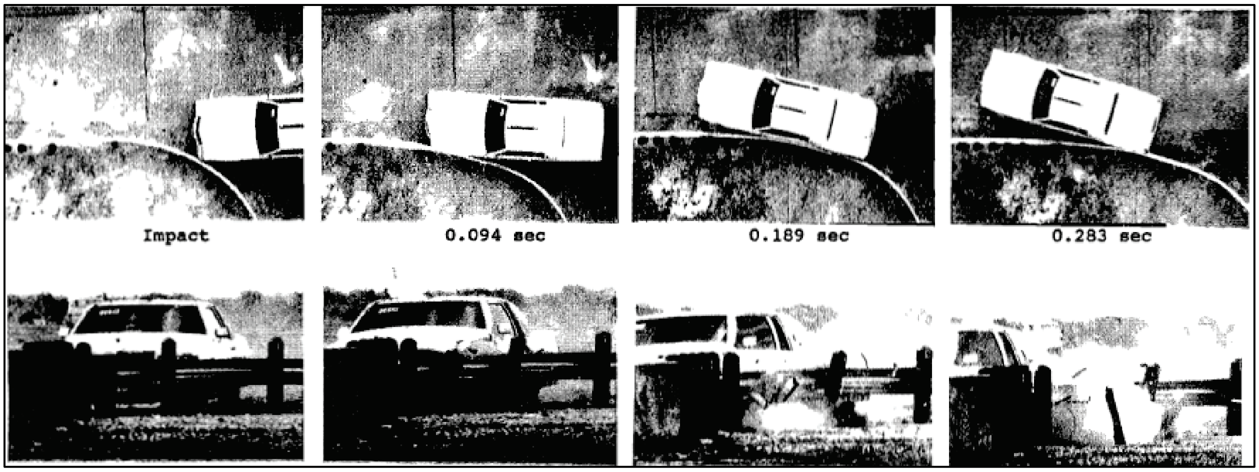

Figure 1.20. Sequential Photographs for Test 1263-6 (*5*).

1.3.1.2.8. Primary Findings

Table 1.2 presents the pertinent test results for the TTI testing on the W-beam system. Weakened posts must be buried deep enough so they fracture instead of pulling out from the ground. If a BCT system is used, a proper cable release must occur or else the vehicle will decelerate too rapidly. Nested W-beams increase the load capacity of the system. However, nested W-beams are difficult to install because the splice holes in the two beams do not always line up. A thrie beam system should be evaluated because of its similar strength of a nested W-beam. Also, the increased width of the thrie beam will better capture the vehicle, reducing the chance of vehicle override or underride.

1.3.1.3. TTI Thrie-Beam System: 1994 (6)

1.3.1.3.1. Design Considerations

The short radius guardrail consisted of a 10-gauge thrie beam supported by weakened, round wooden posts with 6-ft 3-inch spacing. A thrie beam was used because of its advantages over a nested W-beam, which include improved vehicle capture, easier installation and maintenance, and is more cost-effective. The rail height was 31 inches, had a 16-ft radius, extended 32 ft on the primary side, and extended 60 ft on the secondary side. A thrie to W-beam transition was used at the bridge rail connection and before the turndown section on the secondary side.

Table 1.2. Summary of Crash Test Data of TTI W-Beam System (5).

Test Number	Guardrail Description	Test Vehicle (lb)	Impact Speed (mph)	Impact Angle (degrees)	OIV Longitudinal Lateral (ft/s)	RDA Longitudinal Lateral (Gs)	Vehicle Safely Captured/ Redirected
1263-1	14 ft 3 inch radius, W-beam	1970 car	58.4	20.5	41.8 10.7	12.8 2.5	No
1263-2	BCT assembly replaced by a CRT post, increased depth of all CRT posts	1970 car	59.0	20.4	27.1 4.2	10.5 0.8	No
1263-3	1263-2, two nested W-beams	1970 car	60.2	20.7	34.3 7.9	8.9 3.5	Yes
1263-4	1263-3, increased radius to 16 ft	4500 sedan	57.1	24.7	27.6 25.4	4.8 7.7	Yes
1263-5	1263-4	4500 sedan	58.5	26.8	20.3 6.2	7.6 2.3	No
1263-6	1263-4, weakened post at beginning of turndown	4500 sedan	58.3	2.0	10.7 15.4	1.6 5.6	Yes

1.3.1.3.1. Test 1442-1

The purpose of this test was to evaluate the redirective capability of the system when a vehicle strikes the bridge transition. The 4409-lb pickup impacted the system at an impact speed of 60.9 mph and an impact angle of 26.0° (refer to Figure 1.21). The truck immediately contacted the concrete barrier and was pulled sharply to the left. The front end of the vehicle became airborne. After contacting the system for 15.7 ft, the vehicle exited the system at 41.5 mph at an angle of 2.5°. Because the vehicle was safely redirected and values for OIV and RDA were within recommended limits, the system is considered adequate according to *NCHRP Report 350*.

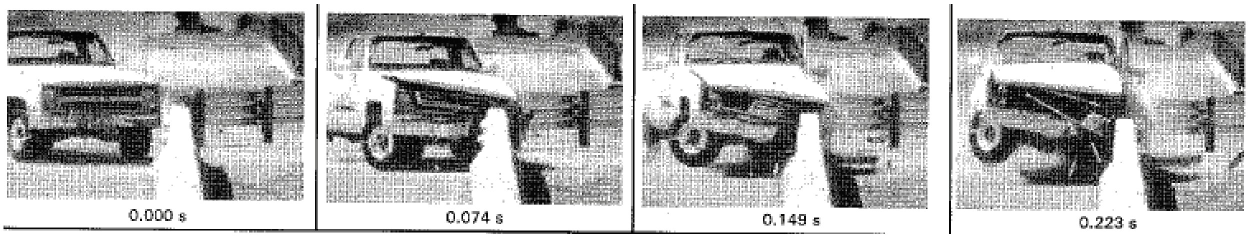

Figure 1.21. Sequential Photographs for Test 1442-1 (*6*).

1.3.1.3.2. Test 1442-2

No changes were made to the system between Test 1442-1 and 1442-2. The purpose of this test was to evaluate the ability of the system to contain a pickup truck, which impacts the centerline of the curved section. The 4409-lb vehicle impacted the centerline of the system at an impact speed of 63.0 mph and an impact angle of 25.6° (refer to Figure 1.22). Immediately after impact, the posts in the curved section rotated instead of fracturing as intended. This caused the rail to twist, and the vehicle began to climb the guardrail. The vehicle vaulted and overrode the barrier. Because the vehicle was not contained, the system is inadequate according to *NCHRP Report 350*.

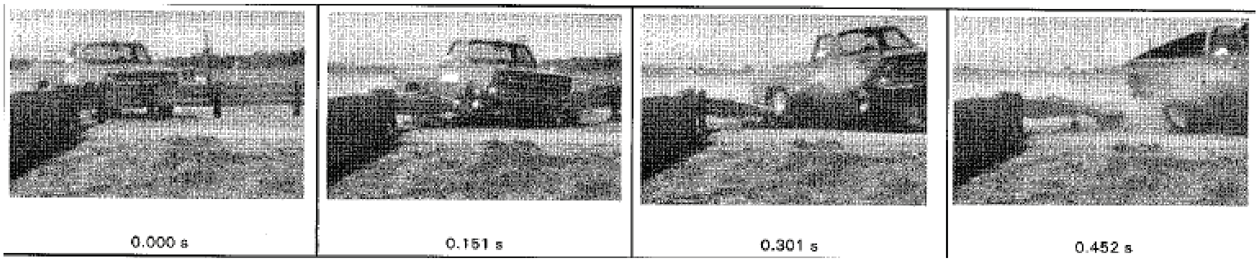

Figure 1.22. Sequential Photographs for Test 1442-2 (*6*).

1.3.1.3.3. Test 1442-3

After researchers analyzed the results of Test 1442-2, they replaced bolts with lag screws in each of the posts in the curved section of the guardrail. This change decreased the rotation of the guardrail by allowing the posts to release properly. The impact conditions for Test 1442-3 were the same as in Test 1442-2. The 4409-lb pickup impacted the centerline of the curved section at an impact speed of 63.0 mph and an impact angle of 24.6° (refer to Figure 1.23). The results of this test were nearly identical to the results of the previous test. Immediately after impact, the loading on the top portion on the rail combined with the low torsional stiffness of the thrie beam caused the rail to twist and the vehicle began to climb the guardrail. The vehicle vaulted and overrode the barrier. Because the vehicle was not contained, the system is inadequate according to *NCHRP Report 350*.

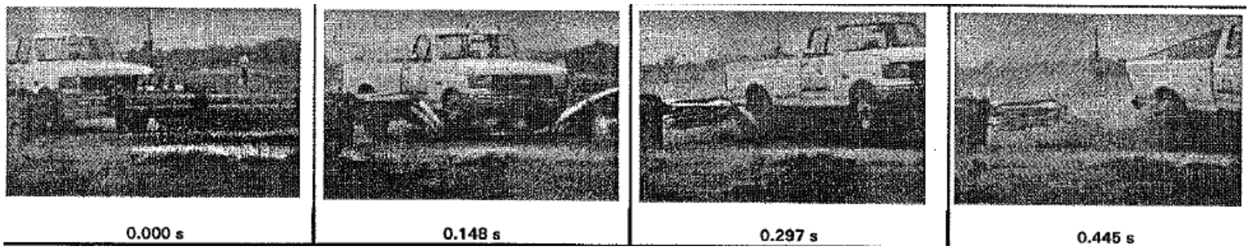

Figure 1.23. Sequential Photographs for Test 1442-3 (*6*).

1.3.1.3.4. Test 1442-4

After analyzing the results of Test 1442-3, researchers decided that the project would now focus on designing a system to be compliant with *NCHRP Report 230* criteria. The system developed during this project could be used until a short radius system meeting *NCHRP Report 350* criteria was designed and tested. The purpose of this test was to evaluate the ability of the system to capture a small car impacting the curved section of the system. The 1978-lb car impacted the centerline of the curved section at an impact speed of 60.1 mph and an impact angle of 19.1° (refer to Figure 1.24). Immediately after impact, the posts in the curved section fractured as intended, and the guardrail began to deform across the front of the vehicle. As the vehicle continued into the system, the rail slipped over the bumper and began to override the hood. Even though vehicle underride did occur, the system is adequate according to *NCHRP Report 230* because the OIV and RDA values were within the limits and the vehicle was safely contained.

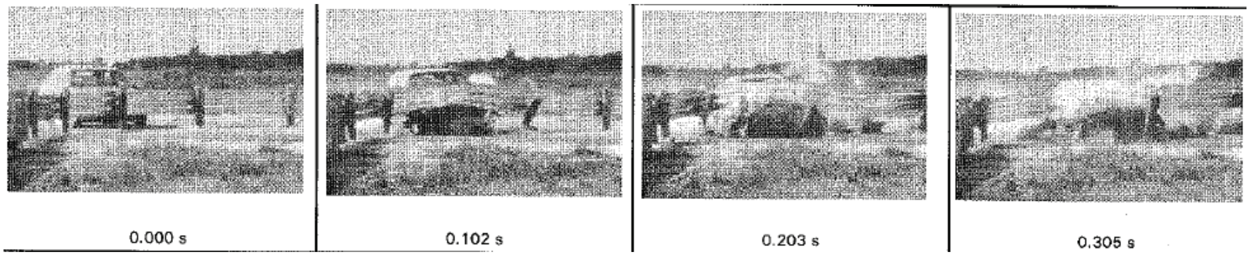

Figure 1.24. Sequential Photographs for Test 1442-4 (*6*).

1.3.1.3.5. Test 1442-5

No changes were made to the system between Tests 1442-4 and 1442-5. The purpose of this test was to evaluate the ability of the system to contain a large vehicle impacting at the centerline of the curved section. The 4500-lb vehicle impacted the centerline of the curved section of the system at an impact speed of 60.4 mph and an impact angle of 24.5° (refer to Figure 1.25). Immediately after impact, the posts in the curved section fractured as intended and the rail deformed across the front of the vehicle. The vehicle came to a stop 21.3 ft into the system. Even though the end anchor failed before the vehicle came to a complete stop the test was not considered a failure because the vehicle was safely contained and the values for OIV and RDA were within recommended limits, the system is adequate according to *NCHRP Report 230.*

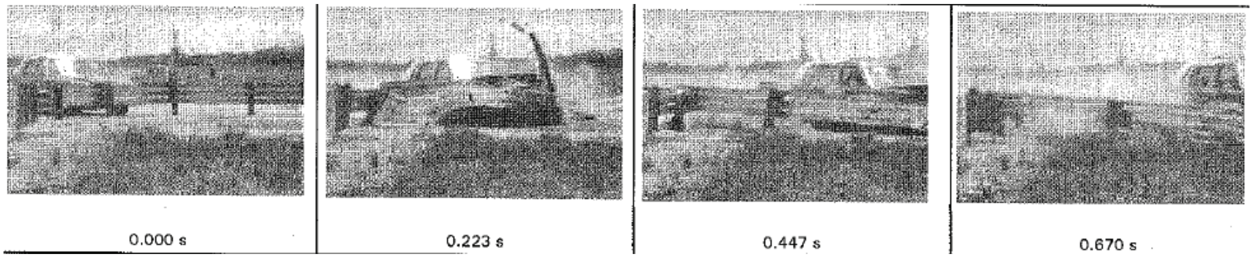

Figure 1.25. Sequential Photographs for Test 1442-5 (*6*).

1.3.1.3.6. Primary Findings

Table 1.3 presents the pertinent test results for the TTI testing on the thrie beam system. A thrie beam has strength and stiffness properties that are comparable to a nested W-beam, but the thrie is cheaper and easier to install. Because the depth of the thrie beam is greater than that of a W-beam, extra care must be taken to ensure vaulting caused by eccentric loading or improper fracturing of posts does not occur.

Table 1.3. Summary of Crash Test Data of TTI Thrie Beam System (*6*).

Test Number	Guardrail Description	Test Vehicle (lb)	Impact Speed (mph)	Impact Angle (degrees)	OIV (ft/s) Longitudinal Lateral	RDA (Gs) Longitudinal Lateral	Vehicle Safely Captured/ Redirected
1442-1	4.78 ft radius, thrie beam	4409 pickup	60.9	26.0	24.1 26.2	7.1 11.7	Yes
1442-2	1442-1	4409 lb pickup	63.0	25.6	17.2 2.6	10.4 5.6	No
1442-3	1442-2, removed bolts from posts in curved section	4409 pickup	63.0	24.6	16.5 3.3	6.17 9.58	No
1442-4	1442-3	1978 car	60.1	19.1	34.7 7.8	8.59 3.02	Yes
1442-5	1442-3	4500 town car	60.4	24.5	20 8.0	5.24 2.75	Yes

1.3.1.4. Midwest Roadside Safety Facility Phase II: 2003 (8)

1.3.1.4.1. Design Considerations

Phase II of the project involved full-scale crash tests on the design developed in phase I (*7*). Phase I of the MwRSF project was a concept development based on previous short radius guardrail designs, FHWA recommendations, and state regulations. An 8-ft radius was selected for this study based on research, which concluded that smaller radius guardrails maintained tension better throughout the system. The smaller radius also reduces the overall size of the system, allowing it to be used at a variety of intersections. The radius was based on the constraint that bending in the nose of the rail would form a 90° angle between each leg. It was determined that the thrie beam had sufficient strength at the nose to prevent sagging, so a post at the centerline of the nose was not needed. Removing this post also reduces the risk of vaulting when vehicles impact the centerline of the curve. The curved section included a rail with slot tabs that should allow the rail to separate at impact and better capture the front of the vehicle.

1.3.1.4.2. Test SR-1

The test was conducted according to *NCHRP Report 350* TL-3 test designation 3-33 using a 4473-lb 1995 GMC pickup truck. The centerline of the truck impacted the centerline of the nose section at an impact speed of 61.5 mph and an impact angle of 19.0° (refer to Figure 1.26). The bumper of the truck made initial contact with the middle hump of the thrie beam. As the beam deformed, the slot tabs did not tear, so the middle hump was pushed below the bumper and the lower hump of the beam was rolled over. Because of the impact orientation, the posts on the left side of the vehicle failed before those on the right side. This caused the left side of the rail to lose tension first, which caused the rail on the right side of the vehicle to lock. The vehicle yawed violently clockwise until it rolled over. Because the vehicle rolled and was not captured, the guardrail was deemed unacceptable according to *NCHRP Report No. 350* criteria.

1.3.1.4.3. Test SR-2

As a result of Test SR-1, two CRT posts were added to the secondary side of the system. This should counteract the yaw of the truck by stiffening the side that lost tension. The test was conducted according to *NCHRP Report 350* TL-3 designation 3-33 using a 4440-lb 1994 Chevrolet pickup truck. The centerline of the truck impacted the centerline of the nose section at 64.7 mph and an impact angle of 16.1° (refer to Figure 1.27). The bumper of the truck made initial contact with the middle hump of the thrie beam. As the rail deformed, the top and middle humps were pushed above the bumper and the lower hump was rolled over. As the vehicle continued into the system, the rail on the primary side deformed along the line of posts while the rail on the secondary side deformed at an angle. This uneven loading caused the vehicle to yaw clockwise. The combination of the yaw from the system and debris gathered on the vehicle's right side caused the pickup to roll over the guardrail. Because the vehicle rolled and was not captured, the guardrail was deemed unacceptable according to *NCHRP Report 350* criteria.

1.3.1.4.4. Test SR-3

After reviewing the geometry of the system, the researchers at MwRSF decided that an impact with the centerline of the vehicle directly aligned with the primary side of the system would be more critical than the impact in *NCHRP Report 350* test designation 3-31. Therefore, Test SR-3 was carried out as a modified *NCHRP Report 350* test designation 3-31 where the truck impacts the primary side of the system at an impact angle of 0° rather than impacting the centerline of the nose at an angle of 0°. The vehicle used for the test was a 4489-lb 1995 Ford pickup truck. The truck impacted the rail at 63.9 mph and an angle of 0.9° (refer to Figure 1.28). The bumper of the truck made initial contact between the top two humps of the thrie beam, which immediately tore the slot tabs between the top and middle humps. As the rail deformed, the top hump slid above the bumper while the middle and bottom humps were pushed beneath the bumper and the pickup truck rolled over. The vehicle buckled the first section of guardrail, but the second section flexed outward instead of buckling. This caused significant deformation to the front of the vehicle. The increased resistance from the rail along with the cable in the nose section locking above the front bumper caused the vehicle to pitch violently downward. The vehicle rolled to the right and yawed counterclockwise such that only the right front corner of the truck contacted the ground. Because the vehicle rolled and was not safely redirected, the guardrail was deemed unacceptable according to *NCHRP Report 350* criteria.

1.3.1.4.5. Test SR-4

The failure to safely stop the vehicle in Tests SR-2 and SR-3 led to several design modifications for Test SR-4. Another section of thrie beam was added to the primary side. This increased the parabolic flare of the system and added four more CRT posts, bringing the total on the primary side to 13 posts. The extra section would allow the rail to absorb more energy, and the additional slotted rail would allow the rail to buckle more easily, reducing the vaulting that occurred in Test SR-3. The system was also raised by 2 inches to better capture the vehicle. The test was a repeat of Test SR-3 and the vehicle used was a 4420-lb 1997 GMC pickup truck. The truck impacted the rail at an impact speed of 66.1 mph and an impact angle of 1.8° (refer to Figure 1.29). The vehicle impacted the curved section of the guardrail. The first two posts were fractured, and the rail was pushed to the left of the vehicle. The loss of these posts eliminated most of the tension upstream of the truck, which led to little redirection by the system. At this point, the vehicle began to redirect slightly. Posts 3 through 8 were fractured, and then the rail slid off the left corner of the vehicle into the front wheels. As the rail snagged the front-left wheel, the vehicle decelerated rapidly and yawed counterclockwise. Because the system did not safely redirect the vehicle, it was deemed unacceptable according to *NCHRP Report 350* criteria.

1.3.1.4.6. Primary Findings

Table 1.4 presents the pertinent test results for MwRSF phase II testing. The addition of parabolic flare and more slotted guardrail sections improved vehicle capture and gave the vehicle a larger distance to decelerate. Increasing the system height from 31.6 inches to 33.8 inches did not have a significant impact on test results and also caused compatibility issues with connecting bridge rails. It was also determined that an additional anchor on the primary side would be necessary to keep tension in the rail.

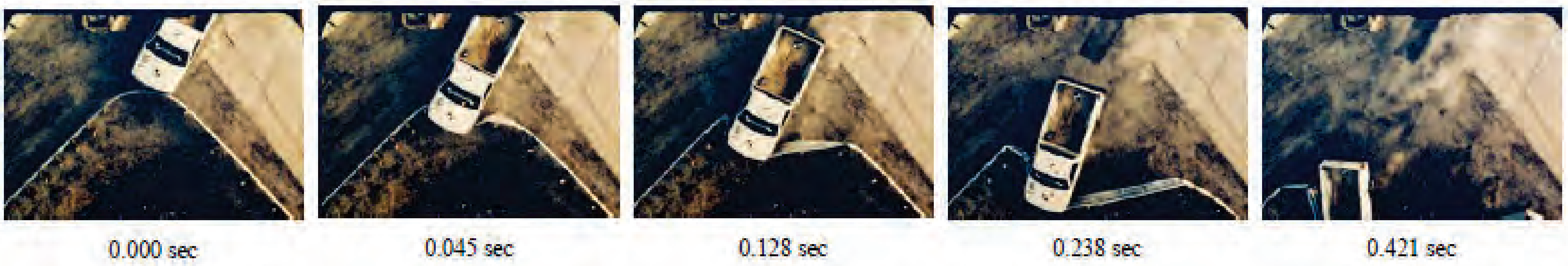

Figure 1.26. Sequential Photographs for Test SR-1 (*8*).

Figure 1.27. Sequential Photographs for Test SR-2 (*8*).

Figure 1.28. Sequential Photographs for Test SR-3 (*8*).

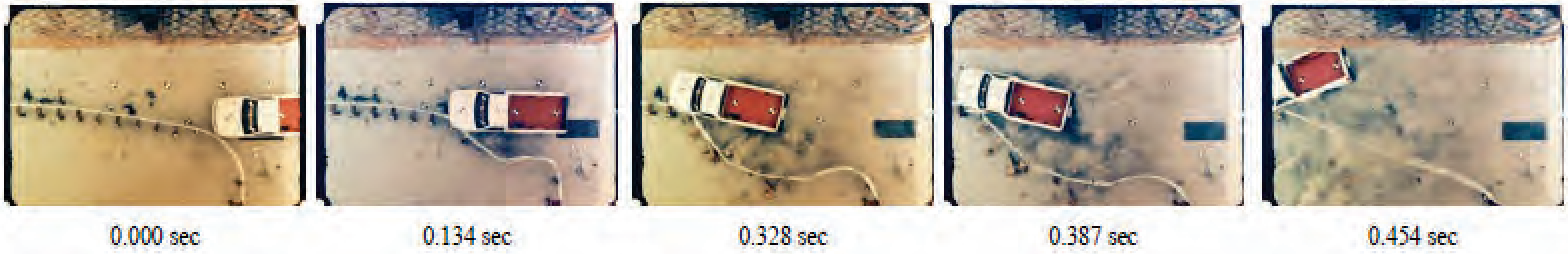

Figure 1.29. Sequential Photographs for Test SR-4 (*8*).

Table 1.4. Summary of MwRSF Phase II Crash Test Data (8).

Test Number	Guardrail Description	Test Condition	Test Vehicle (lb)	Impact Speed (mph)	Impact Angle (degrees)	OIV (ft/s) Longitudinal Lateral	RDA (Gs) Longitudinal Lateral	Vehicle Safely Redirected
SR-1	8 ft radius, thrie beam	*NCHRP Report 350* Test 3-33	4473 pickup	61.5	19.0	20.6 5.2	9.28 7.89	No
SR-2	SR-1, two posts added on secondary side	*NCHRP Report 350* Test 3-33	4440 pickup	64.7	16.1	23.6 9.6	7.05 8.51	No
SR-3	No changes from SR-2	Modified *NCHRP Report 350* Test 3-31	4489 pickup	63.9	0.9	29.0 4.3	12.21 8.01	No
SR-4	SR-2, added section on primary side, raised system to 33.8 inches	Modified *NCHRP Report 350* Test 3-31	4420 pickup	66.1	1.8	14.2 9.9	23.61 11.68	No

1.3.1.5. Midwest Roadside Safety Facility Phase III: 2007 (11)

1.3.1.5.1. Design Considerations

The design of the short radius guardrail for these tests was based on research conducted in phase I and II of the project. Similar to that used in phase II, the system was also designed without a centerline post in the nose section. It also used a slotted thrie beam held by 13 posts on the primary side and eight posts on the secondary side. The parabolic flare on the primary side was kept after it was found to improve the system in Test SR-4. The radius was increased to 9 ft, which should better facilitate vehicle capture while remaining small enough to be used at a variety of intersections. A set of cables was attached to the back of the nose section between the top and middle humps of the thrie beam to contain vehicles if rail rupture occurs. A new anchorage system tangent to the primary side was added to maintain tension in the primary side when redirecting a vehicle. The new anchor needs to provide tension during redirection but must break away when the vehicle is to be captured. Therefore, a release lever was added in front of the curved section of the system.

1.3.1.5.2. Test SR-5

After reviewing the geometry of the system, the researchers at MwRSF decided that an impact with the centerline of the vehicle directly aligned with the primary side of the system would be more critical than the impact in *NCHRP Report 350* test designation 3-31. Therefore, Test SR-3 was carried out as a modified *NCHRP Report 350* test designation 3-31 where the truck impacts the primary side of the system at an impact angle of 0° rather than impacting the centerline of the nose at an impact angle of 0°. The test was conducted using a 4412-lb 1997 Ford pickup truck. The vehicle impacted the system slightly after the first primary post at an impact speed of 63.3 mph and an impact angle of 0.9° (refer to Figure 1.30). The curved nose section deformed inward and wrapped around the front corner of the truck. By the time the vehicle fractured the second primary post, it began to redirect. The rail began to flatten as the vehicle was redirected. After the third post fractured, other posts only bent slightly as they continued to redirect the vehicle. The vehicle exited the system at post 7 at an exit speed of 53 mph and an exit angle of 12.6°. The secondary anchor remained in place for the test and successfully established the tension required to redirect the vehicle. The short radius guardrail system was adequate in safely redirecting the vehicle according to *NCHRP Report 350* TL-3 performance criteria. There were no intrusions into the occupant compartment, the vehicle remained upright, and did not interfere with other lanes of traffic.

1.3.1.5.3. Test SR-6

After Test SR-5, concerns were raised over the location of the cable release mechanism because the current location in front of the guardrail would hinder mowing crews. As a result, the mechanism was eliminated and the cable system on the primary side redesigned. The cable was lengthened and reoriented so it ran from the first post on the primary side to the first post on the secondary side. The anchorage for the secondary side was relocated to post 2S. Test SR-6 was carried out according to *NCHRP Report 350* test designation 3-30 with a 1969-lb 1996 Geo car. When the vehicle impacted the curved section of the guardrail, the right front quarter point of the car was aligned with the centerline of the curved nose section. The vehicle impacted the system while traveling at an impact speed of 61.8 mph at an impact angle of 0.8° (refer to Figure 1.31). The nose section buckled near its midpoint and deformed the hood of the car. The slot tabs began to tear as the car continued into the system. Buckle points formed adjacent to posts 1P and 1S. By this time, the thrie beam spread across the entire front of the car. The rail then disengaged from post 3P and was pushed up over the front of the vehicle, collapsing the hood and contacting the windshield. At 0.770 seconds (s), the car came to a stop. Though the system adequately contained the vehicle, the longitudinal occupant ridedown acceleration was above the maximum allowed value. Excessive deformations and intrusions into occupant compartment also occurred. Therefore, the system was deemed inadequate according to *NCHRP Report 350* TL-3 criteria.

1.3.1.5.4. Primary Findings

Table 1.5 presents the pertinent test results for MwRSF phase III testing. The redesigned anchoring method used for Test SR-6 was adequate in maintaining tension in the primary side. A cable located behind the thrie beam will retain the vehicle in the event of rail rupture. The parabolic flared section continued to perform well when redirecting a vehicle. Care must be taken to keep the vehicle from traveling under the rail during impact in order to minimize occupant compartment damage.

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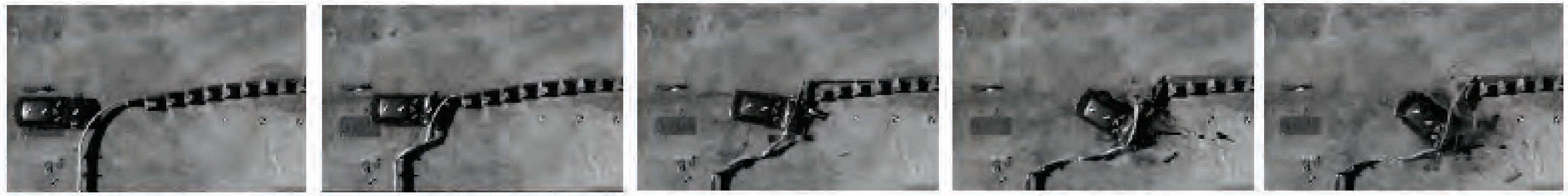
Figure 1.30. Sequential Photographs for Test SR-5 (*11*).



0.000 sec 0.079 sec 0.172 sec 0.313 sec 0.404 sec

Figure 1.31. Sequential Photographs for Test SR-6 (*11*).

Table 1.5. Summary of Midwest Roadside Safety Facility Phase III Crash Test (*11*).

Test Number	Guardrail Description	Test Condition	Test Vehicle (lb)	Impact Speed (mph)	Impact Angle (degrees)	OIV (ft/s) Longitudinal Lateral	RDA (Gs) Longitudinal Lateral	Vehicle Safely Redirected
SR-5	SR-4, added anchorage to primary side, lowered to 31 inches	Modified *NCHRP Report 350* Test 3-31	4412 pickup	63.3	0.9	13.4 10.4	5.72 5.37	Yes
SR-6	SR-5, redesigned anchoring system	*NCHRP Report 350* Test 3-33	1969 car	61.8	0.8	30.8 0.43	20.73 12.05	No

1.3.1.6. Midwest Roadside Safety Facility Phase IV: 2008 (9)

1.3.1.6.1. Design Considerations

The design of the short radius guardrail for these tests was based on research conducted in phase I, II, and III of the project. The system is identical to the one tested in Test SR-6. The radius is 9 ft, with cables attached to the back of the nose section. The guardrail has 13 posts on the primary side and eight posts on the secondary side holding up a slotted thrie beam and no post on the centerline of the nose section.

1.3.1.6.2. Test SR-7

The test was conducted according to *NCHRP Report 350* test designation 3-33 guidelines with a 4989-lb pickup truck. The centerline of the truck impacted the centerline of the curved section of the system at an impact speed of 62.3 mph and an impact angle of 18.1° (refer to Figure 1.32). As the truck traveled through the system, it began to turn toward the secondary side because the number of posts on the primary side offered more resistance. Tension was lost on the secondary side and the guardrail hit the ground in front of the vehicle. As the truck began to roll over the rail, the back right tire hit post 1S, which raised the right-rear corner of the vehicle. Next, the vehicle's front left tire snagged on the sagging rail and pitched the vehicle downward. The truck pivoted about this point and rolled. Because the vehicle rolled over the guardrail and was not contained, the system is not adequate according to *NCHRP Report 350* guidelines.

1.3.1.6.3. Test SR-8

After analyzing the results of Test SR-7, researchers made several design modifications. First, the holes in posts 1P, 1S, and 2S were enlarged from 2.5 inches to 3 inches in diameter. This should ensure a cleaner release of the cable anchor and keep the posts from interfering with the vehicle as it travels through the system. Plate washers were added to the first four posts on each side. This will keep the posts attached to the guardrail after they fail so they do not interact with the vehicle as it travels through the system. Also, the slot tabs were reduced from 2 inches wide to 1 inch wide so that they would tear more easily. The centerline of the truck impacted the centerline of the curved section of the system at an impact speed of 62.9 mph and an impact angle of 17.9° (refer to Figure 1.33). As the truck traveled through the system, it began to turn toward the secondary side because the primary side offered more resistance. By the time the truck became parallel with the secondary side, the guardrail was contacting the entire left side of the vehicle. This caused the vehicle to yaw about its front-left tire. The rail lost tension in the secondary side and the vehicle rolled over it. Because the truck rolled over the guardrail, the system is not adequate according to *NCHRP Report 350* guidelines.

1.3.1.6.4. Primary Findings

Table 1.6 presents the pertinent test results for MwRSF phase IV testing. Though the system in Test SR-8 was not adequate, the modifications after Test SR-7 showed promise. Enlarging transverse holes in the first post on the primary side as well as two posts on the secondary side, reducing slot tab size in the nose section, and attaching the first three posts on each side to the guardrail with washers improved the overall performance of the system by minimizing the amount of debris that the vehicle encountered.

Table 1.6. Summary of Midwest Roadside Safety Facility Phase IV Crash Test Data (*9*).

Test Number	Guardrail Description	Test Condition	Test Vehicle (lb)	Impact Speed (mph)	Impact Angle (degrees)	OIV (ft/s) Longitudinal Lateral	RDA (Gs) Longitudinal Lateral	Vehicle Upright Safely Redirected
SR-7	SR-6	*NCHRP Report 350* Test 3-30	4989 pickup truck	62.3	18.1	20.1 8.0	9.61 5.55	No No
SR-8	SR-7, enlarged holes, added washers, reduced width of slot tabs	*NCHRP Report 350* Test 3-33	5000 pickup truck	62.9	17.9	21.0 10.2	6.80 4.12	Yes No

0.000 sec 0.104 sec 0.216 sec 0.342 sec 0.484 sec

Figure 1.32. Sequential Photographs for Test SR-7 (*9*).

0.000 sec 0.120 sec 0.314 sec 0.556 sec 0.810 sec

Figure 1.33. Sequential Photographs for Test SR-8 (*9*).

1.3.2. Bullnose Guardrail Research and Testing

1.3.2.1. A Need for the Universal Steel Breakaway Post (12)

CRT wood posts were originally used in the thrie-beam bullnose system that MwRSF developed between 1997 through 2000. The bullnose system was developed in order to protect errant vehicles from hazards in highway medians. Using CRT wood posts in this system met the criteria in *NCHRP Report 350*. However, wood posts can have several drawbacks. The quality of wood can largely vary based on factors such as knots, splints, and moisture content, making it difficult to maintain consistency. Two holes are drilled in the CRT wood posts to allow for breakaway capability. The holes allow raw exposure to the environment, which can lead to faster degradation of the post. In addition, the wood is treated with chemical preservatives, making it a hassle to dispose of according to environmental laws. The concerns of using CRT wood posts led to the development of the Universal Breakaway Steel Post (UBSP). The UBSP needed to mimic all breakaway properties of the CRT wood post so that it could serve as a replacement for the wood post in guardrails.

1.3.2.2. Phase I: Investigating the Use of a New Universal Breakaway Steel Post: 2009 (12, 13)

1.3.2.2.1. CRT Wood Post Breakaway Testing

To mimic the properties of CRT wood posts, the UBSP needed to match the bending capacities along the strong, weak, and diagonal axis under similar loading conditions. Also, the shape and mass of the UBSP needed to be comparable to a CRT wood post so it would have the same breakaway characteristics and rotational resistance in the soil. Nine tests were conducted with CRT wood posts in a rigid sleeve to determine dynamic properties of the posts. This provided parameters for the development of the UBSP. The averages of the results from the nine tests are listed in the table below. The tests used southern yellow pine at three impact angles. Table 1.7 presents a summary of results on the CRT wood post bogie tests. From these results and previous experience with CRT posts, MwRSF concluded the peak forces were 12 kips, 8 kips, and 6 kips on the strong, diagonal, and weak axis, respectively.

Table 1.7. Summary of CRT Wood Post Bogie Test Results (*13*).

Test Number	Impact Angle (degrees)	Impact Velocity (mph)	Initial Peak Force		Energy at 5-inch Displacement	Final Total Energy	
			Displacement (inches)	Force (kips)	Energy (kips-inch)	Displacement (inches)	Energy (kip-inch)
MNCRT-1, MNCRT-2, MNCRT-3	0	15.14	1.45	10.27	16.4	12.22	22.69
MNCRT-4, MNCRT-5, MNCRT-6	90	15.82	1.5	9.07	16.9	11.47	21.05
MNCRT-7, MNCRT-8, MNCRT-9	45	15.87	2.79	10.78	23.13	12.21	29.52

1.3.2.2.2. Concept Development of the UBSP

The difficult aspect of developing the UBSPs was using ductile steel to recreate the bending properties of brittle wood. Several concepts were originally introduced and narrowed down to five based on ease of production, cost, and potential to match the characteristics of the CRT wood post. The five concepts included:

- Steel tube in steel tube.
- Steel tube in steel tube with through bolt.
- Upper fiberglass reinforced plastic.
- Fracturing bolt base.
- Circular fillet weld.

In the first round of testing, the five concepts were narrowed down to the circular fillet weld and fracturing bolt concepts. This was based on the practicality and the performance of the five concepts during testing. The two concepts went on to a second round of testing. The fracturing bolt (slipbase) concept consists of two plates, one welded to the top of the base tube and the other welded to the bottom of the post. The two plates are then connected by four breakaway bolts. The design is intended to allow the bolts on the impact side to break in tension and the bolts on the non-impact side to break in shear. The circular fillet weld concept consists of a splice plate with circular holes on the front and back of the posts. The circular holes on the plate are fillet welded to the top post. The failure of the post is based on the failure of the welding.

During the second round of testing, researchers concluded that the fracturing bolt concept was the best option because the circular fillet weld concept depended too much on the variation of the welding.

Prior to a third round of testing for the fracturing bolt concept, researchers conducted a set of tests to evaluate the breakaway properties of a CRT wood post in soil. Earlier testing of breakaway properties was done with the post in a rigid sleeve. Table 1.8 summarizes the test results for the CRT wood posts in soil.

Table 1.8. Wood CRT in Soil (*13*).

Test Number	Impact Velocity (mph)	Impact Angle (degrees)	Peak Load (kips)	Expected Peak Loads from Previous Testing (kips)	Failure Type
UBSP-14	19.1	0	8.3	12	Post Failure
UBSP-15	20.5	0	5	12	Post Rotation
UBSP-16	20.2	90	4	6	Post Rotation
UBSP-17	20.6	90	5	6	Post Failure
UBSP-18	20.0	45	7	8	Post Rotation
UBSP-19	20.0	45	5	8	Post Rotation

The variation in the compaction and strength of soil was apparent in the results of the wood post in soil. This variation can be seen in Tests UBSP-15, UBSP-16, and UBSP-19 where the failure was due to post rotation and a smaller peak load than expected. Also, the large difference in the expected peak load and the experimental peak load in Test UBSP-14 demonstrates the variance in the quality of wood. At the breakaway point of the post in this test, there was a large knot in the wood.

A third round of testing was done with the fracturing bolt steel post to ensure it would match the breakaway properties as the wood posts in soil, and to test the post on the diagonal axis that had not been tested in round 2. Table 1.9 summarizes the second and third rounds of tests of the fracturing bolt UBSP.

Table 1.9. Round 2 and 3 of Tests of Fracturing Bolt Steel Post (*13*).

Test Number	Impact Angle (degrees)	Peak Load (kips)	Soil Type	Description
UBSP-9 (round 2)	0	11	Standard strong soil	One of the impact side nuts stripped off instead of the bolt fracturing
UBSP-10 (round 2)	90	6.42	Standard strong soil	Bolts fractured in tension
UBSP-13 (round 2)	0	5	Standard strong soil	Did not break at expected force level, but did absorb significant energy
UBSP-20 (round 3)	0	10.8	Standard strong soil	Bolts fractured in tension
UBSP-21 (round 3)	45	8.3	Standard strong soil	Bolts fractured in tension and there was damage to the flange

In round two, there were two tests conducted at the same impact angle because in Test UBSP-9, one of the impact side nuts stripped off instead of the bolt fracturing. Test UBSP-13 was conducted to ensure that the behavior of the bolt would fracture instead of the nut stripping. This was done by replacing the double end stud with a hex bolt of the same size (refer to and). MwRSF contributed the small peak load in Test UBSP-13 to the poor impaction of the soil causing the post to rotate instead of breaking away.

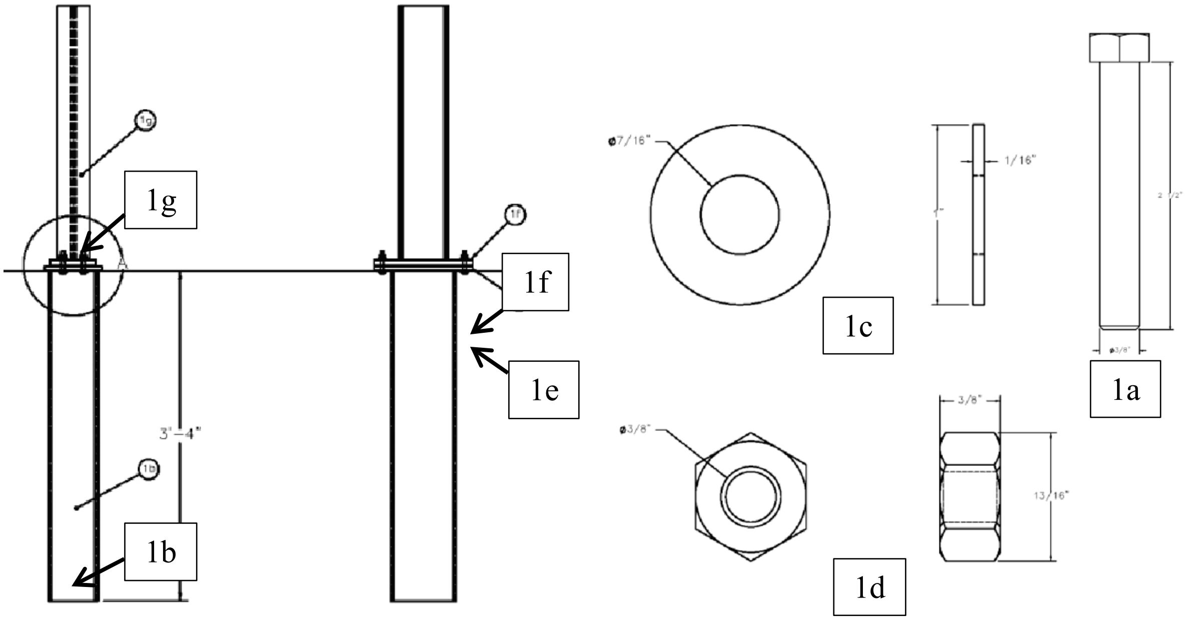


Figure 1.34. Fracturing Bolt Steel Post Design (*13*).

Table 1.10. Details on Fracturing Bolt Steel Post (*13*).

Item No.	Quantity	Description	Material Spec
1a	4	⅜-inch diameter ×2½-inch long Hex	Grade 5
1b	1	6×8×0.1875×40 Foundation Tube	A500
1c	16	⅜-inch Flat Washer	Grade 5
1d	4	⅜-inch Heavy Hex Nut	Grade 5
1e	1	12×7×0.5 Steel Plate	A36
1f	1	12×5.5×0.75 Steel Plate	A36
1g	1	W6×9×30.75	

1.3.2.2.3. Testing the Universal Steel Breakaway Post: UBSPN-1 (*13*)

The barrier design for this test consisted of 28 posts with 14 on each side of the system. On one side of the system, the first post was a BCT post. The next 11 posts were UBSPs and the final two were BCT posts with cable anchors. The other side was an exact mirror. Figure 1.35 shows a diagram of the system.

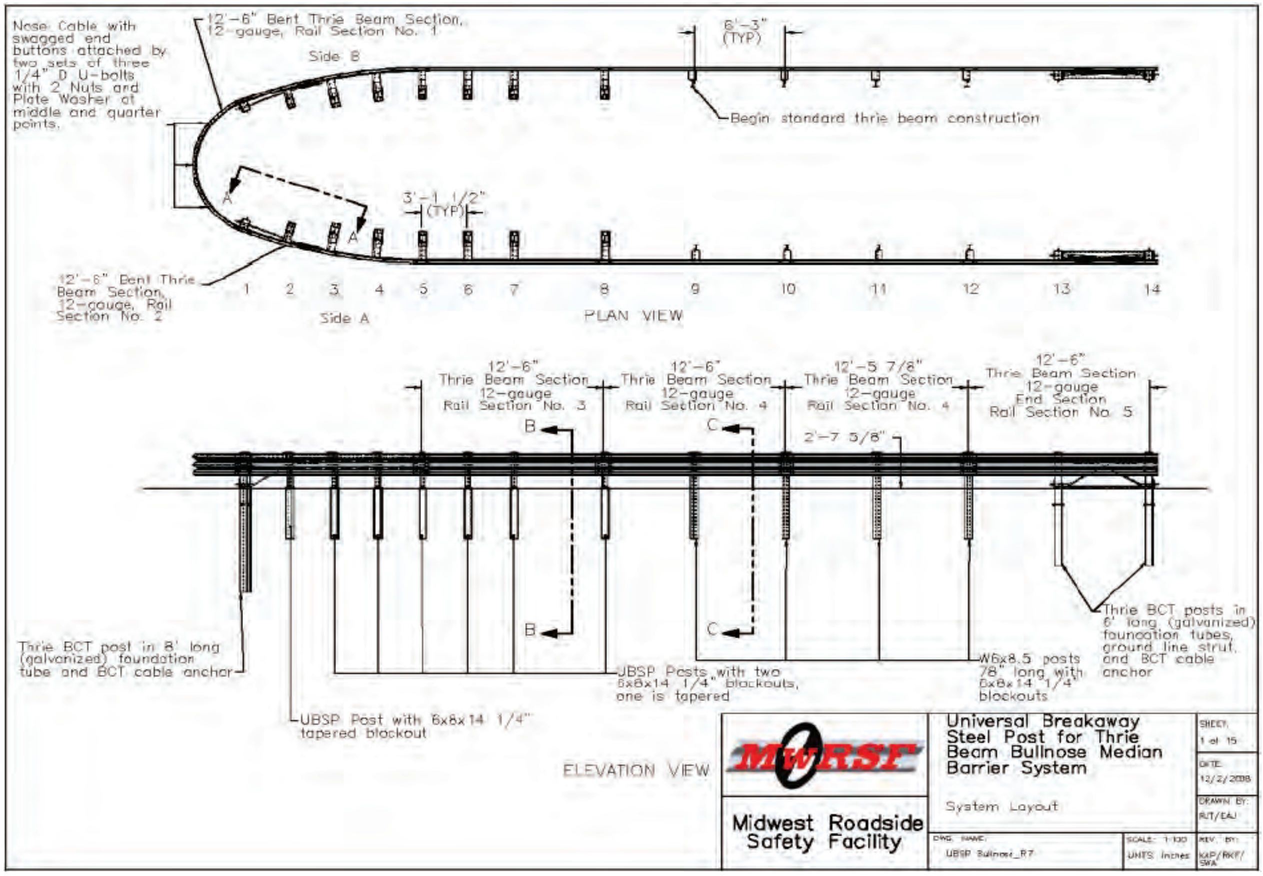


Figure 1.35. Barrier Design Detail of UBSPN-1 (*13*).

The test was conducted according to *NCHRP Report 350* test designation 3-38. A 4473-lb pickup truck impacted the centerline of post 2A at 63.2 mph and an angle of 22.6°.

At impact, the rail immediately began to deform, fracturing the posts near the impact point. It continued to penetrate the barrier even with the release of the cable anchor. As the truck neared the end of the slotted rail, the rail began to buckle, causing the rail to drop to the ground on the passenger side. The truck then began to ramp and override the rail. It made contact with the ground on the front left side, and the continuing momentum of the truck caused it to roll onto its roof. Figure 1.36 shows final displacement of the vehicle.

The truck had moderate damage mostly caused by the roll. The barrier had extensive damage with flattening and tearing. Most of the damage was done on the impact side (side A) with the first 8 posts fracturing. On side B, only posts 11 and 12 were damaged. The system was considered unacceptable according to *NCHRP Report 350* because of the truck override and subsequent rollover. Figure 1.37 shows sequential photographs of the test.

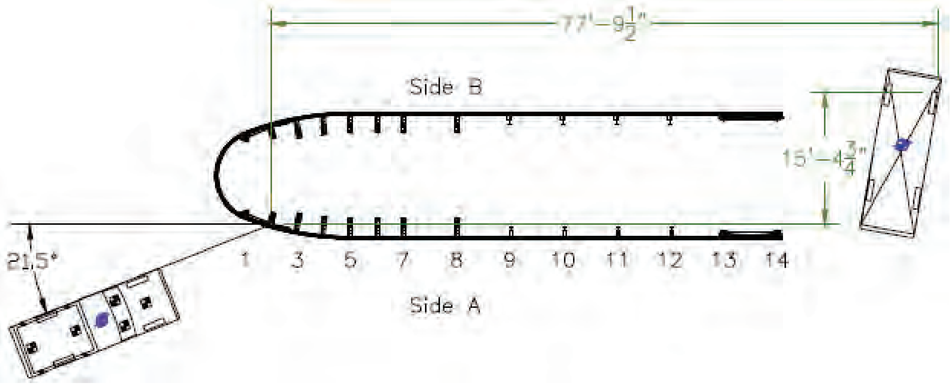


Figure 1.36. Vehicle Final Position for Test UBSPN-1 (*13*).

Figure 1.37. Sequential Photographs for Test UBSPN-1 (*13*).

1.3.2.3. Phase II: Investigating the Use of a New Universal Breakaway Steel Post: 2010 (14)

1.3.2.3.1. UBSPN-2

Test UBSPN-1 was compared to previous *NCHRP Report 350* test designation 3-38 crash tests with CRT wood posts and steel post bullnose systems to find the causes of failure. It was observed that in UBSPN-2, the fracturing bolt posts broke away more quickly than the CRT wood posts. Post 2 actually did not break away as quickly as expected, causing the truck to have greater redirection than in similar previous tests with CRT wood posts.

For this test, modifications were considered based on the occurrences in test UBSPN-1. They include:

- Changing the second post from a UBSP to a BCT breakaway wood post.
- Reducing the embedment depth for the UBSPs.
- Adding another section of slotted thrie beam to both sides.
- Increasing the strength of the fracturing-bolt steel post. Figure 1.38 shows a diagram of the new barrier design.

The test was conducted according to *NCHRP Report 350* test designation 3-38. A 4470-lbpickup truck impacted the centerline of post 2 at 62.9 mph and an angle of 21.7°.

At impact, the rail began to deform. The posts near the impact point fractured and the rail wrapped around the front of the truck, beginning to contain it. The truck continued to penetrate the system, making contact with the other side of the setup and coming to a stop. There was severe damage to the barrier on the impact side (side A) including guardrail buckling and flattening, and posts 1 through 8 were all fractured. On side B, there was minimal damage where posts 1 through 3 were fractured. Since the vehicle was successfully captured and did not ramp or roll, the system was considered acceptable according to *NCHRP Report 350*. Figure 1.39 shows the final displacement of the vehicle and Figure 1.40 shows sequential photographs of the test.

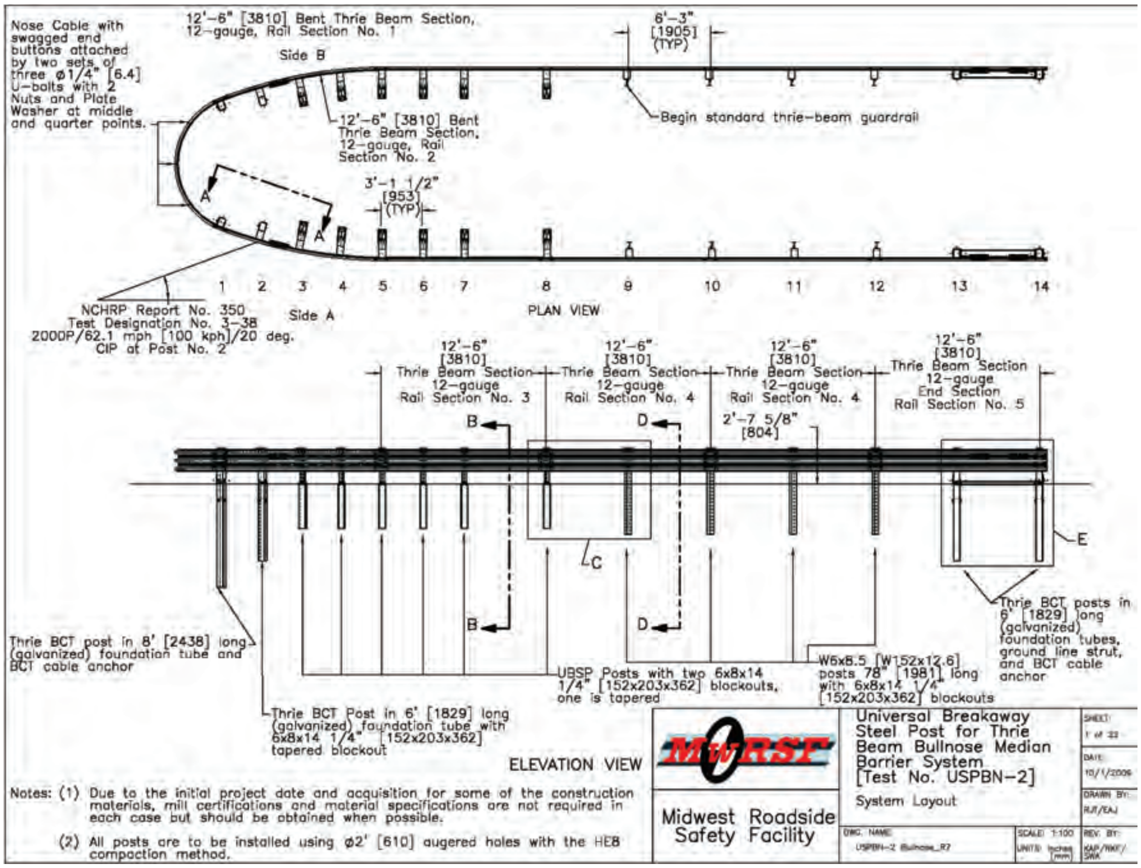


Figure 1.38. Barrier Design Detail of UBSPN-2 (*14*).

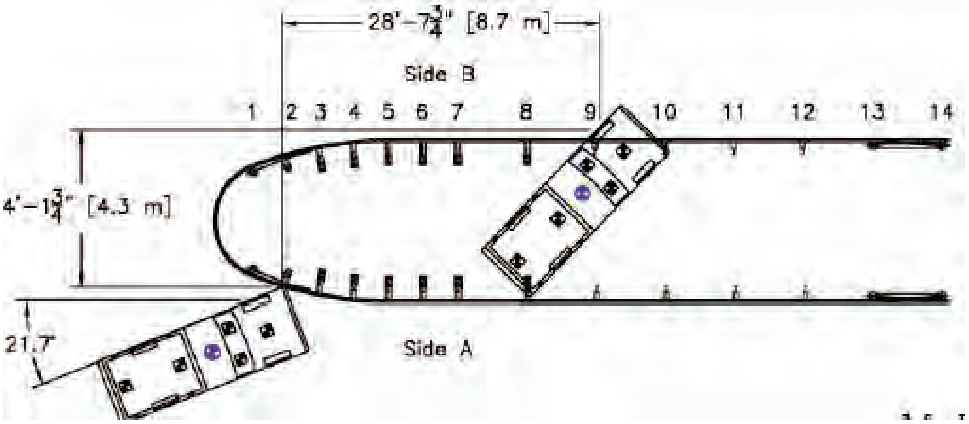


Figure 1.39. Vehicle Final Position Test UBSPN-2 (*14*).

0.000 sec 0.152 sec 0.344 sec 0.492 sec 1.110 sec

Figure 1.40. Sequential Photographs for Test UBSPN-2 (*14*).

1.3.2.4. Phase III: Investigating the Use of a New Universal Breakaway Steel Post: 2010 (15)

1.3.2.4.1. UBSPN-3

A 2024-lb car impacted the barrier at 63.3 mph and an angle of 0°. The system barrier design was the same as UBSPN-2. At impact, the rail immediately began to deform. On side A, the first three posts were fractured and post 4 was twisted. On side B, the first four posts were fractured, post 5 blockouts were rotated, and the rail-to-post bolts on post 6 were pulled out. There was no visible damage to posts 5 through 14 on side A and posts 7 through 14 on side B. The damage to the vehicle was moderate and the beam suffered from buckling, tearing, and flattening. The test was considered adequate because the vehicle was contained and the OIVs and RDAs of both directions were within the limits of *NCHRP Report 350* test designation 3-30. Figure 1.41 shows final displacement of the vehicle, and Figure 1.42 shows sequential photos of the test.

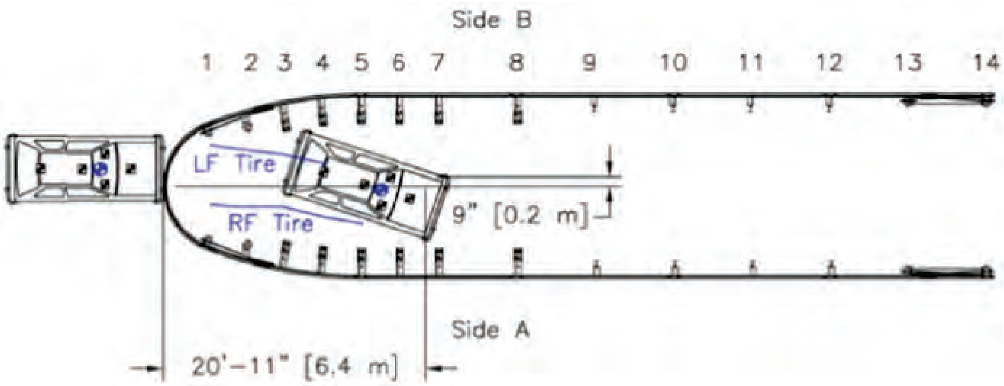


Figure 1.41. Vehicle Final Position Test UBSPN-3 (*15*).

0.000 sec 0.112 sec 0.212 sec 0.366 sec 0.632 sec

Figure 1.42. Sequential Photographs for Test UBSPN-3 (*15*).

1.3.2.4.2. UBSPN-3

A 4429-lb pickup truck impacted the barrier at 64.5 mph and an angle of 0°. The system barrier design was the same as UBSPN-2. At impact, the rail immediately began to deform. On Side A, posts 1 through 6 and post 8 were fractured and post 7 was bent and twisted. Posts 9 and 10 had ½-inch soil gaps. On Side B, the first seven posts were fractured and post 8 was bent slightly. There was no visible damage to posts 11 through 14 on Side A and posts 9 through 14 on Side B. The damage to the vehicle was moderate, and the beam suffered from buckling, tearing, and flattening. The test was considered adequate because the vehicle was contained and the OIVs and RDAs of both directions were within the limits of *NCHRP Report 350* test designation 3-31. Figure 1.43 shows final displacement of the vehicle, and Figure 1.44 shows sequential photographs of the test.

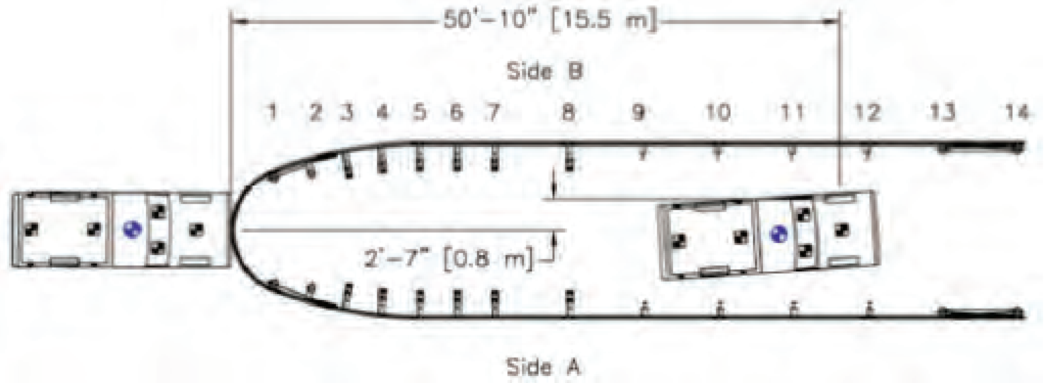


Figure 1.43. Vehicle Final Position UBSPN-4 (*15*).

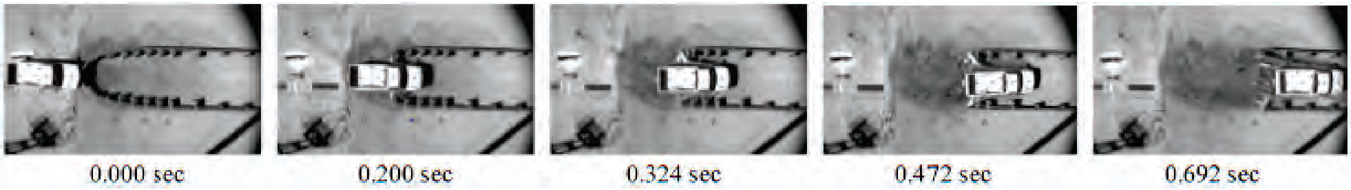


Figure 1.44. Sequential Photographs for Test UBSPN-4 (*15*).

1.3.2.5. Primary Findings

From the full scale crash tests and the bogie tests, MwRSF confirms that the fracturing bolt UBSP is sufficient to replace CRT wood posts under similar conditions. Also, MwRSF believes the foundation tube and foundation plate can be reused as long as these do not display any deformation. During testing, MwRSF observed that replacing step washers with standard washers in the fracturing bolt post design allowed the bolts on the non-impact side of the post to break in shear instead of tension. Table 1.11 provides a summary of pertinent results from the bullnose barrier tests.

Table 1.11. Summary of Bullnose Barrier Tests (*15*).

Test Number	Guardrail Description	Test Condition	Test Vehicle (lb)	Impact Speed (mph)	Impact Angle (degrees)	OIV (ft/s) Longitudinal Lateral	RDA (Gs) Longitudinal Lateral	Vehicle Safely Redirected
UBSPN-1	First post was BCT anchor post	*NCHRP Report 350* Test 3-38	4473	63.2	22.6	21.05 2.68	11.36 6.03	No
UBSPN-2	First two posts were BCT anchor posts	*NCHRP Report 350* Test 3-38	4471	62.9	21.7	28.15 0.74	15.11 17.39	Yes
UBSPN-3	Same system as UBSPN-2	*NCHRP Report 350* Test 3-38	2026	63.3	0	32.18 4.08	7.70 7.79	Yes
UBSPN-4	Same system as UBSPN-2	*NCHRP Report 350* Test 3-31	4429	64.5	0	21.75 0.21	7.84 7.34	Yes

1.3.3. Evaluation of Existing T-Intersection Guardrail Systems: 2010 (*16*)

TTI conducted a study to determine if previously tested short radius guardrail systems met *NCHRP Report 350* TL-2 criteria. The focus was on the crash tests done in Yuma County, Arizona. Table 1.12 shows a summary of the *NCHRP Report 350* test conditions required for TL-2.

Table 1.12. *NCHRP Report 350* TL-2 Criteria (*16*).

Feature	Feature Type[a]	Test Designation	Impact Conditions		
			Vehicle	Nominal Speed (km/h)	Nominal Angle, θ (degrees)
Terminals and Redirective Crash Cushions	G/NG	2-30	820C	70	0
	G/NG	2-31	2000P	70	0
	G/NG	2-32	820C	70	15
	G/NG	2-33	2000P	70	15
	NG	2-36	820C	70	15
	NG	2-37	2000P	70	20
	NG	2-38	2000P	70	20
	G/NG	2-39	2000P	70	20

[a] G/NG—Test applicable to gating and nongating devices
NG—Test applicable to nongating devices

The researchers concluded that tests YC-5 and YC-6 passed on the test conditions for *NCHRP Report 350* test designations 2-32 and 2-36, respectively, for the small car. Also, tests YC-4 and YC-7 passed for test conditions for *NCHRP Report 350* test designations 2-33 and 2-37, respectively, for the pickup truck. Tests conditions for 2-30, 2-31, and 2-38 were satisfied by a cluster of Yuma County tests; and from engineering review, test 2-39 was considered unnecessary. Based on these conclusions, an *NCHRP Report 350* TL-2 T-intersection system was recommended. Figure 1.45 shows details of the recommended system.

The T-intersection system is a 27-inch high rail system. The nose section of this T-intersection system consists of a 12½ ft curved W-beam segment, which has an 8-ft radius. The curved section is attached to a straight W-beam section on the secondary road via common W-beam splicing details. The secondary road W-Beam should be 25 ft minimum and should be terminated with a positive anchor. Five CRT posts, spaced at 6.25 ft, were placed along the curved section and secondary road section. On the primary road direction, the curved section is spliced to a short W-beam segment (6.25 ft) at CRT post 7. The short W-beam section has also two posts measuring 7⅞ × 7⅞ × 72 inches embedded 44 inches in soil.

Starting at post 9, a stiffer rail section is used as a transition to the bridge rail. The transition section consists of a W-beam guardrail, backed by an MC8 × 22.8 structural steel channel that runs from post 9 to the bridge barrier. The transition has three timber posts, which measure 9⅞ × 9⅞ × 78 inches. They are embedded 50 inches in soil. The five timber posts (post 8 to post 12) have 7⅞ × 7⅞ × 14-inch wood blockouts.

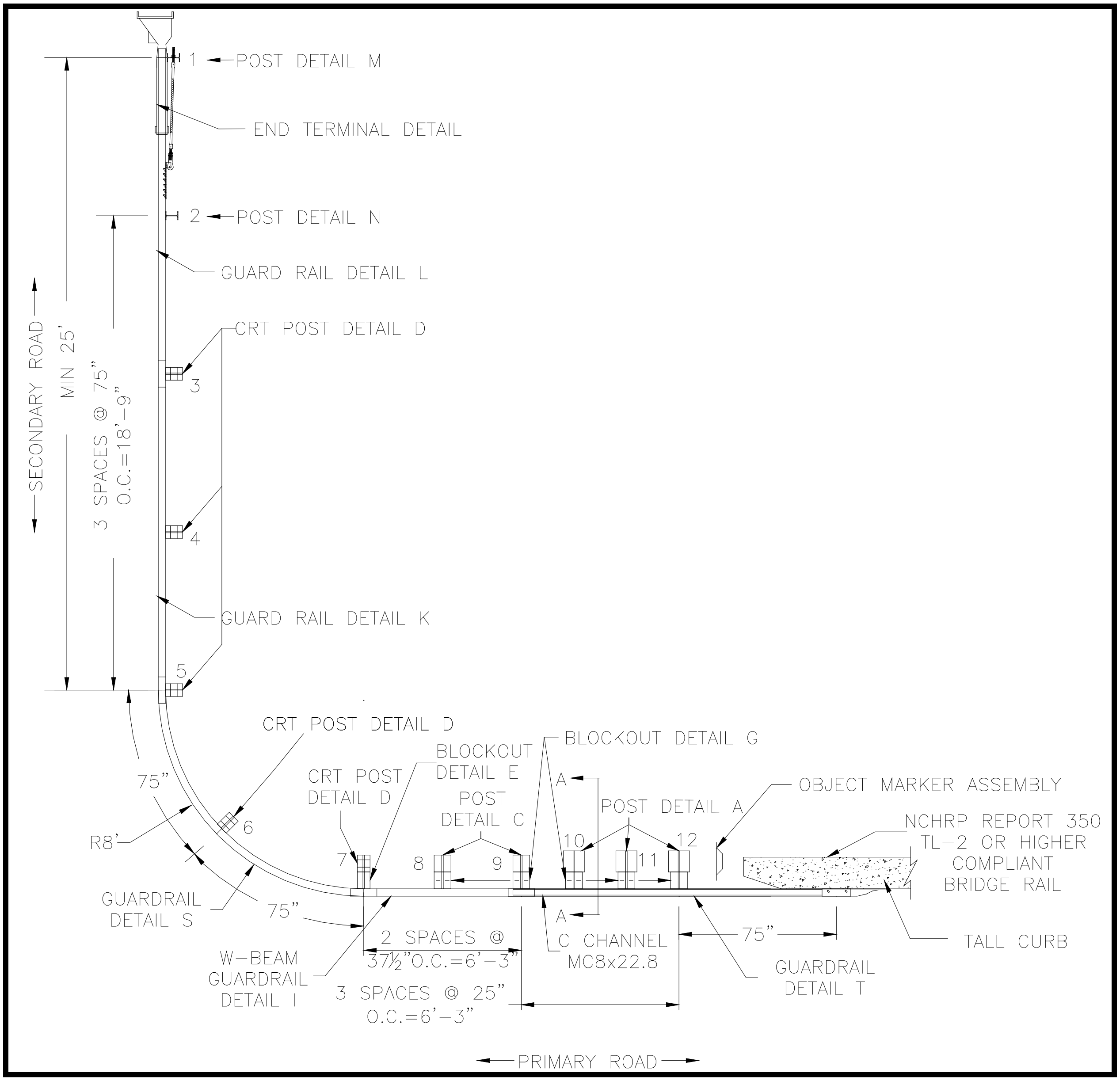


Figure 1.45. Recommended *NCHRP Report 350* TL-2 T-Intersection System (*16*).

CHAPTER 2. SHORT RADIUS CONCEPTS

2.1. SUMMARY OF PREVIOUS LITERATURE REVIEW

2.1.1. Primary Findings

The last short radius TL-3 test that MwRSF conducted showed promising performance (*9*). Enlarging transverse holes in the first post on the primary side, as well as two posts on the secondary side, reducing slot tab size in the nose section, and attaching the first three posts on each side to the guardrail with washers improved the overall performance of the system by minimizing the amount of debris that the vehicle encountered. However, aside from not passing AASHTO *MASH* criteria, the pickup truck required a substantial working width behind the short radius rail, as shown in Figure 2.1 and Figure 2.2. This working width (67.5 ft along the primary road and 38.3 ft along the secondary road) is not available in most intersection locations due to site geometrical constraints.

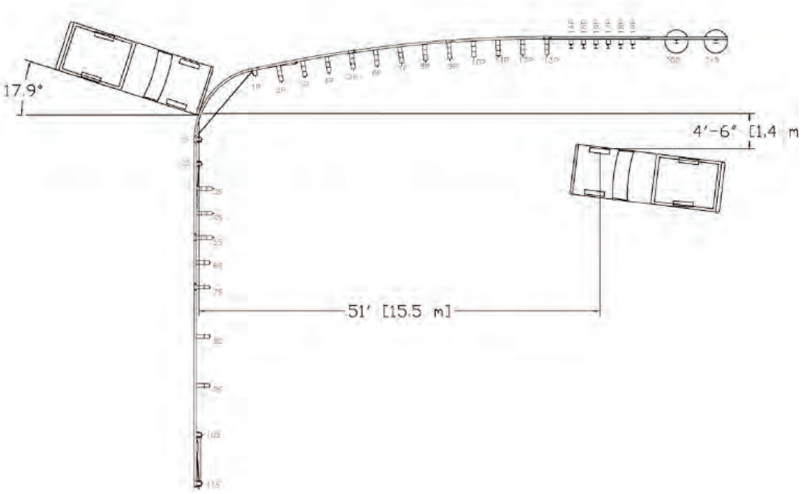


Figure 2.1. Final Vehicle Position for MwRSF Test SR-8 (*9*).

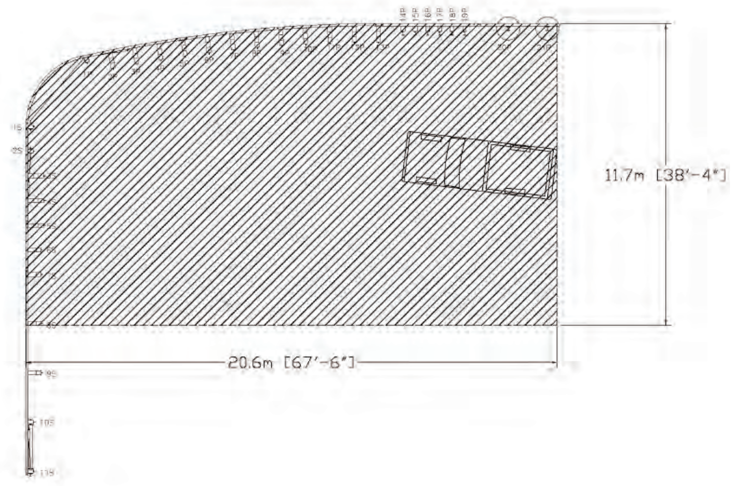


Figure 2.2. Working Width for MwRSF Test SR-8 (*9*).

2.1.2. Recommended Test Matrix

The test matrices that *MASH* defined are broken down into tests for terminals and tests for crash cushions. However, a short radius guardrail acts as a both a terminal and a crash cushion, so deciding which recommended tests are critical poses a significant challenge. Investigation of the geometry of a short radius system suggests the critical tests will be 3-30, 3-31, 3-32, 3-33, and 3-35. Table 2.1 lists the test parameters, and Figure 2.3 shows their impact locations.

Table 2.1. *MASH* TL-3 Recommended Test Matrix.

Test Number	Vehicle Designation	Impact Speed	Impact Angle	Impact Tolerance (KE)
3-30	1100C	62 mph	0°	≥288 kip-ft
3-31	2270P	62 mph	0°	≥594 kip-ft
3-32	1100C	62 mph	5−15°	≥288 kip-ft
3-33	2270P	62 mph	5−15°	≥594 kip-ft
3-35	2270P	62 mph	25°	≥106 kip-ft

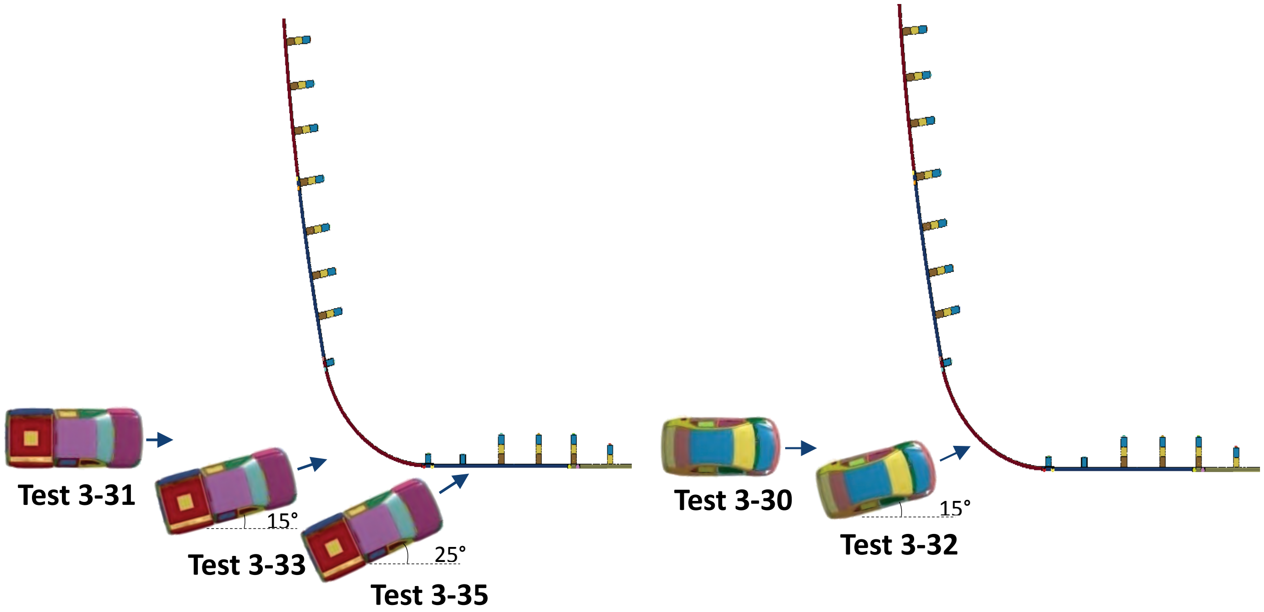


Figure 2.3. *MASH* TL-3 Recommended Test Matrix.

2.2. BASE (TEMPLATE) SHORT RADIUS SYSTEM

The template short radius system used for initial concepts and modeling simulations is based on the *NCHRP Report 350* TL-2 short radius system (*16*) and TxDOT standard 31-inch transition details. Both the *NCHRP Report 350* TL-2 short radius design and the TxDOT transition are shown in Figure 2.4 and Figure 2.5, respectively. The intersection system is comprised of a 12.5-ft curved W-beam section with an 8-ft radius. This section is attached to a W-beam for the secondary road measuring a minimum of 25-ft, and is terminated with a positive anchor, allowing the beam to rotate. The primary road is connected to the curved section with a spliced short W-beam segment measuring 6.25 ft. Along this spliced section, two posts measuring 7⅞ × 7⅞ × 72 inches are embedded 44 inches into the soil.

2.3. CONCEPT ANALYSES

Some simplifications were made during the concept development as needed for efficient simulation. Multiple sections of the rail were bolted together in the real system but were made into one continuous rail with uniform cross-sectional area and inertia throughout the simplified model. The W-beams were simplified to a rectangular cross section of equivalent inertia to that of the original rail. A rail height of 31 inches was selected to account for the increased *MASH* TL-3 vehicular center of gravity. Also, the soil under the system was not included in the model but springs were used instead to simulate the elasticity of the soil. Basic boundary conditions were used in lieu of rail end treatments and simple connections were incorporated instead of bolts.

2.3.1. Baseline Simulation

This model was used as a benchmark for subsequent simulations. It has no attenuators or energy-absorbing systems behind the curved section of the rail. It was used to determine the effectiveness of subsequent design concepts. Figure 2.6 provides several sequential images of the model run. Table 2.2 lists the outcome of the Test Risk Assessment Program (TRAP), which is used for calculating occupant impact velocity, ridedown acceleration, and other pertinent results.

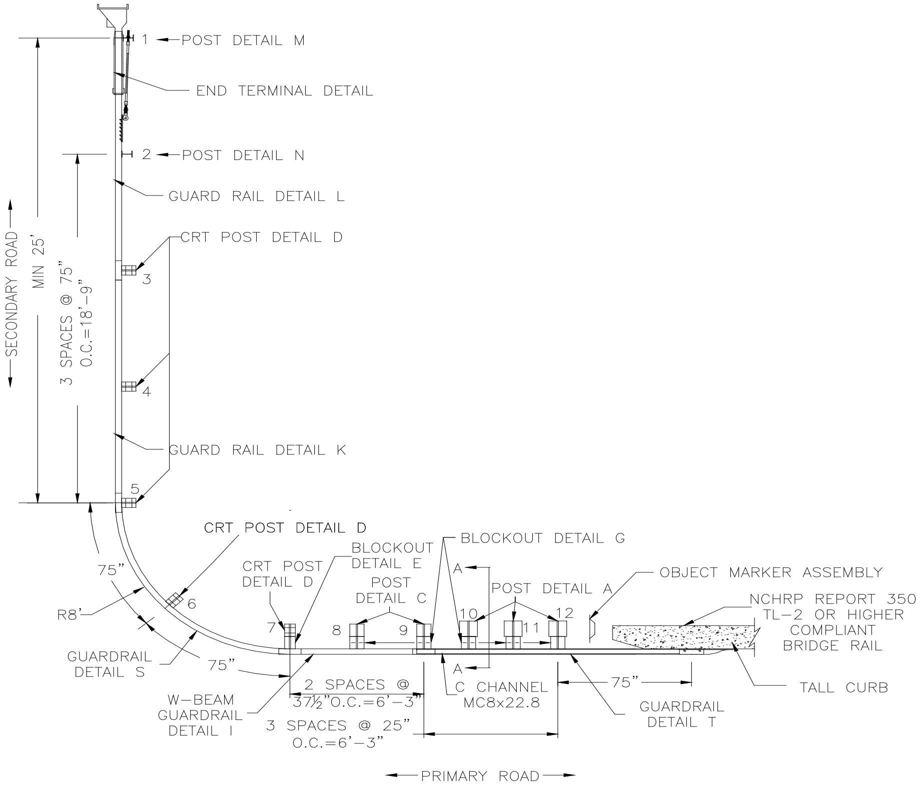


Figure 2.4. Base Short Radius System (*16*).

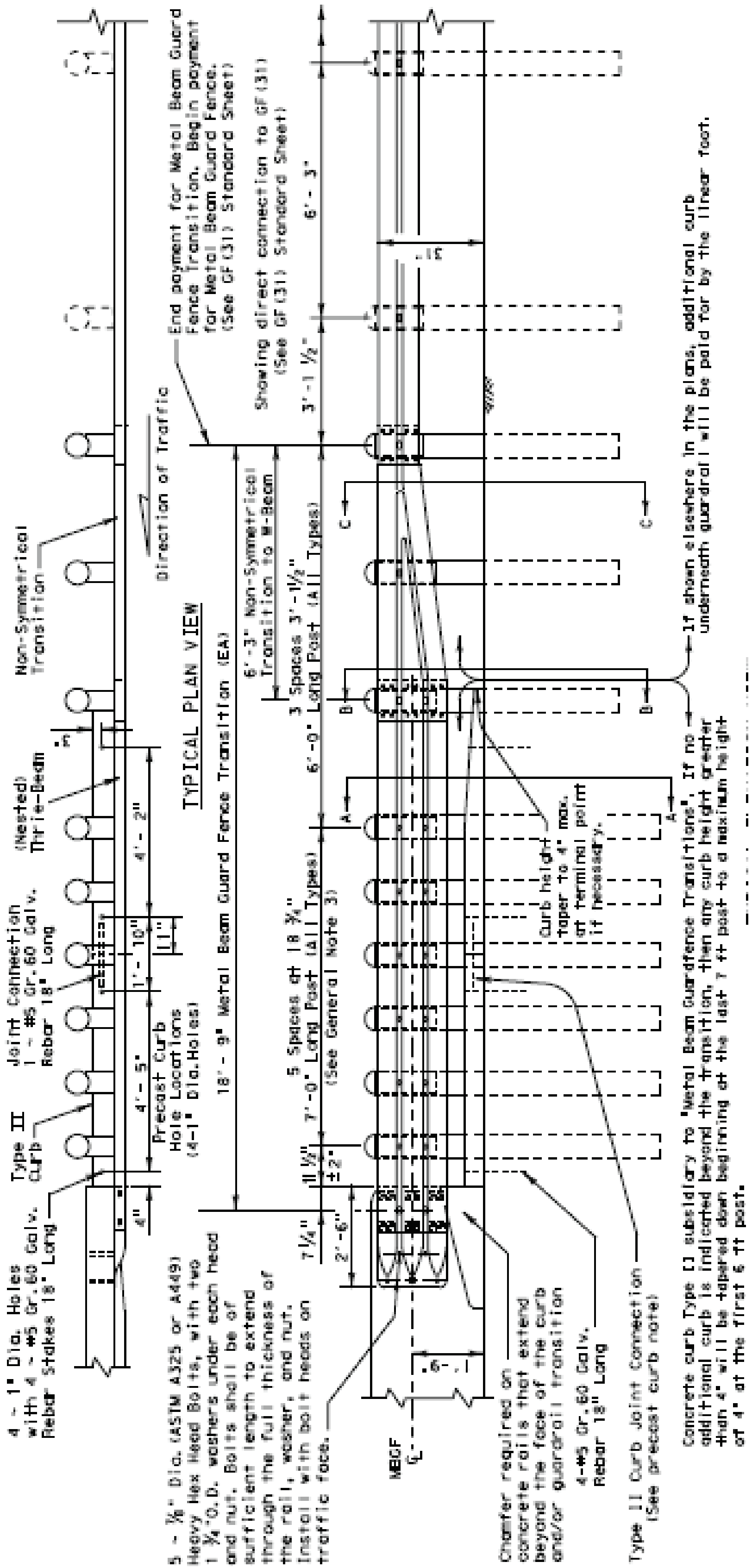
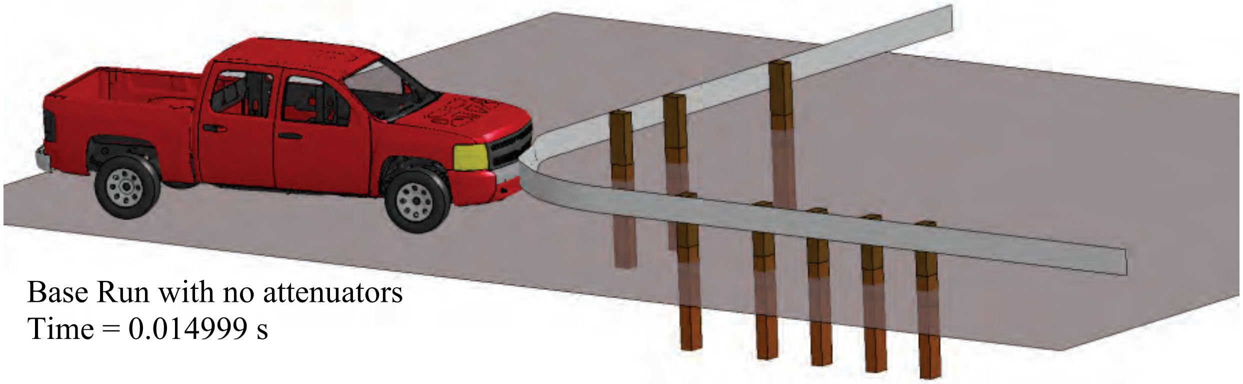
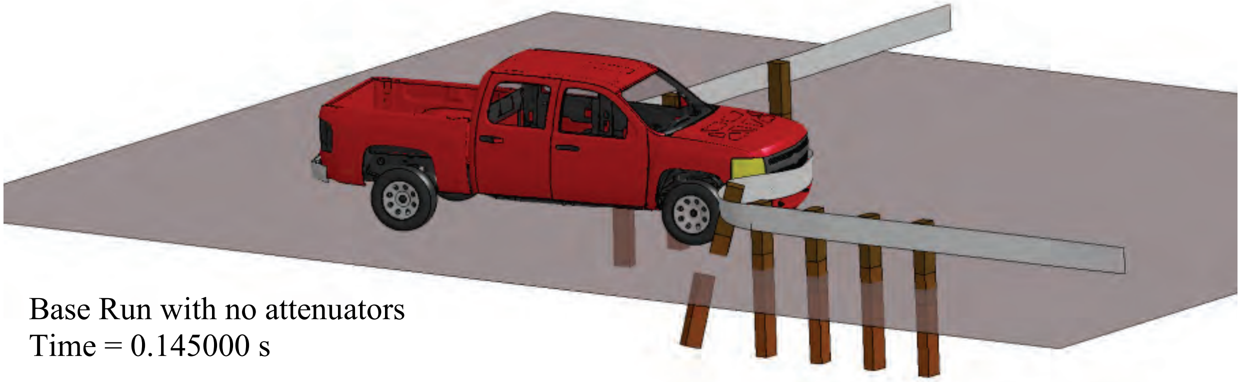


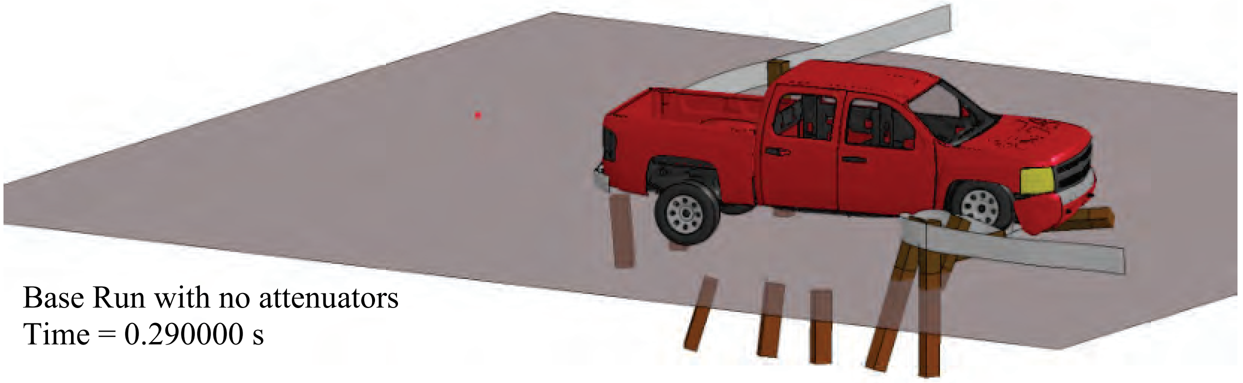
Figure 2.5. TxDOT Transition Detail GF (31) TR-11.



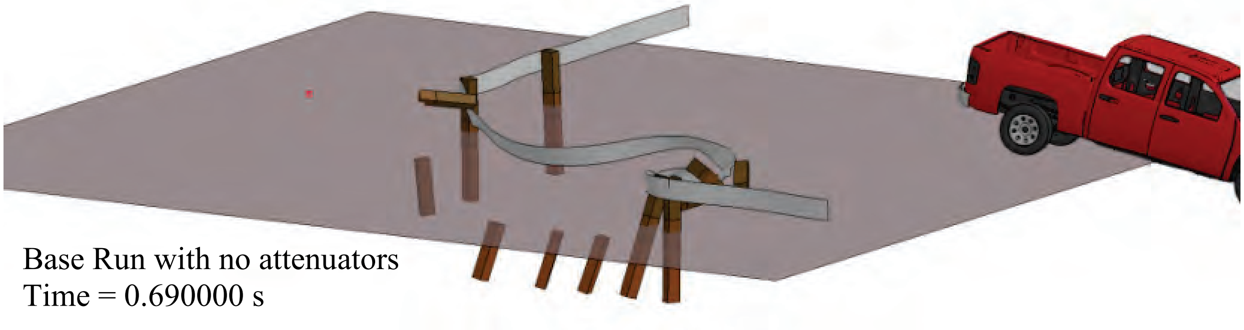
Base Run with no attenuators
Time = 0.014999 s



Base Run with no attenuators
Time = 0.145000 s



Base Run with no attenuators
Time = 0.290000 s



Base Run with no attenuators
Time = 0.690000 s

Figure 2.6. Sequential Images of Truck Impact with Baseline System.

Table 2.2. Baseline Simulation.

TL 3-33 Chevy Silverado	
Impact Speed, mph	62.2
Impact Angle, degrees	15.0
Initial Kinetic Energy of Vehicle, ft-lb	631,515
Kinetic Energy of Vehicle at End of Run, ft-lb	337,349 (47% reduction)
X-Velocity of Vehicle at End of Run, ft/s	63.57
Max Occupant Impact Velocity (OIV), ft/s	15.09
Ridedown Acceleration, Gs	11.0
Maximum Angle Movement, degrees	17.9 (pitch)

The results for this test proved that the system without any attenuators would absorb very little energy, and the vehicle was still moving at a relatively high velocity when the simulation ended. These findings were used as a foundation for comparing the results of design concepts and the efficiency of each system.

2.3.2. Sliding Posts

Sliding posts were implemented for this system. Figure 2.7 shows the sliding posts. Figure 2.8 depicts the whole system. Figure 2.9 presents sequential images of the truck impact. There were no CRT posts in the nose section for this concept. Five W6×9 steel posts were placed in the nose section and weighted to create friction due to the contact between the soil and the sled bases. As a result, energy would ideally be absorbed from friction instead of fracture on impact. Results revealed that the sled did not actually absorb any significant initial energy from the collision. Modeling this concept provided the findings given in Table 2.3.

This concept intended for the sleds to stay in contact with the ground to provide resistance to the vehicle impact on the system; however, it can be seen from the images of the model run that this was not the case. In order for the concept to be effective, the posts would need to be heavier to create enough friction for energy absorption. The necessary weight for this to work proved that constructing the sliding posts from steel would be impractical.

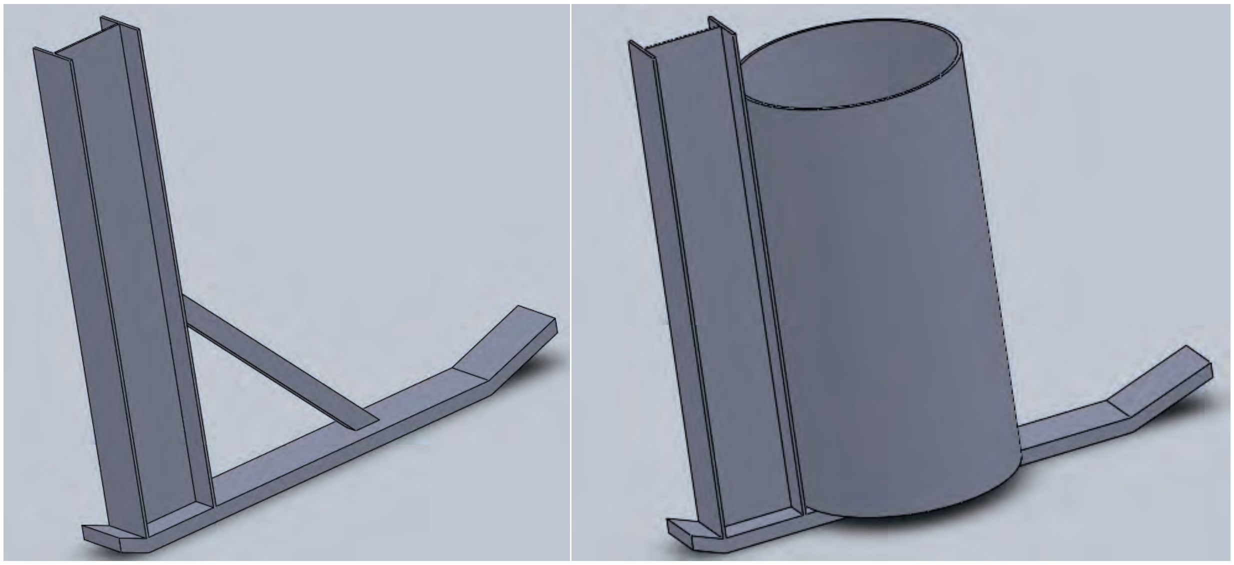


Figure 2.7. Sliding Post Models.

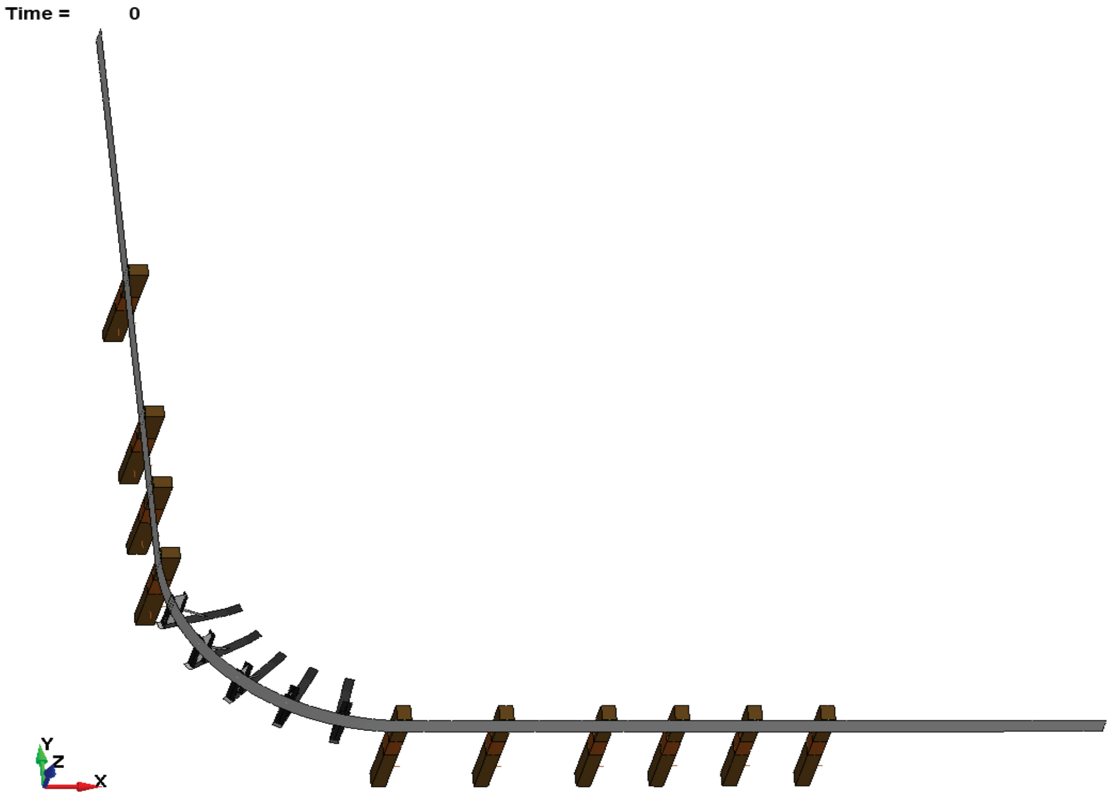


Figure 2.8. Short Radius Design with Sliding Posts.

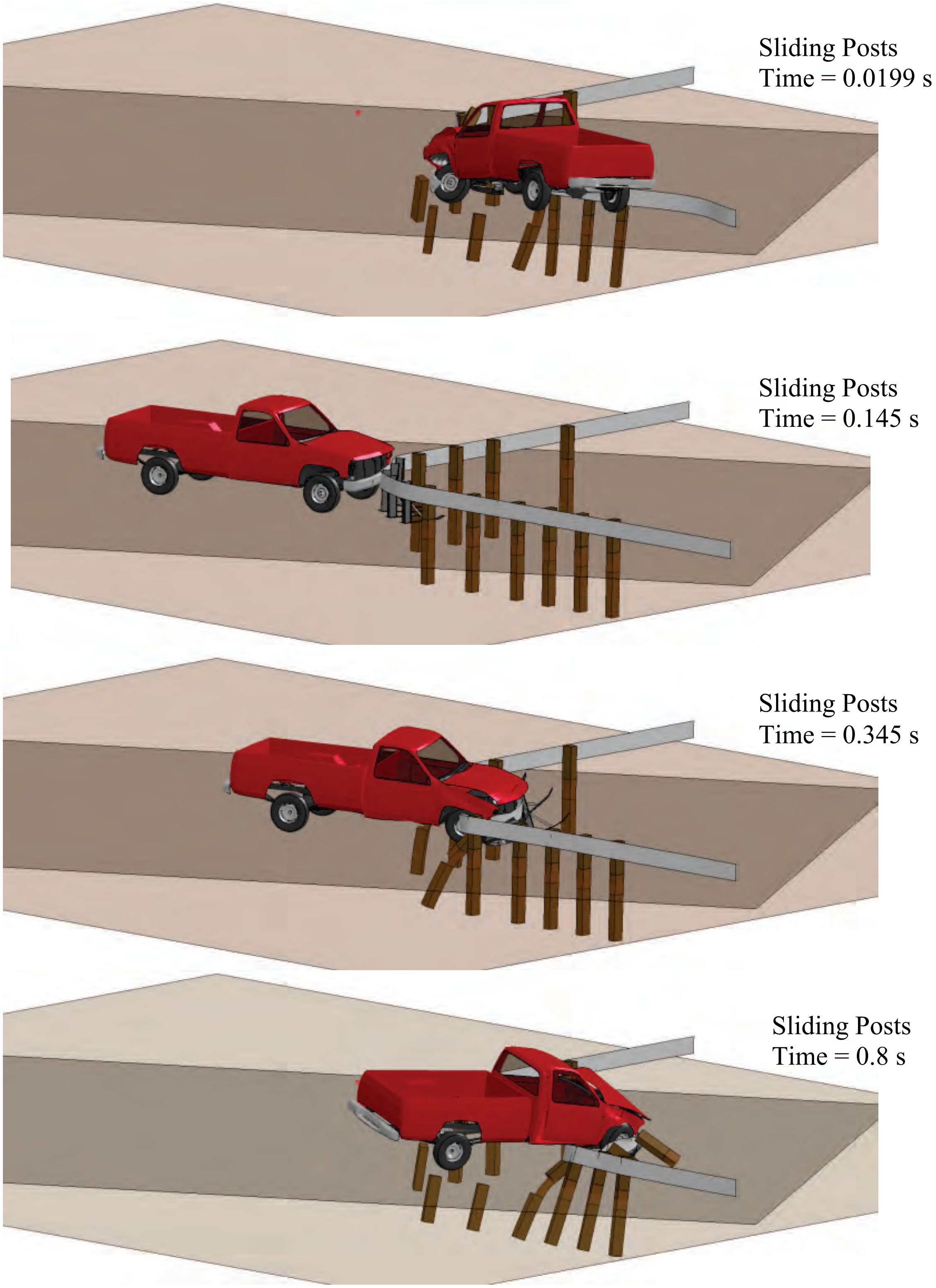


Figure 2.9. Sequential Images of Truck Impact with Sliding Posts System.

Table 2.3. Sliding Posts System.

TL 3-33 C2500	
Impact Speed, mph	62.2
Impact Angle, degrees	15.0
Initial Kinetic Energy of Vehicle, ft-lb	524,578
Kinetic Energy of Vehicle at End of Run, ft-lb	40,418 (92% reduction)
X-Velocity of Vehicle at End of Run, ft/s	−1.75
Max OIV, ft/s	32.48
Ridedown Acceleration, Gs	12.7
Maximum Angle Movement, degrees	211.3 (yaw)

2.3.3. Parallel Cable to Post

The concept of parallel cables uses the initial TTI T-intersection system with two additional cables behind the nose of the guardrail to help contain the vehicle. The cables behind the system were ½-inch in diameter, and a CRT post was placed at the center of the curved guardrail section. Figure 2.10 shows a visual representation of the concept. Several systems were modeled using 3, 4, 5, and 6 cables. However, the results revealed that only the cables perpendicular to the point of impact were effective because they were the only ones that were placed in tension upon contact. The two-cable system was modeled and yielded the results shown in Table 2.4. Figure 2.11 presents sequential images of the truck impact.

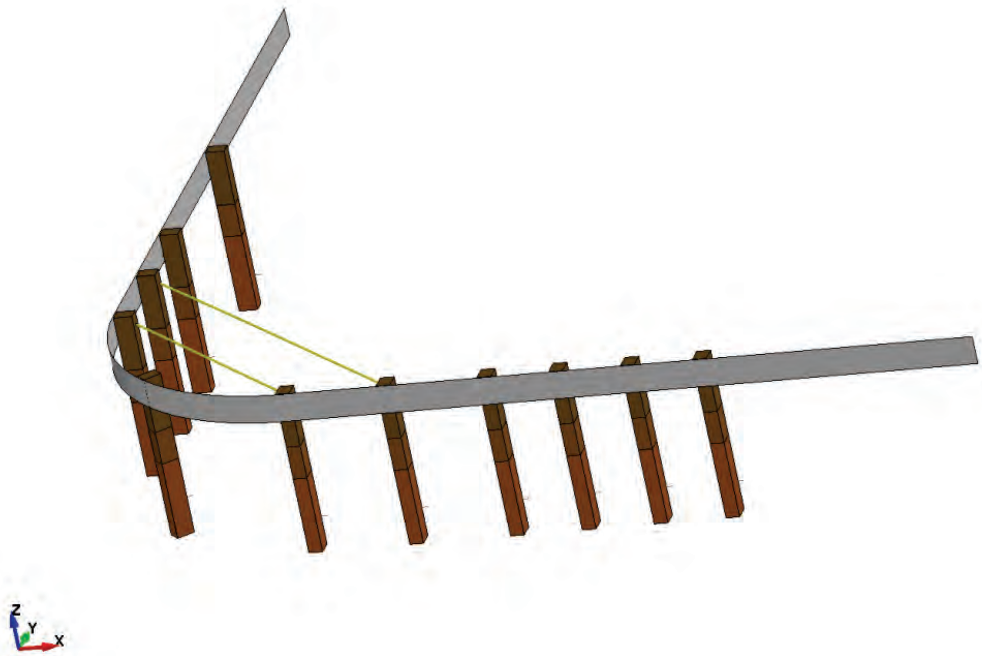


Figure 2.10. Short Radius Design with Parallel Cables Attached to Posts.

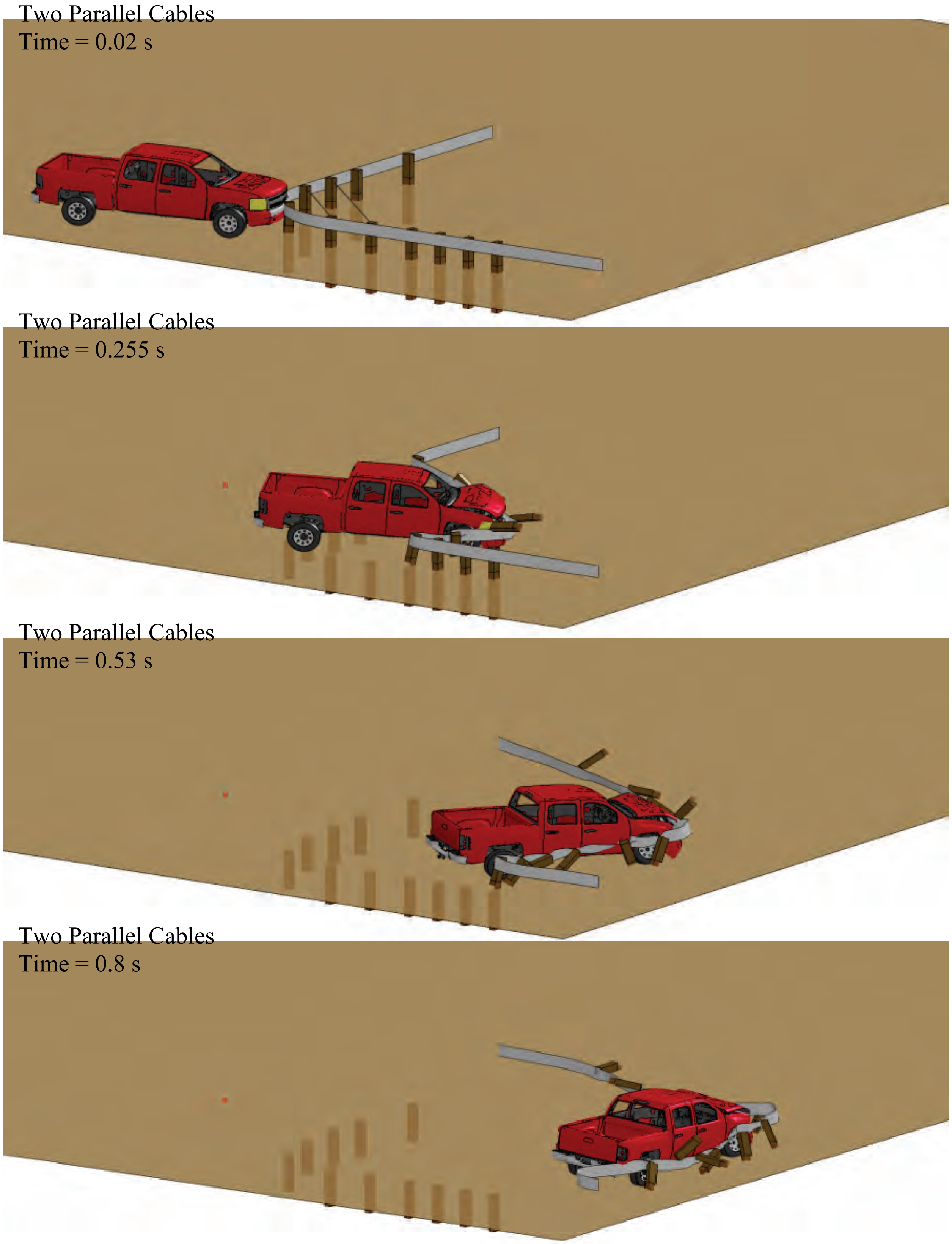


Figure 2.11. Sequential Images of Truck Impact with Parallel Cables Attached to Posts.

Table 2.4. Parallel Cables to Post.

TL 3-33 Chevy Silverado	
Impact Speed, mph	62.2
Impact Angle, degrees	15.0
Initial Kinetic Energy of Vehicle, ft-lb	631,516
Kinetic Energy of Vehicle at End of Run, ft-lb	44,229 (93 % reduction)
X-Velocity of Vehicle at End of Run, ft/s	15.8
Max OIV, ft/s	24.28
Ridedown Acceleration, Gs	7.7
Maximum Angle Movement, degrees	76.3 (yaw)

According to the results, this concept was considered promising because the vehicle did not override the system. It was at a complete stop at the end of the run, and the system absorbed almost twice the amount of internal energy as the base system. The TRAP results also revealed that the occupant impact velocity and ridedown acceleration would pass the safety requirements of *NCHRP Report 350* TL-3.

2.3.4. Stacked Parallel Cables

When the cable concept was tested, the cables were attached to the posts rather than the rail. Attaching the cables to the rail would be the realistic situation and Figure 2.12 illustrates this concept. A model test was run to determine the consequence of attaching the cables to the rail rather than to the posts. The results from this test proved that there was little difference between attaching cables to the rail and previous analyses based on attaching cables to the posts. However, the cables will need to be attached to the rail when detailed simulations and crash tests are performed.

2.3.5. Four Stacked Cables Attached to Rail

Based on the effectiveness of the two-cable system at absorbing energy, it seemed logical to double the cables behind the system. This two-cable concept was the first that brought the vehicle to a stop without exceeding OIV or ridedown acceleration. The vehicle did not override the system, and there was almost no roll or pitch during the simulation. Figure 2.13 shows a visual representation of the system, and Table 2.5 gives the TRAP results for this concept.

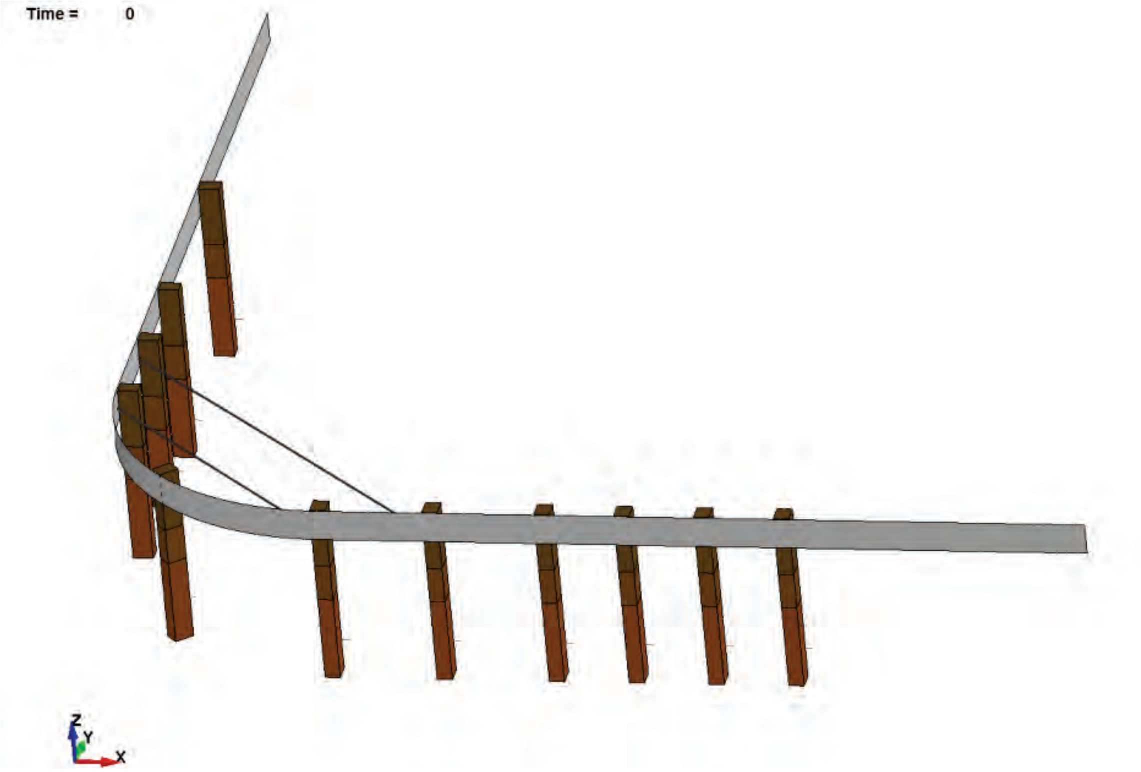


Figure 2.12. Short Radius Design with Parallel Cables Attached to Rail.

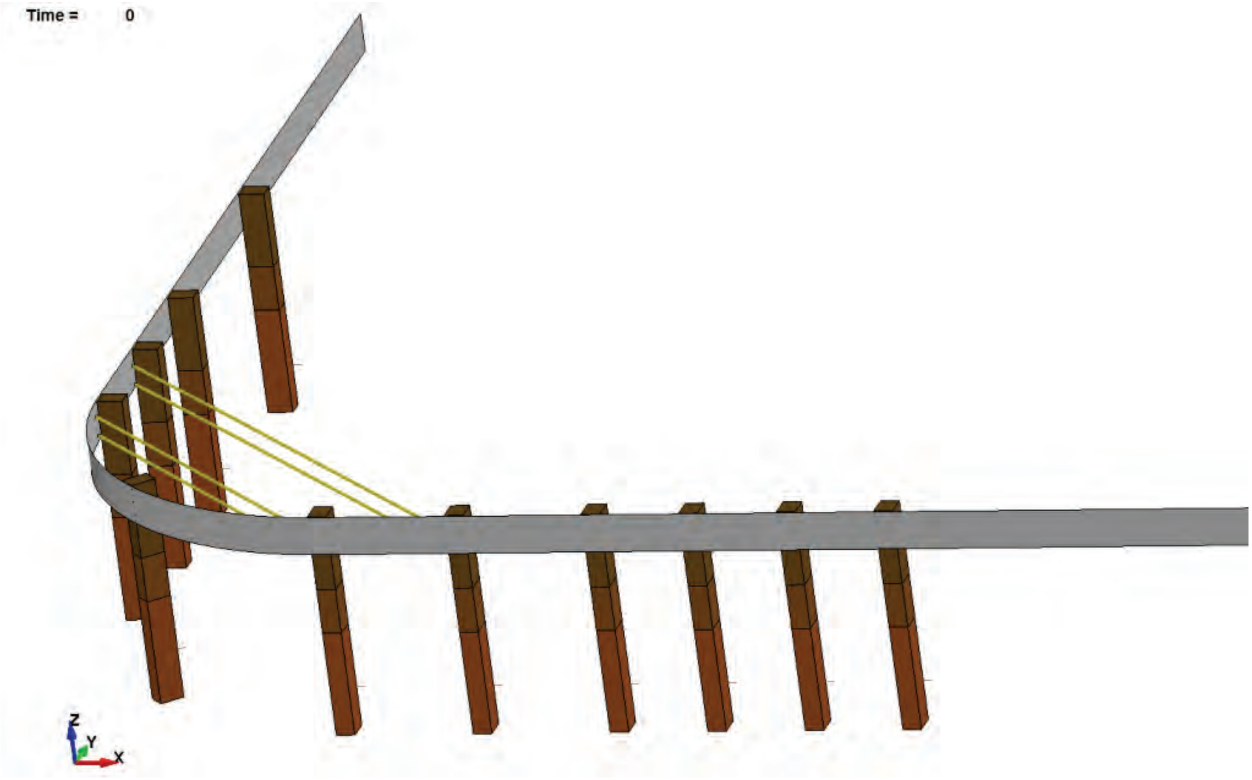


Figure 2.13. Four Stacked Parallel Cables to Rail.

Table 2.5. Four Stacked Cables Attached to Rail.

TL 3-33 Chevy Silverado	
Impact Speed, mph	62.2
Impact Angle, degrees	15.0
Initial Kinetic Energy of Vehicle, ft-lb	631,516
Kinetic Energy of Vehicle at End of Run, ft-lb	22,100 (97% reduction)
X-Velocity of Vehicle at End of Run, ft/s	1.98
Max OIV, ft/s	24.93
Ridedown Acceleration, Gs	18.4
Maximum Angle Movement, degrees	156 (yaw)

2.3.6. Sand-Filled Barrels

Steel barrels filled with sand were used for a crash cushion design to absorb kinetic energy from the vehicle impact. The idea came from the use of traditional crash attenuators. The number of barrels and back connectivity was varied for multiple simulations to determine what setup would be the most effective. Figure 2.14 shows an example of this concept.

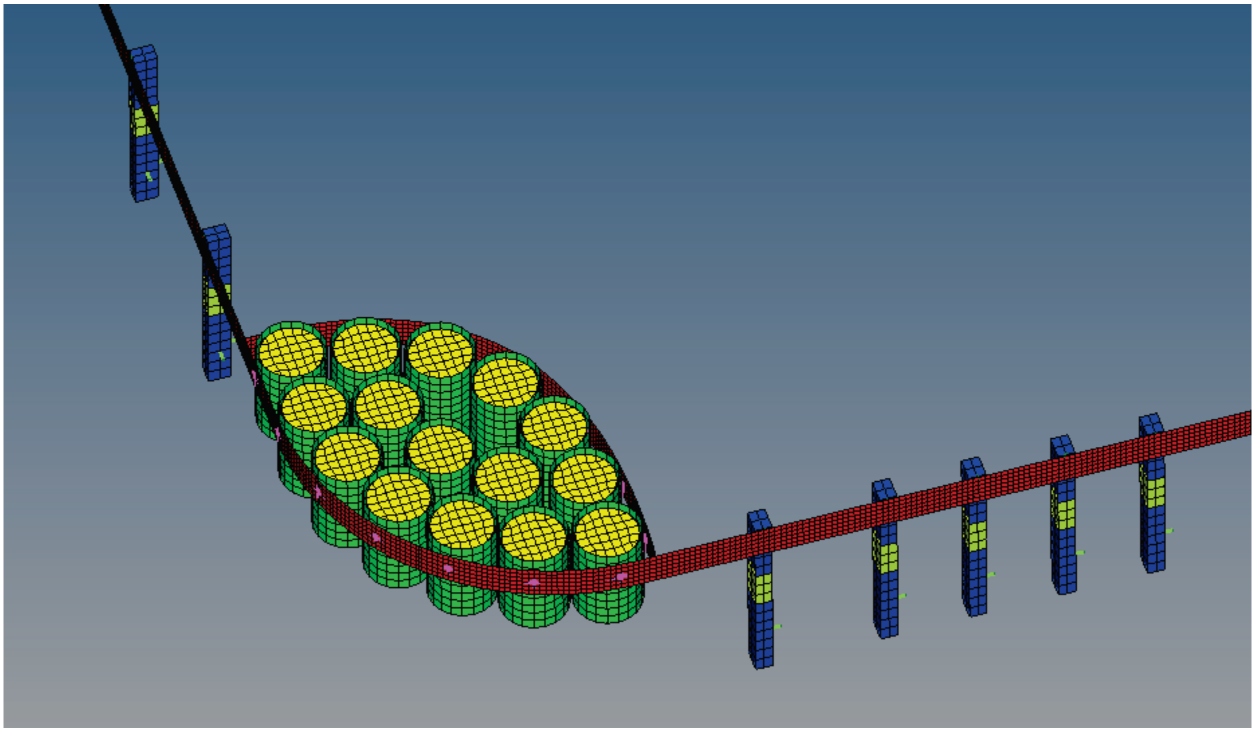


Figure 2.14. Short Radius Design with Sand-Filled Barrels.

2.3.6.1. 5-Barrel System with Back Rail

A crash cushion was simulated with five barrels behind the guardrail held in place by a back rail. Figure 2.15 presents sequential images of the truck impact. Table 2.6 gives the results for this concept. The results from the model show that the occupant impact velocity (indicated in red) was too high for *NCHRP Report 350* recommended values.

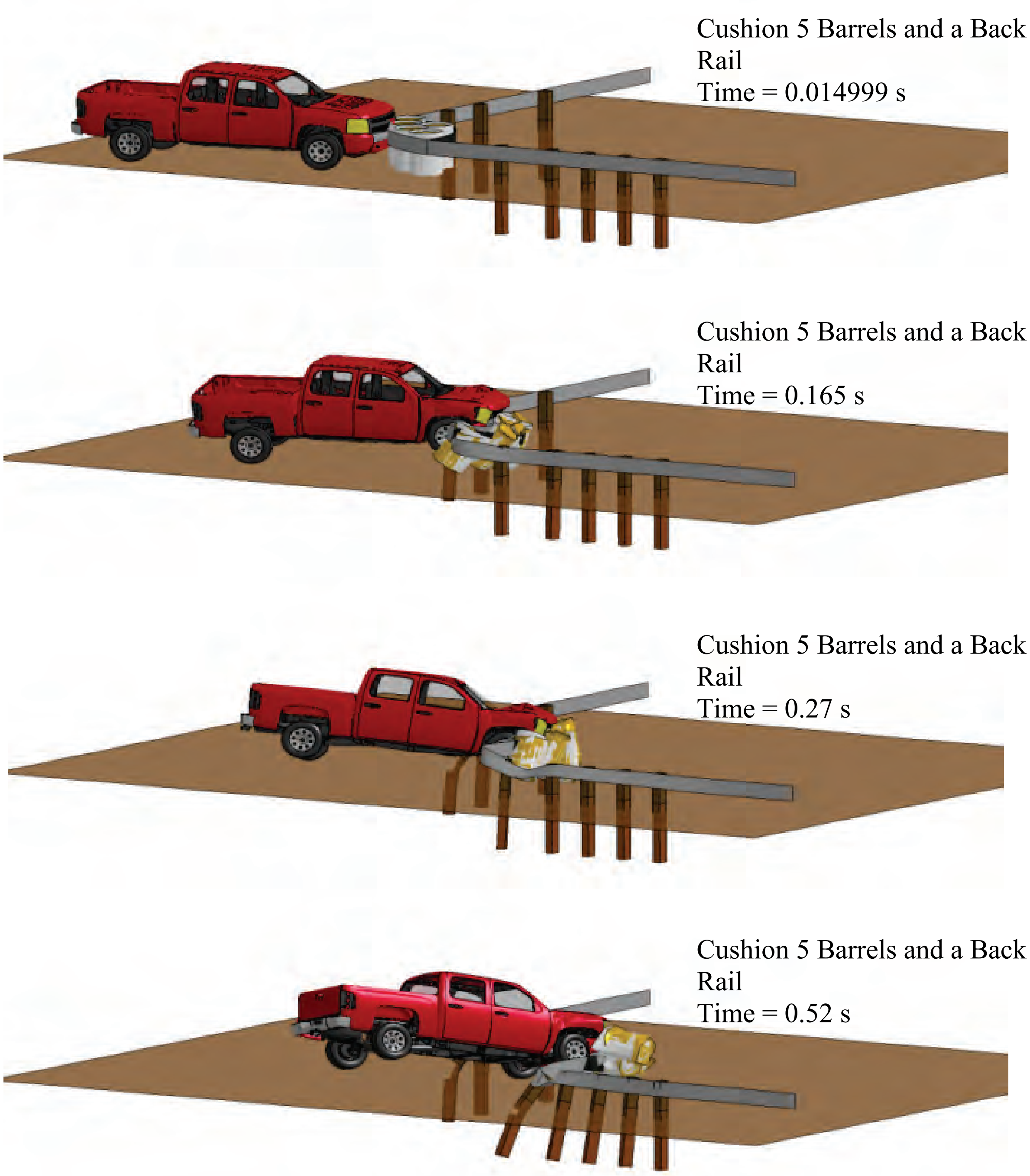


Figure 2.15. Sequential Images of Truck Impact with 5-Barrel System with Back Rail.

Table 2.6. 5-Barrel System with Back Rail.

TL 3-33 Chevy Silverado	
Impact Speed, mph	62.2
Impact Angle, degrees	15.0
Initial Kinetic Energy of Vehicle, ft-lb	631,518
Kinetic Energy of Vehicle at End of Run, ft-lb	20,245 (97% reduction)
X-Velocity of Vehicle at End of Run, ft/s	2.66 (0.81)
Max OIV, ft/s	51.51
Ridedown Acceleration, Gs	9.0
Maximum Angle Movement, degrees	46.3 (yaw)

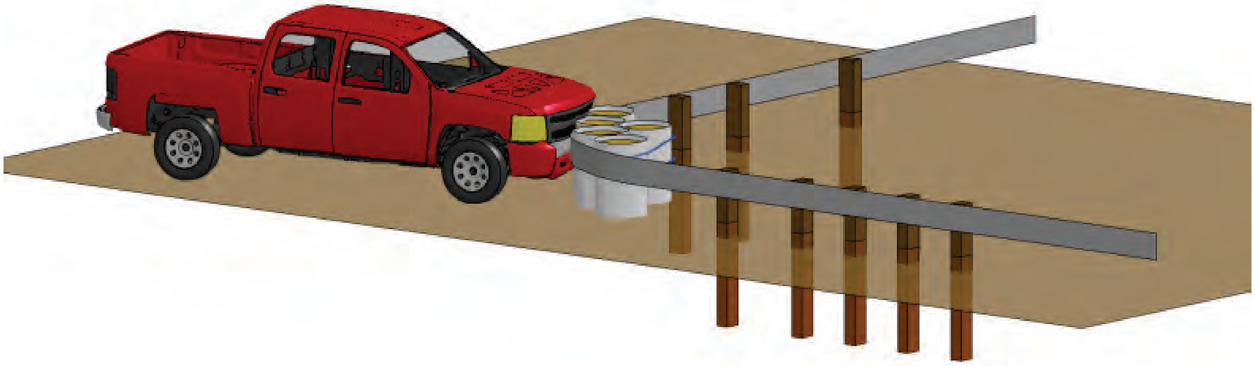
2.3.6.2. 5-Barrel System with Two Cables

The 5-barrel crash cushion was kept in place with two cables instead of a back rail. Table 2.7 gives the TRAP results for this model. Figure 2.16 depicts sequential images of the truck impact. Using the cables instead of a back rail had very little effect on the results. The vehicle did not override the system or pitch upward significantly. In addition, the vehicle was almost brought to a complete stop by the system. However, the occupant impact velocity was still very high, violating *MASH* TL-3 OIV criterion limit.

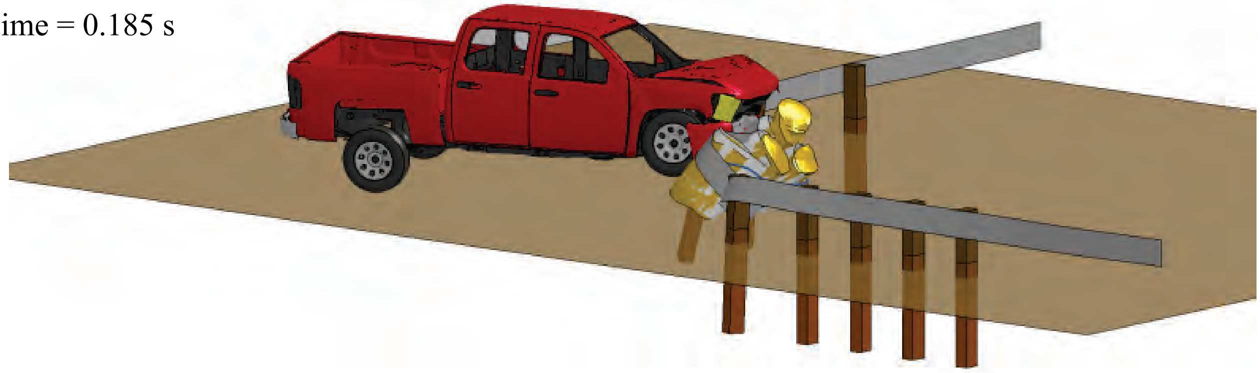
Table 2.7. 5-Barrel System with Two Cables.

TL 3-33 Chevy Silverado	
Impact Speed, mph	62.2
Impact Angle, degrees	15.0
Initial Kinetic Energy of Vehicle, ft-lb	631,519
Kinetic Energy of Vehicle at End of Run, ft-lb	11,251 (98% reduction)
X-Velocity of Vehicle at End of Run, ft/s	2.61
Max OIV, ft/s	52.17
Ridedown Acceleration, Gs	−10.5
Maximum Angle Movement, degrees	36.4 (yaw)

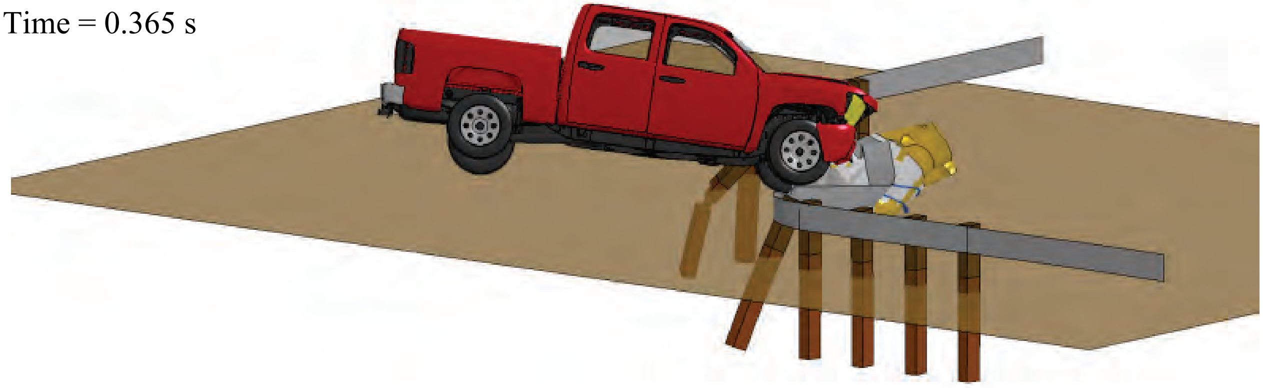
Cushion 5 Barrels and 2 Cables
Time = 0.02 s



Cushion 5 Barrels and 2 Cables
Time = 0.185 s



Cushion 5 Barrels and 2 Cables
Time = 0.365 s



Cushion 5 Barrels and 2 Cables
Time = 0.515 s

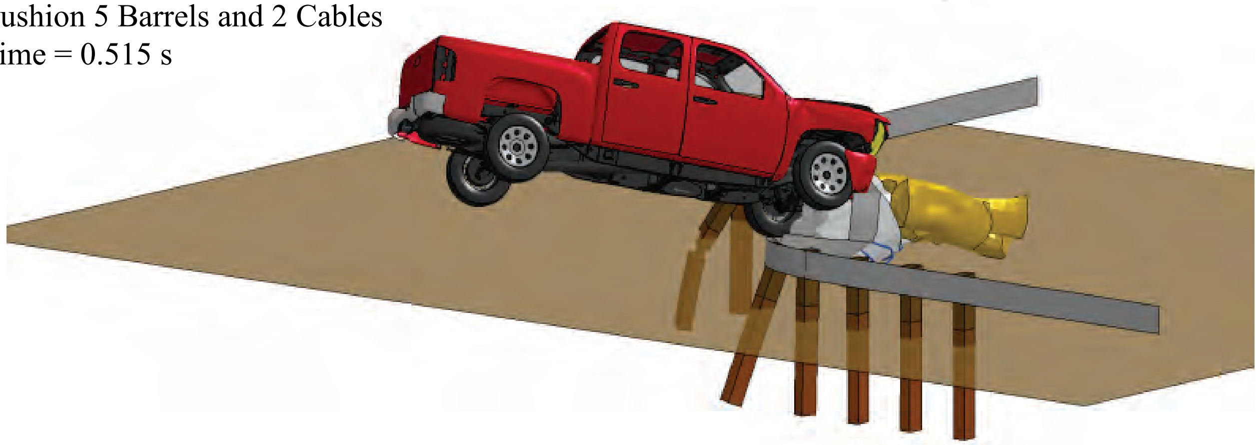


Figure 2.16. Sequential Images of Truck Impact with 5-Barrel System with Two Cables.

2.3.6.3. 15-Barrel System

The system that was modeled and analyzed was comprised of a 15-barrel system with a back rail. Table 2.8 gives the results for the 15-barrel system with a back rail. Figure 2.17 presents sequential images of the truck impact

The results from the model show that the occupant impact velocity (indicated in red) was too high for *NCHRP Report 350* recommended values due to the extremely high mass of the 15-barrel system.

Table 2.8. 15-Barrel System.

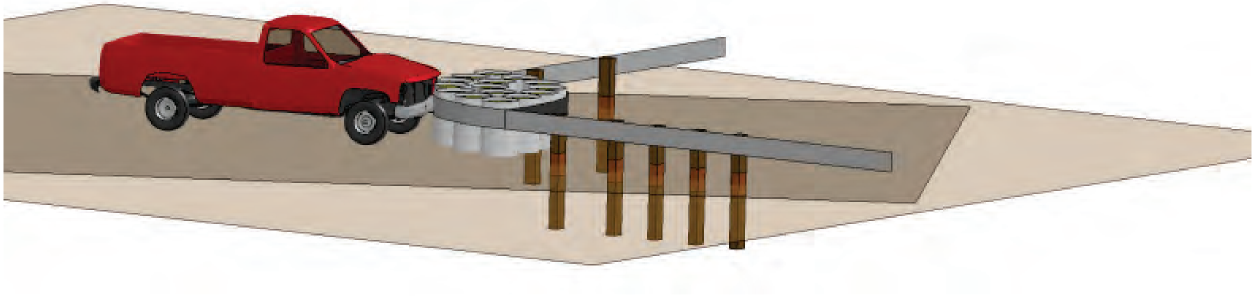
TL 3-33	
Impact Speed, mph (km/h)	62.2
Impact Angle, degrees	15.0
Initial Kinetic Energy of Vehicle, ft-lb	524,578
Kinetic Energy of Vehicle at End of Run, ft-lb	13,593 (97% reduction)
X-Velocity of Vehicle at End of Run, ft/s	8.45
Max OIV, ft/s	52.82
Ridedown Acceleration, Gs	9.0
Maximum Angle Movement, degrees	35.3 (yaw)

2.3.6.4. 3-Barrel System with Stacked Rail

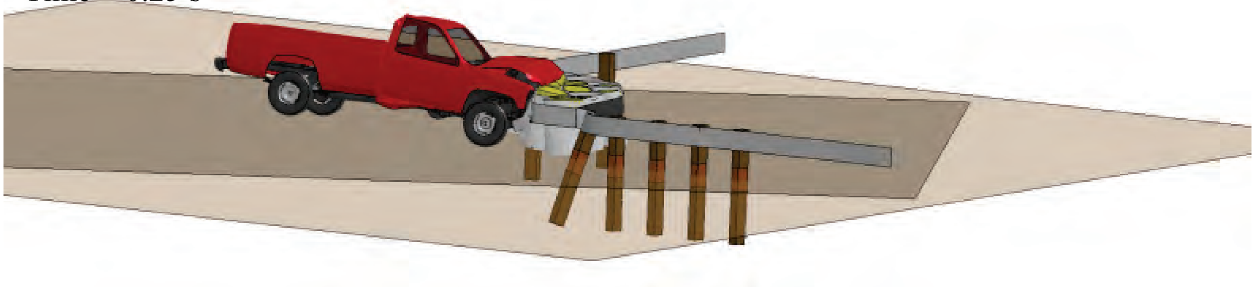
The number of barrels was reduced and a rubrail was added to decrease the vehicle's chance of overriding the system. Figure 2.18 shows a visual representation of the system. Table 2.9 provides the TRAP results for this simulation.

The addition of the second rail aided in maintaining rail height and the vehicle did not override the system. The vehicle was almost brought to a complete stop but did pitch up significantly. Although the impact velocity for this run was less than in previous crash cushion tests, it was slightly too high to meet *NCHRP Report 350* standards.

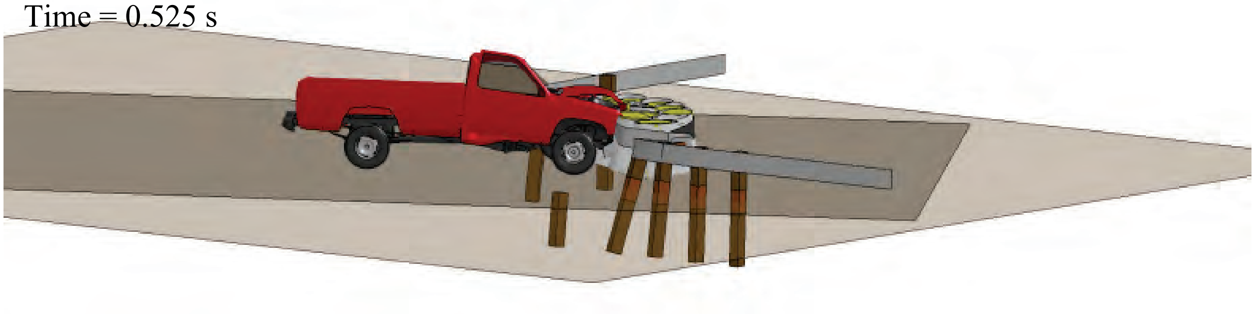
Cushion 15 Barrels and Back Rail
Time = 0.019999 s



Cushion 15 Barrels and Back Rail
Time = 0.25 s



Cushion 15 Barrels and Back Rail
Time = 0.525 s



Cushion 15 Barrels and Back Rail
Time = 0.8 s

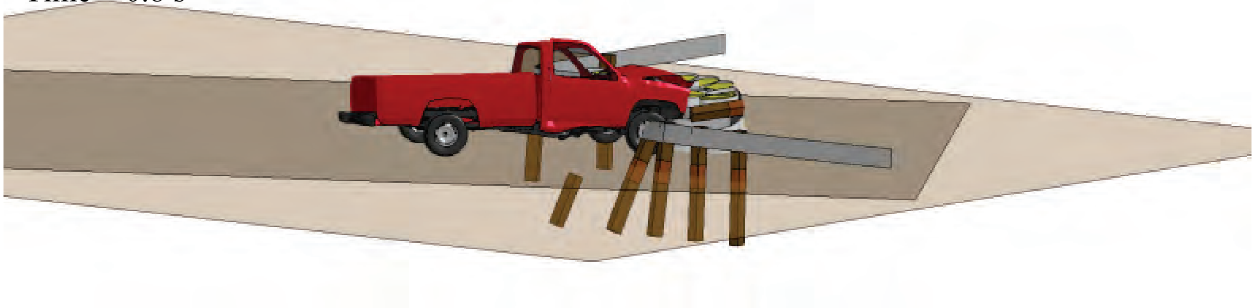


Figure 2.17. Sequential Images of Truck Impact with 15-Barrel System.

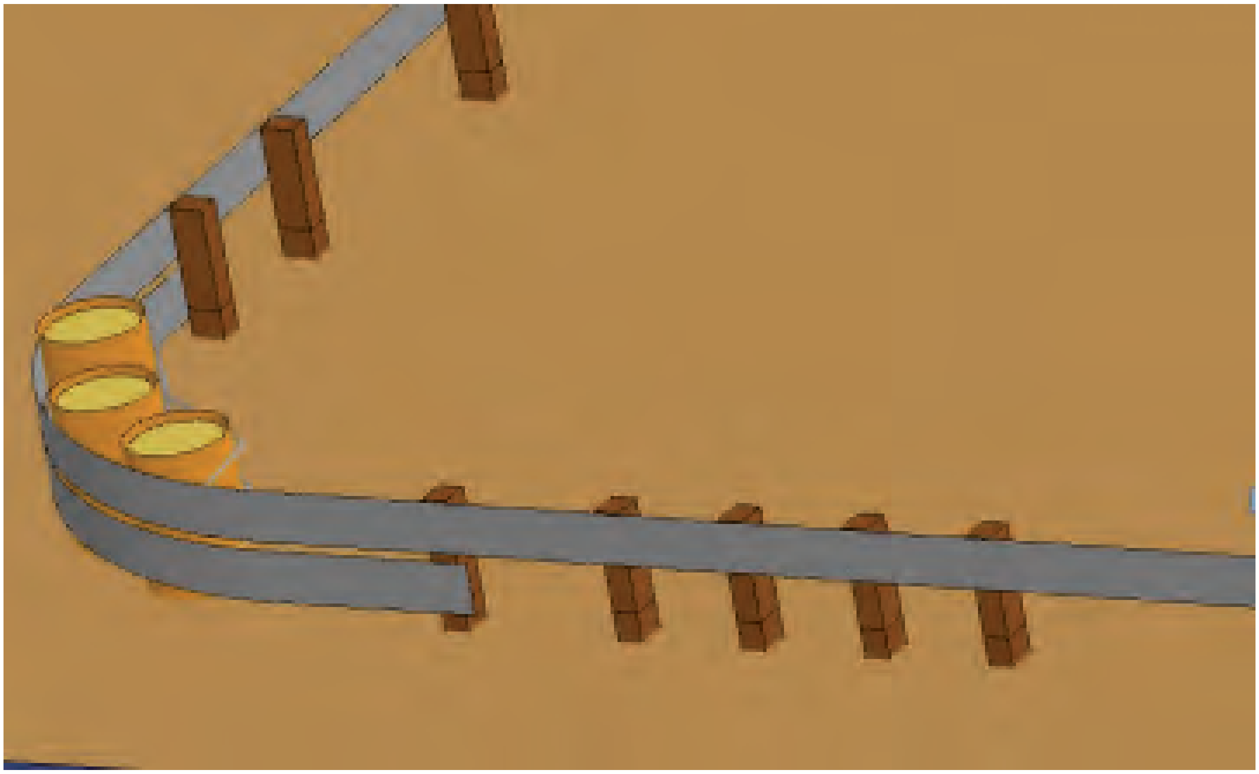


Figure 2.18. Short Radius Design of 3-Barrel System with Stacked Rail.

Table 2.9. 3-Barrel System with Stacked Rail.

TL 3-33	
Impact Speed, mph	62.2
Impact Angle, degrees	15.0
Initial Kinetic Energy of Vehicle, ft-lb	631,520
Kinetic Energy of Vehicle at End of Run, ft-lb	17,610 (97% reduction)
X-Velocity of Vehicle at End of Run, ft/s	−2.80
Max OIV, ft/s	53.48
Ridedown Acceleration, Gs	9.0
Maximum Angle Movement, degrees	32.9 (yaw)

2.3.6.5. 3-Barrel System with Reinforcement

This concept was comprised of a 3-barrel crash cushion behind the rail. The barrels are placed on top of sleds in order to help absorb more energy. Figure 2.19 shows the sleds that were used for this system, and Figure 2.20 shows the guardrail system for this model. Figure 2.21 provides sequential images of the model run. Table 2.10 presents the TRAP results.

The vehicle was almost brought to a complete stop; however, the occupant impact velocity was slightly high to meet *NCRHP Report 350* requirements. The vehicle did not override the system and the vehicle experienced almost no pitch or roll (less than 8° at any point).

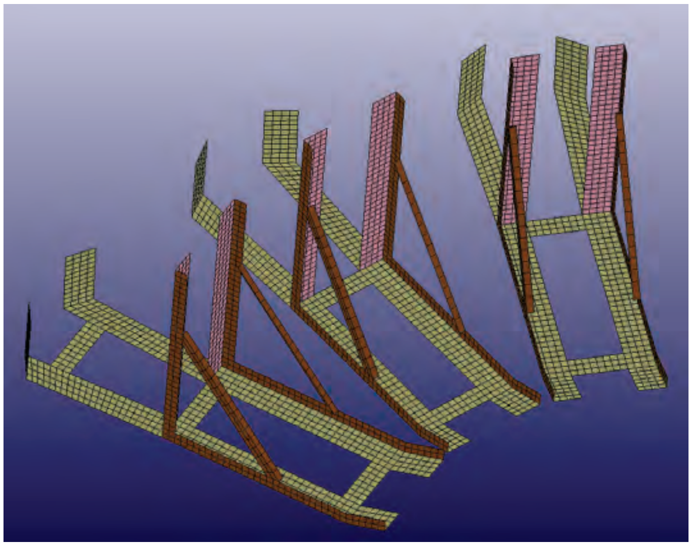


Figure 2.19. Sleds for Barrels.

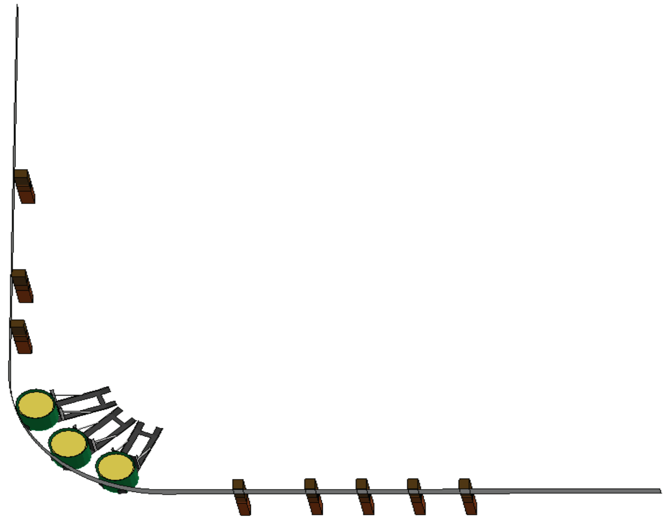


Figure 2.20. Short Radius Design of Three Barrels with Sled Reinforcement.

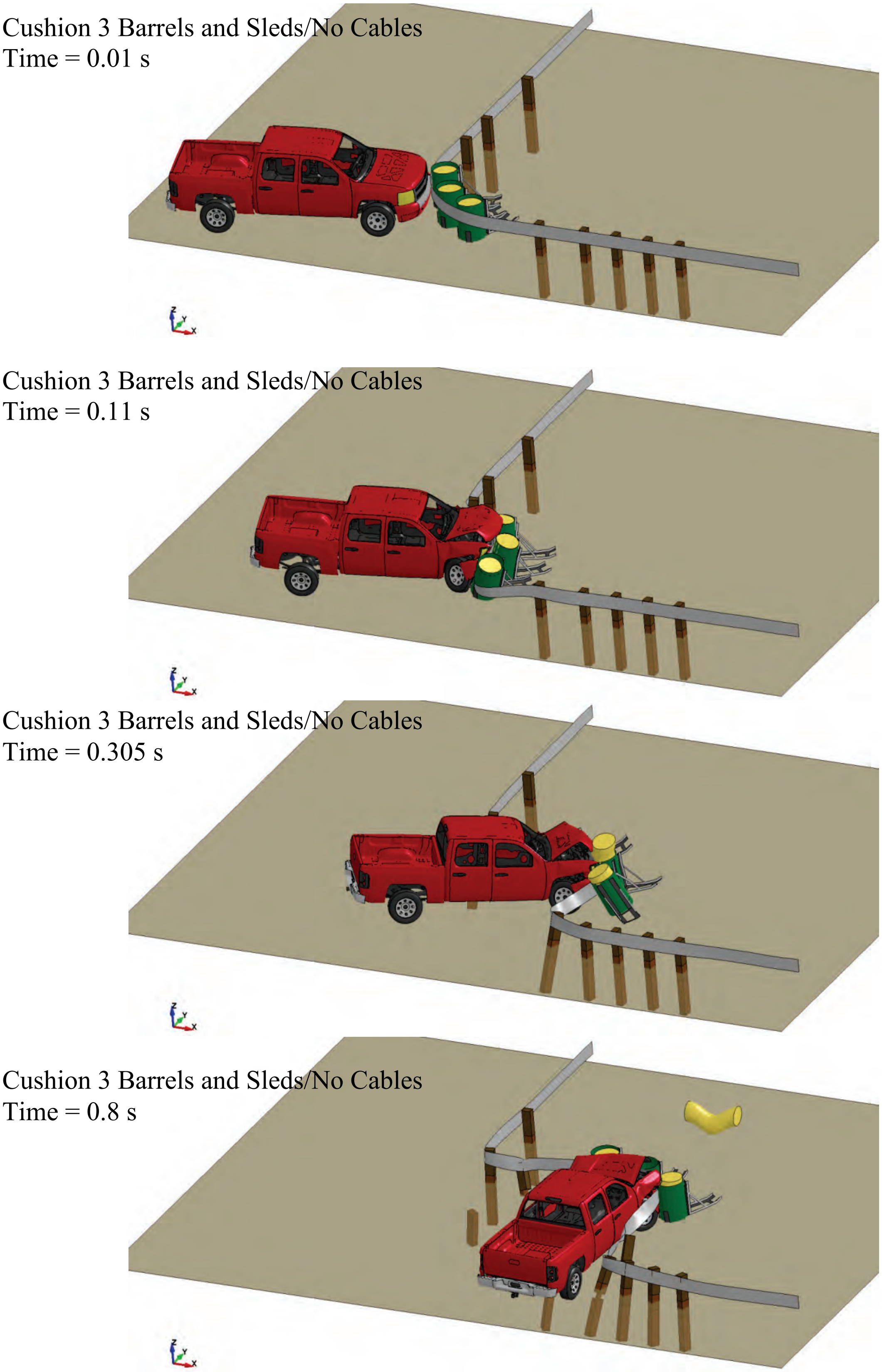


Figure 2.21. Sequential Images of Truck Impact with 3-Barrel System with Sled Reinforcement.

Table 2.10. 3-Barrel System with Sled Reinforcement.

TL 3-33	
Impact Speed, mph	62.2
Impact Angle, degrees	15.0
Initial Kinetic Energy of Vehicle, ft-lb	631,517
Kinetic Energy of Vehicle at End of Run, ft-lb	8,231 (99% reduction)
X-Velocity of Vehicle at End of Run, ft/s	−7.90
Max OIV, ft/s	48.6
Ridedown Acceleration, Gs	9.4
Maximum Angle Movement, degrees	74.4 (yaw)

2.3.7. Short Radius with Cable Barrier

Some recent concepts were developed after evaluating the results from the previously described concepts. Since the cable concepts showed some success, a standard cable median barrier system was put in place behind the guardrail system to aid in absorbing additional kinetic energy. Figure 2.22 shows the system for this concept. A test was performed on this new concept by impacting the system at 25° relative to the primary roadway to determine the energy absorption abilities in a shorter segment. Results demonstrated that this could be a feasible option as long as the slope behind the guardrail is not an issue. The cable median was beneficial for absorbing additional energy out of the system. It was also determined that the cables themselves absorbed a significant amount of kinetic energy in the form of internal energy.

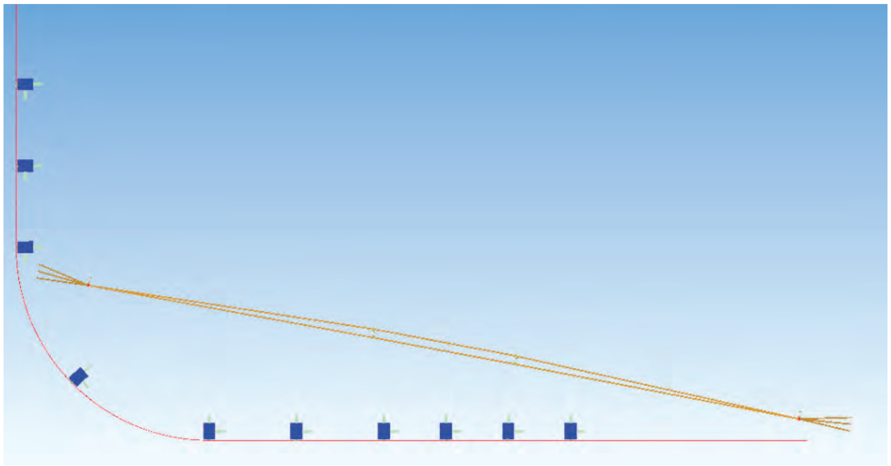


Figure 2.22. Short Radius Design with Cable Median behind Rail.

The concept was considered an inapplicable design for this situation. The cable would be too far behind the guardrail to be sufficiently effective and would only work if the system was on a level corner, which is not the case for this condition.

2.3.8. Short Radius with Added Nose Mass

This concept used thin rectangular containers placed behind the posts and filled with sand to aid in attenuating some of the kinetic energy through momentum transfer. Figure 2.23 shows the system. Figure 2.24 shows sequential images of truck impact. The rectangular tubes were made of polystyrene because it is inexpensive, easy to form, and has brittle properties that allow fracturing upon impact. Results of the model indicate that the vehicle would override this system and the back right wheel would snag on the guardrail. Table 2.11 provides the TRAP results for the run.

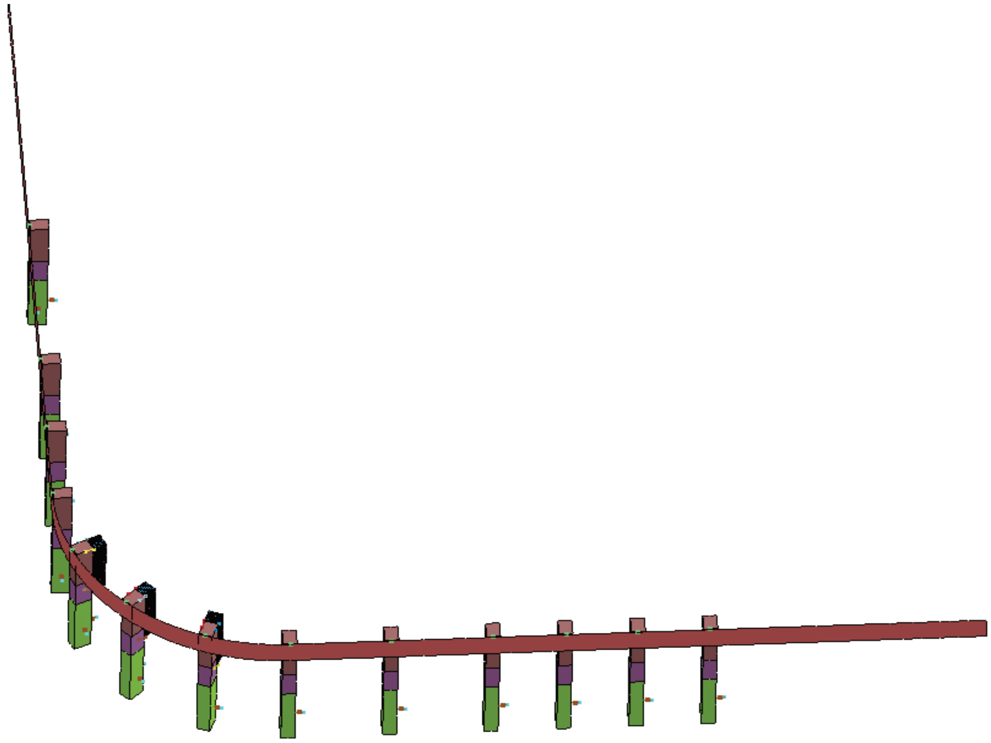


Figure 2.23. Short Radius Design with Free Mass.

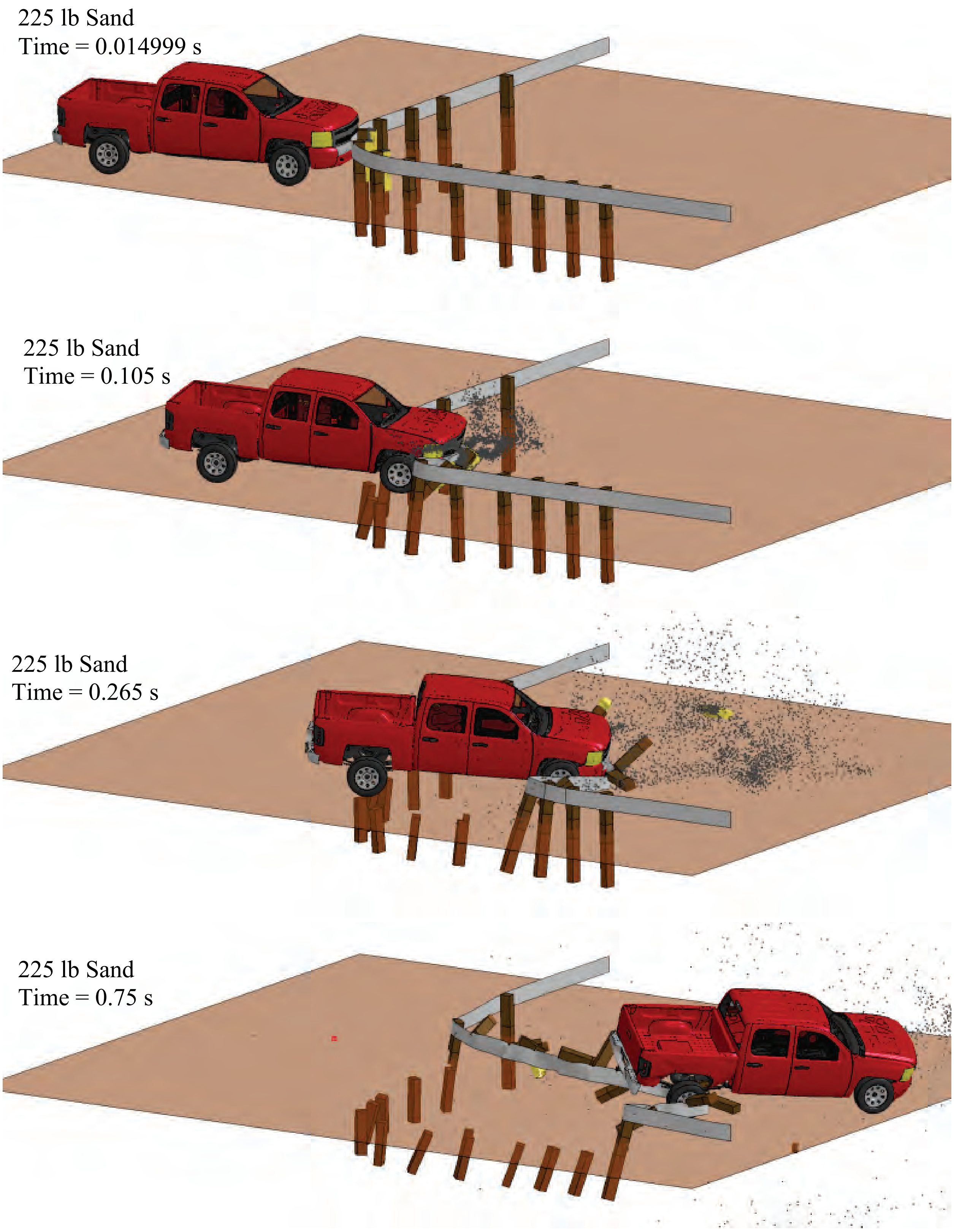


Figure 2.24. Sequential Images of Truck Impact with Free Mass System.

Table 2.11. Free Mass System Results.

TL 3-33 Chevy Silverado	
Impact Speed, mph	62.2
Impact Angle (degrees)	15.0
Initial Kinetic Energy of Vehicle, ft-lb	631,523
Kinetic Energy of Vehicle at End of Run, ft-lb	72,105 (89% reduction)
X-Velocity of Vehicle at End of Run, ft/s	27.9
Max OIV, ft/s	33.14
Ridedown Acceleration, Gs	13.7
Maximum Angle Movement, degrees	50.6 (yaw)

2.4. DETAILED MODELING

Design requests required a base model to be developed in full detail. Modifications were implemented to analyze the most applicable concepts for this project. The images below represent these concepts. The system consists of 6-inch × 8-inch CRT breakaway posts, 10-gauge W-beams, a rotating deadman anchor, a rail height of 31 inches, ASTM A307 button head bolts, and TxDOT metal beam guard fence transition. The rotating anchor is simulated in the model with the use of a fixed rigid cylinder that allows the rail to rotate.

2.4.1. Double Rail System

The double rail concept is a detailed model composed of two attached rails. The double rail was used because the top rail was raised to 31 inches. The lower rail was implemented to prevent a small vehicle from snagging on the upper rail, which could shear off the top of the car. The system was run with a Chevy Silverado truck even though the concept was created as a precaution for small vehicle impact. Figure 2.25 shows the system. The x-direction runs along the primary roadway. The y-direction runs along the secondary roadway or driveway. Figure 2.26 presents sequential images of the truck impact. Table 2.12 provides the TRAP results for this model.

Figure 2.27 depicts the longitudinal velocity of the vehicle from the initial state of the test to the end of the run. Figure 2.28 visually represents the distance that the vehicle traveled from the initial state to the point of zero velocity. The graph in Figure 2.29 provides the x and y displacement from the initial position of the truck at time zero until the end of the run. The displacement values on the y-axis are given in feet and the x-axis is in seconds (s). The truck approached zero velocity at time 0.745 s. The x and y displacements at this time were 36.6 ft and 15.8 ft.

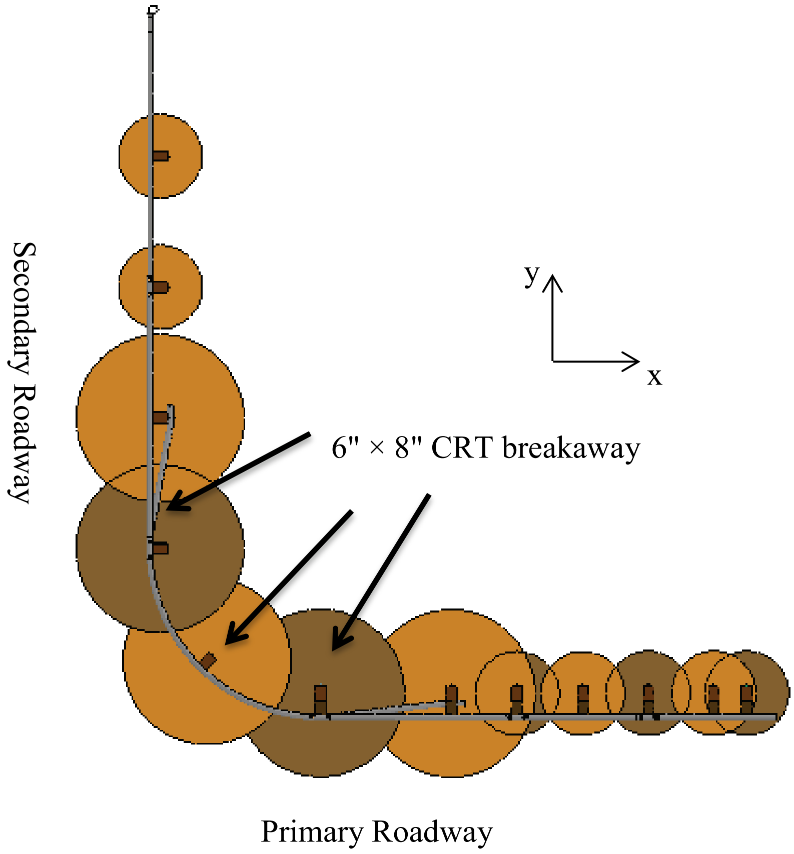


Figure 2.25. Short Radius Design with Detailed Double Rail.

Table 2.12. Detailed Double Rail System.

TL 3-33 Chevy Silverado	
Impact Speed, mph	62.2
Impact Angle, degrees	15.0
Initial Kinetic Energy of Vehicle, ft-lb	631,523
Kinetic Energy of Vehicle at End of Run, ft-lb	18,634 (97% reduction)
X-Velocity of Vehicle at End of Run, ft/s	−2.24
Max OIV, ft/s	26.57
Ridedown Acceleration, Gs	11.6
Maximum Angle Movement, degrees	100.6 (yaw)

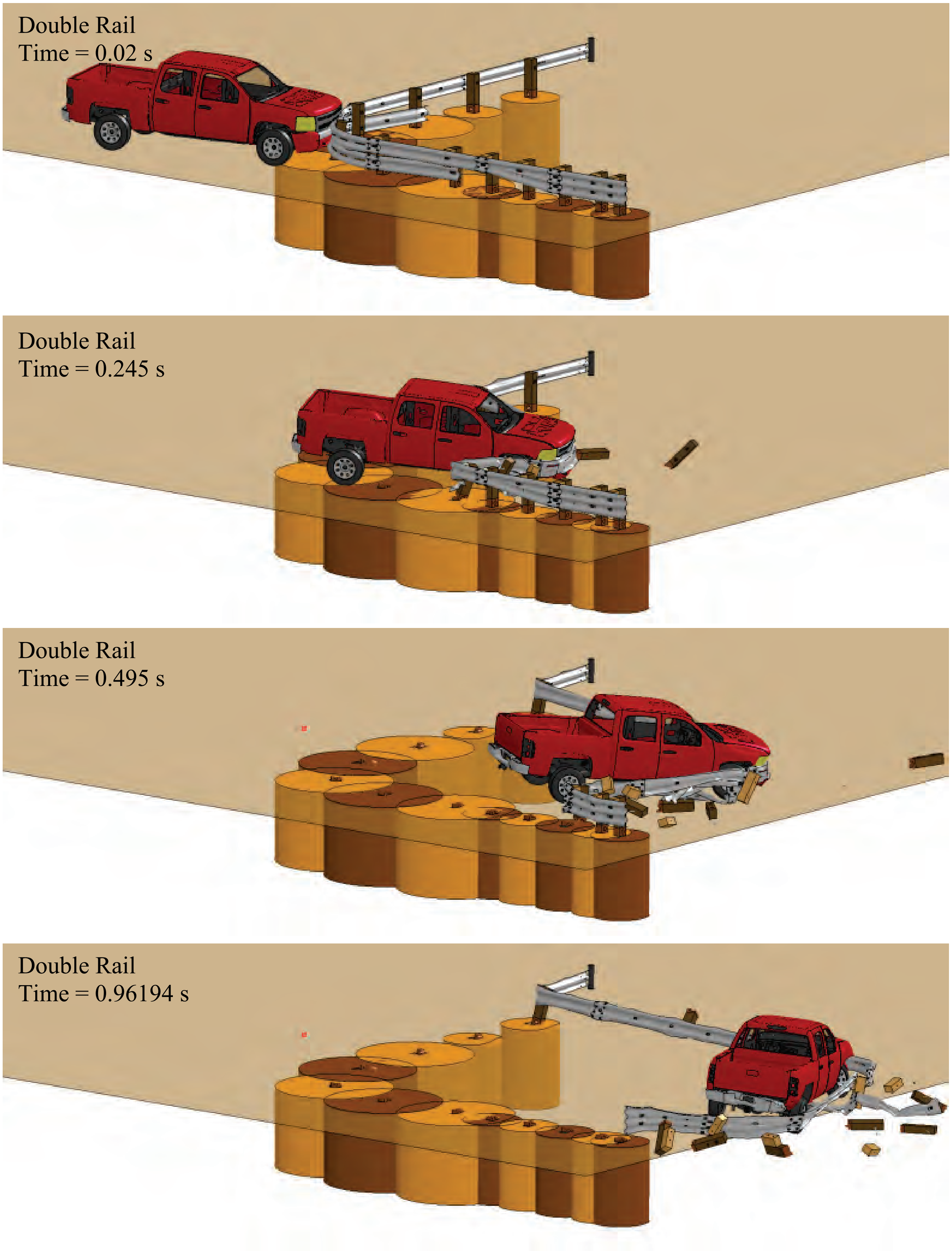


Figure 2.26. Sequential Images of Truck Impact with Detailed Double Rail System.

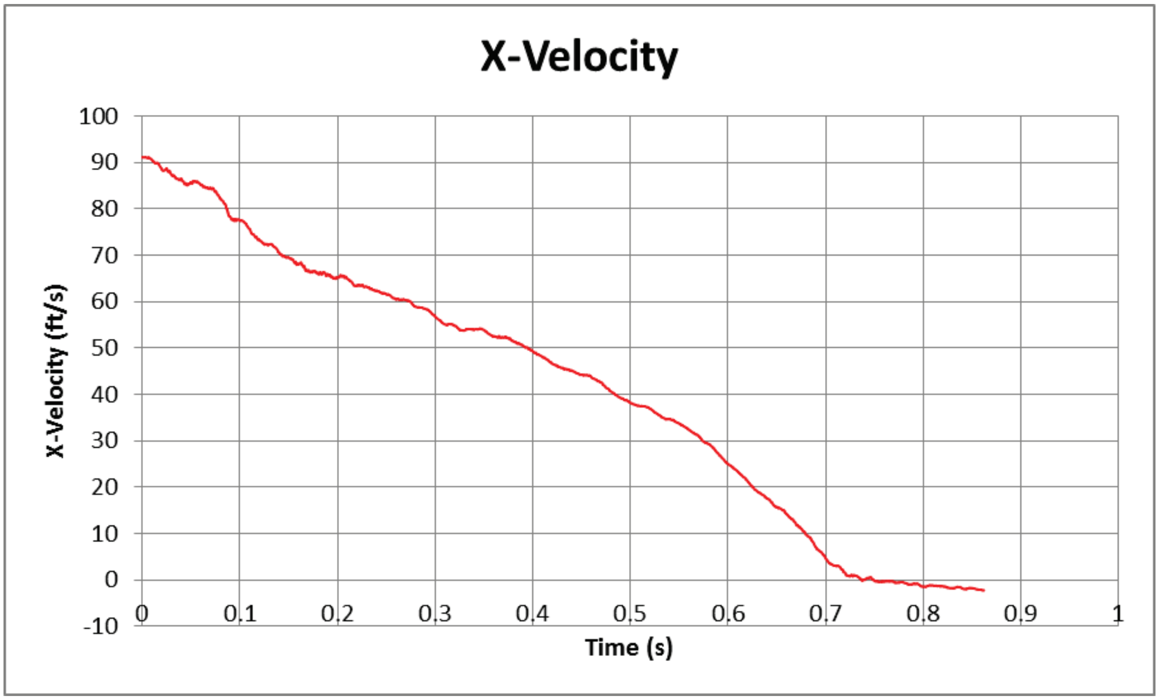


Figure 2.27. Longitudinal Velocity of the Pickup Impacting the Double Rail System.

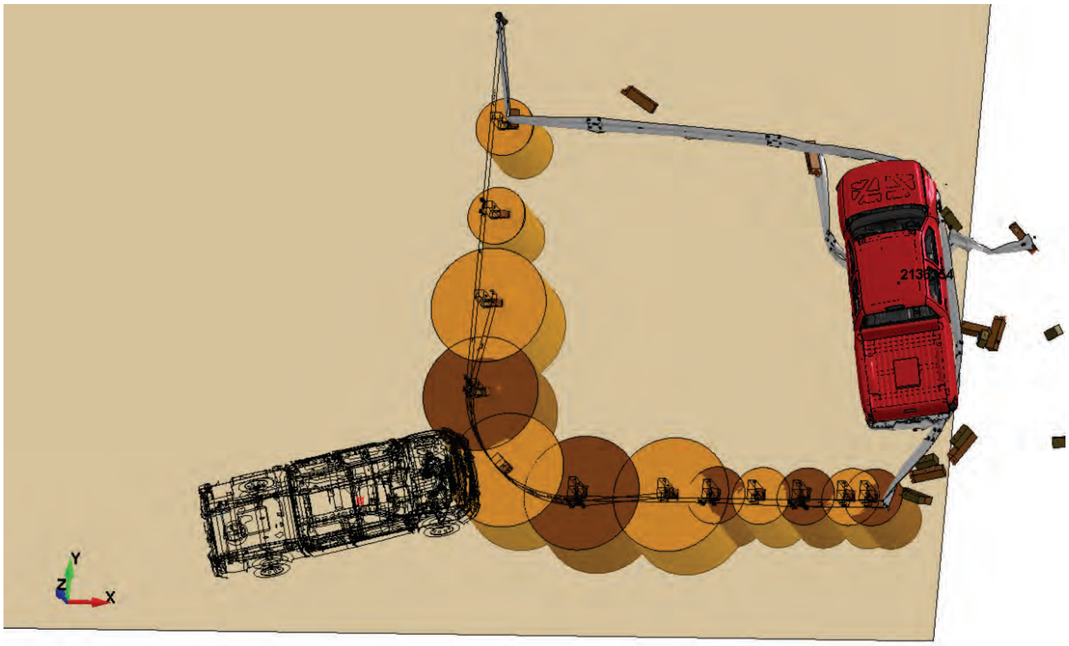


Figure 2.28. Vehicle Displacement of Detailed Double Rail System.

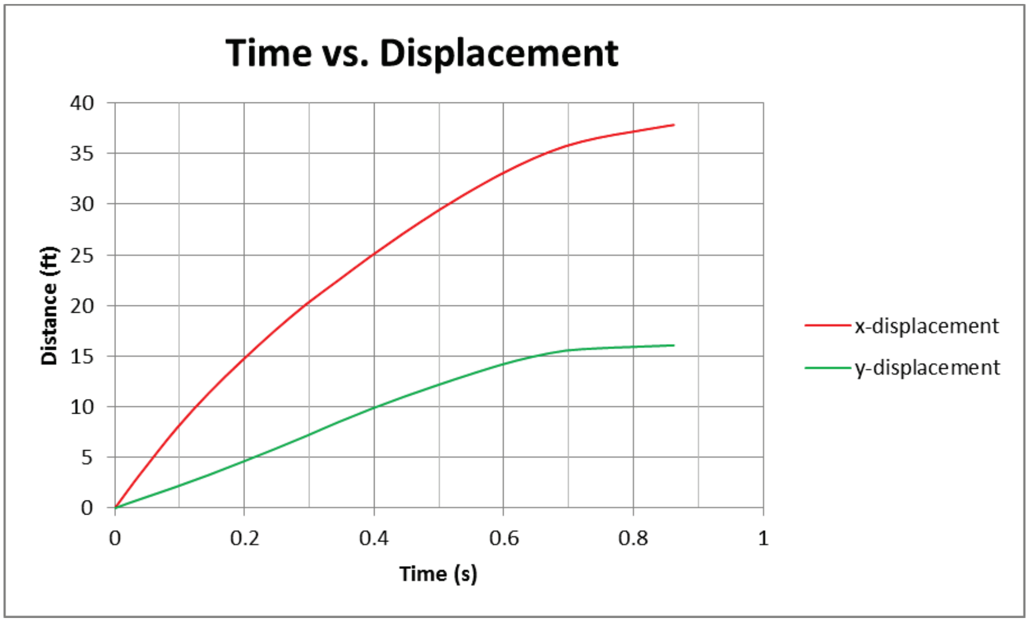


Figure 2.29. Vehicle Trajectory of Detailed Double Rail System.

2.4.2. Double Rail System with Free Mass

This was the first detailed model for the double rail system with the free mass attenuators. There were three posts at the mid-section, each filled with approximately 100 lb of sand. Figure 2.30 shows the system. The x-axis runs along the primary roadway and the y-axis runs along the secondary roadway. Figure 2.31 presents sequential images of the truck impact. Table 2.13 gives the TRAP results.

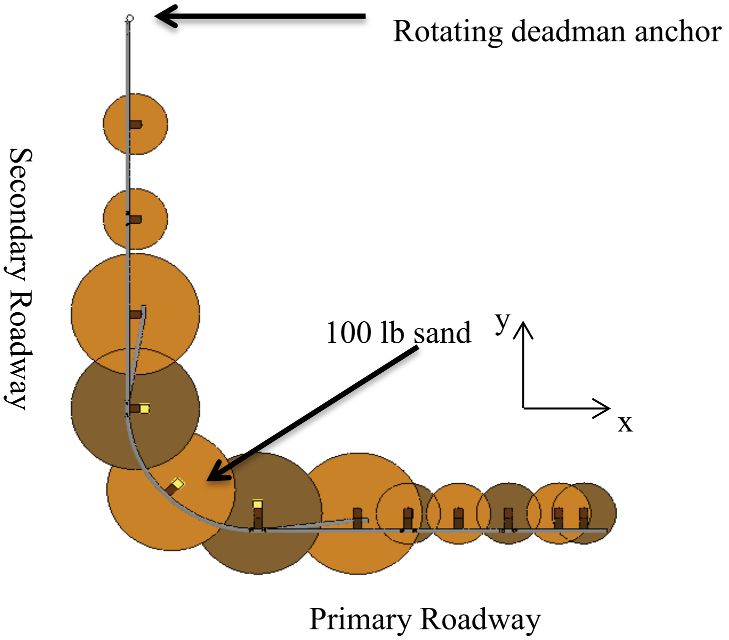


Figure 2.30. Short Radius Design of Detailed Rail with Free Mass.

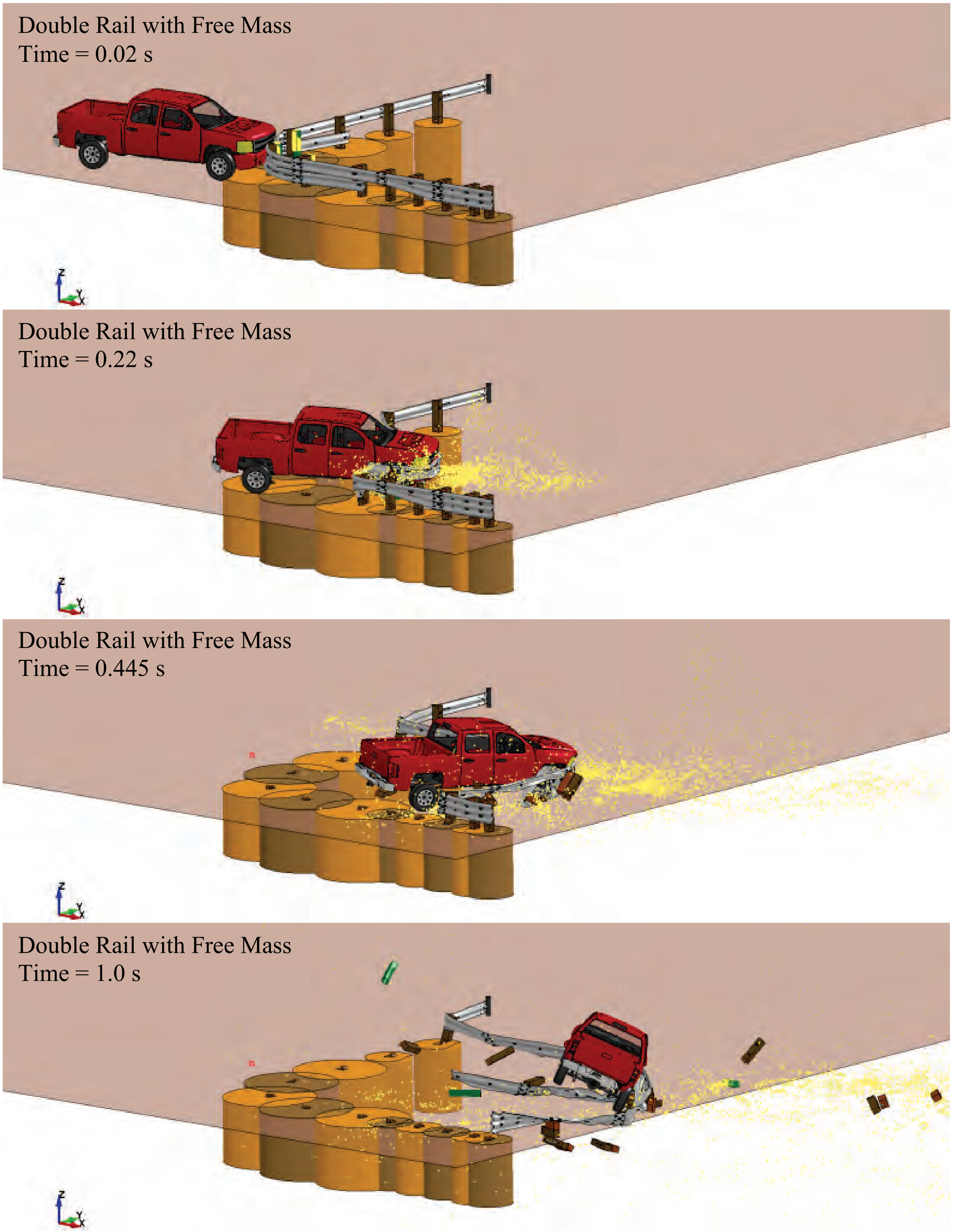


Figure 2.31. Sequential Images of Truck Impact with Double Rail System with Free Mass.

Table 2.13. Double Rail System with Free Mass.

TL 3-33 Chevy Silverado	
Impact Speed, mph	62.2
Impact Angle (degrees)	15.0
Initial Kinetic Energy of Vehicle, ft-lb	631,518
Kinetic Energy of Vehicle at End of Run, ft-lb	3,580 (99% reduction)
X-Velocity of Vehicle at End of Run, ft/s	0.23
Max OIV, ft/s	26.9
Ridedown Acceleration, Gs	12.0
Maximum Angle Movement, degrees	116.2 (yaw)

The results from the simulation revealed a maximum total kinetic energy of 674,121 ft-lb. The maximum kinetic energy of the free mass component of the system was 24,707 ft-lb. The free mass component of the system only absorbed 3.65 percent of the kinetic energy from impact.

In Figure 2.32, the graph represents the x-velocity of the vehicle from the initial state of the test to the end of the run. Figure 2.33 visually represents the distance the vehicle traveled from the initial state to the time of zero velocity. The graph in Figure 2.34 represents the x and y displacement from the initial position of the truck at time zero until the end of the run. The truck approached zero velocity at 0.695 s. The x-displacement at this time was 34.1 ft and y-displacement was 15.8 ft.

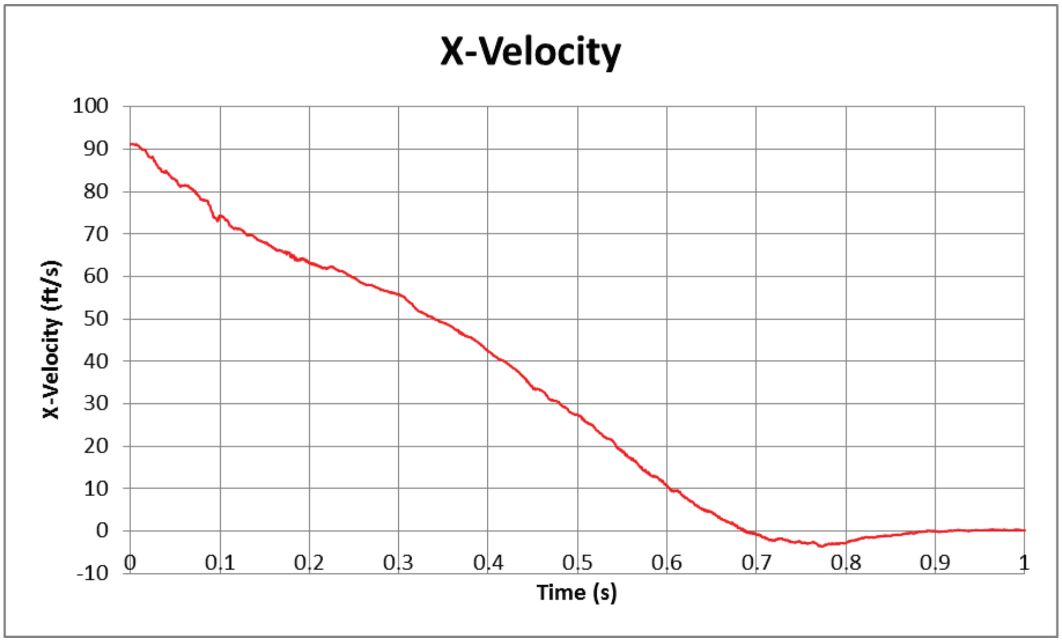


Figure 2.32. X-Velocity of Double Rail System with Free Mass.

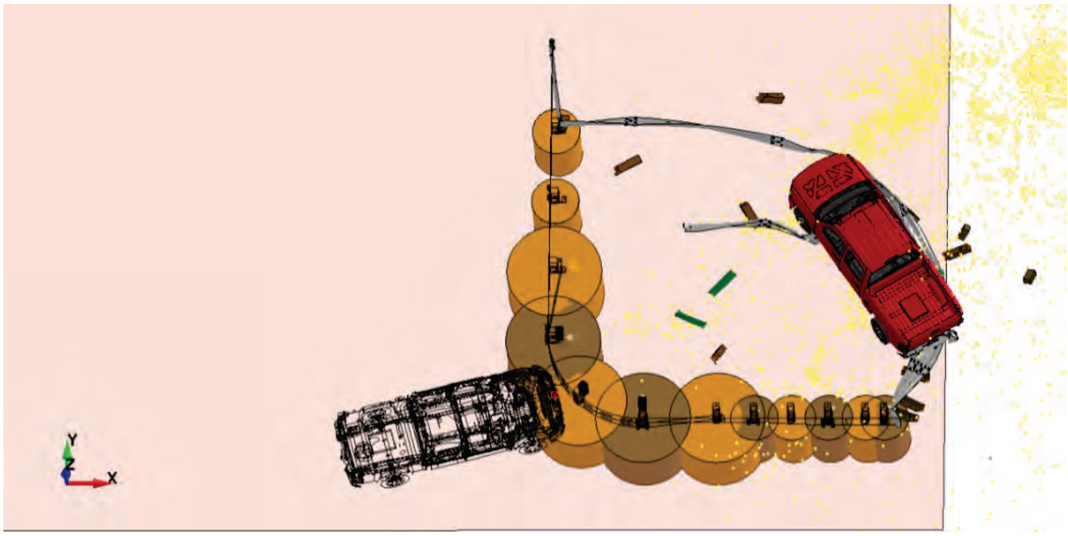


Figure 2.33. Vehicle Displacement of Double Rail System with Free Mass.

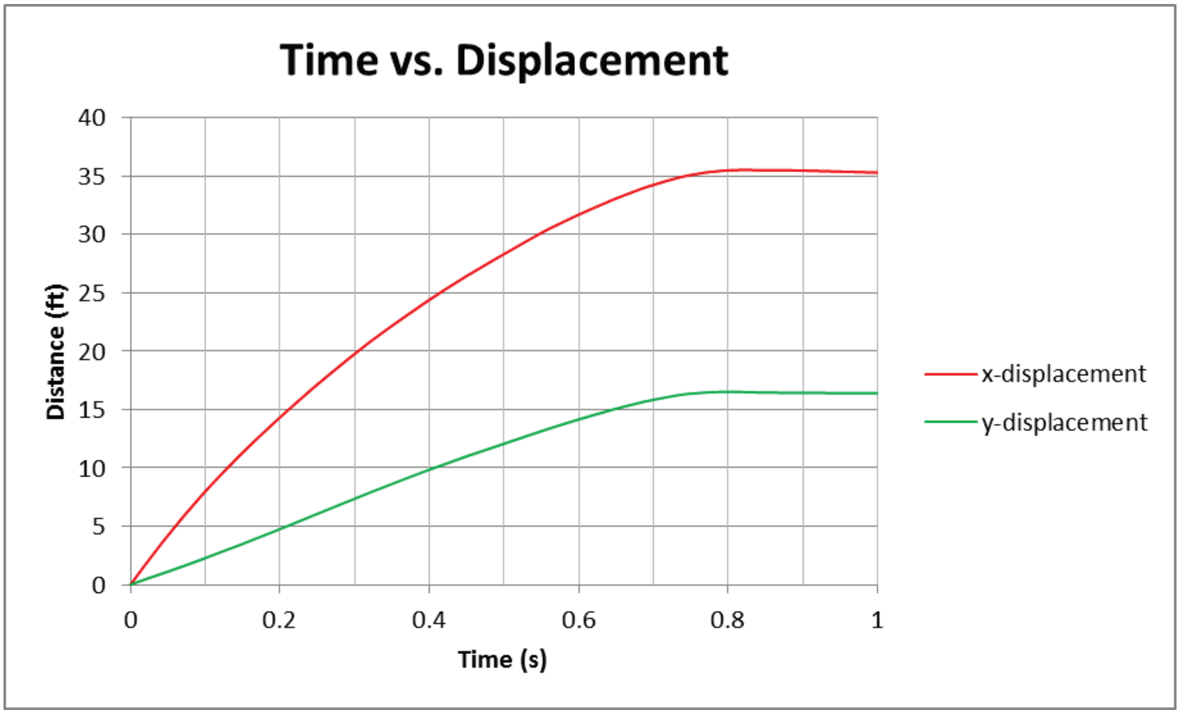


Figure 2.34. Vehicle Trajectory of Double Rail System with Free Mass.

2.4.3. Double Rail with Freestanding Mass and Posts

The system was a modification of the detailed double rail with free mass. Freestanding posts with 100 lb of sand were added behind the system to absorb more kinetic energy. Figure 2.35 shows the system. The x-axis runs along the primary roadway and the y-axis runs along the secondary roadway. Figure 2.36 depicts sequential images of the run. Table 2.14 provides the TRAP analysis results.

The results from the model run revealed a maximum total kinetic energy of 673,723 ft-lb. The maximum kinetic energy of the free mass component of the system was 45,686 ft-lb. The free mass component of the system absorbed only 6.78 percent of the kinetic energy from impact.

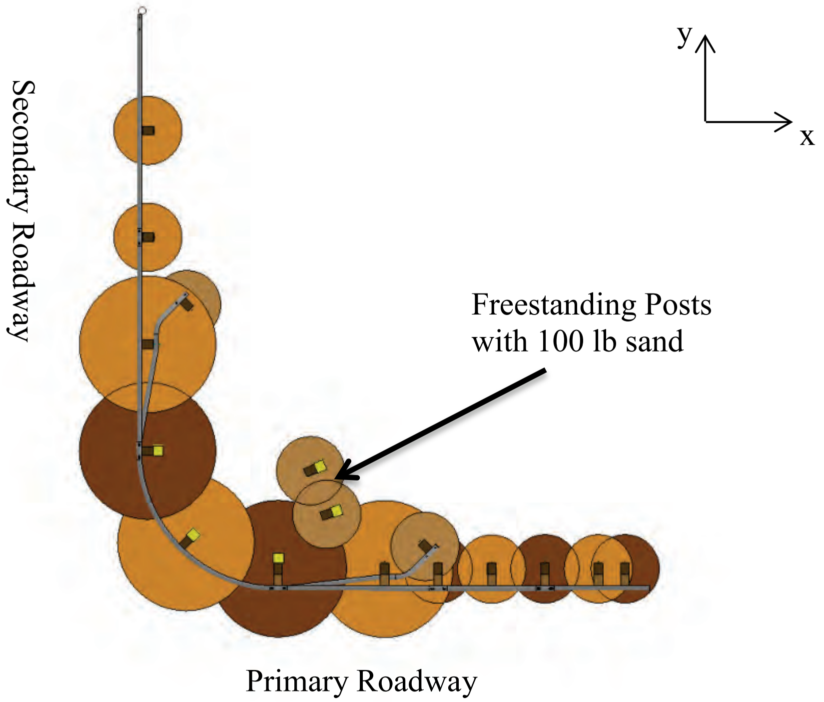


Figure 2.35. Short Radius Design of Detailed Rail with Additional Posts.

Table 2.14. Double Rail with Additional Posts.

TL 3-33 Chevy Silverado	
Impact Speed, mph	62.2
Impact Angle (degrees)	15.0
Initial Kinetic Energy of Vehicle, ft-lb	631,532
Kinetic Energy of Vehicle at End of Run, ft-lb	3,338 (99% reduction)
X-Velocity of Vehicle at End of Run, ft/s	−4.84
Max OIV, ft/s	32.2
Ridedown Acceleration, Gs	10.6
Maximum Angle Movement, degrees	116.3 (yaw)

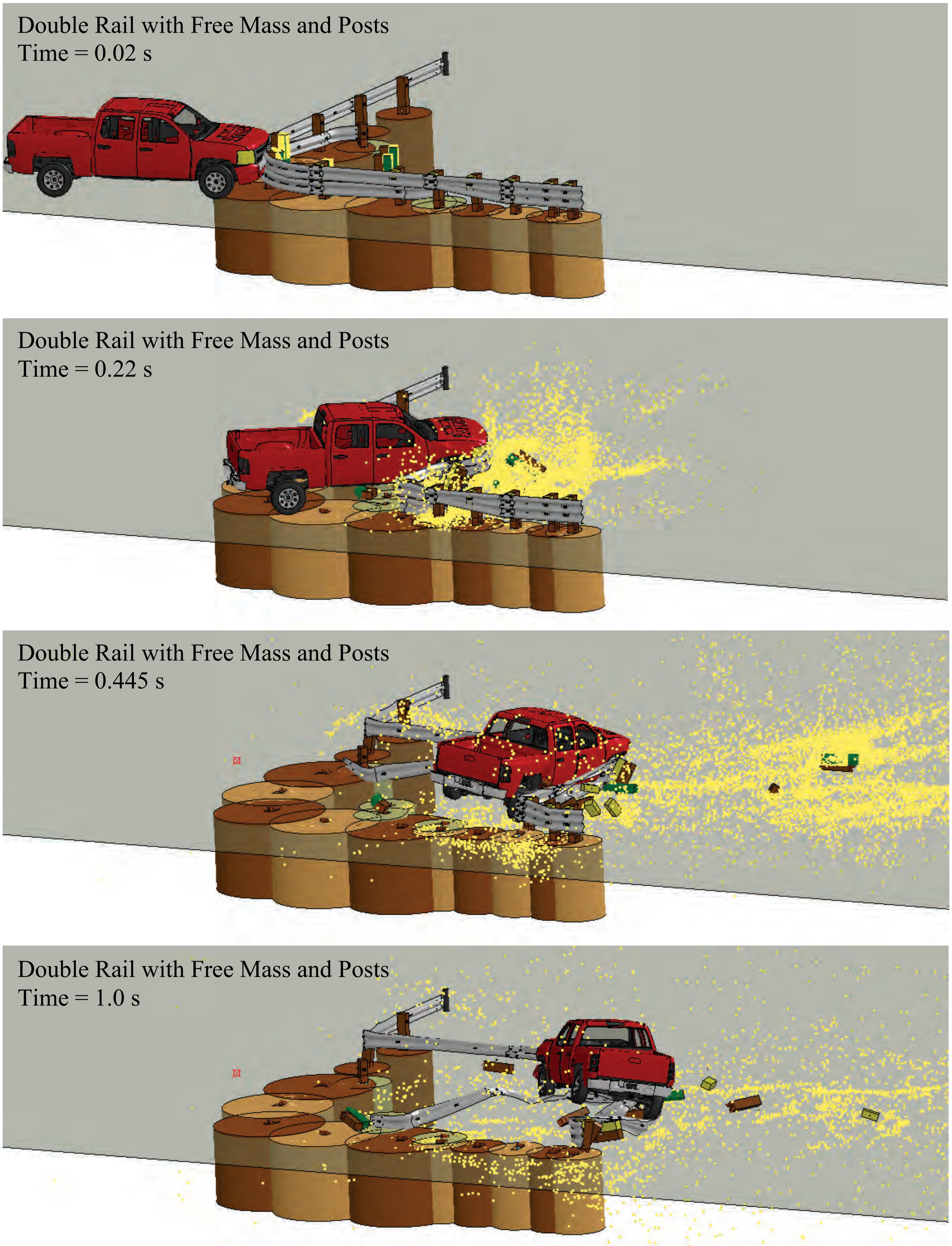


Figure 2.36. Sequential Images of Truck Impact with Double Rail System with Additional Posts.

The results for this model show that the guardrail was more effective in containing the vehicle and the rail did not tear away from the posts. Figure 2.37 represents the x-velocity of the vehicle from the initial state of the test to the end of the run. The vehicle displacement from the initial state to zero velocity is visually represented in Figure 2.38, and the displacement is depicted graphically in Figure 2.39. The vehicle only traveled about 29.5 ft in the x-direction until it reached zero velocity at 0.77 s. This x-displacement value was less than the previous model, thus proving that the additional posts aided in vehicle containment.

2.4.4. Summary for Double Rail Analysis

The aforementioned simulations point to a potential short radius design that can pass *MASH* evaluation criteria, yet perform within the site constraint of most of these intersection locations. The rail along the primary roadway will have additional details including the rest of the transition and the bridge rail end. More simulations and calculations are required to determine the optimum position and number of steel posts in this segment. The rail along the secondary roadway will be shortened because the current length was not fully utilized during this impact simulation It is evident that the inertial contribution from the sand mass as seen in the last system in Figure 2.35 aided in reducing the vehicle trajectory. Additional simulations and calculations are planned to optimize the sand's mass and position within the system to bring the vehicle to a complete stop within the desired site constraint and *MASH* evaluation criteria. Figure 2.40 to Figure 2.43 depict the details of the prototype short radius system under evaluation.

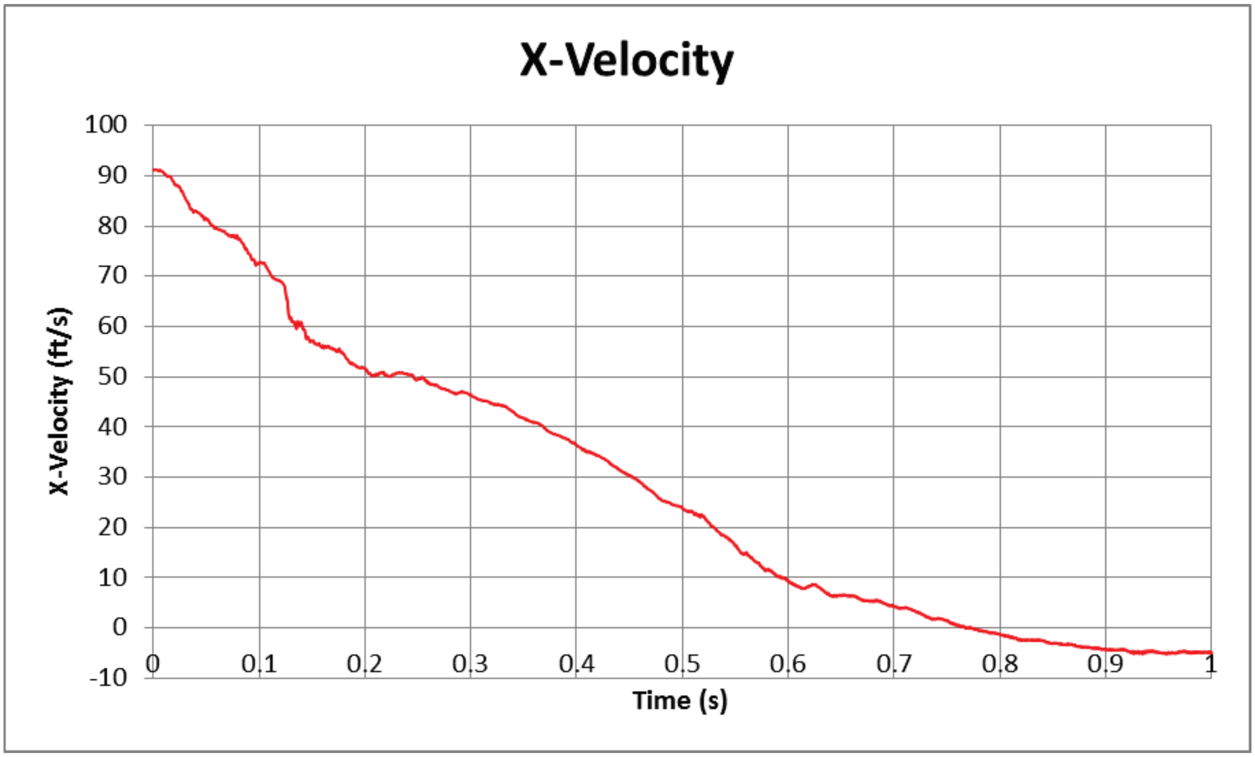


Figure 2.37. X-Velocity of Double Rail System with Additional Posts.

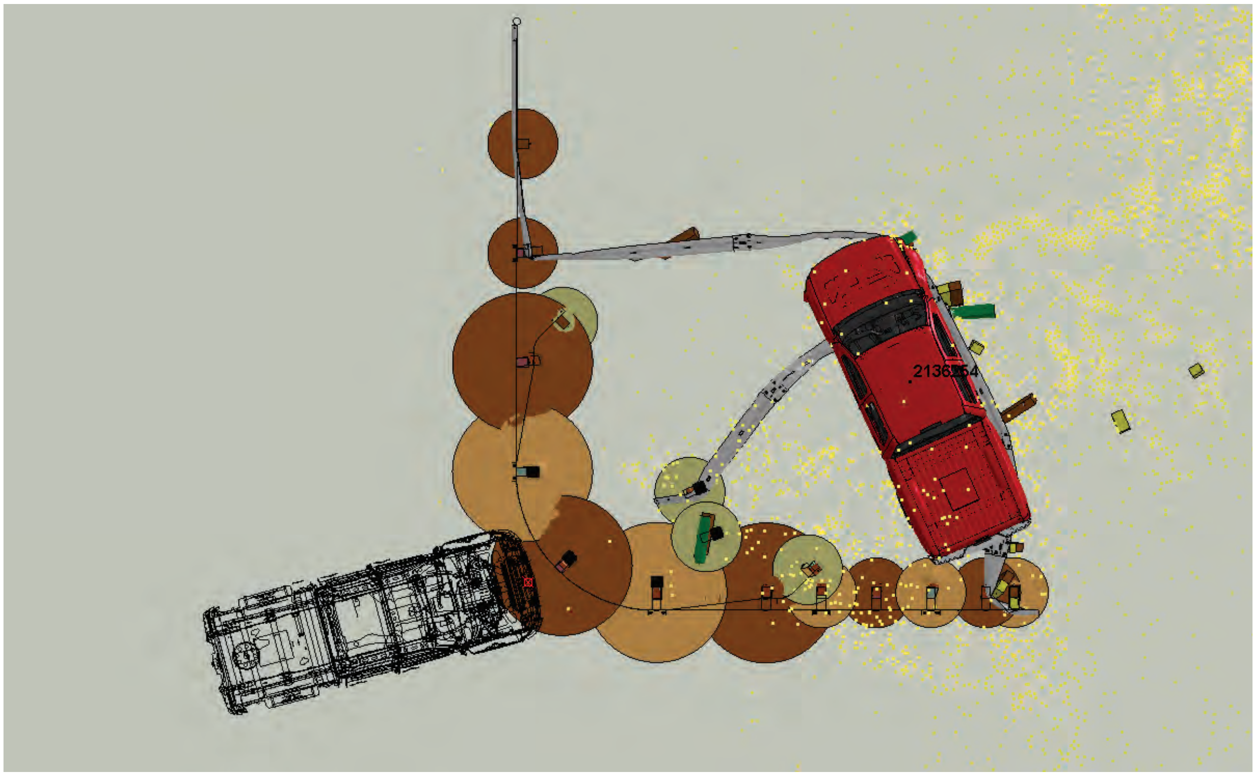


Figure 2.38. Vehicle Displacement of Double Rail System with Additional Posts.

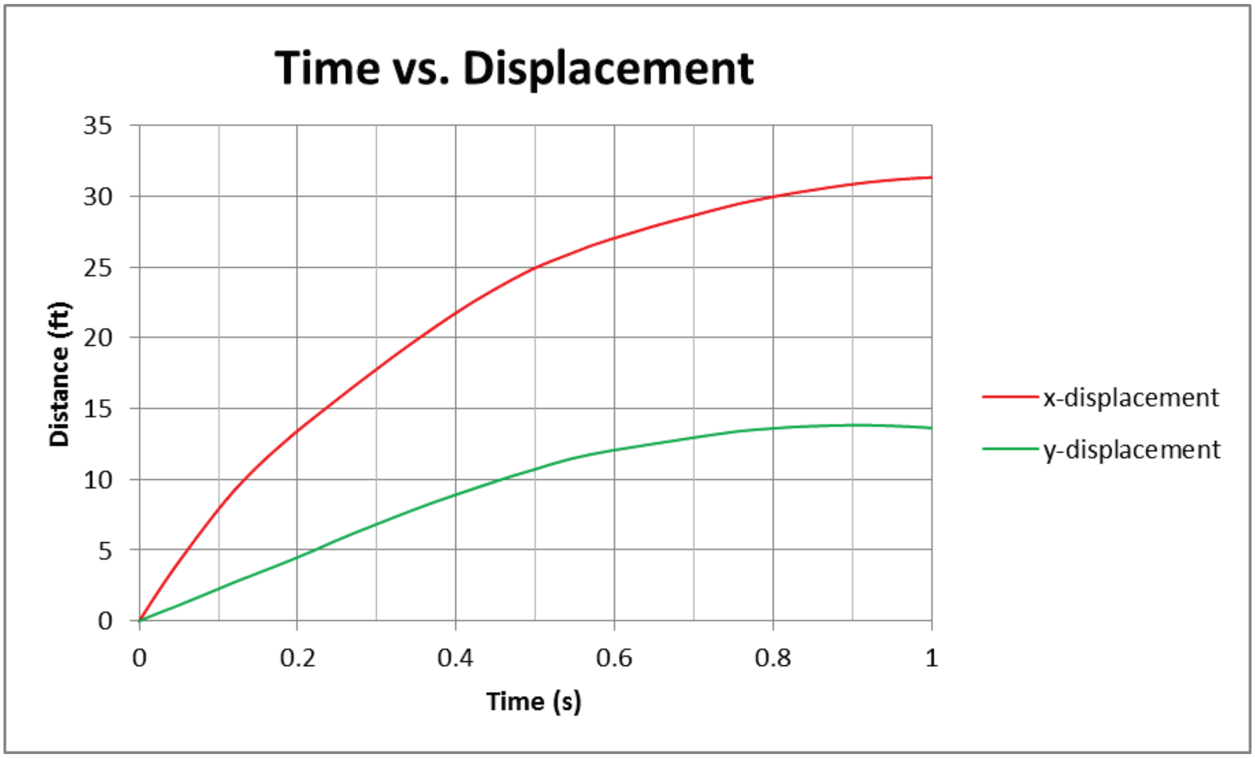


Figure 2.39. Vehicle Trajectory of Double Rail System with Additional Posts.

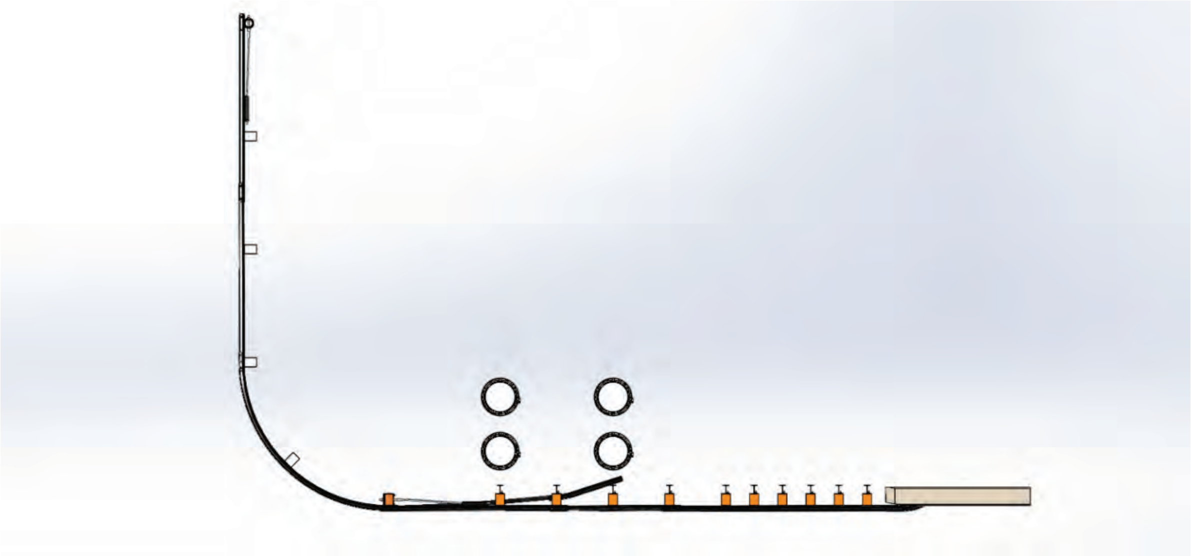


Figure 2.40. Overhead View of the Short Radius System.

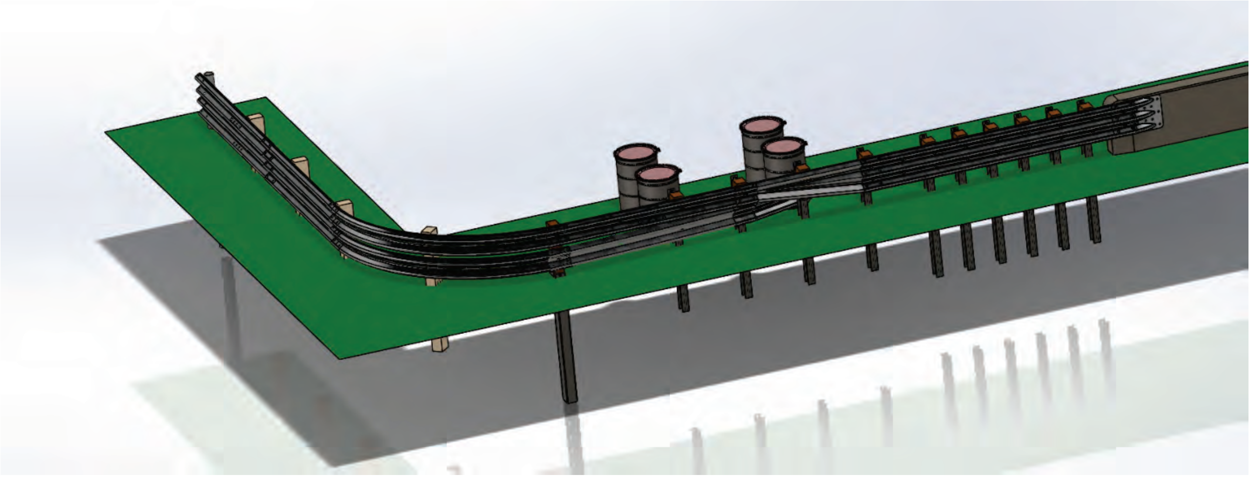


Figure 2.41. Isometric View of the Short Radius System.

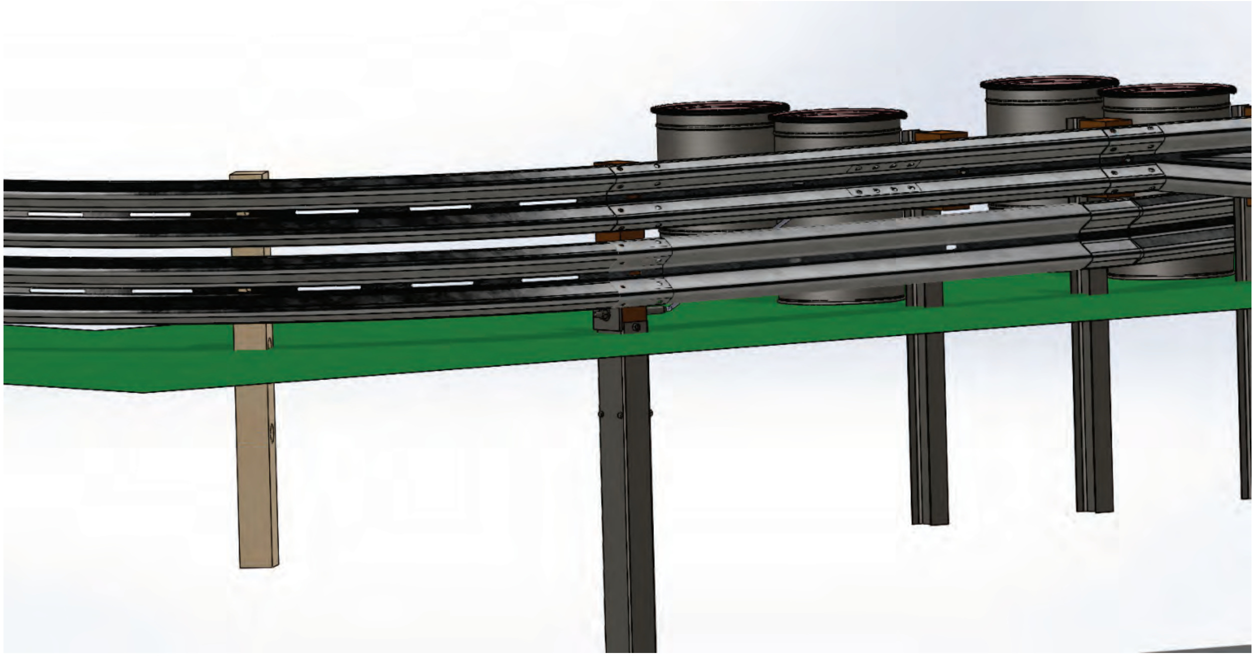


Figure 2.42. Close-Up View of the Short Radius System.

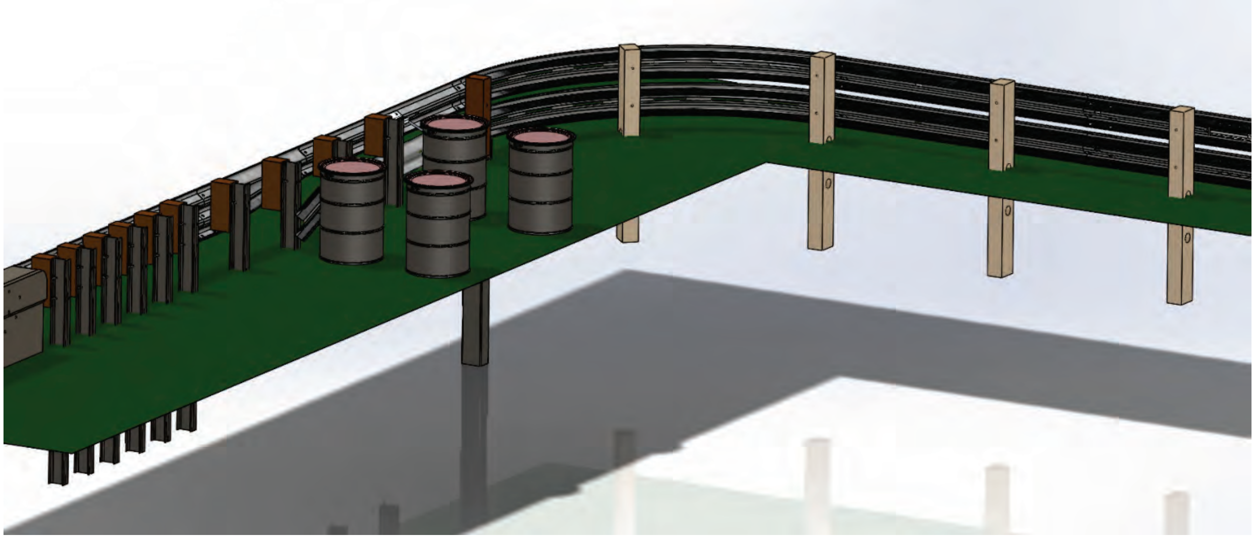


Figure 2.43. Field Side View of the Short Radius System.

2.5. EXPERIMENTAL EVALUATION OF NEEDED ENERGY

The sand inertial system was the attenuator chosen to increase the energy dissipation of the system. To find the optimum combination of barrels and masses, several simulations were run. Simplified vehicles were modeled to decrease the run time on the simulations. Figure 2.44 and Figure 2.45 show the simplified vehicles that were used.

Figure 2.44. Simplified Car Model.

Figure 2.45. Simplified Truck Model.

Once the last few barrel layouts were being chosen, the simulations were run with the Yaris model and Silverado model instead of the simplified vehicle models. Physical experiments were then performed on the most promising barrel layouts. These tests served as a calibration and baseline for the simulations. There was very good correlation between the simulation and physical experiment results.

2.5.1. Summary of Simplified Simulations

Table 2.15 and Table 2.16 are summaries of the previous simulations done to investigate the use of sand barrels as an attenuator in the short radius system. Table 2.15 consists of all the simulations that were run with the simplified car and simplified truck and the tests results. Table 2.16 is a summary of the simulations run for the Yaris (small car) and the Silverado truck models.

2.5.2. Dimensions of Barrel Layouts

The simulations and the experiments mentioned below have the dimensions shown in Figure 2.46. The barrels' radius is 36 inches.

The only changes made to the barrels are to their weights. Throughout this report, the weights of the barrels are presented in the order that the vehicle encounters them. Figure 2.47 shows an example of a 400-lb, 400-lb, and 700-lb barrel layout.

Table 2.15. Summary of Simulations with Simplified Car and Truck Models.

CASE		***DESCRIPTION***				***RESULTS FOR MASH***	***PERCENT LOSS IN KINETIC ENERGY***	***EXTRA INFORMATION***
		First Row	**Second Row**	**Third Row**	**Spacing (between rows)**			
Simplified Car: One Row								
	Case 1	Two barrels: 200 lb (90 kg)	N/A	N/A	N/A	Pass	36.51%	N/A
	Case 2	Two barrels: 400 lb (180 kg)	N/A	N/A	N/A	Pass	50.83%	N/A
Simplified Car: Two Rows								
	Case 1	Two barrels: 400 lb (180 kg)	Two barrels: 400 lb (180 kg)	N/A	13 inches (330 mm)	Violates	73.56%	N/A
	Case 2	Two barrels: 400 lb (180 kg)	Two barrels: 700 lb (320 kg)	N/A	13 inches (330 mm)	Pass	82.52%	N/A
	Case 3	Two barrels: 400 lb (180 kg)	Two barrels: 400 lb (180 kg)	N/A	24 inches (610 mm)	Pass	73.91%	N/A
Simplified Car: Three Rows								
	Case 1	Two barrels: 400 lb (180 kg)	Two barrels: 400 lb (180 kg)	Two barrels: 700 lb (320	1st to 2nd: 13 inches (330 mm) 2nd to 3rd: 43 inches (1086 mm)	Pass	89.70%	N/A
Simplified Truck: Two Rows								
	Case 1	Two barrels: 400 lb (180 kg)	Two barrels: 400 lb (180 kg)	N/A	13 inches (330 mm)	Pass	50.79%	N/A
	Case 2	Two barrels: 400 lb (180 kg)	Two barrels: 700 lb (320 kg)	N/A	13 inches (330 mm)	Violates	60.28%	N/A
Simplified Truck: Three Rows								
	Case 1	Two barrels: 400 lb (180 kg)	Two barrels: 400 lb (180 kg)	Two barrels: 700 lb (320	1st to 2nd: 13 inches (330 mm) 2nd to 3rd: 43 inches (1086 mm)	Pass	71.24%	N/A

Table 2.16. Summary of Simulations with Small Car and Truck Models.

CASE	***DESCRIPTION***				***RESULTS FOR MASH***	***PERCENT LOSS IN KINETIC ENERGY***	***EXTRA INFORMATION***
	First Row	**Second Row**	**Third Row**	**Spacing (between rows)**			
Actual Car: Three Rows							
Case 1	Two barrels: 400 lb (180 kg)	Two barrels: 400 lb (180 kg)	Two barrels: 700 lb (320	1st to 2nd: 24 inches (610 mm) 2nd to 3rd: 24 inches (610 mm)	Pass	78.67%	N/A
Case 2	Two barrels: 400 lb (180 kg)	Two barrels: 400 lb (180 kg)	Two barrels: 700 lb (320	1st to 2nd: 24 inches (610 mm) 2nd to 3rd: 24 inches (610 mm)	Pass	74.37%	Finer Mesh Failure = 0.015
Case 3	Two barrels: 400 lb (180 kg)	Two barrels: 700 lb (320 kg)	Two barrels: 700 lb (320	1st to 2nd: 24 inches (610 mm) 2nd to 3rd: 24 inches (610 mm)	Pass	80.98%	Finer Mesh Failure = 0.015
Case 4	Two barrels: 700 lb (320 kg)	Two barrels: 700 lb (320 kg)	Two barrels: 700 lb (320	1st to 2nd: 24 inches (610 mm) 2nd to 3rd: 24 inches (610 mm)	Pass	82.87%	Finer Mesh Failure = 0.015
Actual Truck: Three Rows							
Case 1	Two barrels: 400 lb (180 kg)	Two barrels: 400 lb (180 kg)	Two barrels: 700 lb (320	1st to 2nd: 24 inches (610 mm) 2nd to 3rd: 24 inches (610 mm)	Pass	67.16%	N/A
Case 2	Two barrels: 400 lb (180 kg)	Two barrels: 400 lb (180 kg)	Two barrels: 700 lb (320	1st to 2nd: 24 inches (610 mm) 2nd to 3rd: 24 inches (610 mm)	Pass	67.81%	Finer Mesh Failure = 0.015
Case 3	Two barrels: 400 lb (180 kg)	Two barrels: 700 lb (320 kg)	Two barrels: 700 lb (320	1st to 2nd: 24 inches (610 mm) 2nd to 3rd: 24 inches (610 mm)	Pass	70.53%	Finer Mesh Failure = 0.015
Case 4	Two barrels: 700 lb (320 kg)	Two barrels: 700 lb (320 kg)	Two barrels: 700 lb (320	1st to 2nd: 24 inches (610 mm) 2nd to 3rd: 24 inches (610 mm)	Pass	75.24%	Finer Mesh Failure = 0.015

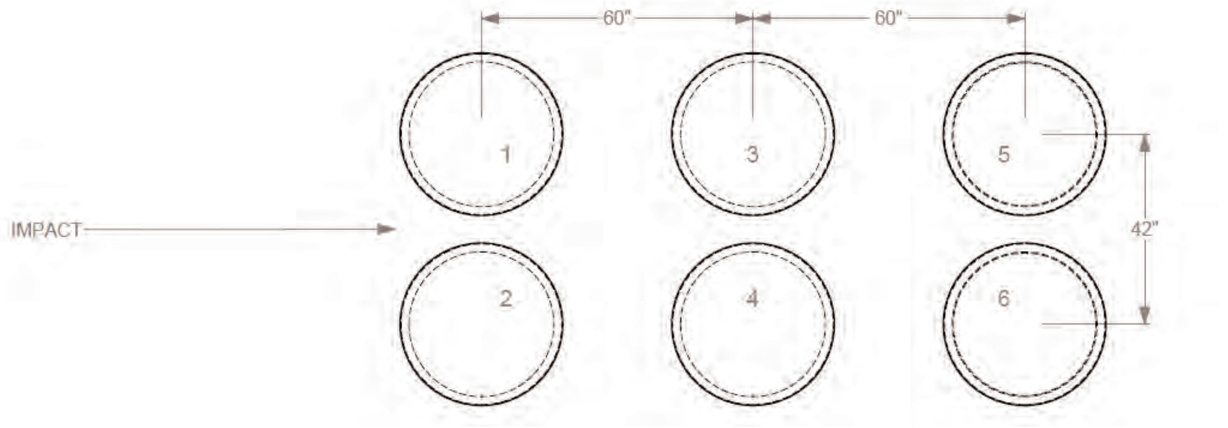


Figure 2.46. Dimensions of Barrel Layout.

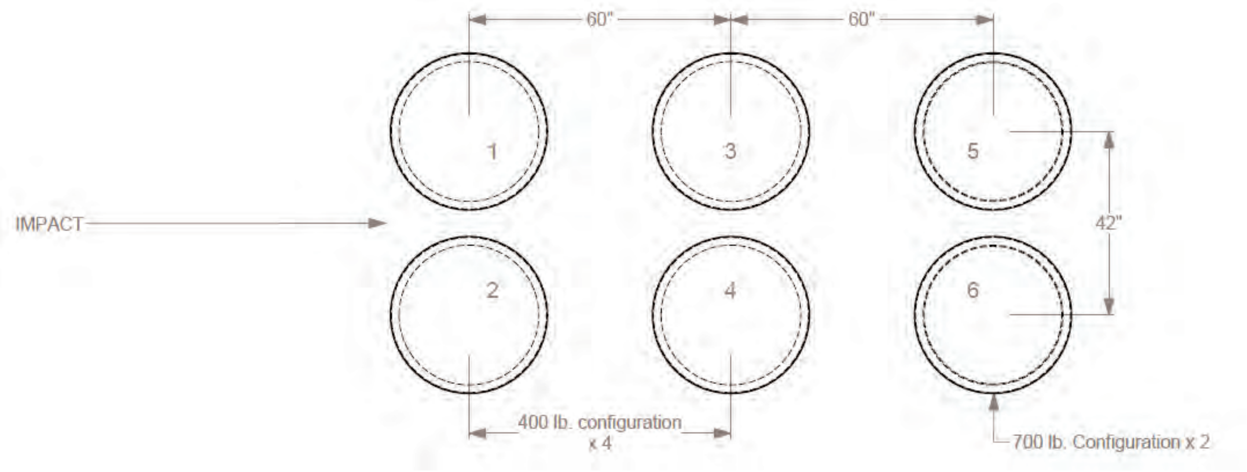


Figure 2.47. Weight Example for Barrel Layout Naming Convention.

2.5.3. Simulation—Car: 400-Lb, 400-Lb, and 700-Lb Barrel Layout

Two simulations were done with the 400-lb, 400-lb, and 700-lb barrel layout. In the second run, two changes made were a finer mesh and a lower material failure. These changes were done to better simulate how the barrels broke into pieces during the physical experiment, which is discussed later. Figure 2.48 shows that these changes did not affect the results in a significant way.

Figure 2.49 shows the kinetic energy of the car in the simulation. The results are from the larger mesh and material failure that were used since more data points were available. The correspondence between the different meshes implies that the results will be similar. The car lost 78.67 percent of its initial kinetic energy.

Table 2.17 presents the TRAP results of this simulation. The small car passed the *MASH* criteria for this barrel layout.

Since this barrel layout passes the *MASH* criteria but just exceeds the preferred limit in OIV, it was chosen for a physical experiment. The purpose of this physical experiment is to serve as a comparison for the simulations. How well the simulation compares to the experiment will speak to the validity of the simulation's results.

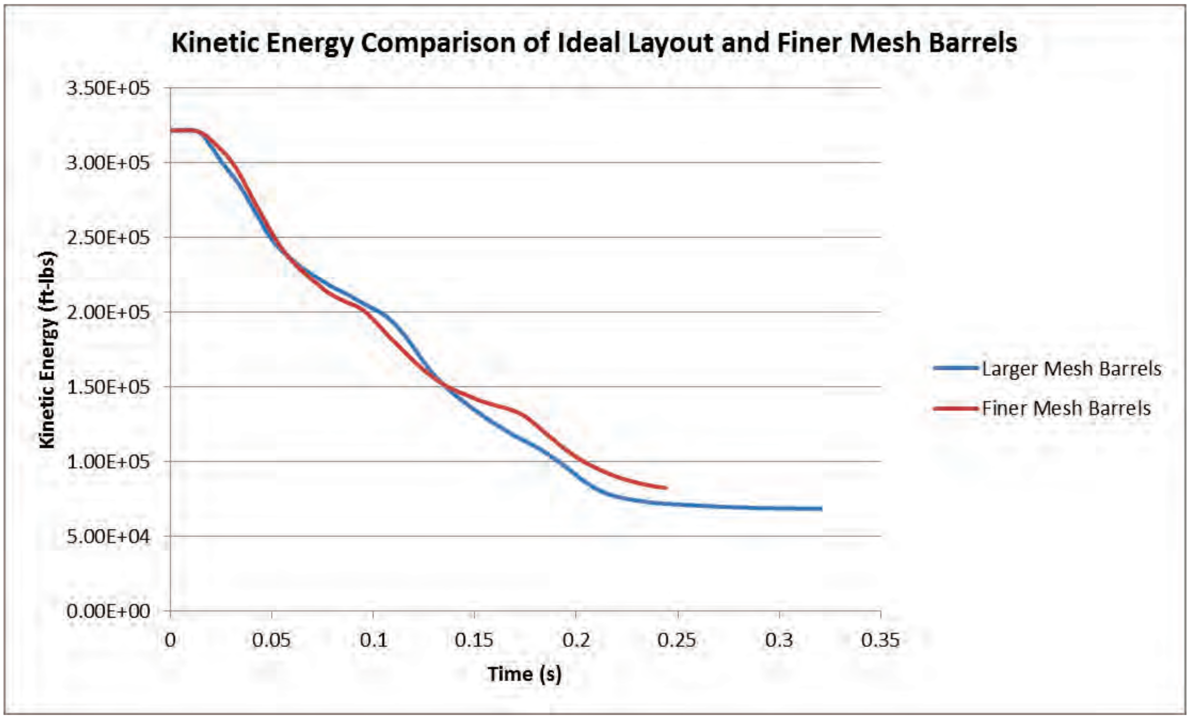


Figure 2.48. Comparison of Simulations with 400-Lb, 400-Lb, and 700-Lb Barrel Layout.

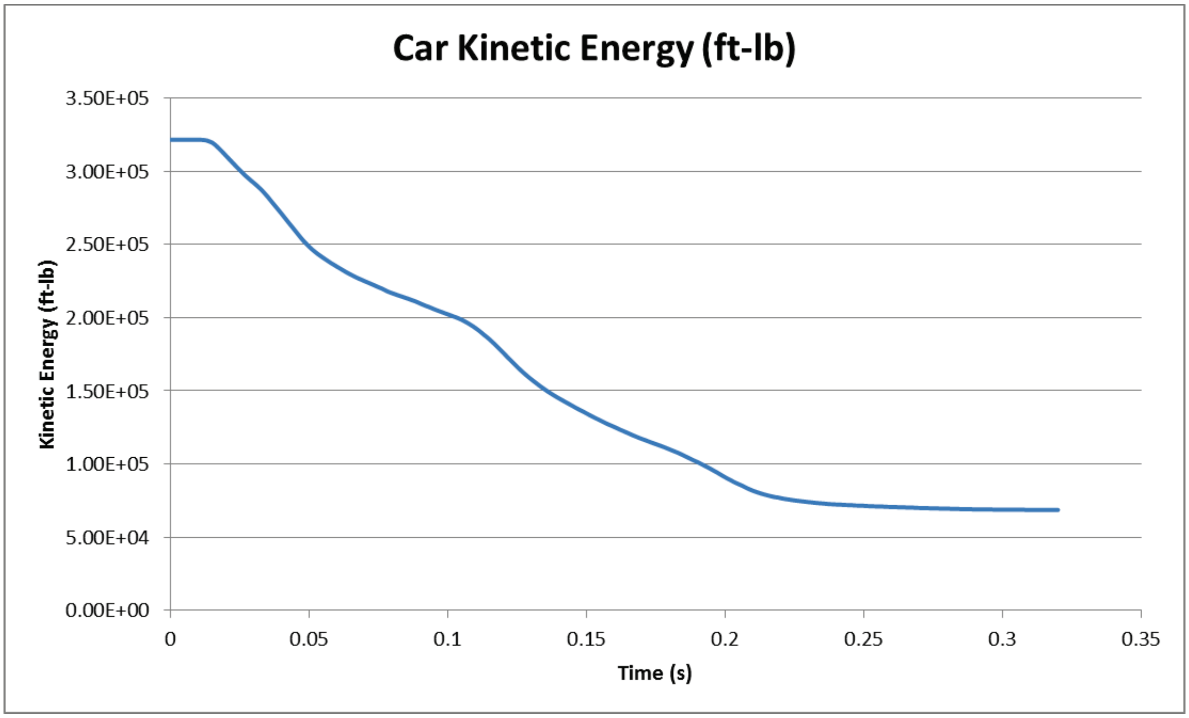


Figure 2.49. Kinetic Energy of the Yaris for 400-Lb, 400-Lb, and 700-Lb Barrel Layout.

Table 2.17. TRAP Results for Yaris with 400-Lb, 400-Lb, and 700-Lb Barrel Layout.

TRAP Results: Car with 400-lb, 400-lb, 700-lb Barrel Layout	
Impact Velocity, mph	62.2
Impact Angle (degrees)	0
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	29.9
y-direction	0.3
Ridedown Accelerations (Gs)	
x-direction	9.9
y-direction	2.3
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	1.7
Pitch	−5.7
Yaw	−1.5

2.5.4. Physical Experiment—Car: 400-Lb, 400-Lb, and 700-Lb Barrel Layout.

Figure 2.50 shows the kinetic energy of the car during the physical experiment. The car lost 77.55 percent of its initial kinetic energy in this experiment. Recall that in the simulation, the car lost 78.67 percent of its initial kinetic energy. Therefore, the percent difference between the simulation and the experiment is 1.44 percent.

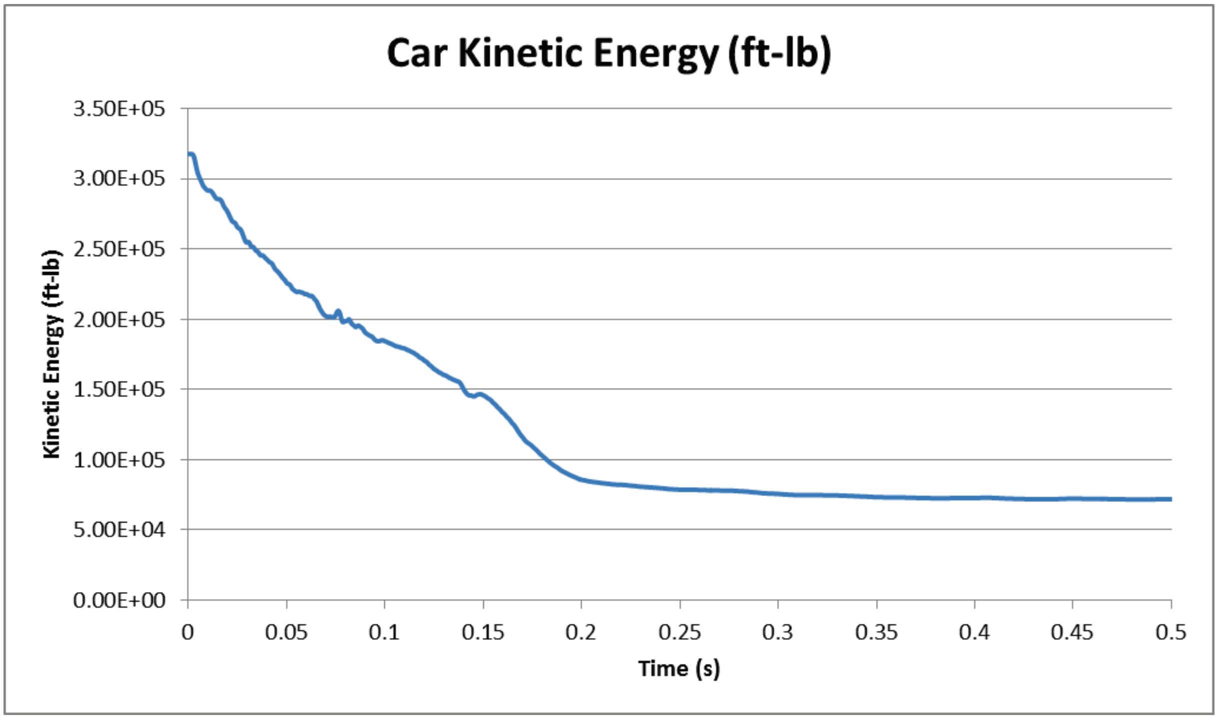


Figure 2.50. Kinetic Energy of Car with 400-Lb, 400-Lb, and 700-Lb Barrel Layout Experiment.

While the numbers matched well between the experiment and the simulation, the barrels in the simulation did not break into pieces as they did in the experiment (Figure 2.51). To create more frangible simulated barrels, a finer mesh and smaller material failure value were defined for the barrels. As previously shown, this did not impact the results of the simulation. However, these adjustments did help the modeled barrels break apart more like they did in the physical experiment (Figure 2.52).

Table 2.18 shows the TRAP results for the car in the physical experiment with the 400-lb, 400-lb, and 700-lb barrel layout. The car passed the *MASH* criteria in both OIV and ridedown accelerations. Since this barrel layout passed, more barrel layouts with increased weights will be simulated. The most promising of these heavier layouts will become a second physical experiment. Figure 2.53 shows the correspondence between the simulation and the physical experiment.

Figure 2.51. Pieces of Barrel after Experiment.

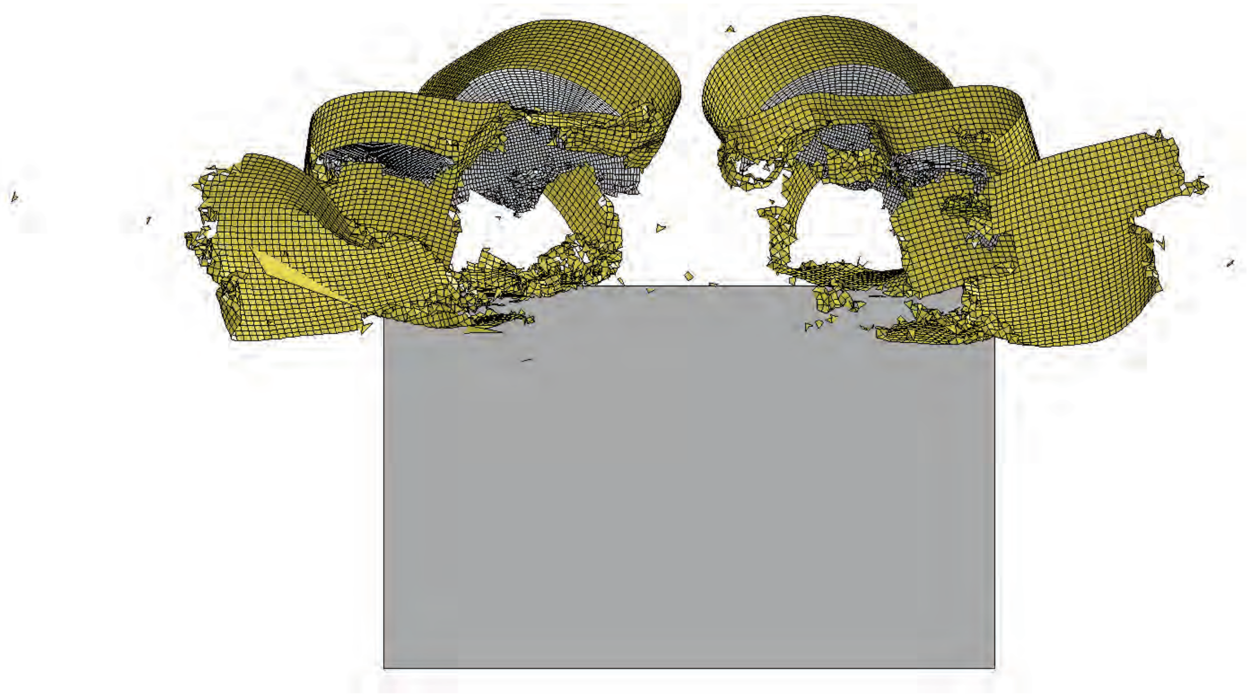


Figure 2.52. Pieces of Barrels during Simulation.

Table 2.18. TRAP Results for Car with 400-Lb, 400-Lb, and 700-Lb Barrel Layout Experiment.

TRAP Results: Car with 400-lb, 400-lb, 700-lb Barrel Layout—Experiment	
Impact Velocity, mph	62.6
Impact Angle (degrees)	0
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	26.2
y-direction	1.3
Ridedown Accelerations (Gs)	
x-direction	13.0
y-direction	2.3
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	−6.1
Pitch	4.1
Yaw	−6.7

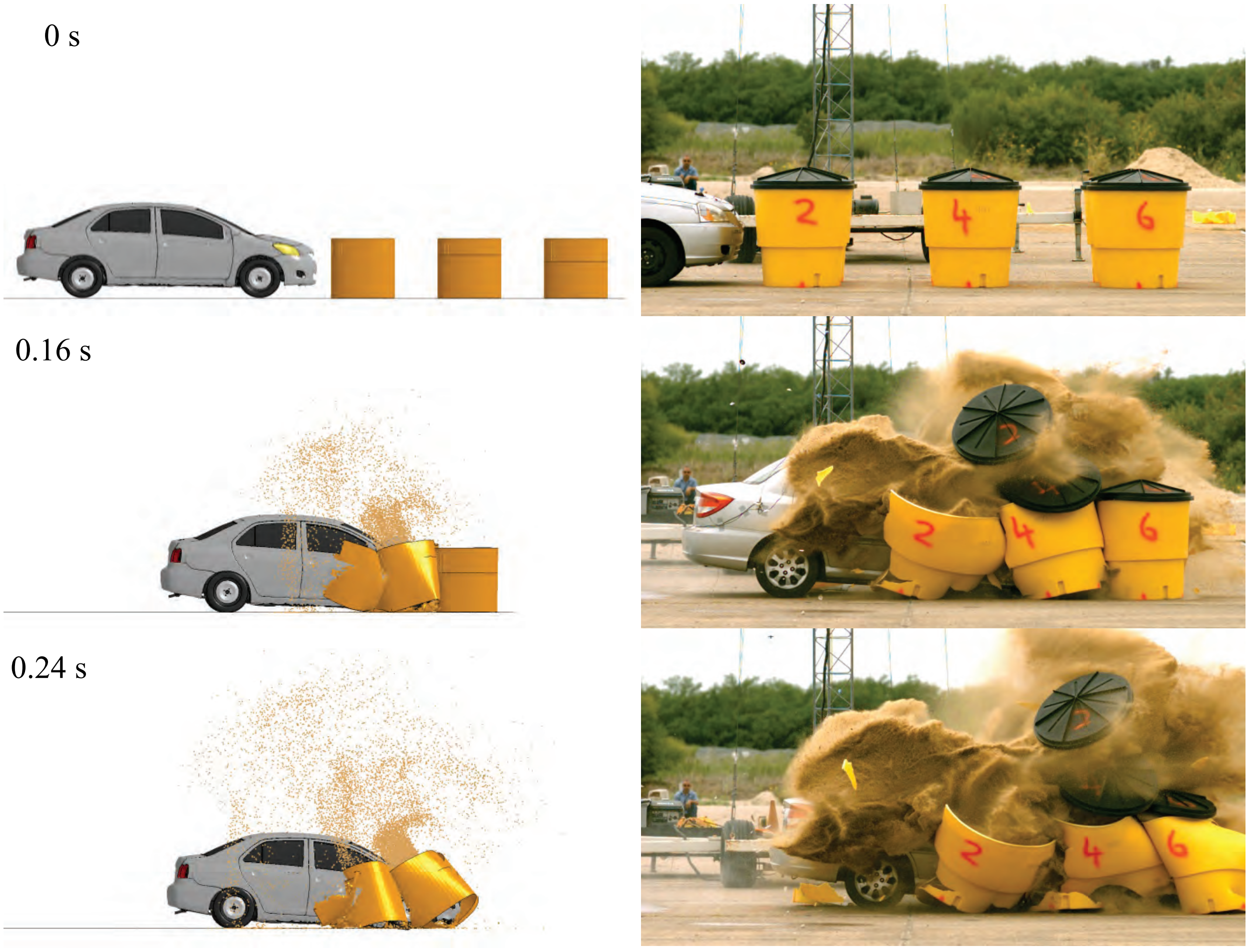


Figure 2.53. Simulation and Physical Experiment Comparison with 400-Lb, 400-Lb, and 700-Lb Layout.

2.5.5. Simulation—Car: 400-Lb, 700-Lb, and 700-Lb Barrel Layout

Figure 2.54 shows the kinetic energy loss throughout the simulation. The car lost 80.98 percent of its initial kinetic energy. Table 2.19 shows the TRAP results for the Yaris in the simulation with the 400-lb, 700-lb, and 700-lb barrel layout. The *MASH* criteria are all met. The OIV in the x-direction just surpassed the preferred limit of 29.53 ft/s at 34.1 ft/s.

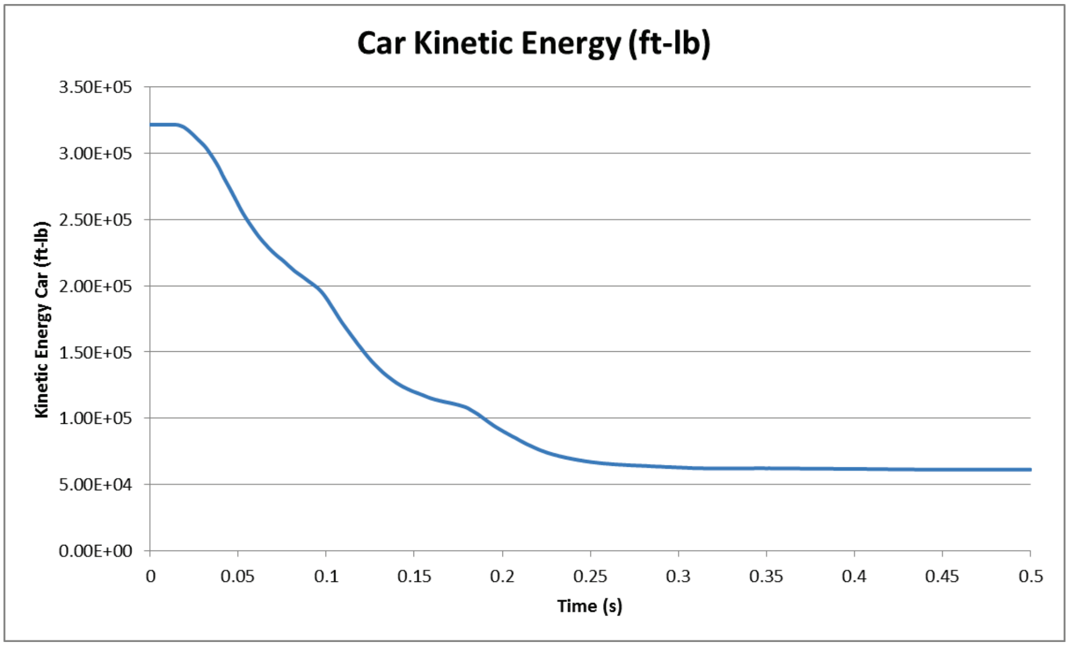


Figure 2.54. Kinetic Energy of the Yaris for 400-Lb, 700-Lb, and 700-Lb Barrel Layout.

Table 2.19. TRAP Results for Yaris with 400-Lb, 700-Lb, and 700-Lb Barrel Layout.

TRAP Results: Car with 400-lb, 700-lb, 700-lb Barrel Layout	
Impact Velocity, mph	62.2
Impact Angle (degrees)	0
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	34.1
y-direction	0.3
Ridedown Accelerations (Gs)	
x-direction	8.4
y-direction	2.4
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	2.5
Pitch	−2.6
Yaw	−2.6

2.5.6. Simulation−—Car: 700-Lb, 700-Lb, and 700-Lb Barrel Impact

Figure 2.55 shows the kinetic energy of the car during the simulation with the 700-lb, 700-lb, and 700-lb barrel layout. The car lost 82.87 percent of its initial kinetic energy. Table 2.20 presents the TRAP results for the Yaris when simulated with the 700-lb, 700-lb, and 700-lb barrel layout. The *MASH* criteria were met during this simulation. The OIV in the x-direction just exceeded the preferred limit of 29.53 ft/s at 33.5 ft/s. Since this barrel layout passed the *MASH* criteria, a second physical experiment was performed using the same layout.

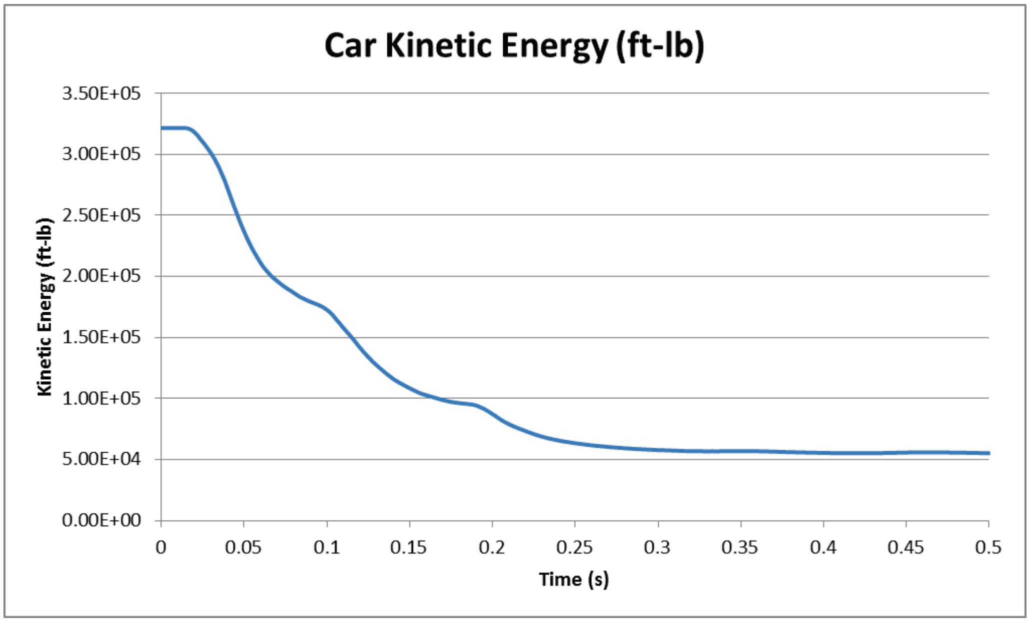


Figure 2.55. Kinetic Energy of the Yaris for 700-Lb, 700-Lb, and 700-Lb Barrel Layout.

Table 2.20. TRAP Results for the Yaris with 700-Lb, 700-Lb, and 700-Lb Barrel Layout.

TRAP Results: Car with 700-lb, 700-lb, and 700-lb Barrel Layout	
Impact Velocity, mph	62.2
Impact Angle (degrees)	0
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	33.5
y-direction	0.0
Ridedown Accelerations (Gs)	
x-direction	9.7
y-direction	3.5
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	1.7
Pitch	−4.0
Yaw	−0.9

2.5.7. Physical Experiment—Car: 700-Lb, 700-Lb, and 700-Lb Barrel Layout

Figure 2.56 presents the kinetic energy of the car throughout the experiment. The car lost 86.30 percent of its initial kinetic energy. Recall that in the simulation, the car lost 82.87 percent of its kinetic energy that equates to a 4.0 percent difference between the experiment and the simulation. Therefore, the correlation between the simulation and experiment is still acceptable.

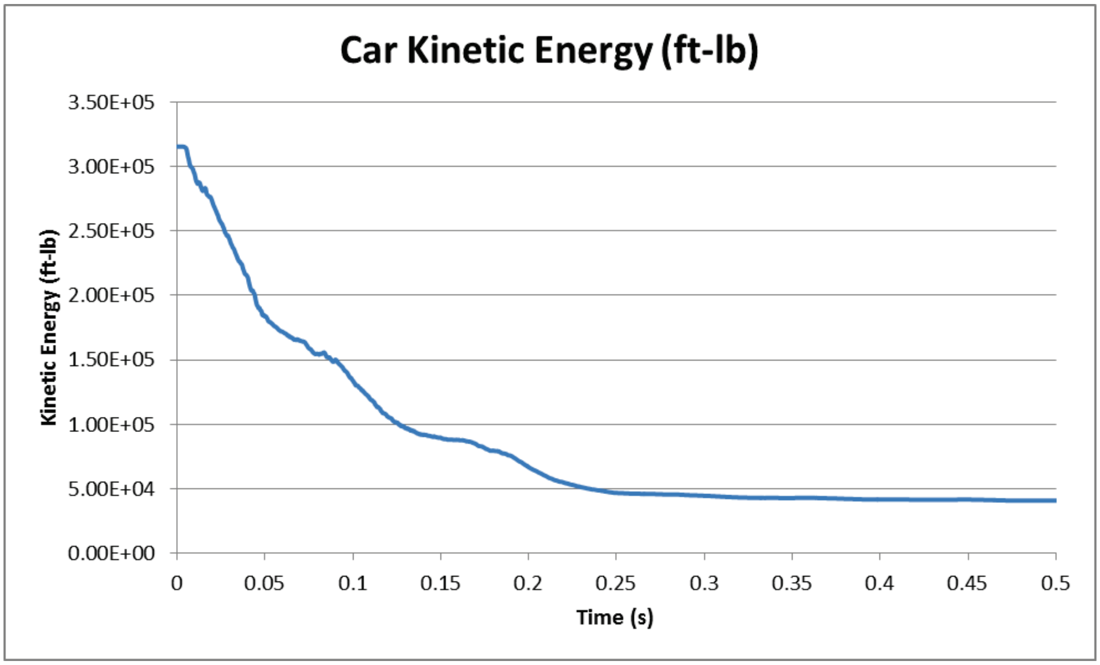


Figure 2.56. Kinetic Energy of Car with 700-Lb, 700-Lb, and 700-Lb Barrel Layout Experiment.

Table 2.21 displays the TRAP results for the physical experiment. The OIV and ridedown accelerations passed the *MASH* criteria. Therefore, the weight of the barrels that will be used in the short radius system will be 700-lb sand barrels. Figure 2.57 displays the correspondence between the simulation and the physical experiment.

Table 2.21. TRAP Results for Car with 700-Lb, 700-Lb, and 700-Lb Barrel Layout Experiment.

TRAP Results: Car with 700-lb, 700-lb, and 700-lb Barrel Layout - Experiment	
Impact Velocity, mph	62.4
Impact Angle (degrees)	0
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	33.8
y-direction	1.0
Ridedown Accelerations (Gs)	
x-direction	11.3
y-direction	1.5
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	−5.0
Pitch	−3.9
Yaw	−1.9

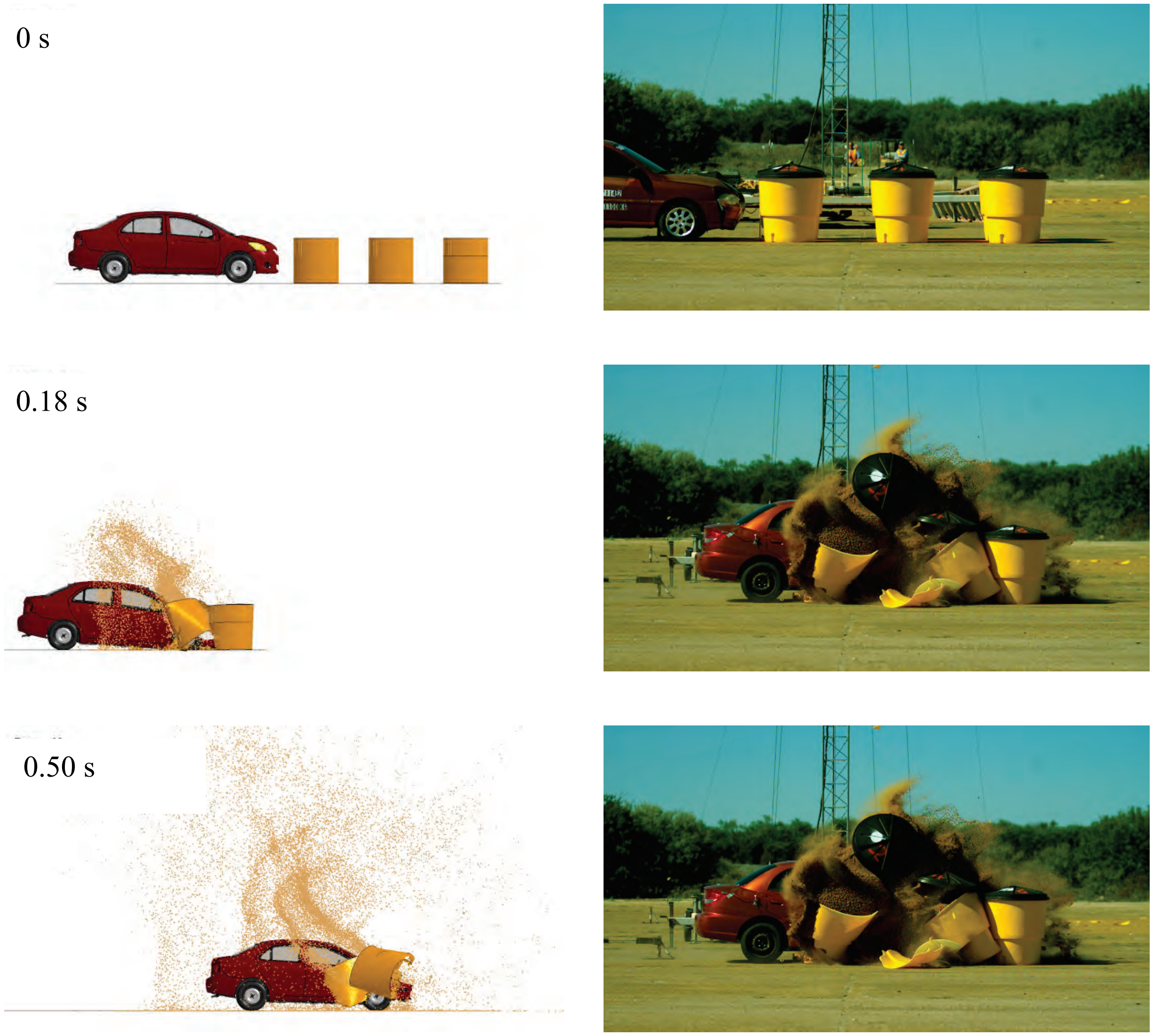


Figure 2.57. Simulation and Physical Experiment Comparison with 700-Lb, 700-Lb, and 700-Lb Layout.

2.5.8. Simulation—Truck: 400-Lb, 400-Lb, and 700-Lb Barrel Layout

Figure 2.58 displays the kinetic energy of the truck throughout the run with the 400-lb, 400-lb, and 700-lb barrel layout. The truck lost 67.81 percent of its initial kinetic energy in this simulation. Table 2.22 presents the TRAP results. The truck passed the *MASH* criteria.

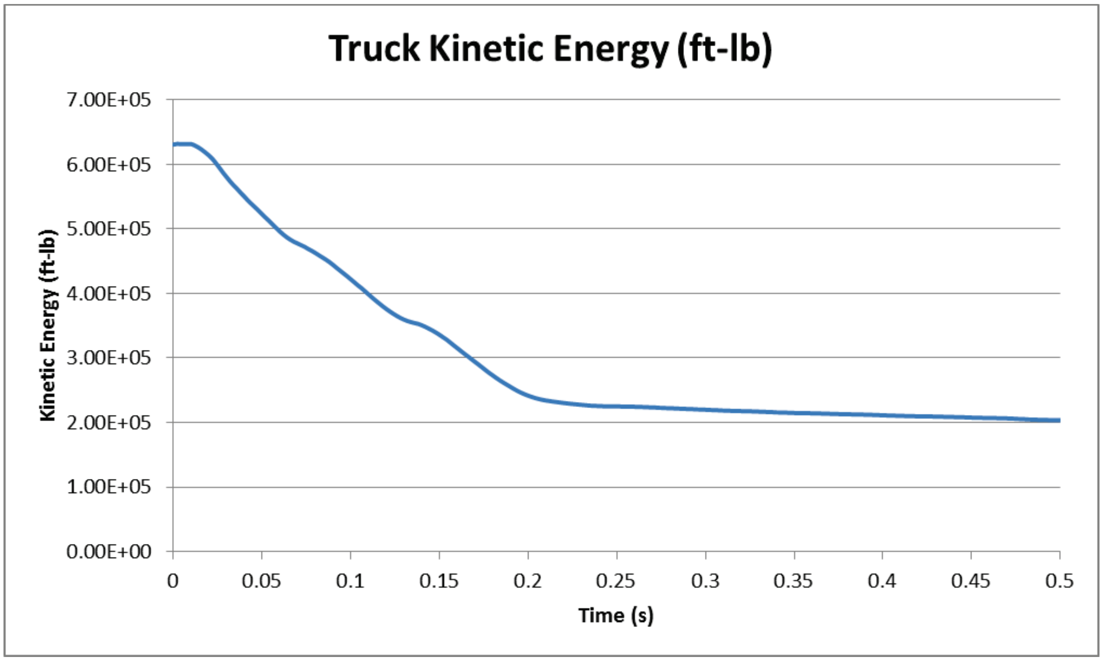


Figure 2.58. Kinetic Energy of the Truck with 400-Lb, 400-Lb, and 700-Lb Barrel Layout.

Table 2.22. TRAP Results for Truck with 400-Lb, 400-Lb, and 700-Lb Barrel Layout.

TRAP Results: Truck With 400-lb, 400-lb, and 700-lb Barrel Layout	
Impact Velocity, mph	62.2
Impact Angle (degrees)	0
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	26.2
y-direction	0.0
Ridedown Accelerations (Gs)	
x-direction	8.6
y-direction	1.9
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	1.5
Pitch	−3.1
Yaw	0.2

2.5.9. Physical Experiment—Truck: 400-Lb, 400-Lb, and 700-Lb Barrel Layout

Figure 2.59 depicts the kinetic energy during the truck's experiment. The truck lost 61.67 percent of its initial kinetic energy in the physical experiment. Recall that during the simulation, the truck lost 67.81 percent of its initial kinetic energy. Therefore, this is about a 6 percent difference between the experiment and the simulation. Note that in the experiment, the truck hit the first row at 64.4 mph, a higher velocity than the simulation.

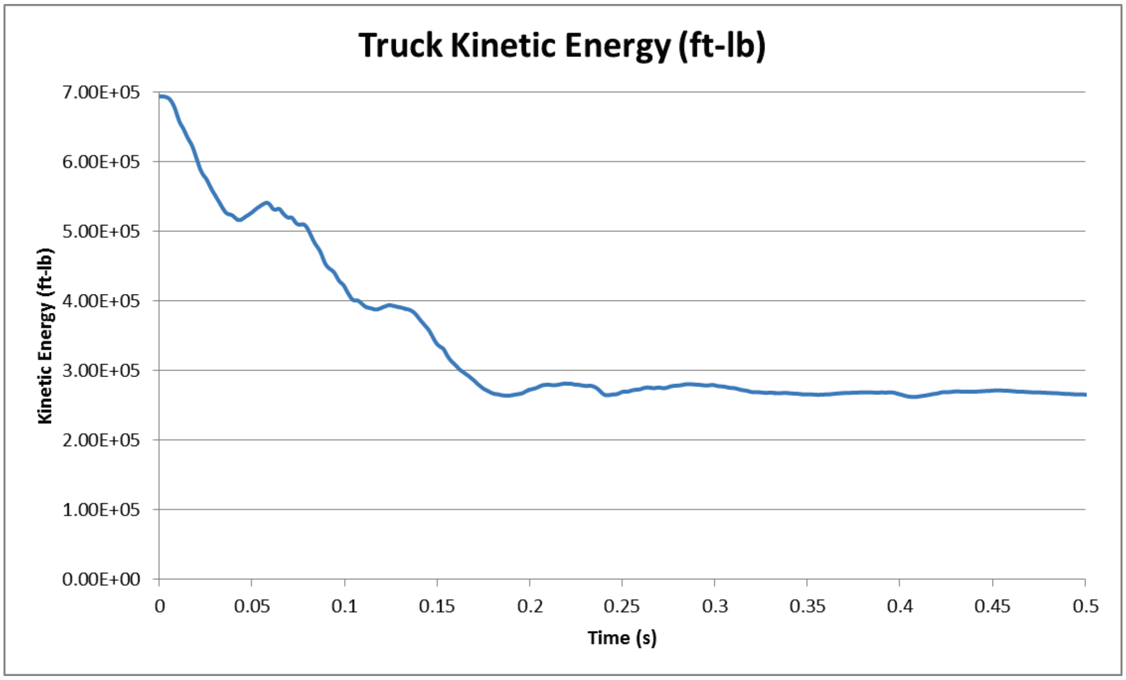


Figure 2.59. Kinetic Energy of Truck with 400-Lb, 400-Lb, and 700-Lb Barrel Layout Experiment.

Table 2.23 shows the TRAP results for the truck during this run. The truck passed all criteria. Figure 2.60 displays the correlation between the simulations and the physical experiment.

Table 2.23. TRAP Results for Truck with 400-Lb, 400-Lb, and 700-Lb Barrel Layout Physical Experiment.

TRAP Results: Truck With 400-lb, 400-lb, and 700-lb Barrel Layout—Physical Experiment	
Impact Velocity, mph	64.4
Impact Angle (degrees)	0
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	24.3
y-direction	0.3
Ridedown Accelerations (Gs)	
x-direction	11.2
y-direction	2.1
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	1.5
Pitch	−2.6
Yaw	0.8

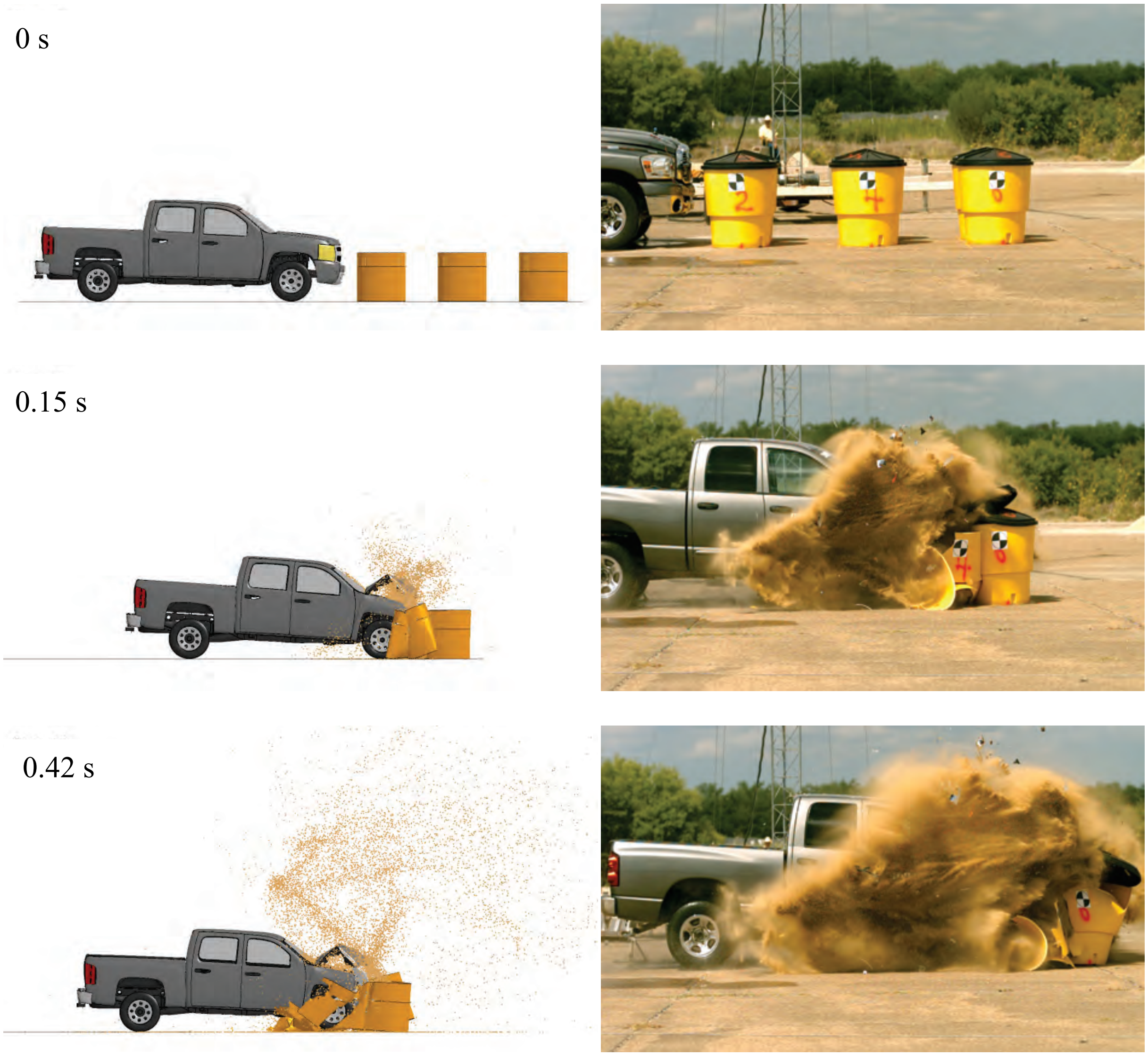


Figure 2.60. Simulation and Physical Experiment Comparison with 400-Lb, 400-Lb, and 700-Lb Layout.

2.5.10. Simulation—Truck: 400-Lb, 700-Lb, and 700-Lb Barrel Layout

Figure 2.61 shows the kinetic energy of the truck during the simulation with the 400-lb, 700-lb, and 700-lb barrel layout. The truck lost 70.53 percent of its initial kinetic energy. Table 2.24 displays the TRAP results for this simulation. The truck passed the *MASH* criteria.

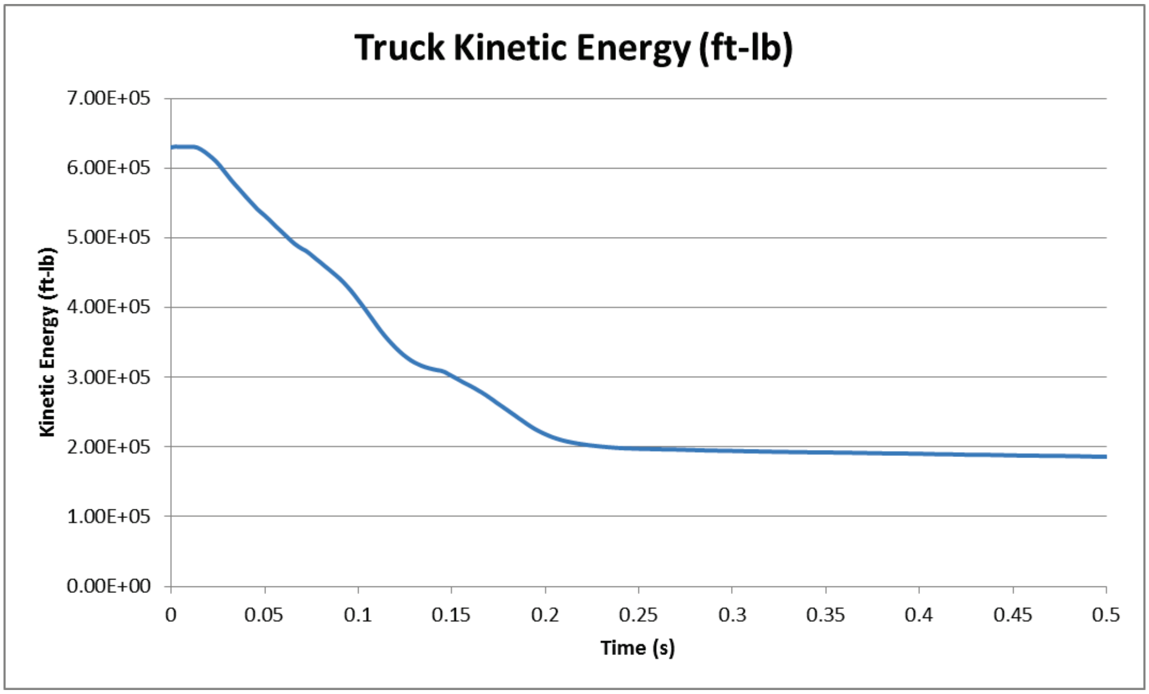


Figure 2.61. Kinetic Energy of the Truck with 400-Lb, 700-Lb, and 700-Lb Barrel Layout.

Table 2.24. TRAP Results for Truck with 400-Lb, 700-Lb, and 700-Lb Barrel Layout.

TRAP Results: Truck with 400-lb, 700-lb, and 700-lb Barrel Layout	
Impact Velocity, mph	62.2
Impact Angle (degrees)	0
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	29.2
y-direction	0.0
Ridedown Accelerations (Gs)	
x-direction	8.6
y-direction	2.3
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	1.0
Pitch	−2.0
Yaw	0.3

2.5.11. Simulation—Truck 700-Lb, 700-Lb, and 700-Lb Barrel Layout

Figure 2.62 shows the kinetic energy of the truck through the simulation. The truck lost 75.24 percent of its initial kinetic energy. Table 2.25 presents the TRAP results for the truck. The OIV and ridedown accelerations pass the preferred *MASH* limits.

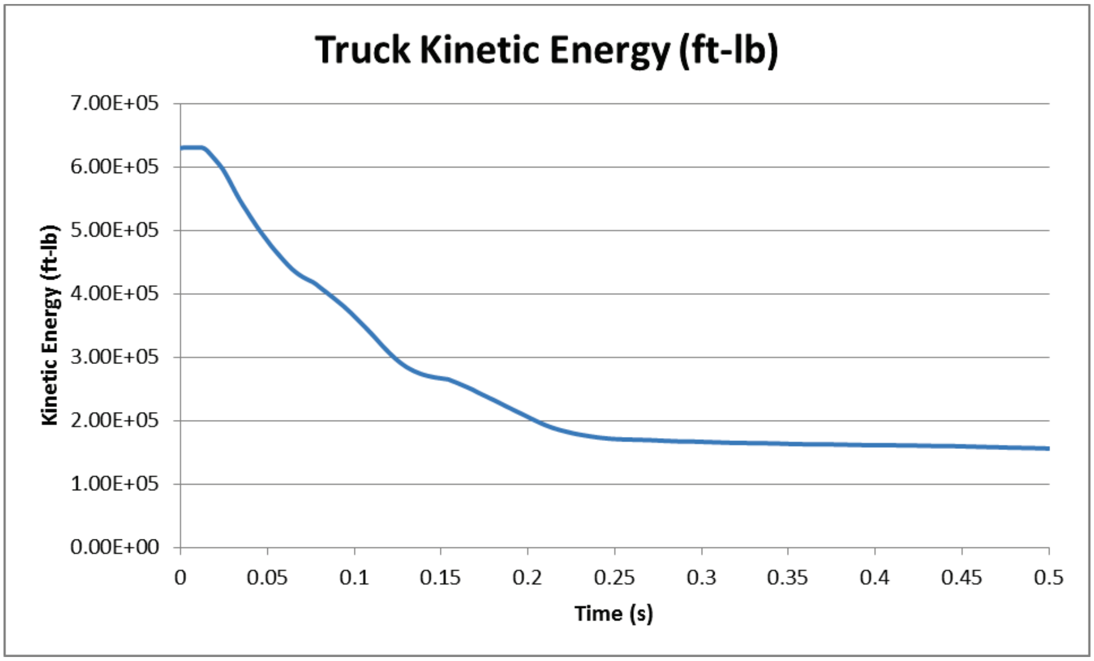


Figure 2.62. Kinetic Energy of Truck with 700-Lb, 700-Lb, and 700-Lb Barrel Layout.

Table 2.25. TRAP Results for Truck with 700-Lb, 700-Lb, and 700-Lb Barrel Layout.

TRAP Results: Truck with 700-lb, 700-lb, and 700-lb Barrel Layout	
Impact Velocity, mph	62.2
Impact Angle (degrees)	0
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	30.5
y-direction	0.0
Ridedown Accelerations (Gs)	
x-direction	6.3
y-direction	1.3
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	0.3
Pitch	−3.0
Yaw	−0.3

2.5.12. Physical Experiment—Truck: 700-Lb, 700-Lb, and 700-Lb Barrel Layout

Figure 2.63 displays the dissipation of the kinetic energy of the truck throughout the physical experiment. The truck lost 74.43 percent of its initial kinetic energy in the physical experiment. Recall that during the simulation, the truck lost 75.24 percent of its initial kinetic energy. Therefore, this is about a 1 percent difference between the experiment and the simulation. In the physical experiment, the truck impacted the initial row of barrels at 63.5 mph.

Table 2.26 presents the *MASH* criteria for the physical experiment. All criteria were passed. Figure 2.64 shows the correlation between the simulation and the physical experiment. Since the 700-lb barrels attenuated almost 75 percent of the trucks energy while not causing the car to fail OIV and RDA, this is the mass that will be placed in the short radius system.

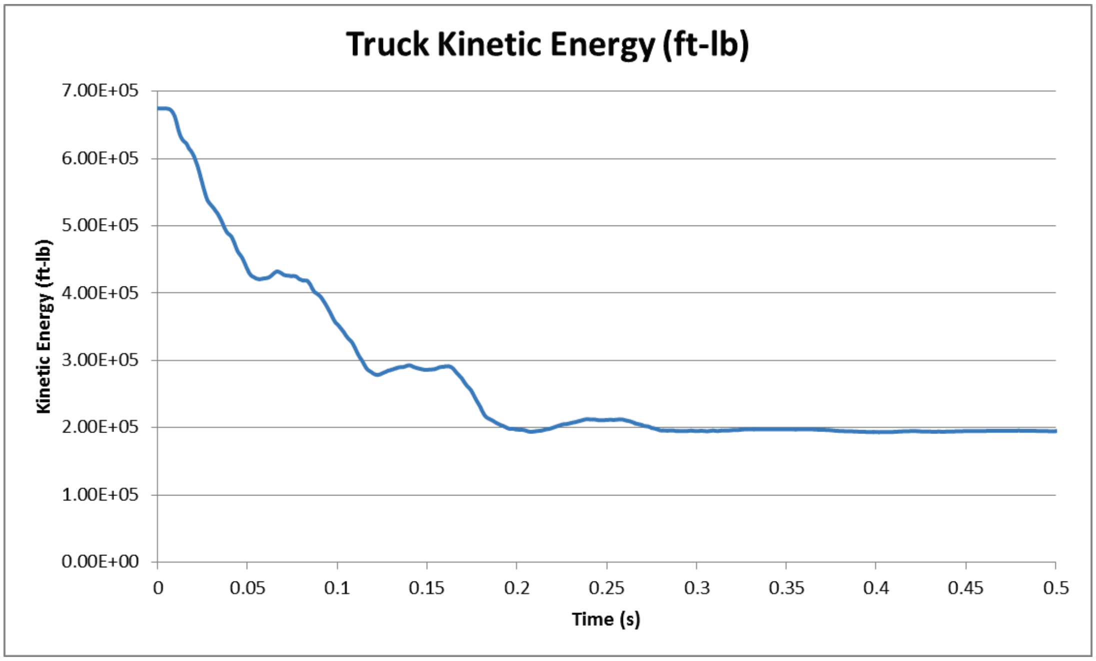


Figure 2.63. Kinetic Energy of Truck with 700-Lb, 700-Lb, and 700-Lb Barrel Layout Experiment.

Table 2.26. TRAP Results for Truck with 700-Lb, 700-Lb, and 700-Lb Barrel Layout Physical Experiment.

TRAP Results: Truck With 700-lb, 700-lb, and 700-lb Barrel Layout—Physical Experiment	
Impact Velocity, mph	63.5
Impact Angle (degrees)	0
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	32.8
y-direction	−0.3
Ridedown Accelerations (Gs)	
x-direction	16.0
y-direction	2.1
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	2.6
Pitch	−4.2
Yaw	−5.5

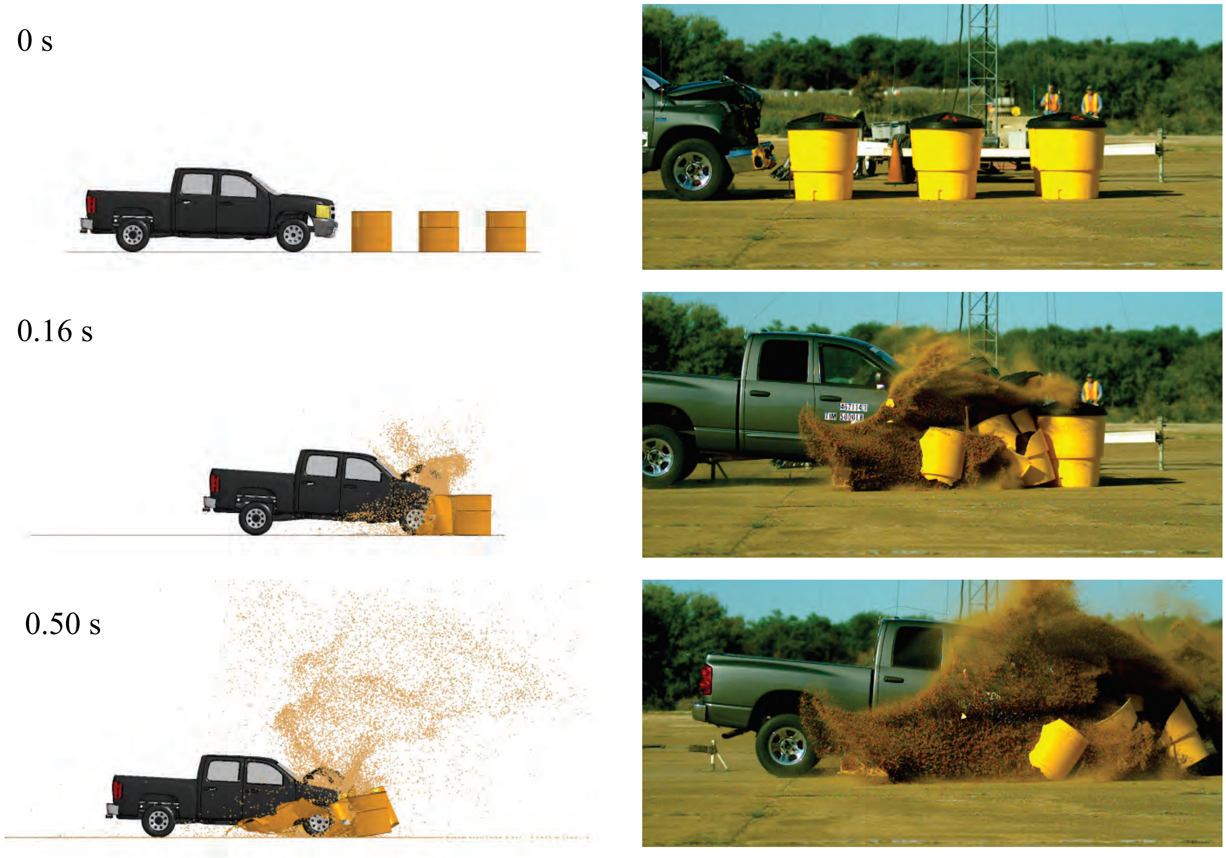


Figure 2.64. Simulation and Physical Experiment Comparison with 700-Lb, 700-Lb, and 700-Lb Layout.

2.6. UPDATED MODEL

The updated model has a few changes from the last model. The two W-beams were replaced with a single thrie beam for the entire model. This was done to help improve the over-and under-riding of the truck and car, respectively. Freestanding barrels weighing 700 lb each were placed behind the radius to act as an attenuator. Figure 2.65 shows an example of this layout.

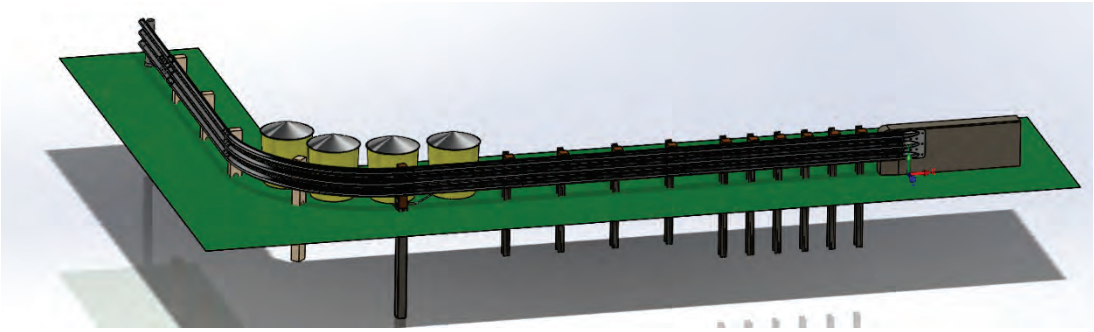


Figure 2.65. Most Recent Model.

2.7. EARLIER SYSTEMS

Figure 2.66 displays the last system that was modeled and run earlier. Figure 2.67 displays the primary roadway in this older system. There is a W-beam and rub rail in the radius for about half of the primary roadway side, and then, there is a transition to a thrie beam. Figure 2.68 shows the secondary roadway with the W-beam and rubrail. An anchor post ends this section of the rail.

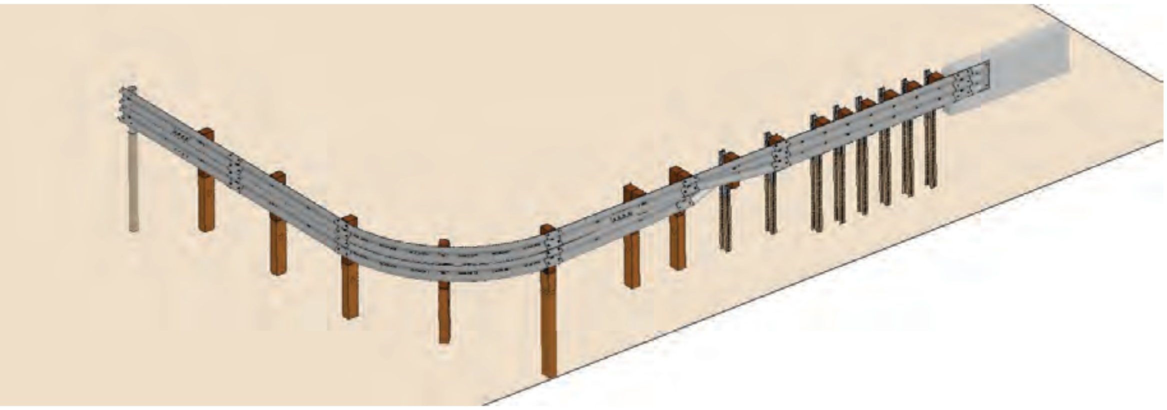


Figure 2.66. Whole System with Two W-Beams.

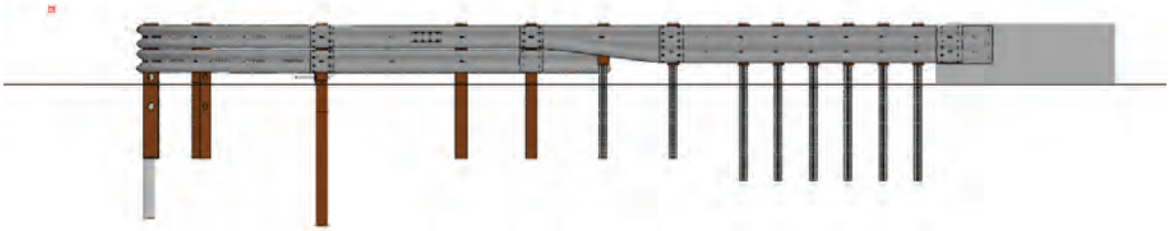


Figure 2.67. Primary Roadway Side View.

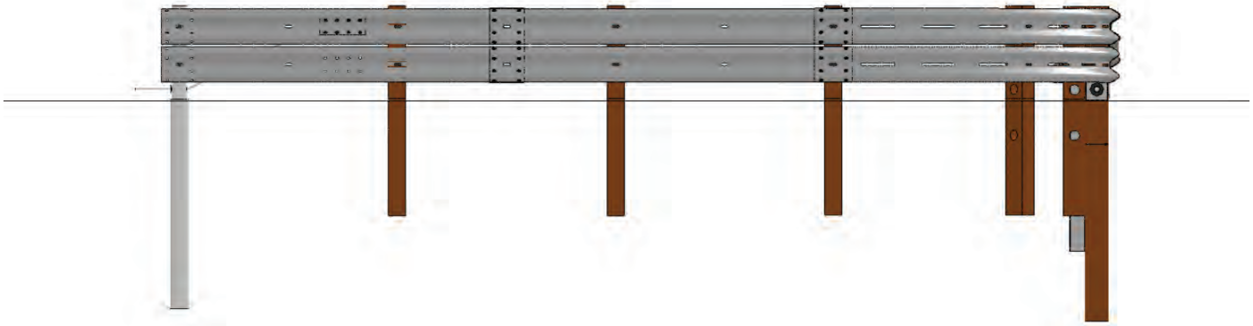


Figure 2.68. Primary Secondary Roadway Side View.

Figure 2.69 shows the progression of the impact. The last picture of the set depicts the truck beginning to separate the two rails. If this is a problem for the truck, the car will probably separate the rails as well. There were also concerns about the height of the rail from the ground. It was thought that this short distance above the ground would exacerbate the vehicle, either separating the rails or overriding the system. Therefore, the W-beam and rubrail were changed to a single thrie beam in the system design under consideration.

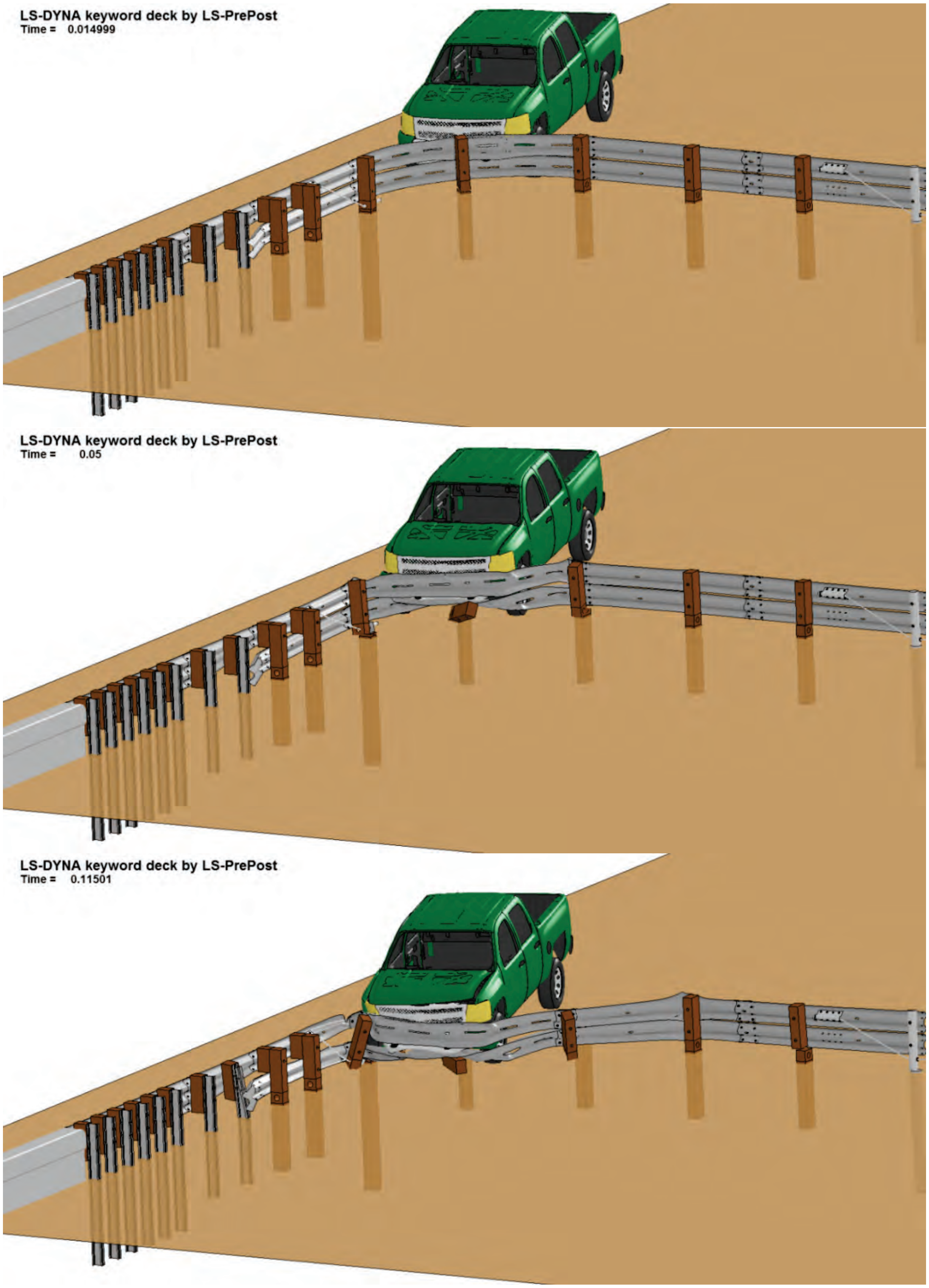


Figure 2.69. Progression of Truck Impact.

2.8. CURRENT SHORT RADIUS SYSTEM DESIGN

Figure 2.70 shows the current system that was modeled and run with the *MASH* 2270P vehicle.

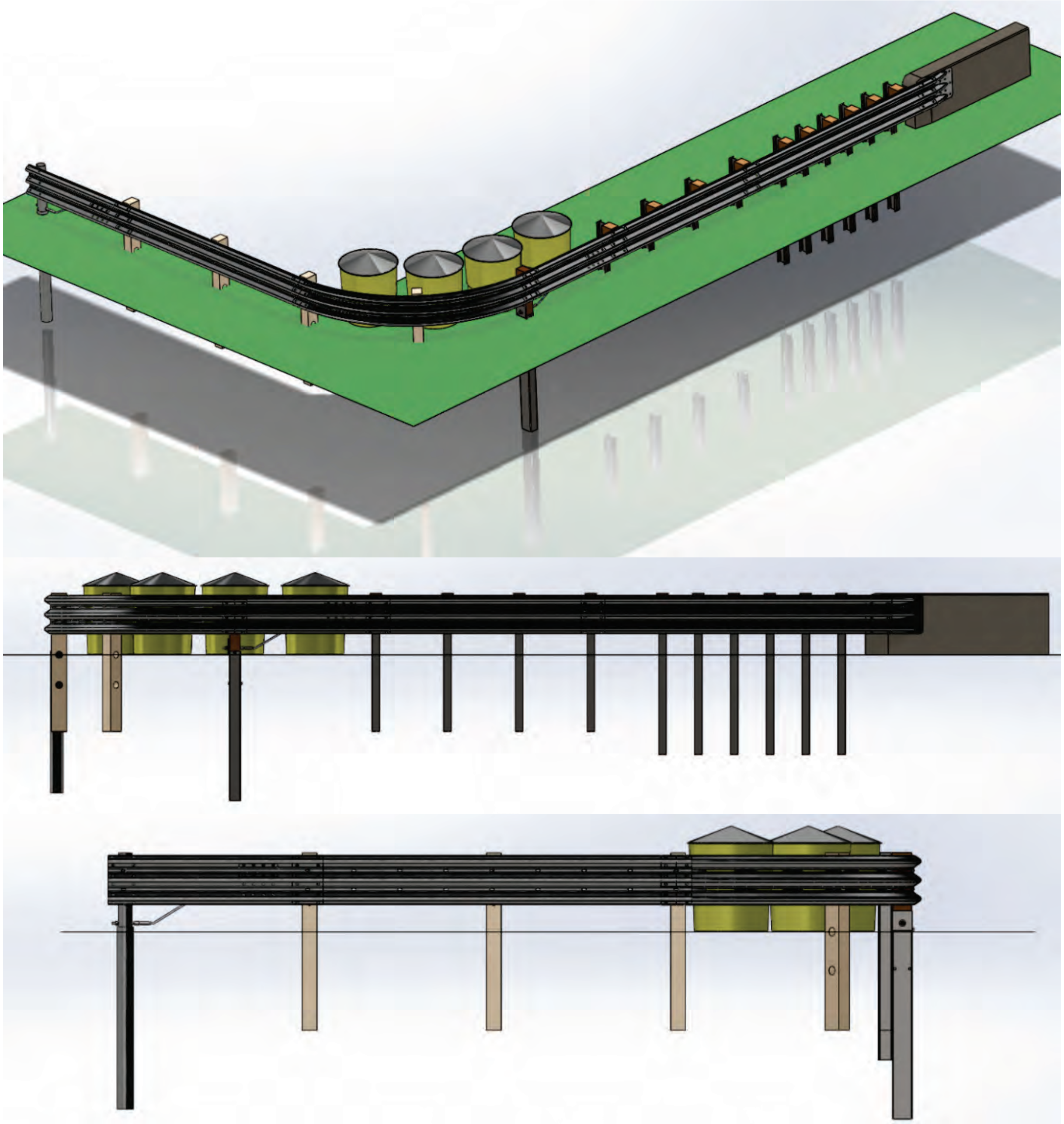


Figure 2.70. Current System under Investigation.

The system has a short driveway rail to accommodate the right-of-way (ROW) consideration while still providing positive anchor. Figure 2.71 and Figure 2.72 show the anchor chosen as a rotating post design. The TTI research team has identified two design options for this anchor.

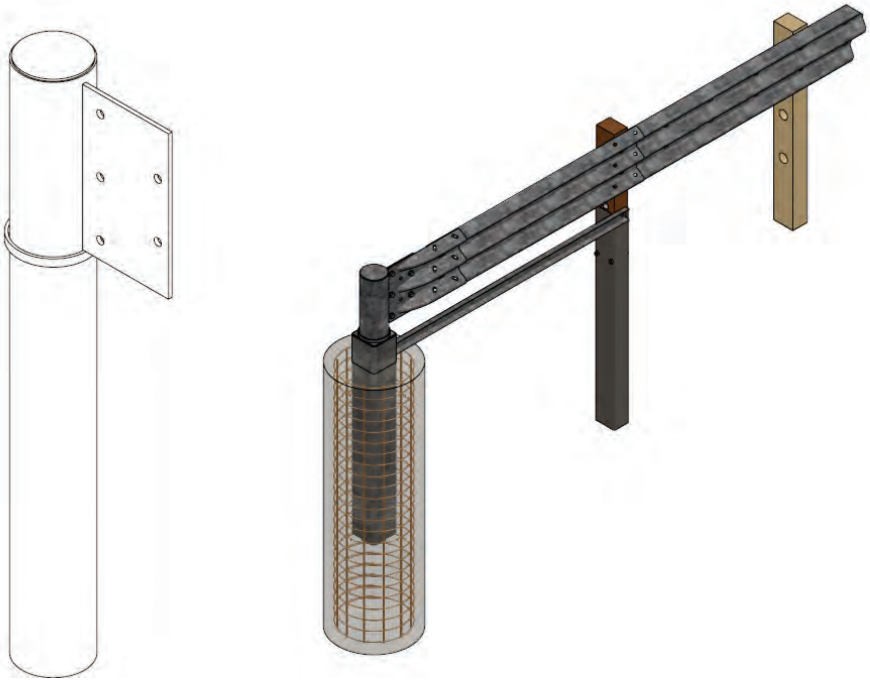


Figure 2.71. Rotating Anchor Design Option 1.

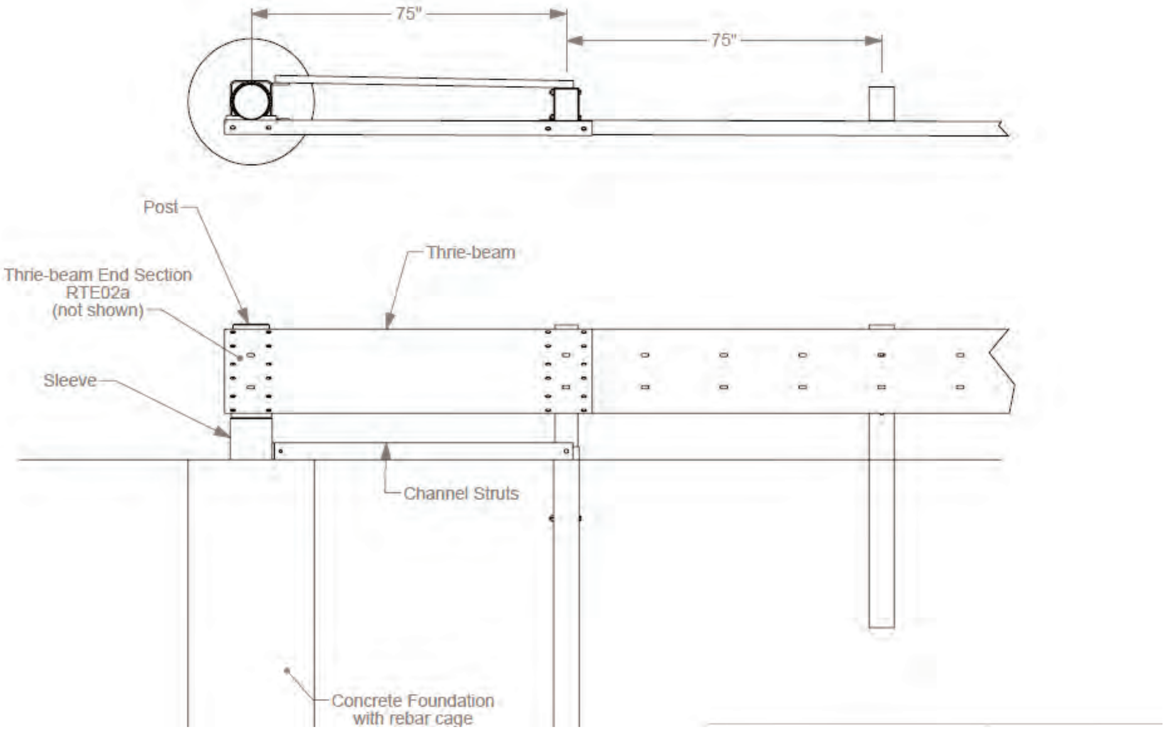


Figure 2.72. Rotating Anchor Design Option 2.

2.9. SIMULATION OF *MASH* TEST 3-33; TRUCK IMPACTING SHORT RADIUS WITHOUT SAND BARRELS

The research team began to evaluate the single thrie beam system design through simulations. Figure 2.73 depicts the whole system. Figure 2.74 shows the side view of the primary roadway. This side contains a cable anchor in the rail section right after the curve. There is also a nested thrie beam where the steel posts transition to quarter spacing. An endshoe and concrete parapet represents the stiffer portion of the rail. Figure 2.75 represents the side view of the secondary roadway. A rigid post in the simulation anchored this end. The truck impacted this system in the center of the radius at a 15° angle.

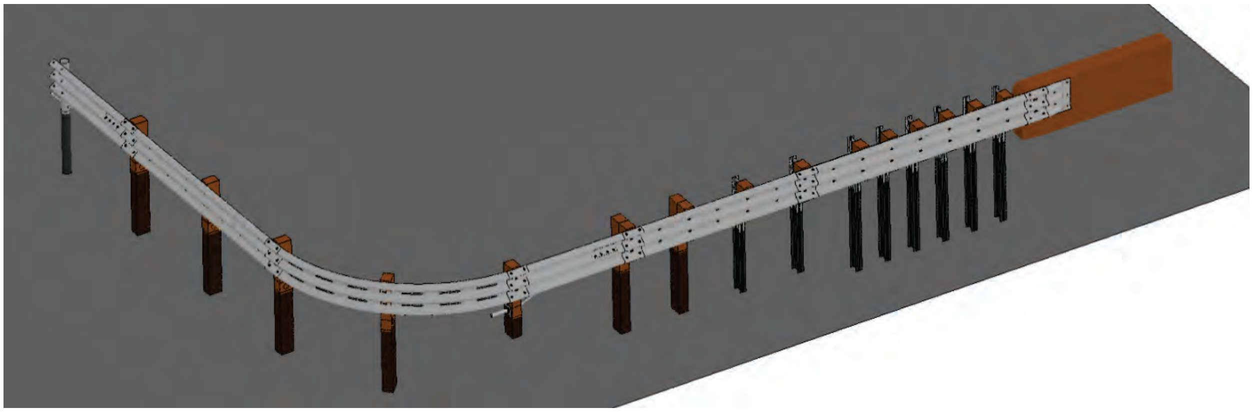


Figure 2.73. Entire System.

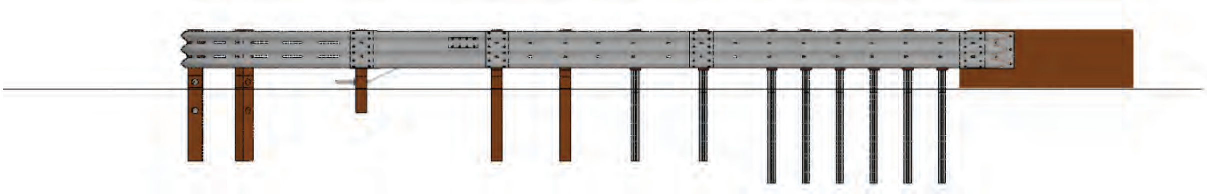


Figure 2.74. Side View of Primary Roadway.

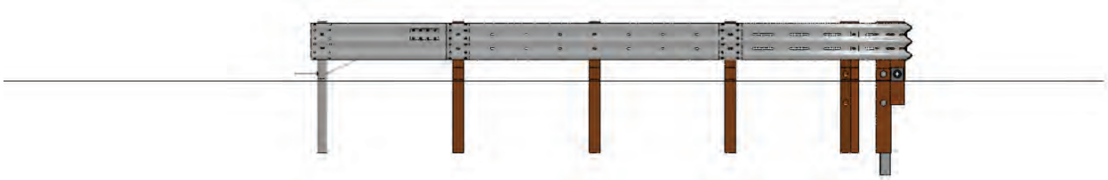


Figure 2.75. Side View of Secondary Roadway.

Figure 2.76 shows the truck's velocity during the simulation. The initial slope is gradual and followed by a steeper slope. The gradual slope represents the initial impact with the radius. In this simulation, there are no additional objects to absorb the kinetic energy (i.e., sand barrels) upon impact. As the simulation continues, the rail gets stretched and tension increases in the system. Furthermore, the stiffer portion of the system is engaged and increased tension in the rail causes more energy to be absorbed. The negative velocity indicates that the truck experiences a slight rebound toward the end of the simulation. The truck was experiencing dynamic instability at the end of the simulation. It is apparent that the truck would probably roll over the system as time progressed.

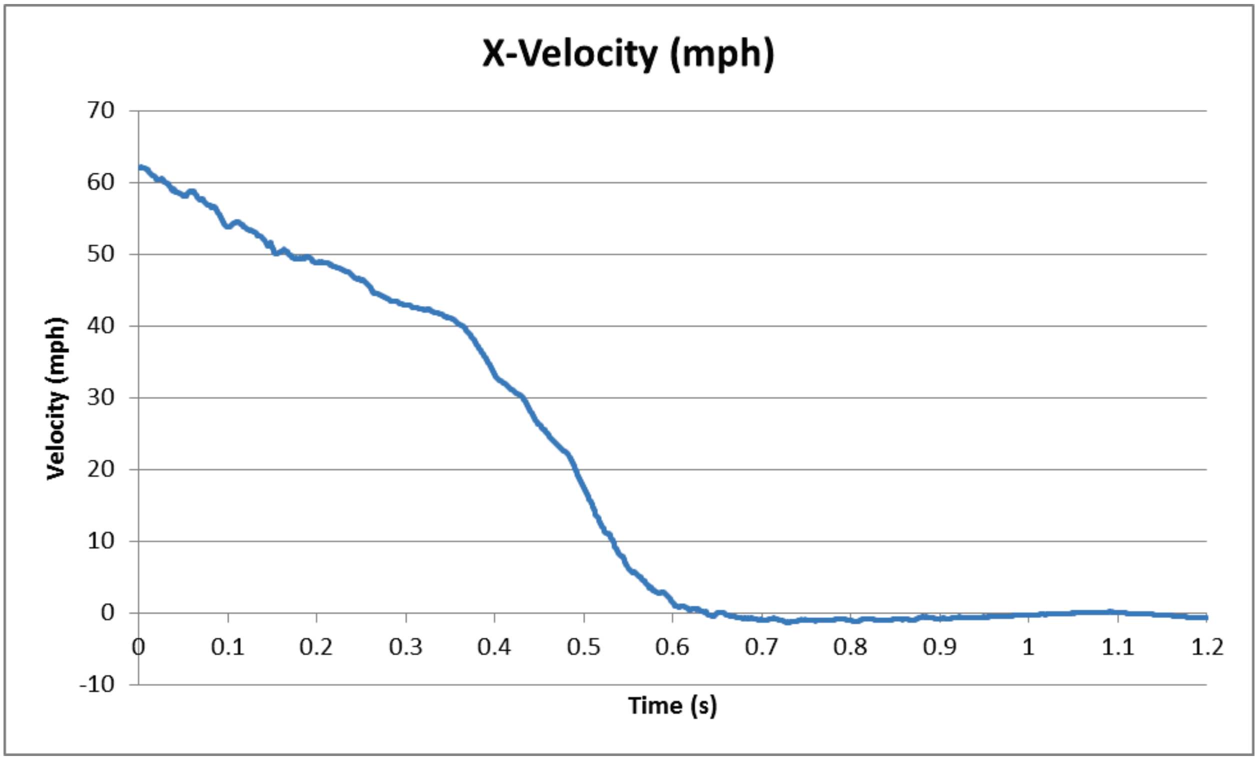


Figure 2.76. X-Velocity in Mph.

Figure 2.77 shows sequential images of the simulation upon impact. The first image shows initial contact with the rail and is followed by two images of the truck interacting with the rail. The last image displays the end state of the simulation. At time equal to 0.245 s and 0.545 s, the rail shows good containment of the truck, displaying little yaw, roll, and pitch. The last image shows the truck with a high yaw and roll, and potential to override the rail or flip.

Figure 2.78 shows the plastic strain. The areas of interest that show potential for tearing are enlarged. The rail begins to twist, as shown in the bottom right figure, just before the primary roadway transitions to quarter spacing on the steel posts and a nested thrie beam. This behavior and other areas of high strain distribution may point to the failure of the W-beam, and therefore a lack of containment of the vehicle.

The maximum dynamic deflection of the rail along the primary roadway is 28.2 ft. The maximum dynamic deflection of the rail along the secondary roadway is 21.8 ft.

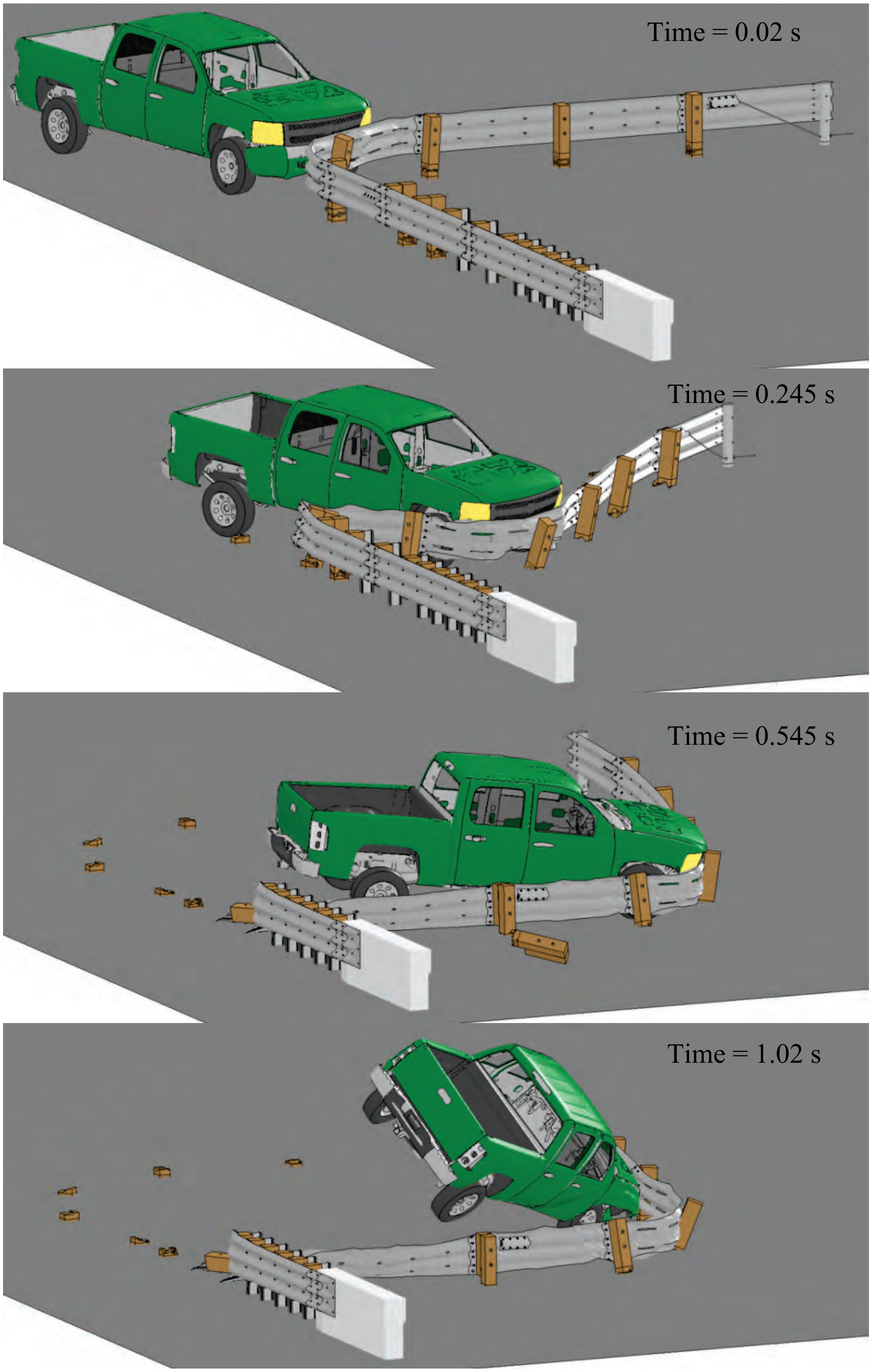


Figure 2.77. Sequential Images of Simulation.

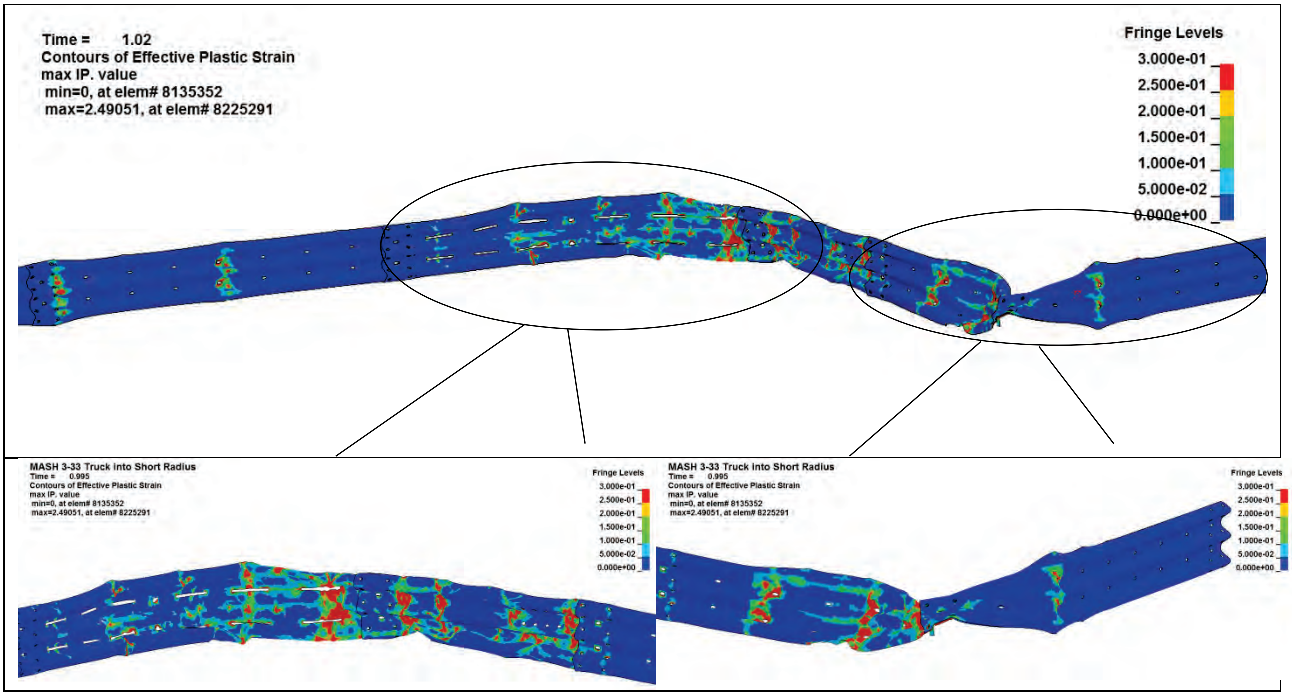


Figure 2.78. Plastic Strain.

Figure 2.79 displays the maximum dynamic deflection of the rail. Table 2.27 shows the TRAP results for this simulation. The OIV and ridedown accelerations passed the criteria but the yaw, roll, and pitch are a concern in this run.

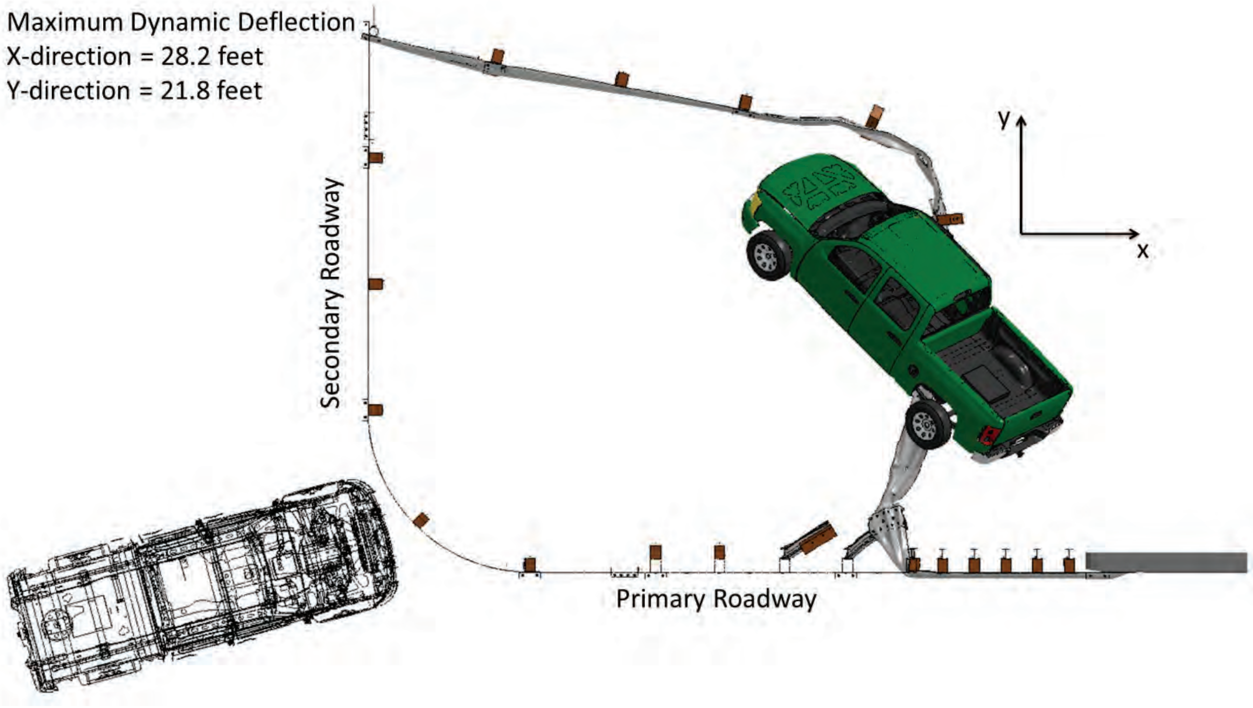


Figure 2.79. Total Displacement.

Table 2.27. TRAP Results for *MASH* Test 3-33 without Barrels.

TRAP Results: TL 3-33 Silverado	
Impact Velocity, mph	62.2
Impact Angle (degrees)	15
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	19.03
y-direction	9.84
Ridedown Accelerations (Gs)	
x-direction	10.4
y-direction	13.4
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	49.1
Pitch	−17.0
Yaw	−128.3

2.10. SIMULATION OF *MASH* TEST 3-33; TRUCK IMPACTING SHORT RADIUS WITH SAND BARRELS

Four 700-lb barrels were placed immediately behind the radius in this system. This addition is shown in multiple views in Figure 2.80.

Figure 2.81 is a graph of the x-velocity of the truck during the simulation. The initial steep slope in this plot represents the time period where the sand barrels behind the rail are absorbing the energy of the impact. The next section, which has a more gradual slope, denotes the part of the simulation when the rail is absorbing the kinetic energy of the crash. The final steeper section of the graph signifies when the stiffer part of the rail is engaged in absorbing the kinetic energy. The truck then passes through zero velocity before rebounding back, hence the section of negative velocity.

Figure 2.82 to Figure 2.85 display the interaction of the truck and the system throughout the simulation. Figure 2.82 shows when the first impact occurs.

Figure 2.83 represents the point on the x-velocity curve where the first steep portion ends. The barrels have less impact on velocity attenuation from this point forward. The rail will continue to absorb kinetic energy, which denotes the milder slope section on the velocity curve.

Figure 2.84 shows the time in the run when the stiffer portion of the rail is engaged and helping to absorb kinetic energy. This corresponds to the second steep slope in the velocity plot. Figure 2.85 shows the truck at the time of zero velocity before it begins to rebound. Figure 2.86 shows the plastic strain in the rail. There are several areas where the rail may rupture.

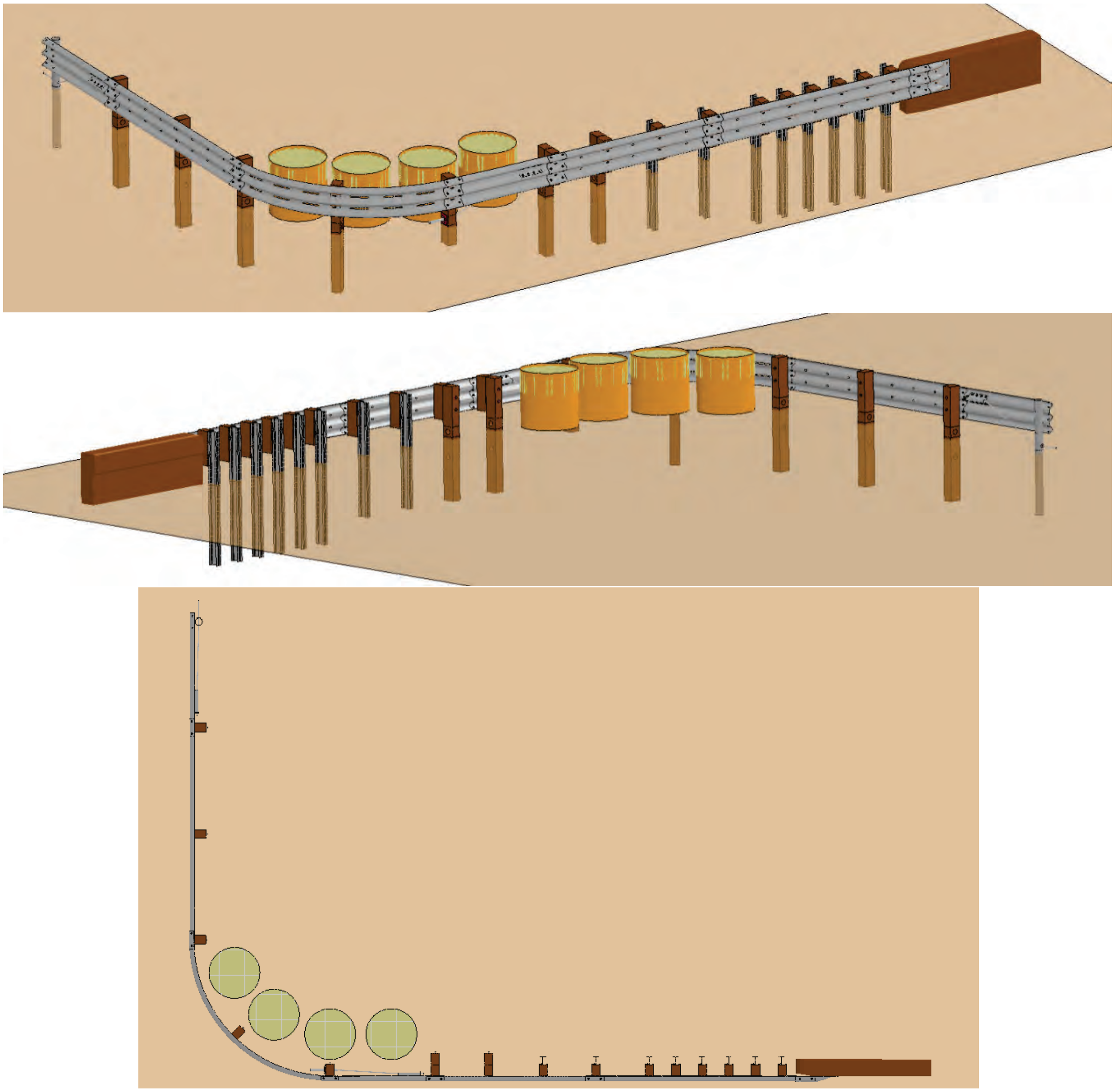


Figure 2.80. Entire System with Barrels (Front, Back, and Top Views).

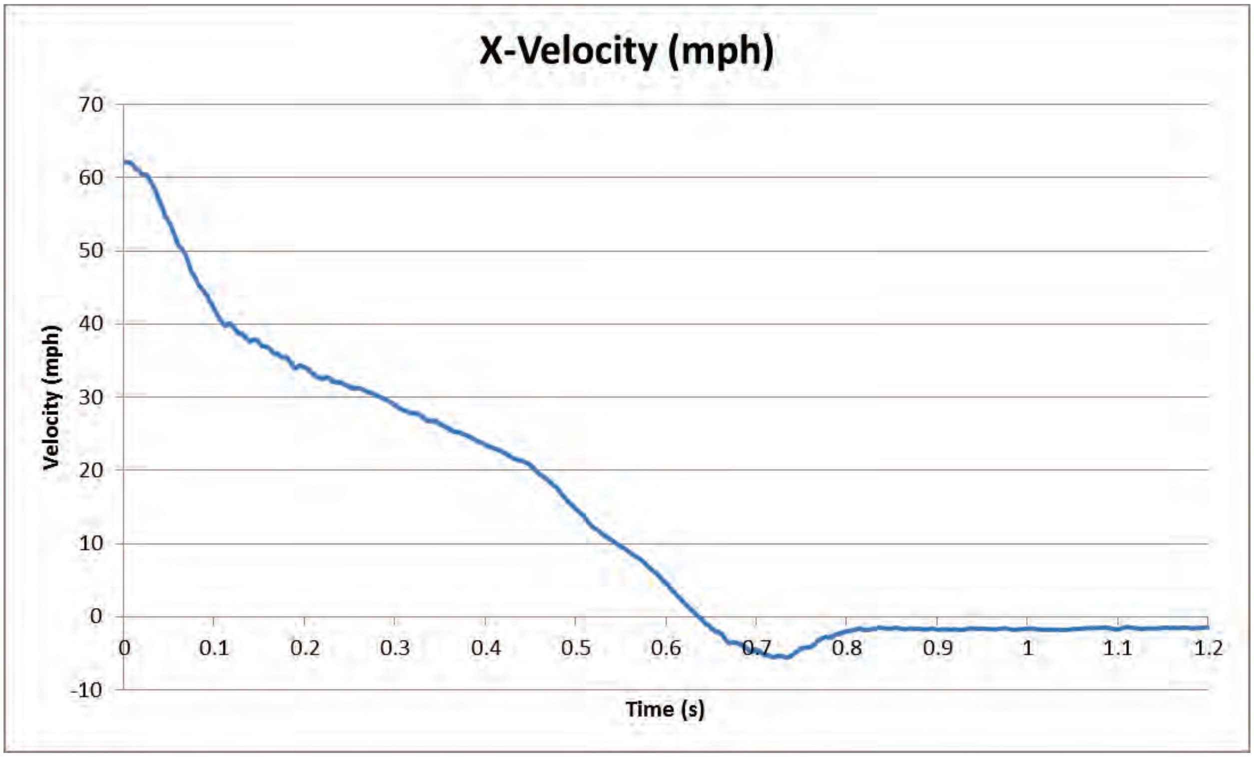


Figure 2.81. X-Velocity in Mph.

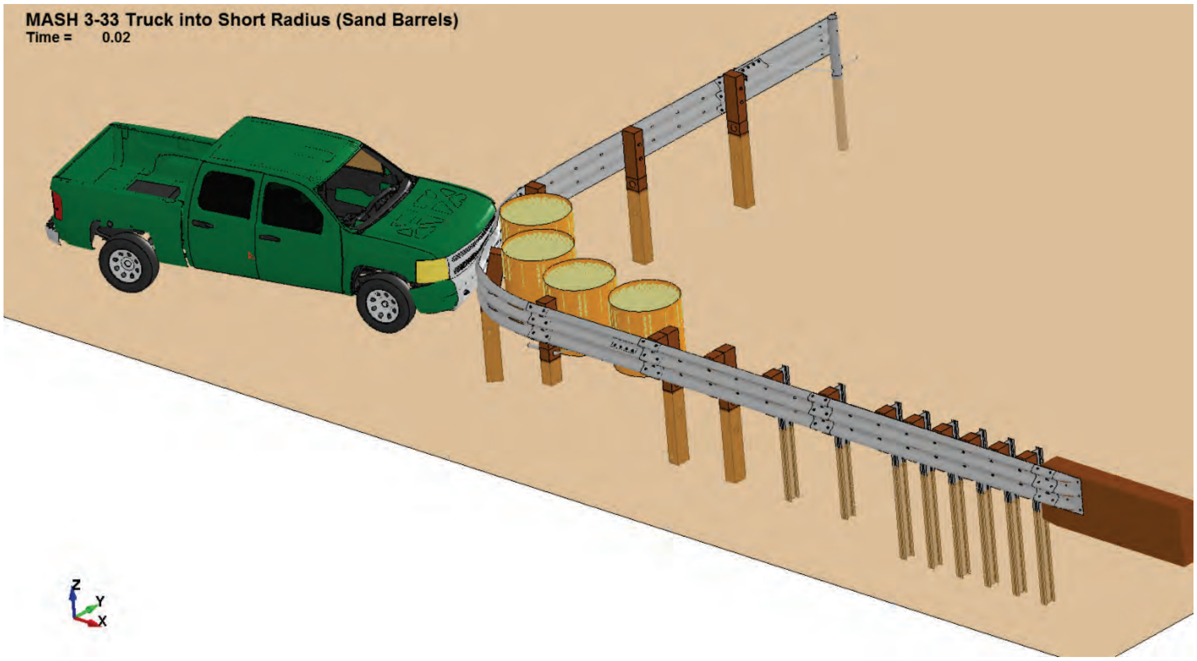


Figure 2.82. Time = 0.02 s when Impact Begins.

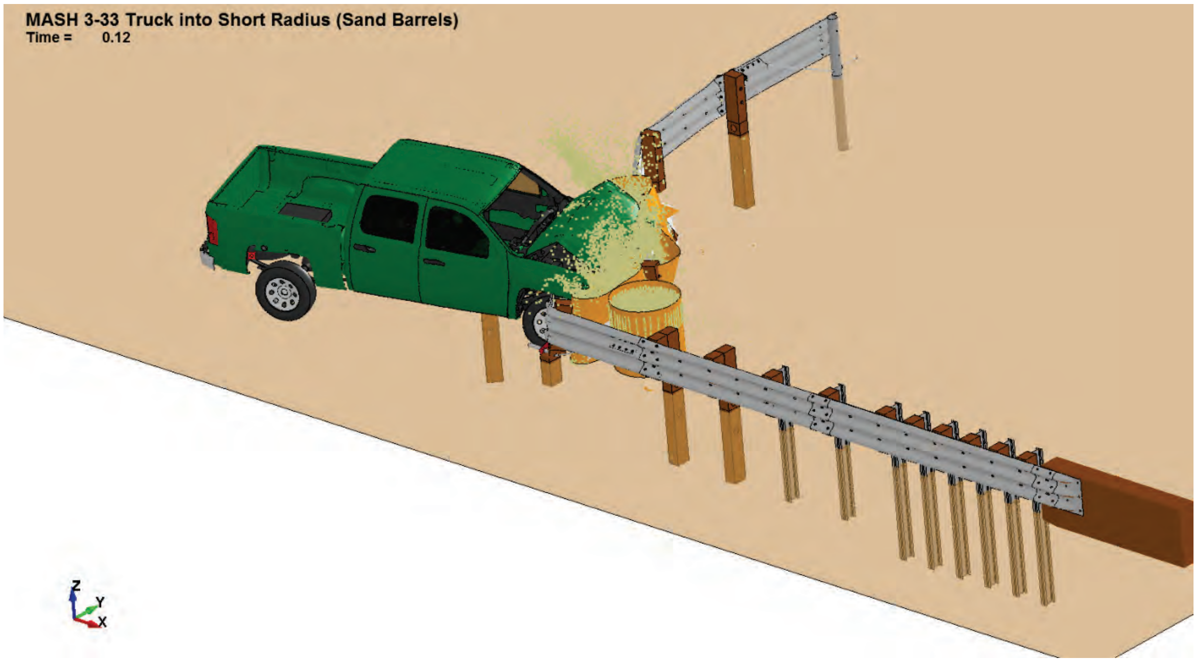


Figure 2.83. Time = 0.12 s, after Barrels Have Had Their Greatest Impact.

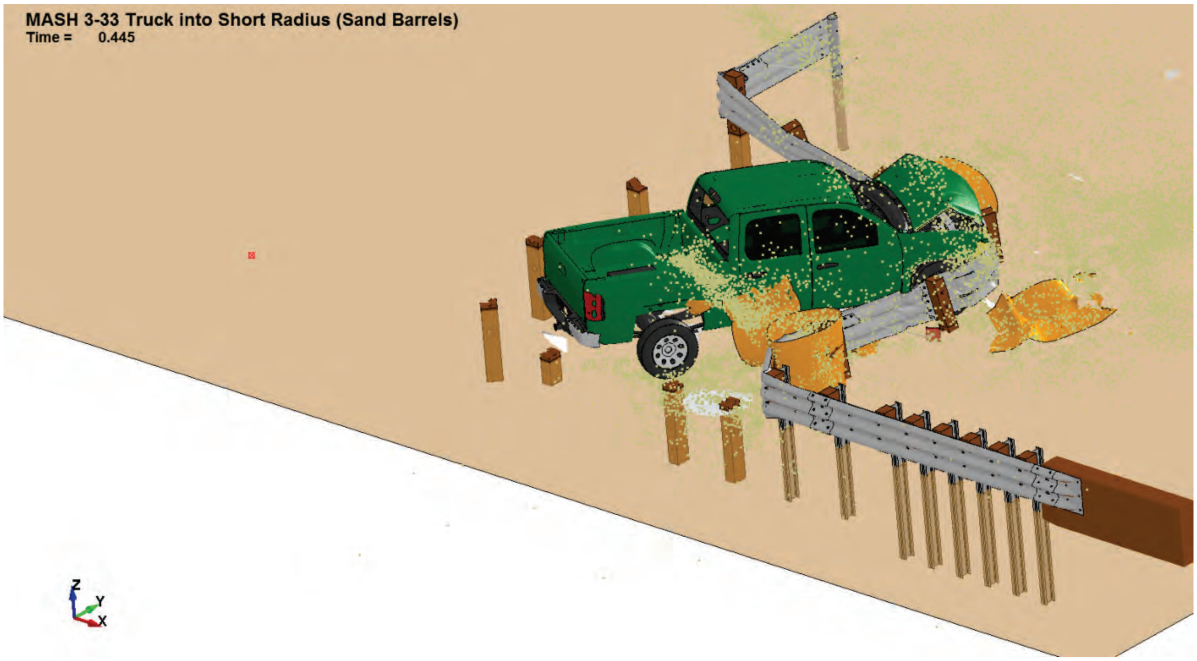


Figure 2.84. Time = 0.445 s, after the System Has Had Its Impact.

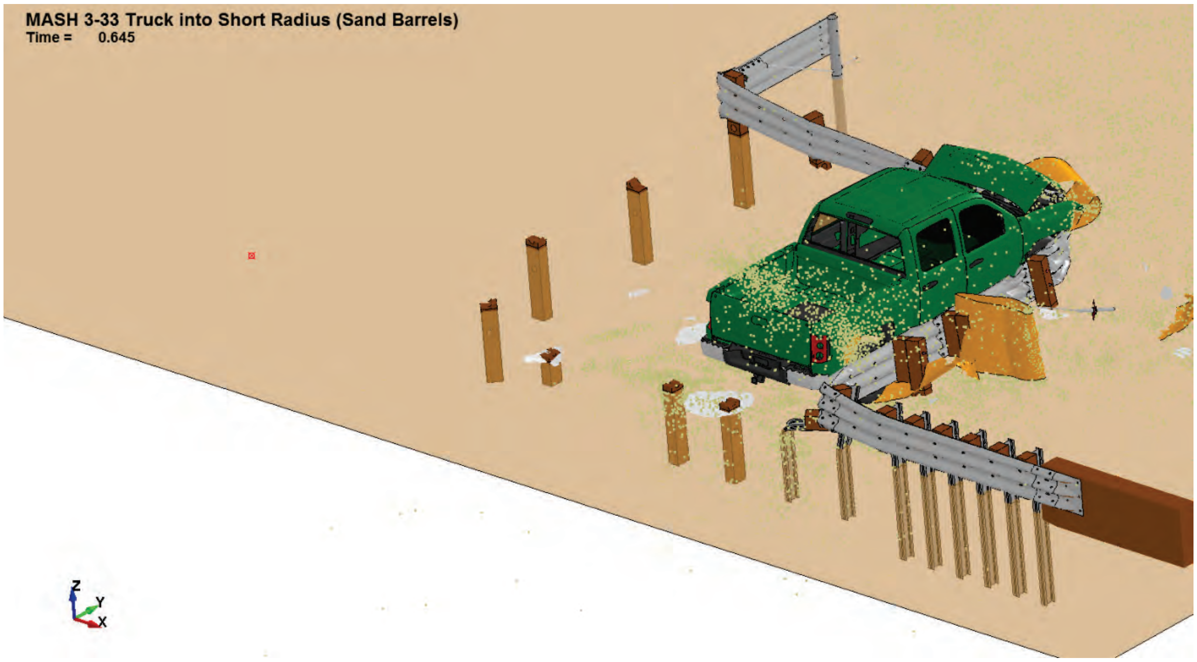


Figure 2.85. Time = 0.645 s, when Vehicle Reaches Zero Velocity.

Figure 2.86. Plastic Strain on Entire Rail.

Figure 2.87 zooms in on part of the radius and primary roadway that contained most of the areas where rail rupture may occur. This zoomed-in section is encircled by an oval in Figure 2.86.

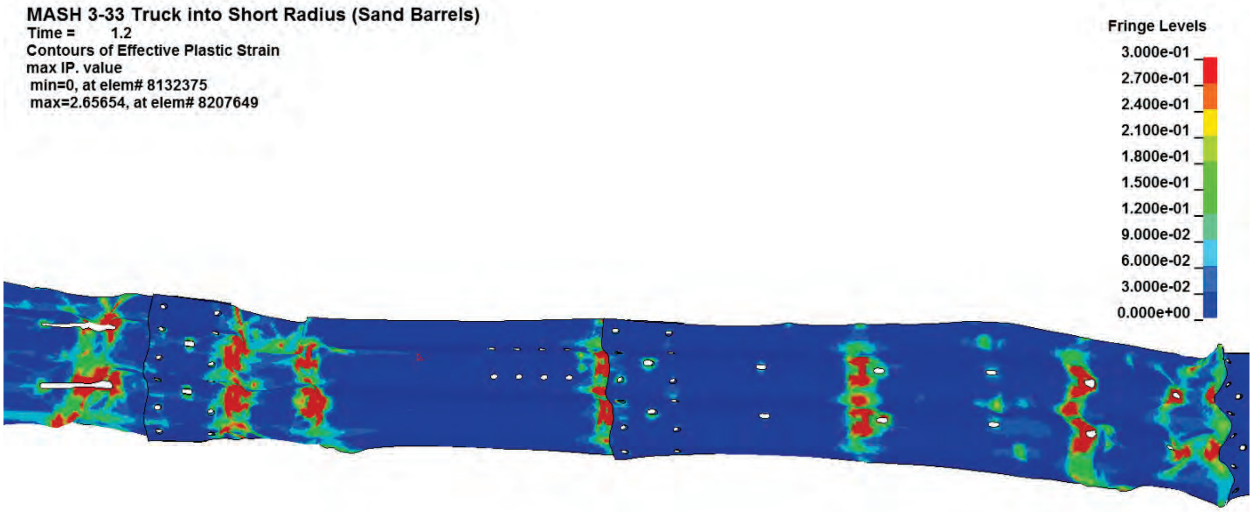


Figure 2.87. Plastic Strain in Several Problem Areas.

Figure 2.88 displays the maximum dynamic deflection of the primary and secondary roadways. The maximum deflection of the rail along the primary roadway was 24.4 ft, and 18.6 ft along the secondary roadway. The maximum deflection along the primary roadway for the same system without sand barrels was 28.2 ft. The maximum deflection along the secondary roadway for the same system without sand barrels was 21.8 ft. The added mass had a significant impact on decreasing the velocity of the truck within a shorter distance while maintaining *MASH* criteria for OIV and ridedown accelerations.

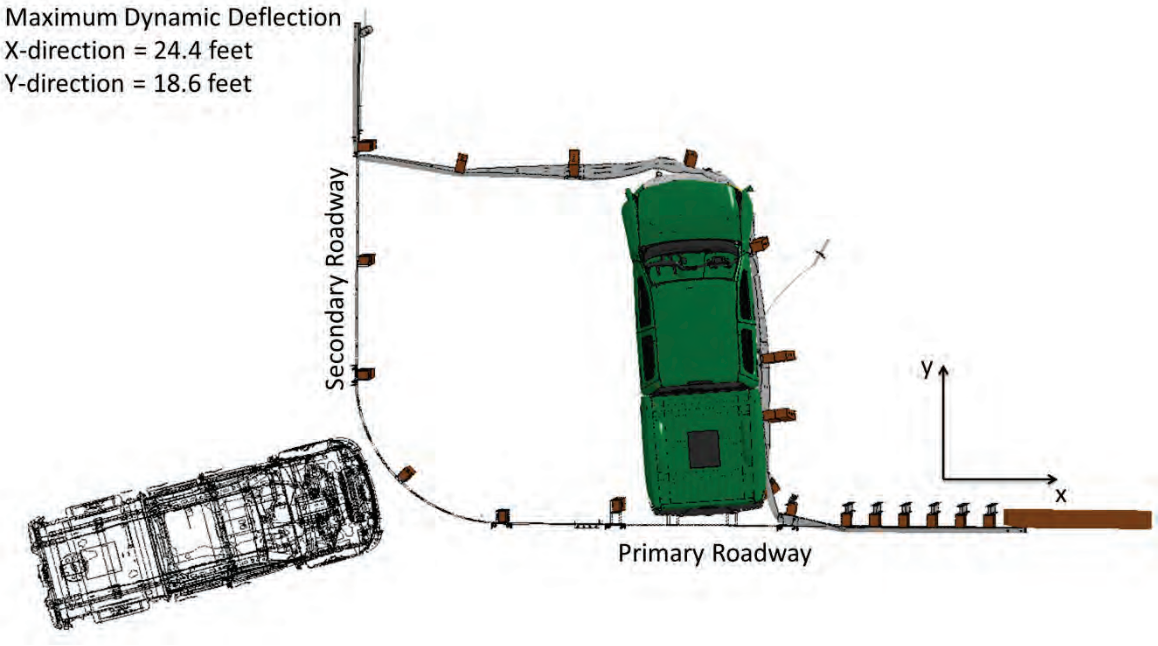


Figure 2.88. Total Displacement.

Table 2.28 displays the TRAP results for the simulation. This simulation passed all of the *MASH* criteria and just surpassed the preferred limit for the x-direction OIV.

Table 2.28. TRAP Results for *MASH* Test 3-33 with Barrels.

TRAP Results: TL 3-33 Silverado	
Impact Velocity, mph	62.2
Impact Angle (degrees)	15
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	33.14
y-direction	6.56
Ridedown Accelerations (Gs)	
x-direction	6.9
y-direction	7
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	4.6
Pitch	−3.8
Yaw	−88.7

2.11. CONCLUSIONS

The change to a single thrie beam instead of the two W-beams helped improve the interaction of the vehicle with the rail system. Adding the sand barrels to the new system not only helped dissipate more energy but also helped improve the behavior of the truck with the system as well.

The system without sand barrels had vehicular instabilities. At the end of the simulation, the truck looked as if it was going to flip over. The sand barrels mitigated this behavior. Therefore, the yaw, pitch, and roll in the simulation with the sand barrels were significantly less than those in the system without mass. The roll was reduced from 49.1° to 4.6°. The yaw was reduced from 128.3° to 88.7°. The pitch of the vehicle was also reduced by adding sand barrels to the system, but the vehicle's pitch was not critical for either simulation.

For the simulation without the sand barrels, the truck remained under the preferred OIV and ridedown accelerations. The simulation with the sand barrels slightly exceeded the preferred limits for the OIV in the x-direction. All other areas remained under the preferred criteria for the simulation with the sand barrels.

Adding the four 700-lb sand barrels to the rail system decreased the deflection of the rail along the primary roadway by 4 ft and the deflection of the rail along the secondary roadway by 3 ft. In the simulation for the system with the sand mass, the vehicle came to a stop before the last post along the secondary roadway failed. In the system without sand, the vehicle was still rolling on its right side when the rail was wrapping around the anchor post at the end of the rail on the secondary roadway. Therefore, the sand barrels significantly helped to attenuate the energy of the impact.

The system with sand barrels had less overall distribution of high plastic strain areas within the rail element. The system without sand barrels had more high plastic strain areas in the radius of the rail. Additionally, a section of the rail along the primary roadway began to twist in the simulation without barrels. This occurred just before the steel post spacing switched from half to quarter spacing.

2.12. RECOMMENDATION

The research team recommended further evaluation of the latest design through enhanced modeling and detailed simulations due to its promising performance. The system has accepted test evaluation criteria while maintaining a functional performance in terms of reduced overall displacement into the back side of the short radius design.

CHAPTER 3. SIMULATION OF RECOMMENDED DESIGN CONCEPTS

3.1. SIMULATION OF *MASH* TEST 3-32 SMALL CAR IMPACTING SHORT RADIUS WITHOUT FLARE AND WITHOUT SAND BARRELS

Figure 3.1 presents the system used in this simulation. The system had no flare and no sand barrels. In summary, this system adequately stopped the truck within the *MASH* Impact Severity criteria and within appropriate overall displacement behind the system. The purpose of this simulation is to show that the system can adequately contain the small car without surpassing the *MASH* Impact Severity criteria.

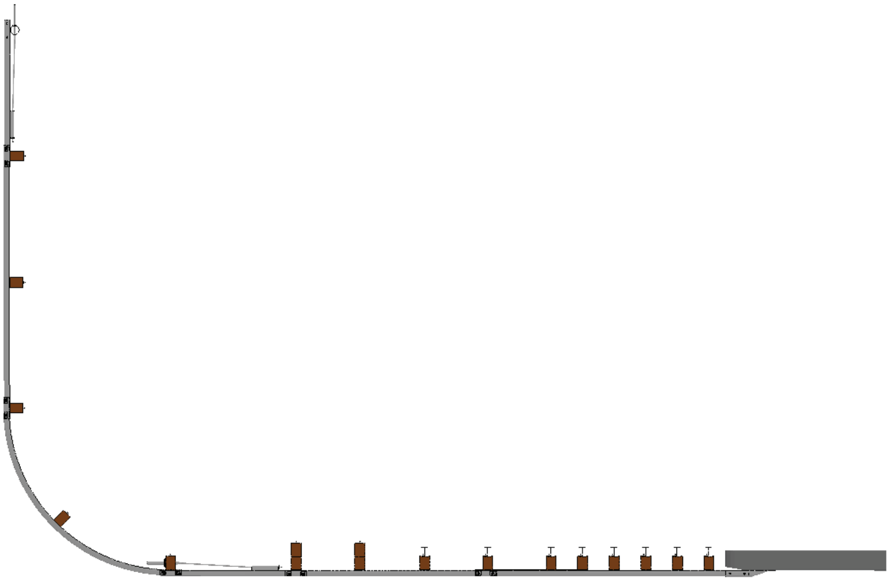


Figure 3.1. No Flare and No Sand Barrels.

Figure 3.2 presents the progression of the small car in this simulation. The car remains stable during the simulation. The rail and deformation of the front of the car seem to progress into the windshield of the car, which may not pass the penetration or intrusion/deformation limits.

Figure 3.3 plots the x-velocity of the car throughout the simulation. The system brought the vehicle to zero velocity and then the vehicle began to rebound.

The maximum dynamic displacement of the rail was 21.8 ft in the x-direction along the primary roadway. The maximum dynamic y-displacement along the secondary roadway is 17 ft. Figure 3.4 depicts the maximum dynamic displacement of the rail.

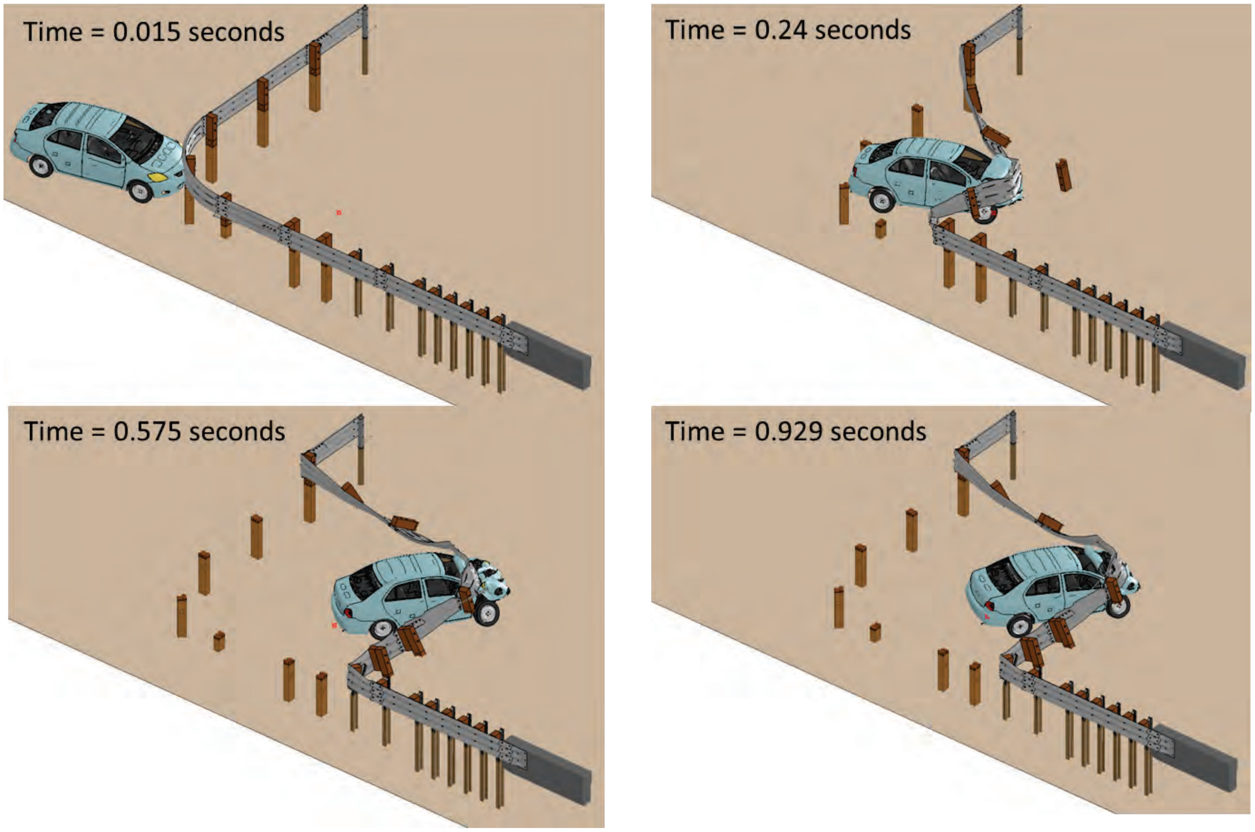


Figure 3.2. Sequential Images of Simulation with No Flare and No Sand Barrels.

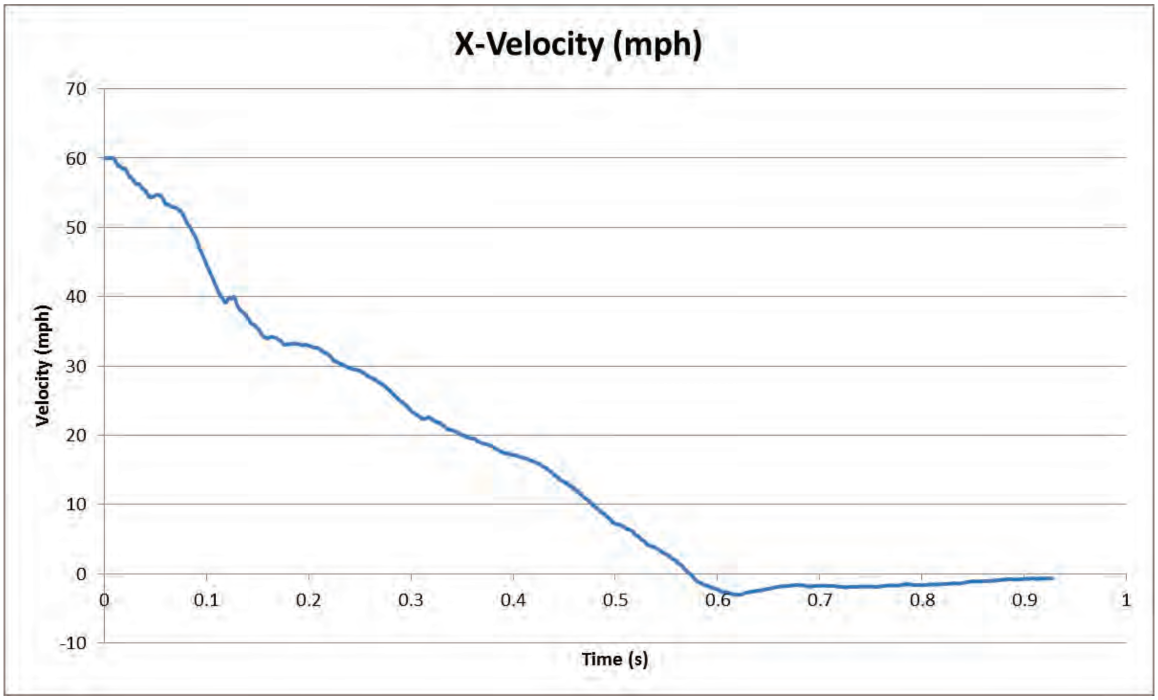


Figure 3.3. X-Velocity in Mph in Simulation with No Flare and No Sand Barrels.

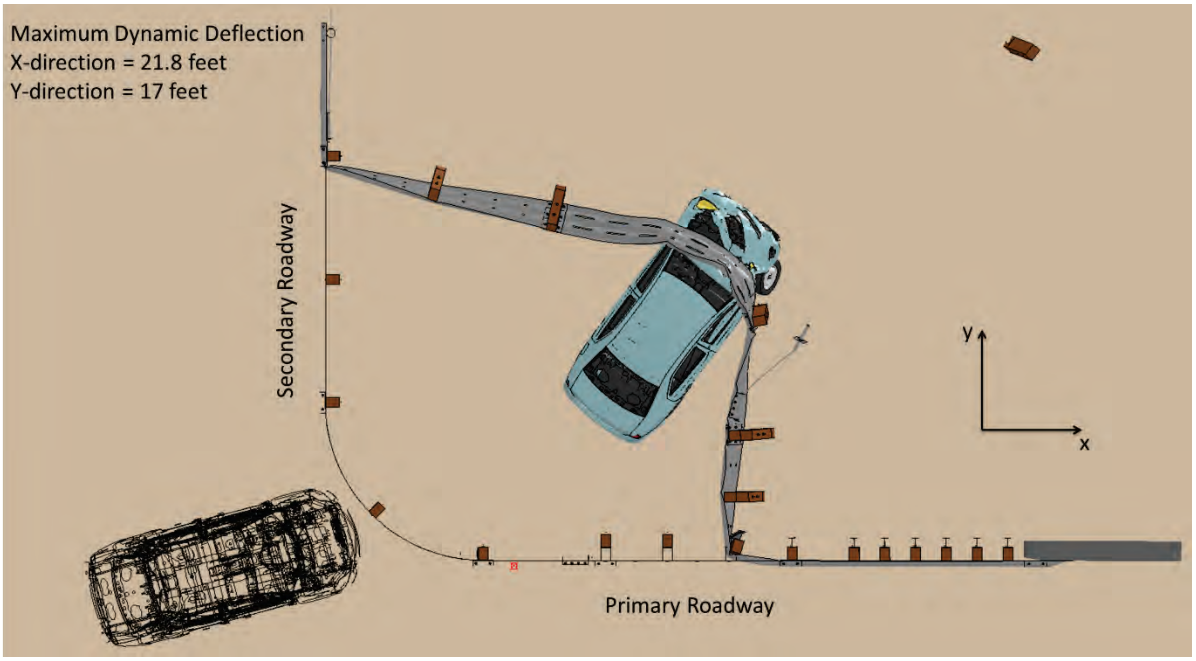


Figure 3.4. Total Displacement in Simulation with No Flare and No Sand Barrels.

Table 3.1 shows that the small car passed the *MASH* impact severity criteria. The car surpassed the preferred limit for the OIV in the x-direction but was under the maximum limit. Since the small car is close to surpassing the OIV limit without sand barrels in this system, a simulation was run with 400-lb barrels clustered in the radius section. It was thought that the 700-lb barrels used in previous truck runs would cause the car to surpass the OIV limit if clustered in the radius.

Table 3.1. TRAP Summary Data in Simulation with No Flare and No Sand Barrels.

TRAP Results: TL 3-32 (Small Car) No Flare and No Sand Barrels	
Impact Velocity, mph	62.2
Impact Angle (degrees)	15
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	33.5
y-direction	2.3
Ridedown Accelerations (Gs)	
x-direction	8.1
y-direction	8.7
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	−15.7
Pitch	−16.3
Yaw	−41.2

3.2. SIMULATION OF *MASH* TEST 3-32 SMALL CAR IMPACTING SHORT RADIUS WITH FLARE AND 400-LB SAND BARRELS

Figure 3.5 presents the system layout for this simulation. As mentioned before, since the OIV was close to being over the acceptable limit in the last run without barrels, 400-lb barrels were added behind the rail in the radius. This is a reduced mass from the 700-lb barrels that were clustered in the radius in the truck simulation.

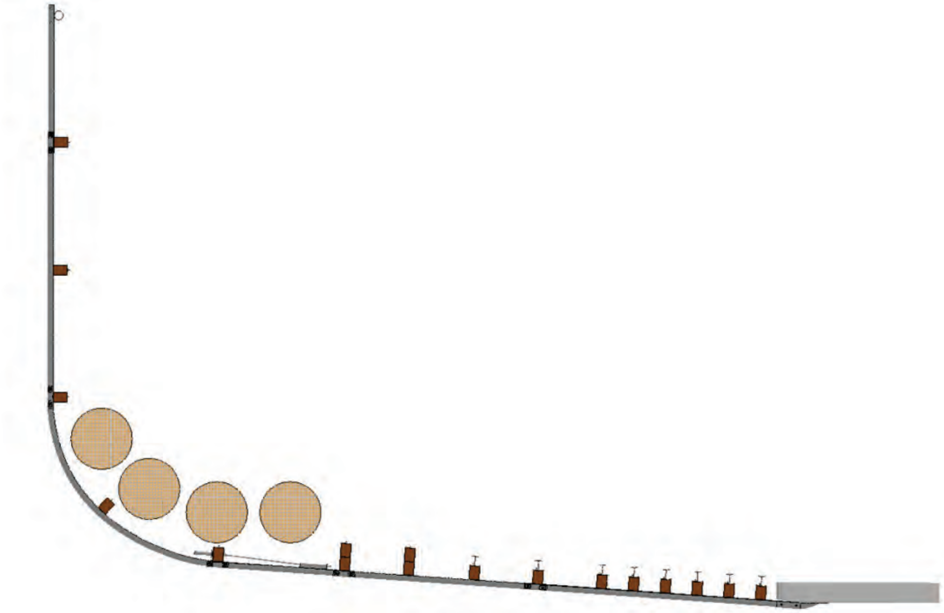


Figure 3.5. Flare and 400-Lb Sand Barrels Behind the Radius.

The other change to the system included a linear 4° flare added to the primary roadway to help with the TL 3-31 crash condition, which is presented and discussed later.

Figure 3.6 displays sequential images of the car throughout this simulation. The car remained stable. The rail and the deformation of the front of the car did not pass as far into the windshield as it did in the previous run, suggesting that the penetration or intrusion/deformation limits are more likely to be passed.

Figure 3.7 shows the x-velocity of the small car throughout the simulation. The car reached zero velocity and began to rebound. The steeper slope at the beginning of the velocity curve represents where the small car is impacting the sand barrels and experiencing greater energy attenuation. Once the car's interaction with the barrels is complete, the slope flattens out.

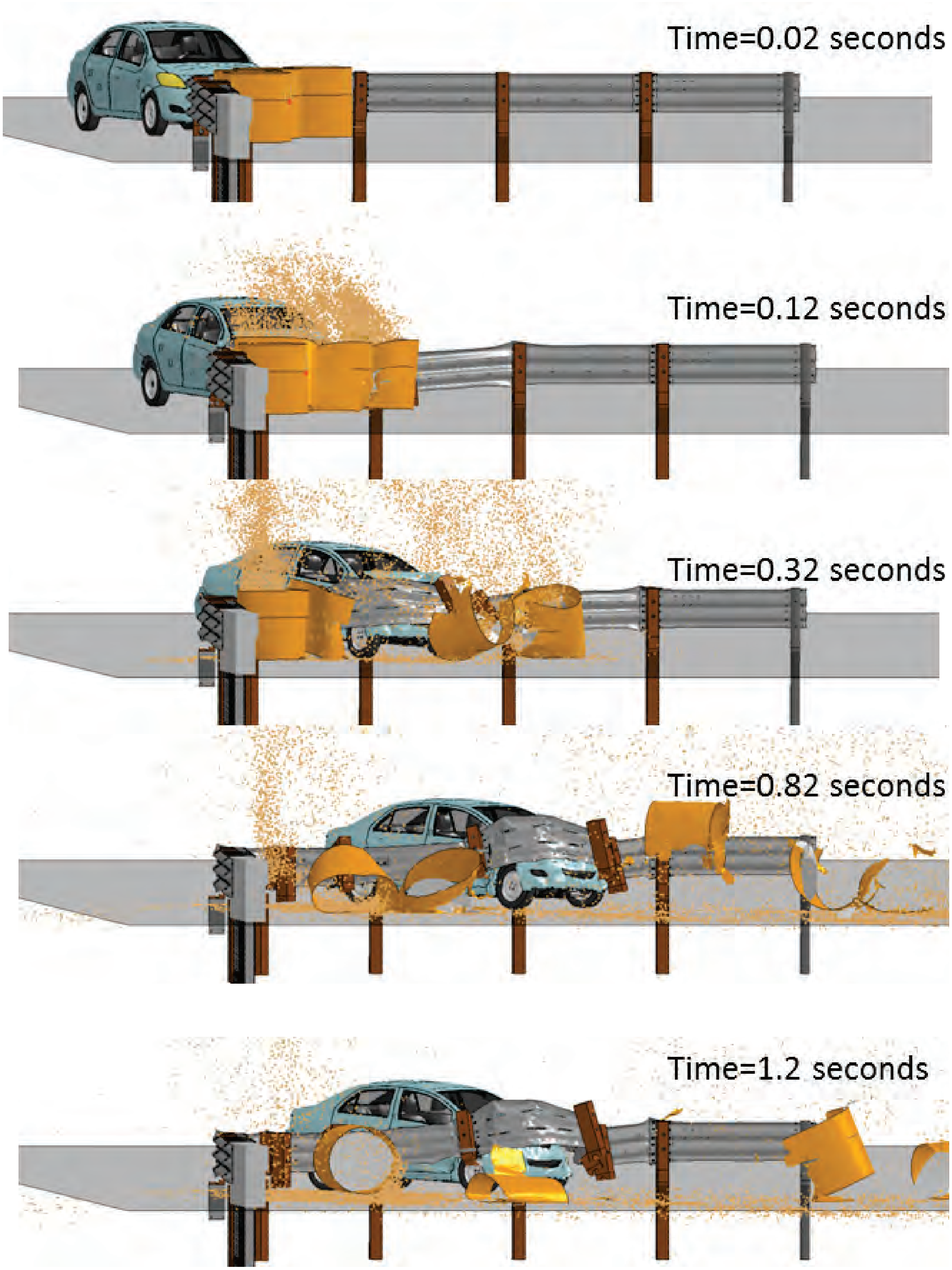


Figure 3.6. Sequential Images of Simulation with Flare and 400-Lb Sand Barrels.

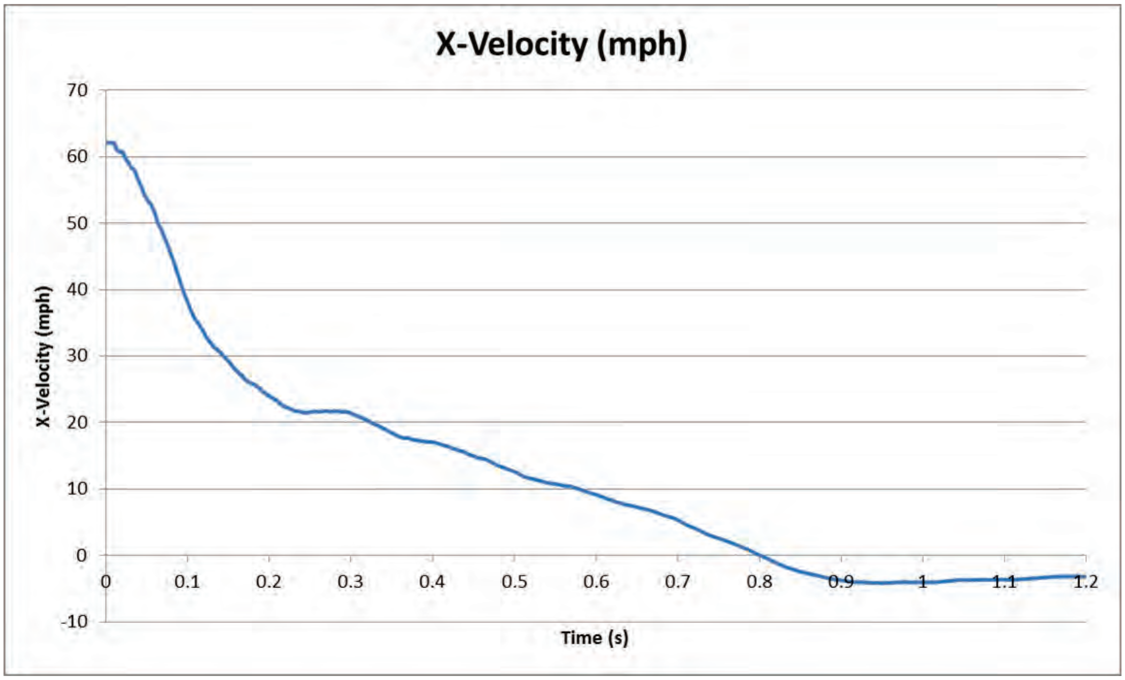


Figure 3.7. X-Velocity in Mph on Simulation with Flare and 400-Lb Sand Barrels.

The maximum dynamic deflection of the rail was 19.8 ft in the x-direction along the primary roadway. This is a reduction of 2 ft compared to the last simulation of the system without sand barrels and without a flare. The maximum dynamic displacement was 17.6 ft in the y-direction along the secondary roadway, which is an increase of 0.6 ft from the last system. Figure 3.8 depicts the displacement of the rail in the system. The sand and the barrels have been hidden from the total displacement figure for clarity.

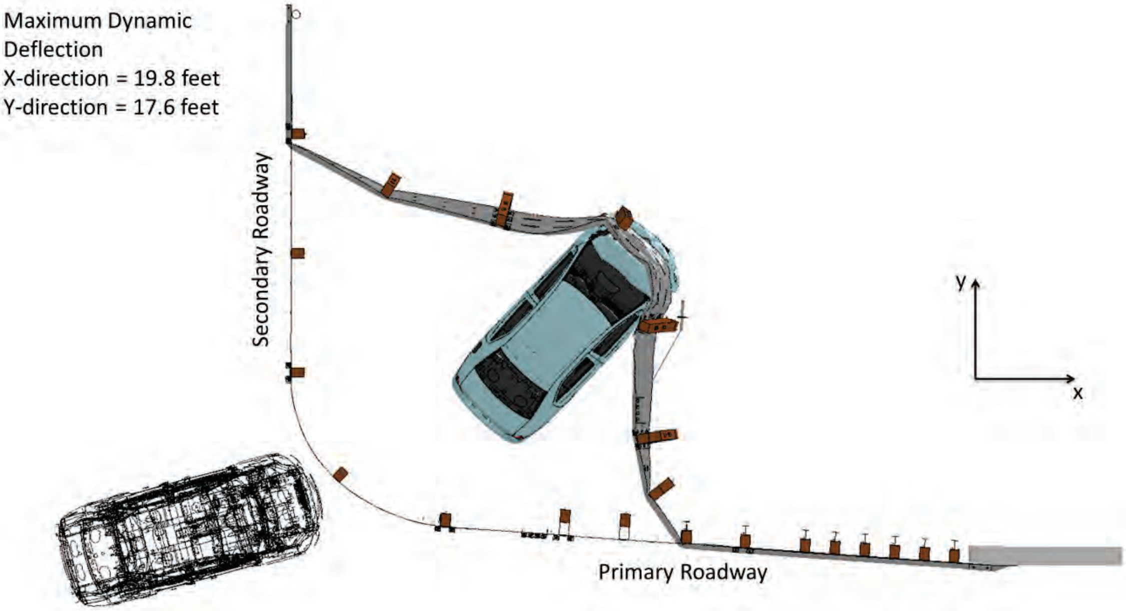


Figure 3.8. Total Displacement on Simulation with Flare and 400-Lb Sand Barrels (Sand Hidden).

The small car did not pass the *MASH* impact severity criteria. Table 3.2 shows that the car failed to fall under the x-direction OIV limit. The barrel layout will be assessed and changed before the next simulation.

Table 3.2. TRAP Summary Data on Simulation with Flare and 400-Lb Sand Barrels.

TRAP Results: TL 3-32 (Small Car) Flare and 400-lb Barrels	
Impact Velocity, mph	62.2
Impact Angle (degrees)	15
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	40.7
y-direction	4.6
Ridedown Accelerations (Gs)	
x-direction	9.1
y-direction	7.0
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	−4.8
Pitch	−2.0
Yaw	−32.2

3.3. SIMULATION OF *MASH* TEST 3-32 SMALL CAR IMPACTING SHORT RADIUS WITH FLARE AND 700-LB SAND BARRELS SPREAD OUT ALONG RAIL

The x-velocity in the last run was over the limit by approximately 1 ft/s. To keep the OIV below the limit, the barrels were spread out behind the rail system instead of clustered behind the radius. With the barrels spread out behind the system, the car will see less mass at any single given moment in the simulation. The barrel mass was increased to 700 lb from 400 lb since spreading out the barrels would help mitigate the severity of the impact. Figure 3.9 shows the system tested in this simulation. Two barrels were grouped closely together along the primary roadway: one barrel in the center of the radius, and one barrel approximately halfway up the secondary roadway.

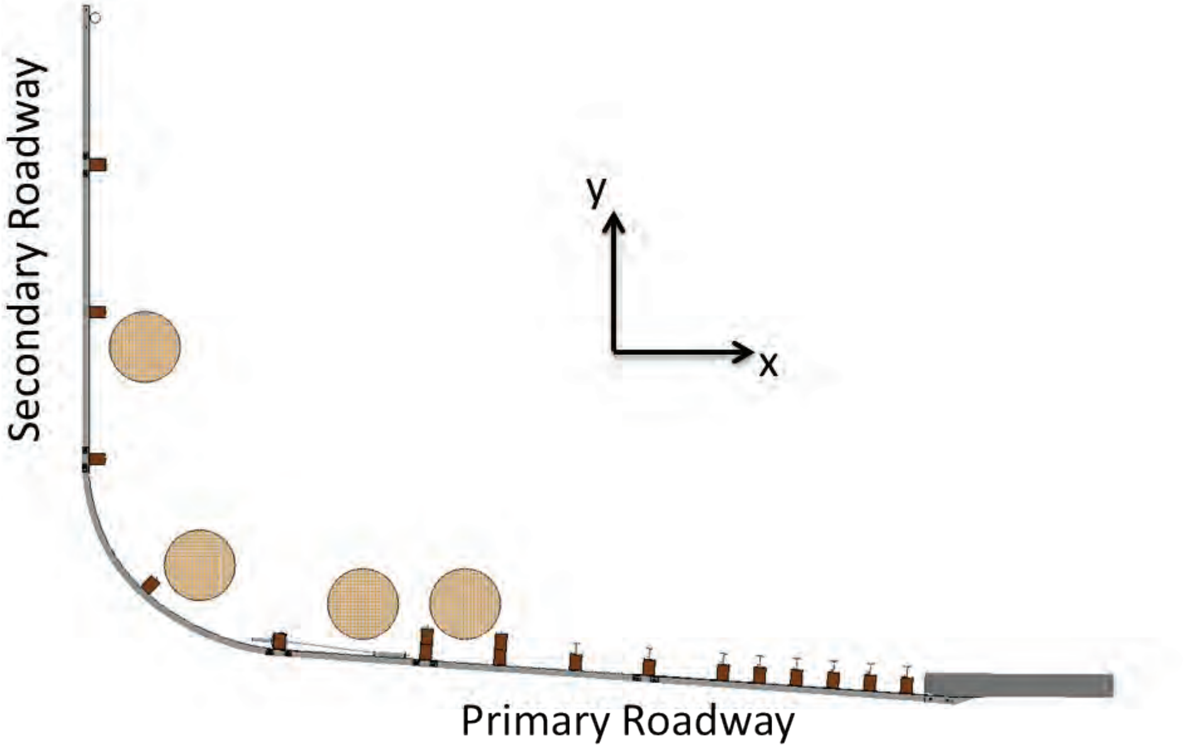


Figure 3.9. Flare and Spread Out 700-Lb Barrels.

Figure 3.10 presents sequential images of the simulation to summarize the behavior of the vehicle. The car remained stable. Figure 3.11 presents the x-velocity of the small car throughout the simulation. The car reaches zero velocity at approximately 0.74 s and then begins to rebound.

The maximum dynamic deflection of the rail was 18.7 ft in the x-direction along the primary roadway and 16.5 ft in the y-direction along the secondary roadway. The x-direction deflection was reduced by 1 ft compared to the previous simulation of the system with a flare and the four 400-lb barrels clustered behind the radius. The y-direction deflection was reduced by about 1 ft as compared to the previous system. Figure 3.12 shows the car's displacement within the whole system. The sand and the barrels have been hidden from the total displacement figure for clarity.

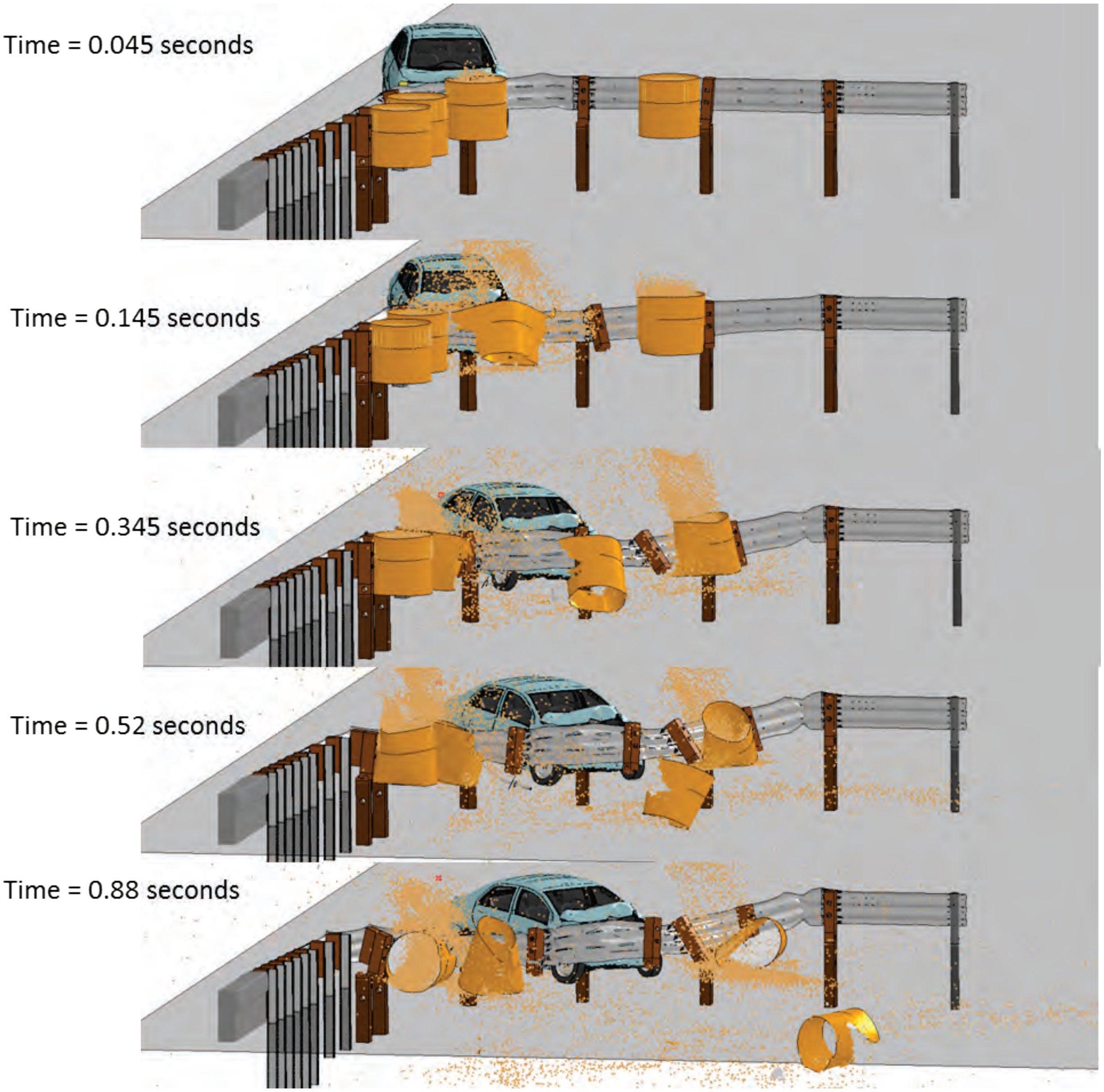


Figure 3.10. Sequential Images of Simulation with Flare and Spread Out 700-Lb Barrels.

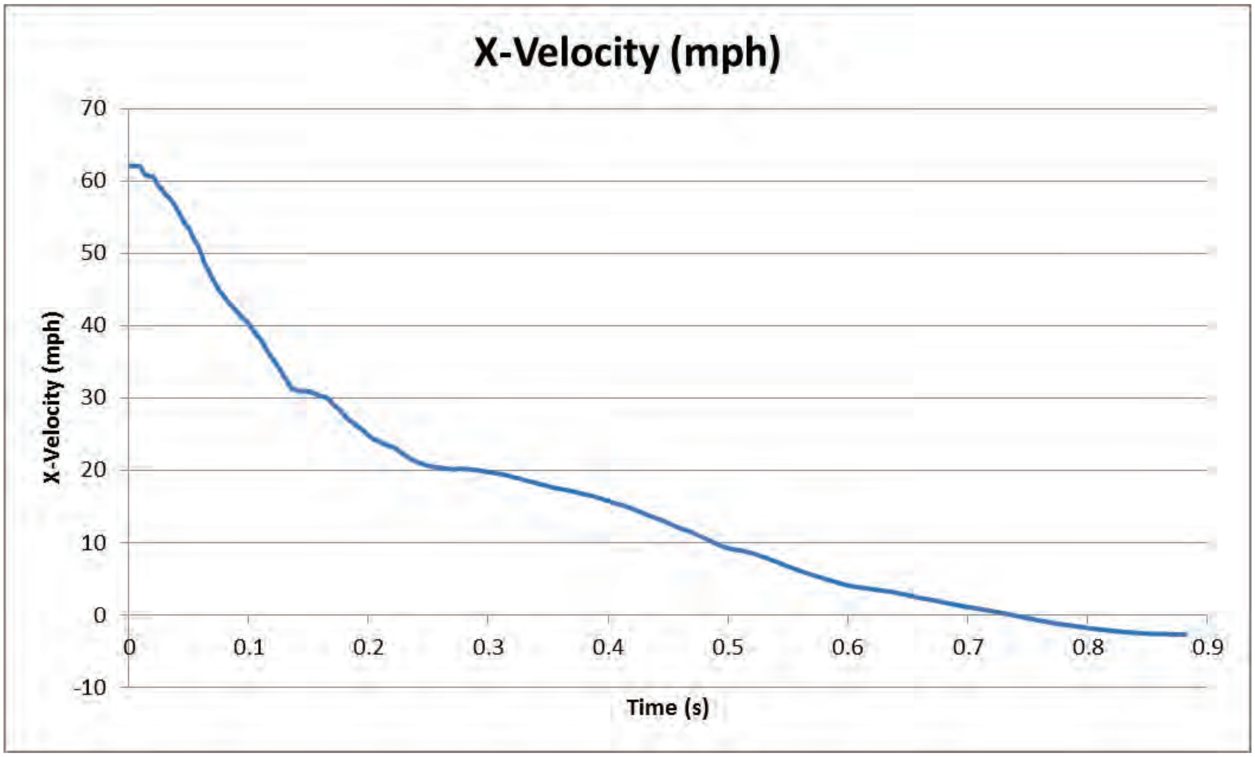


Figure 3.11. X-Velocity in Mph of Simulation with Flare and Spread Out 700-Lb Barrels.

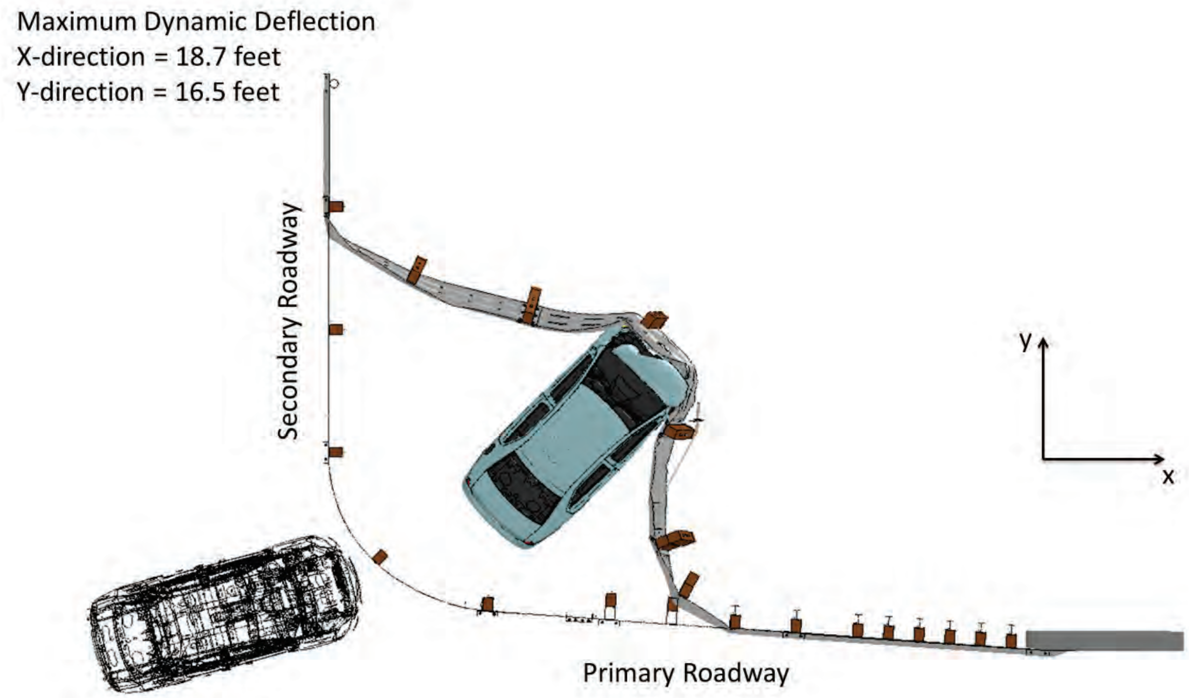


Figure 3.12. Total Displacement of Simulation with Flare and Spread Out 700-Lb Barrels (Sand Hidden).

Table 3.3 shows that the small car passed the *MASH* impact severity criteria in this simulation. Therefore, the 700-lb barrels spread out behind the rail is the promising barrel layout for the short radius system. This layout is run with the truck in the next simulation to see how the system performs in the TL 3-33 case.

Table 3.3. TRAP Summary Data of Simulation with Flare and Spread Out 700-Lb Barrels.

TRAP Results: TL 3-32 (Small Car) Flare and 700-lb Barrels	
Impact Velocity, mph	62.2
Impact Angle (degrees)	15
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	37.4
y-direction	4.6
Ridedown Accelerations (Gs)	
x-direction	12.2
y-direction	8.1
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	−2.4
Pitch	−1.8
Yaw	−30.0

3.4. SIMULATION OF *MASH* TEST 3-33 TRUCK IMPACTING SHORT RADIUS WITH FLARE AND SAND BARRELS

The following changes were made to the system in response to the simulations of the short radius system with the small car presented above. There are four 700-lb barrels in the system used in this simulation, spread out from the radius along the primary and secondary roadways. Spreading out the barrels adequately attenuated the severity of the small car's OIV and ridedown acceleration. The goal of this simulation is to affirm that the truck is adequately captured within an acceptable distance behind the rail. Figure 3.13 shows the system used in this simulation.

Figure 3.14 plots the x-velocity of the truck throughout the simulation. The vehicle reached zero velocity at approximately 0.68 s and began to rebound at the end of the simulation. Figure 3.15 depicts the truck throughout the simulation. The truck remained stable during the simulation and is adequately contained by the system.

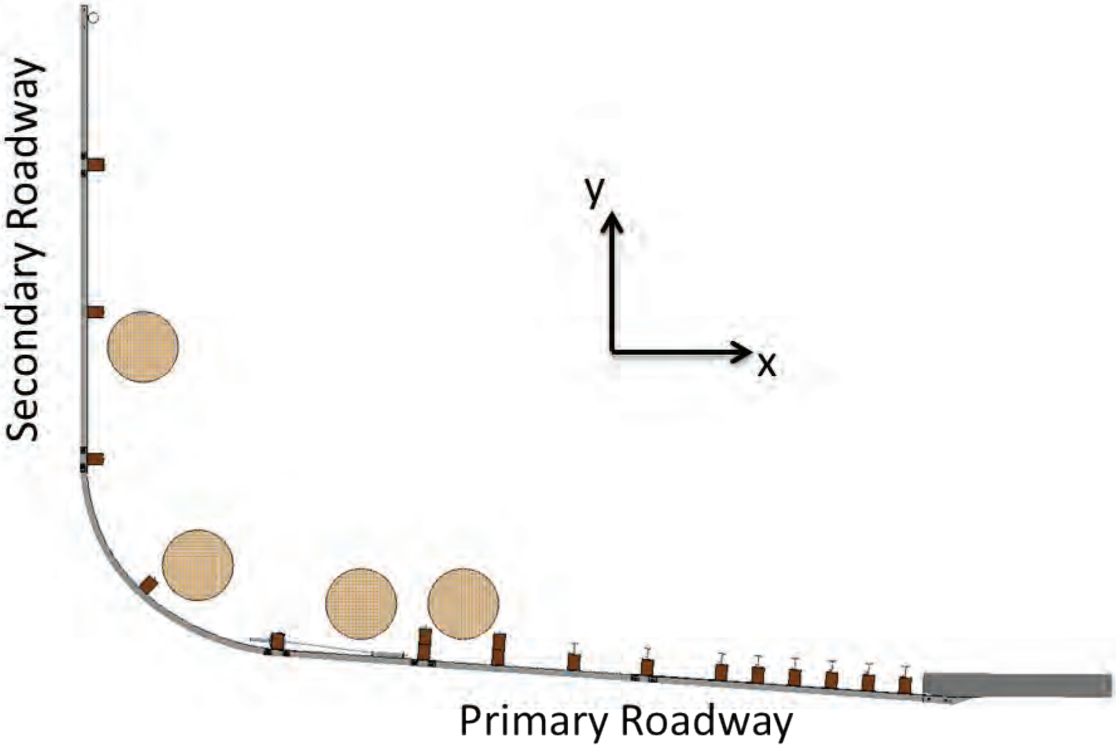


Figure 3.13. Flare and Spread Out 700-Lb Barrels.

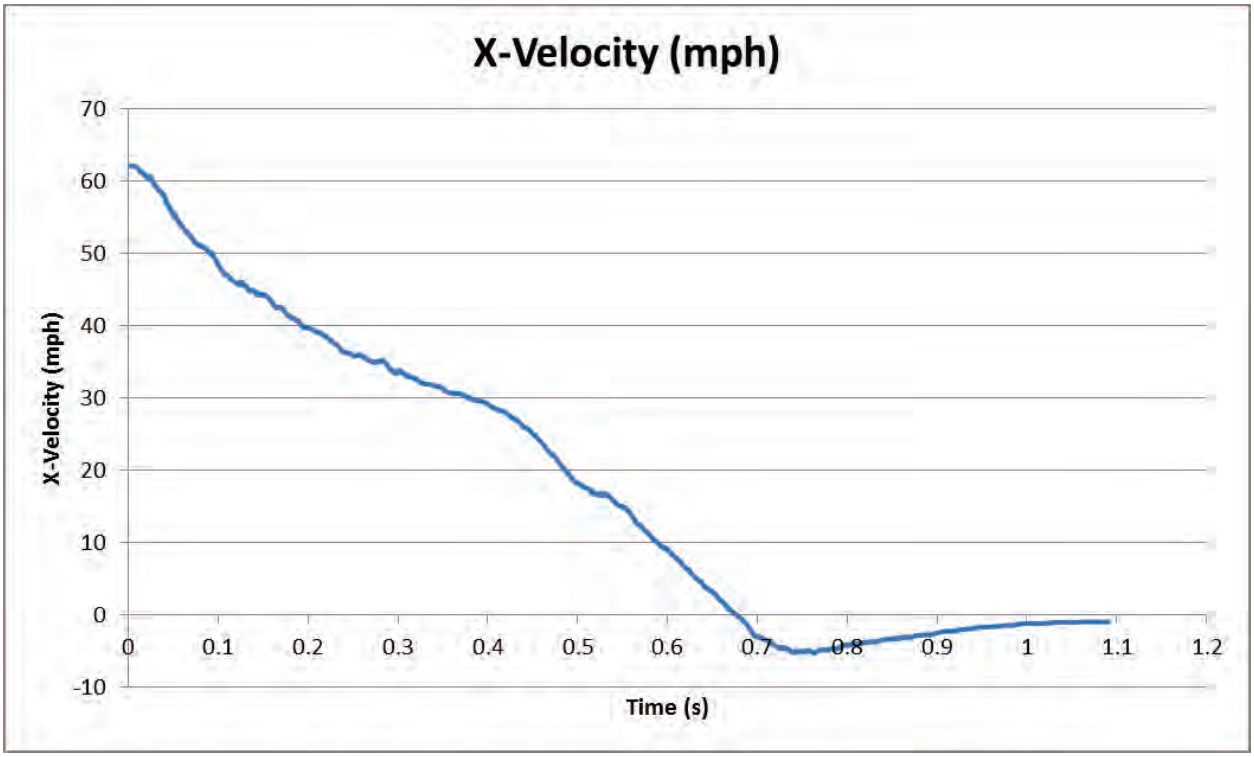


Figure 3.14. X-Velocity in Mph of Simulation with Truck, Flare, and Spread Out 700-Lb Barrels.

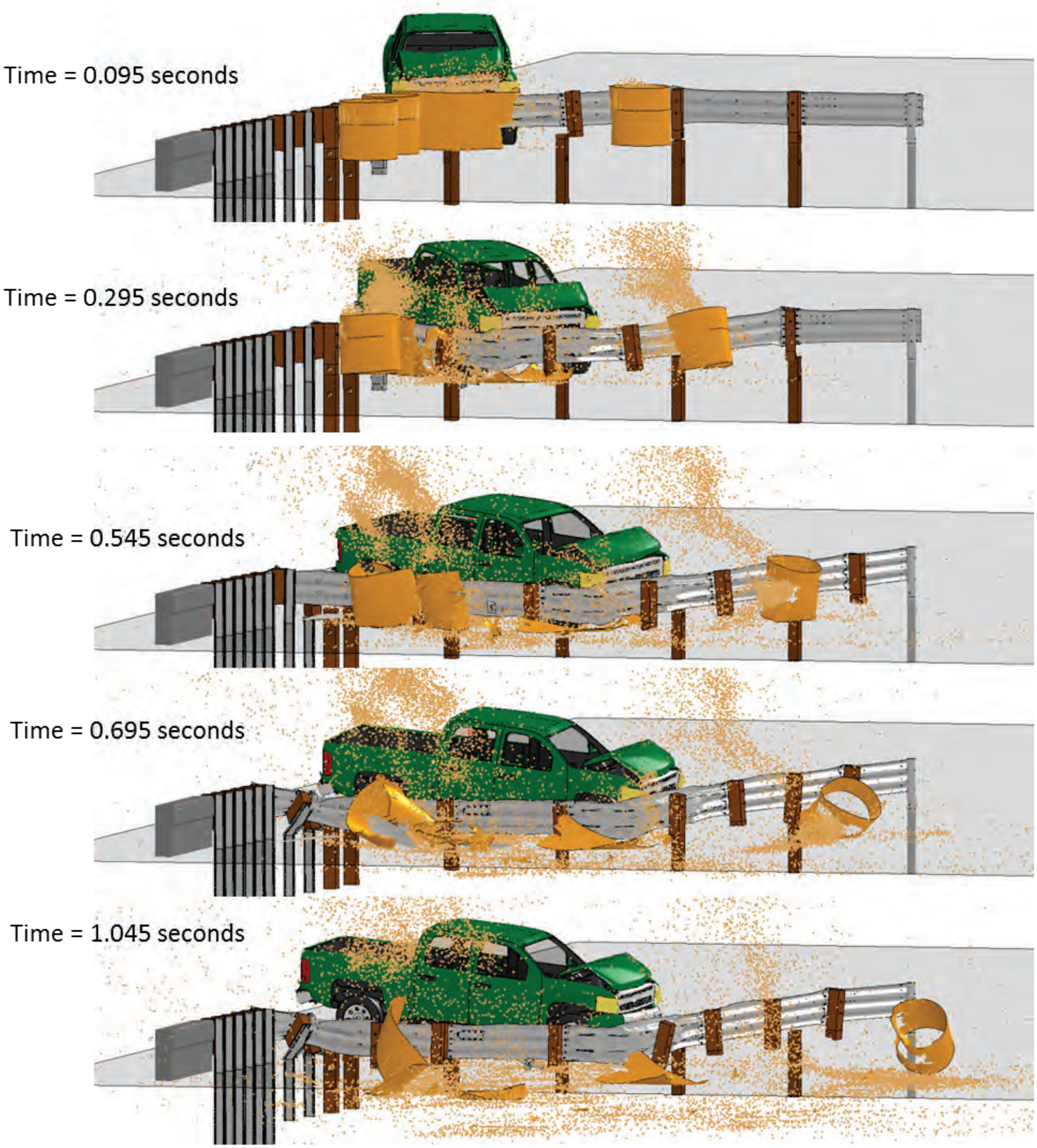


Figure 3.15. Sequential Images of Simulation with Truck, Flare, and Spread Out 700-Lb Barrels.

The previous simulation with the truck and the system that was not flared and had 700-lb barrels clustered in the radius had a maximum dynamic deflection in the x-direction of 24.4 ft and 18.6 ft in the y-direction. The maximum dynamic deflection in the x-direction of the flared system with the spread out 700-lb barrels is 27 ft, and the maximum dynamic deflection in the y-direction is 23 ft.

Figure 3.16 depicts the maximum dynamic deflection of the rail. The sand and barrels have been hidden from the following figure for clarity.

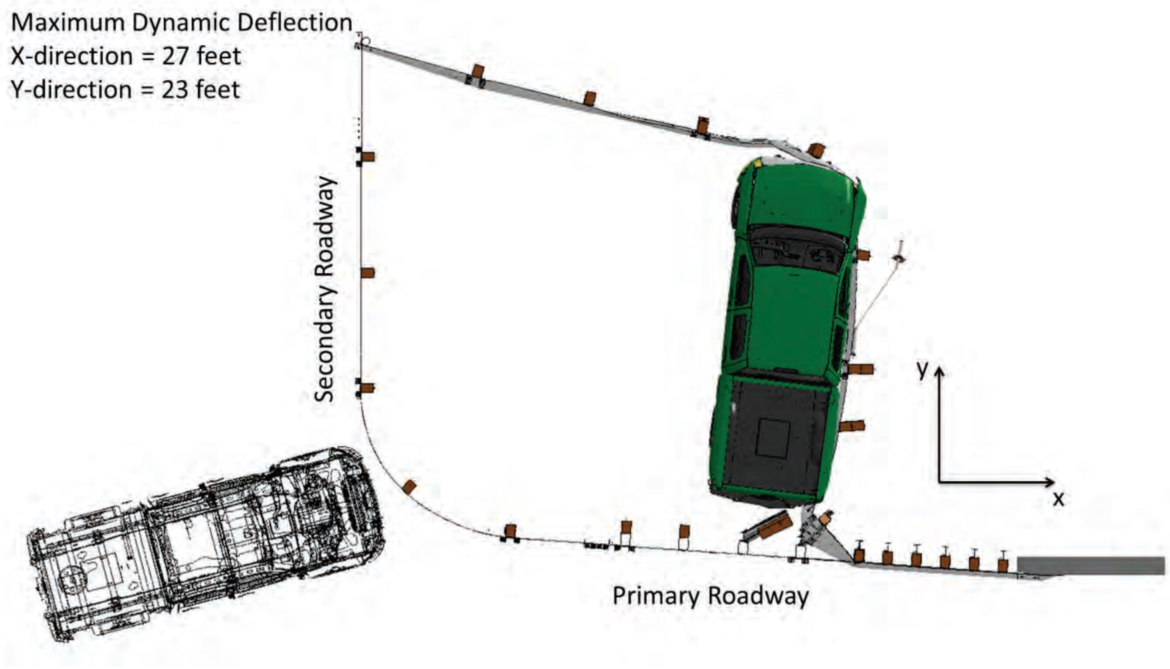


Figure 3.16. Total Displacement in Simulation with Truck, Flare, and 700-lb Sand Barrels (Sand Hidden).

The truck passed the *MASH* impact severity criteria. Table 3.4 presents the TRAP results. The 700-lb spread out barrel layout captured the truck within an acceptable displacement while also bringing the car to a stop at adequate OIV and ridedown acceleration. Therefore, this barrel layout will be used in the final system.

3.5. SIMULATION OF *MASH* TEST 3-31 TRUCK IMPACTING SHORT RADIUS WITH FLARE AND 700-LB SAND BARRELS SPREAD OUT ALONG RAIL

This test case aligns the truck parallel with the primary roadway. Figure 3.17 shows the system used in this simulation and the alignment of the truck within the system. The system contains the spread out 700-lb sand barrel layout as well as the 4° flare.

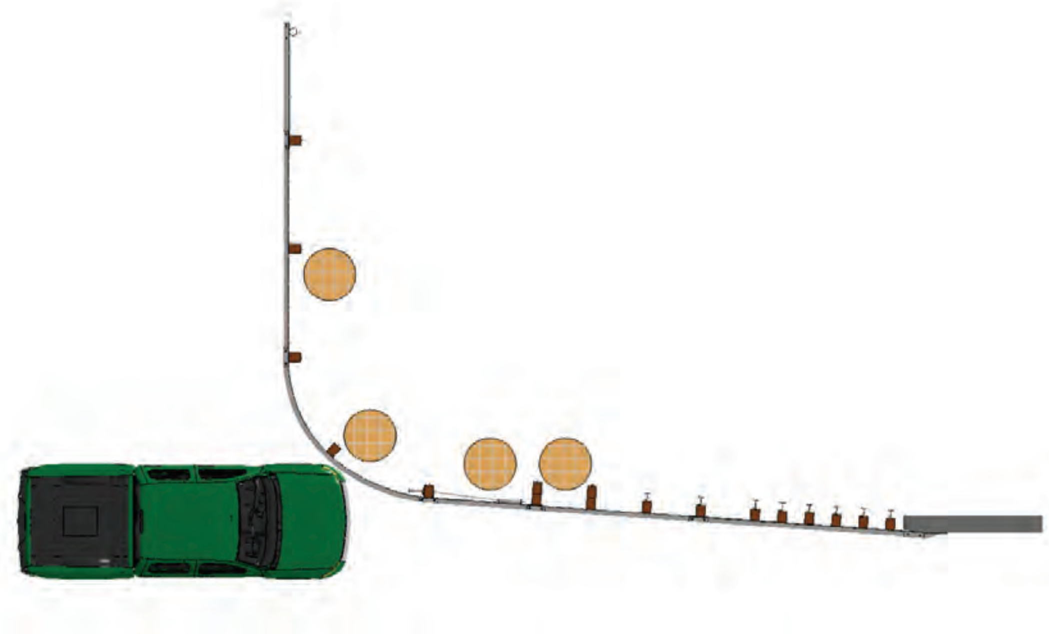


Figure 3.17. Flare and 700-Lb Barrels Spread Out behind Rail.

Figure 3.18 displays the truck in sequential images throughout the simulation. The first BCT post along the primary roadway after the radius breaks and the cable loses its tension capacity. After the tension cable loses its capacity, the rail begins to turn down and the driver-side front wheel begins to ride up onto the rail at approximately 0.12 s. The truck becomes unstable as early as 0.17 s.

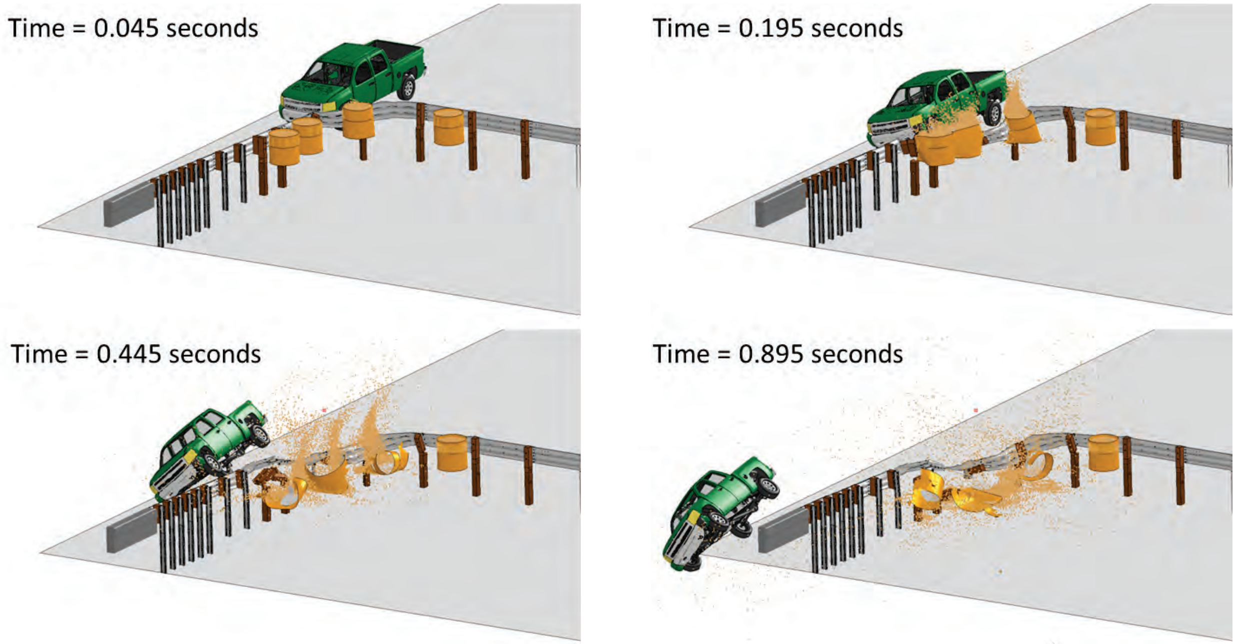


Figure 3.18. Sequential Images of Simulation with Truck, Flare, and 700-Lb Barrels Spread Out behind Rail.

Figure 3.19 shows the velocity of the truck throughout the simulation. The truck passed the *MASH* impact severity criteria but was unstable at the end of the run, and therefore did not pass. Table 3.4 shows the TRAP summary.

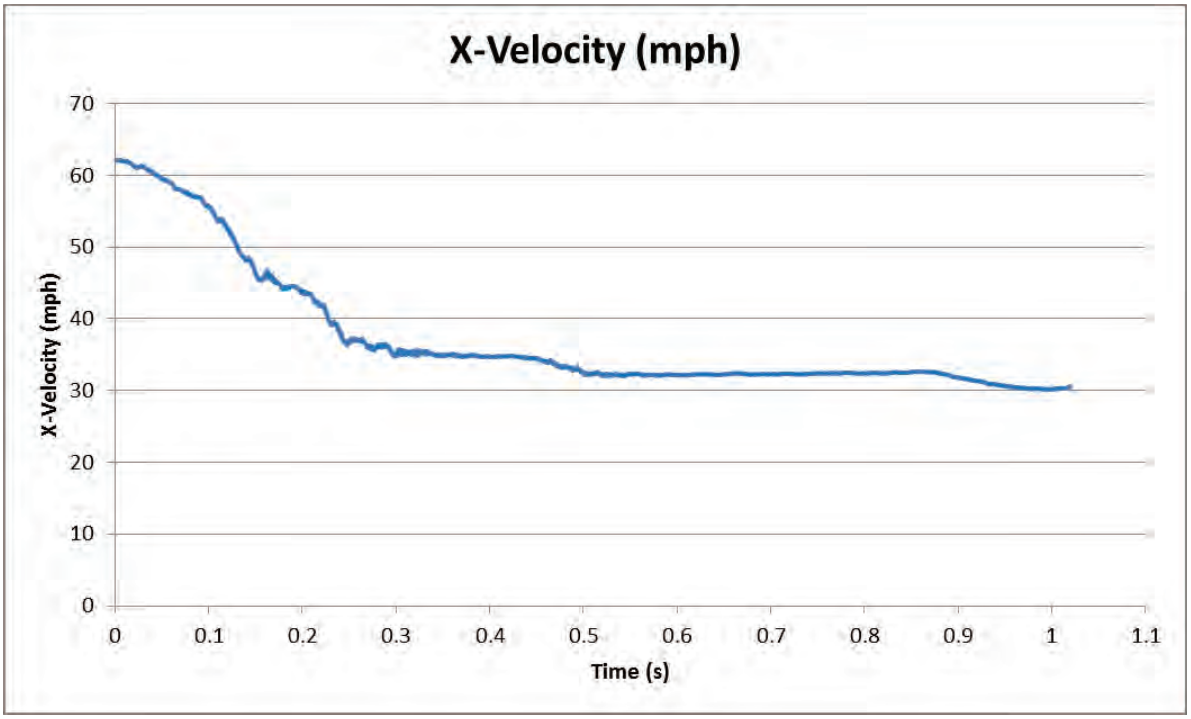


Figure 3.19. X-Velocity in Mph of Simulation with Truck, Flare, and 700-Lb Barrels Spread Out behind Rail.

Table 3.4. TRAP Summary Data for Simulation with Truck, Flare, and 700-Lb Barrels Spread Out behind Rail.

TRAP Results: TL 3-31 (Truck) Flare and Spread Out 700-lb Barrels	
Impact Velocity, mph	62.2
Impact Angle (degrees)	0
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	26.2
y-direction	1.3
Ridedown Accelerations (Gs)	
x-direction	11.9
y-direction	5.6
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	58.6
Pitch	4.5
Yaw	−10.0

Since the instability problem arose from the BCT post breaking and the tension cable losing its capacity, a new system design, which would allow the cable to remain in tension despite the BCT post on the primary roadway breaking, will be simulated next.

3.6. SIMULATION OF *MASH* TEST 3-31 TRUCK IMPACTING SHORT RADIUS WITH FLARE, SPREAD OUT 700-LB SAND BARRELS, AND TENSION CABLE AROUND POST IN RADIUS

The following simulation includes the updated tension cable design. This new design moved the cable anchor from the upper valley of the thrie beam to the lower valley of the thrie. This design reduces the angle at which the tension cable must be oriented to get to the ground by the first BCT post on the primary roadway. The tension cable runs under the angle attached at ground level to the BCT post on the primary roadway. The cable then runs along the ground and under the angle attached to the BCT post at the center of the radius. The tension cable passes along the ground and terminates at the BCT post on the secondary roadway. Figure 3.20 and Figure 3.21 depict the new tension cable design that is described above. Figure 3.22 and Figure 3.23 provide a back and front view, respectively, of the tension cable from the simulation. The sand barrels are hidden from the last two figures for clarity.

Figure 3.24 depicts the truck alignment with the system. The centerline of the truck is aligned with the traffic face of the concrete parapet located on the primary roadway.

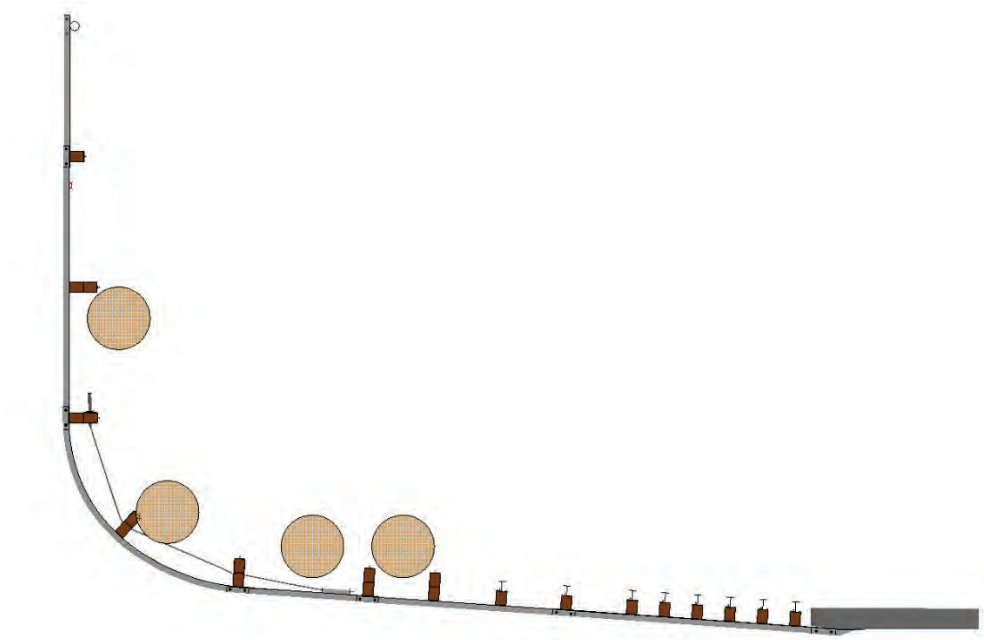


Figure 3.20. Flare, Spread Out 700-Lb Sand Barrels, and Tension Cable around Post in Radius.

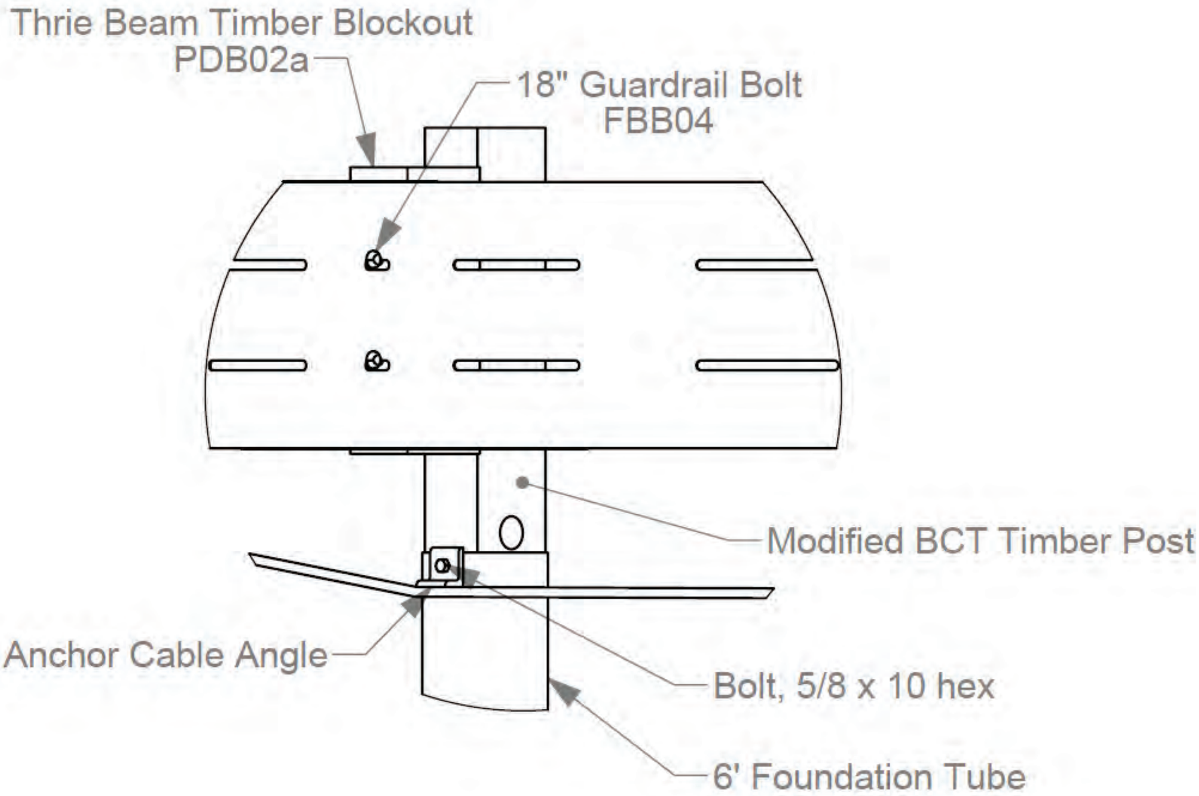


Figure 3.21. Anchor Cable Angle Attachment to BCT Post.

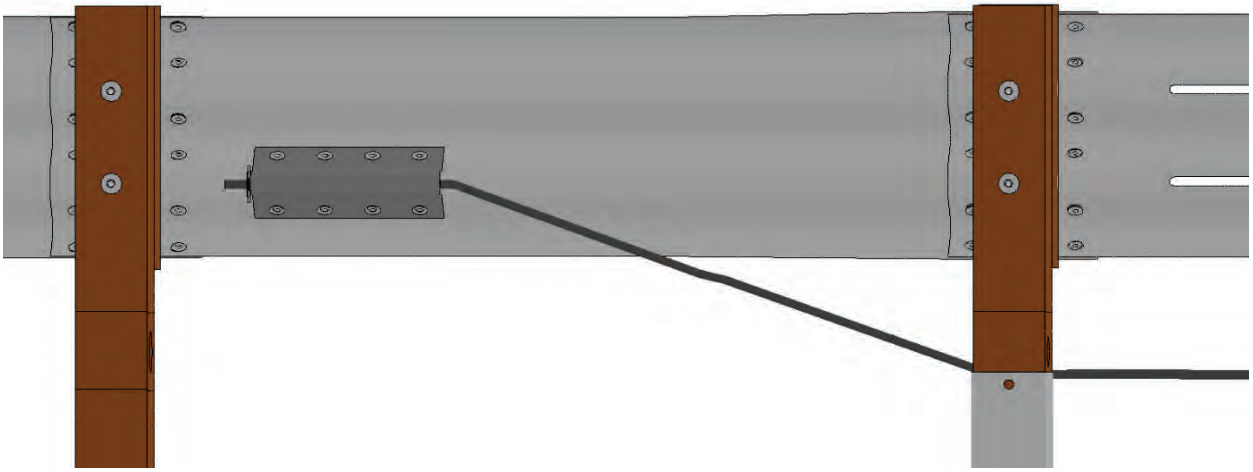


Figure 3.22. Back View of Tension Cable (Sand Hidden).

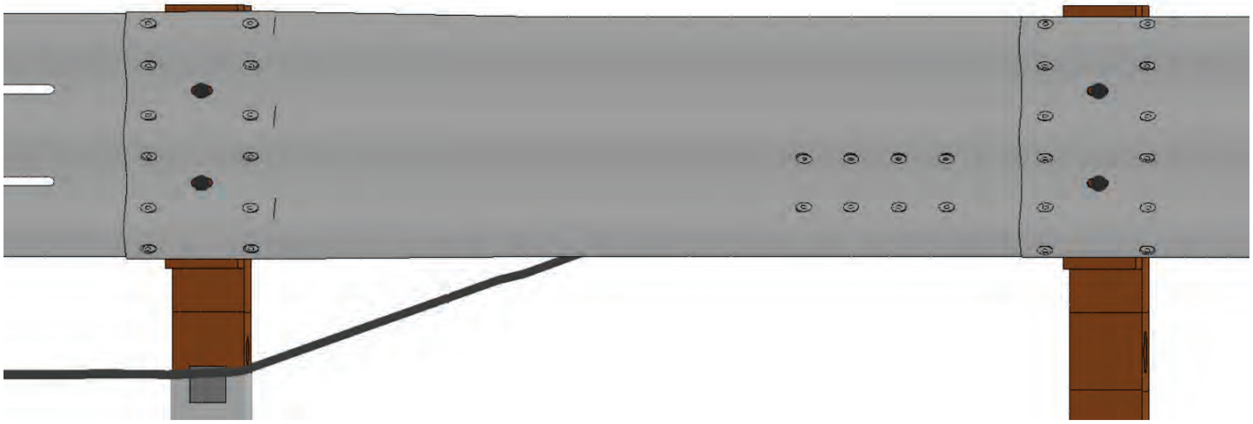


Figure 3.23. Front View of Cable (Sand Hidden).

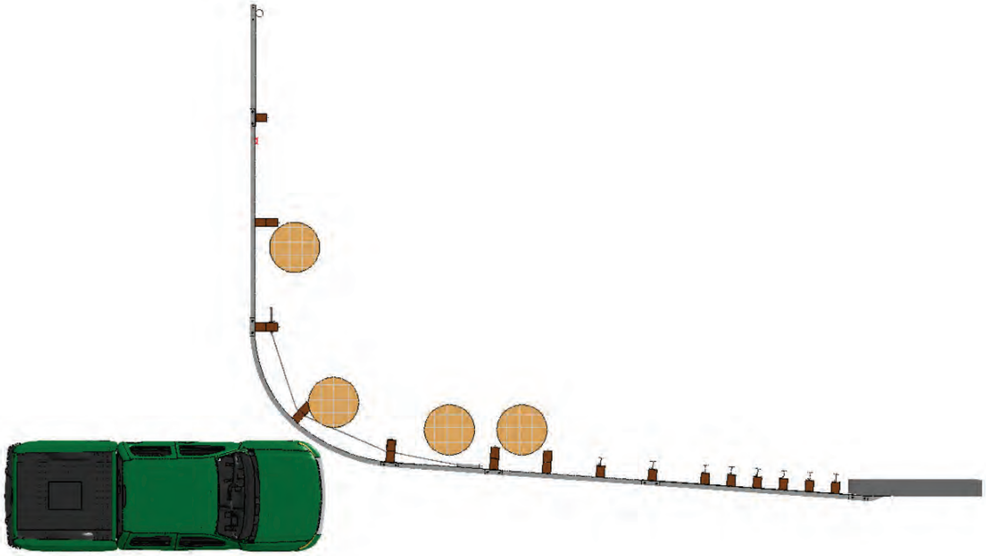


Figure 3.24. Alignment of Truck with System.

Figure 3.25 shows sequential images depicting the performance of the system. The first BCT post on the primary roadway breaks at 0.045 s. The cable maintains tension capacity and is still under the angle attached to the steel tube of the broken BCT post. The tire begins to ride along the cable at 0.09 s. By 0.12 s, the front left truck tire has passed from riding along the cable to riding up the rail. The front left truck tire leaves the rail before 0.245 s and the truck is unstable. From studying the behavior of the tire riding along the tension cable, it became evident that the cable was behaving more like a rod than a wire cable. Therefore, before running another simulation with the tension cable, researchers will calculate the wire cable's moment of inertia in order to have better behavioral representation of the wire cable.

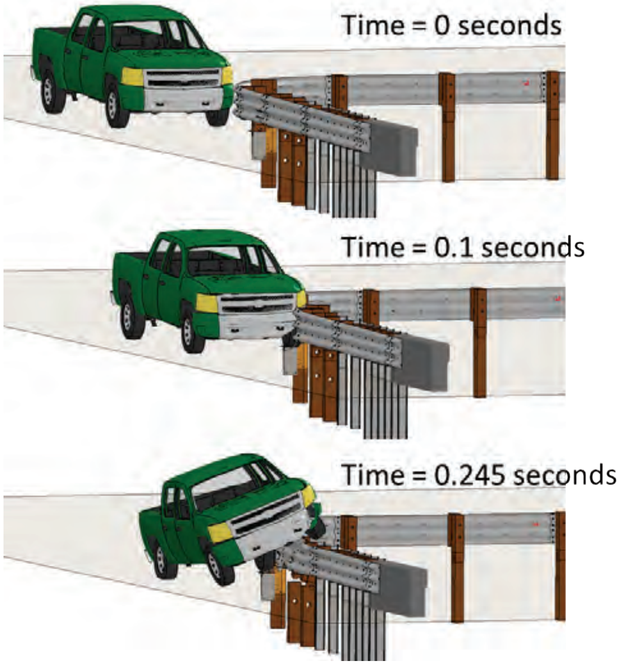
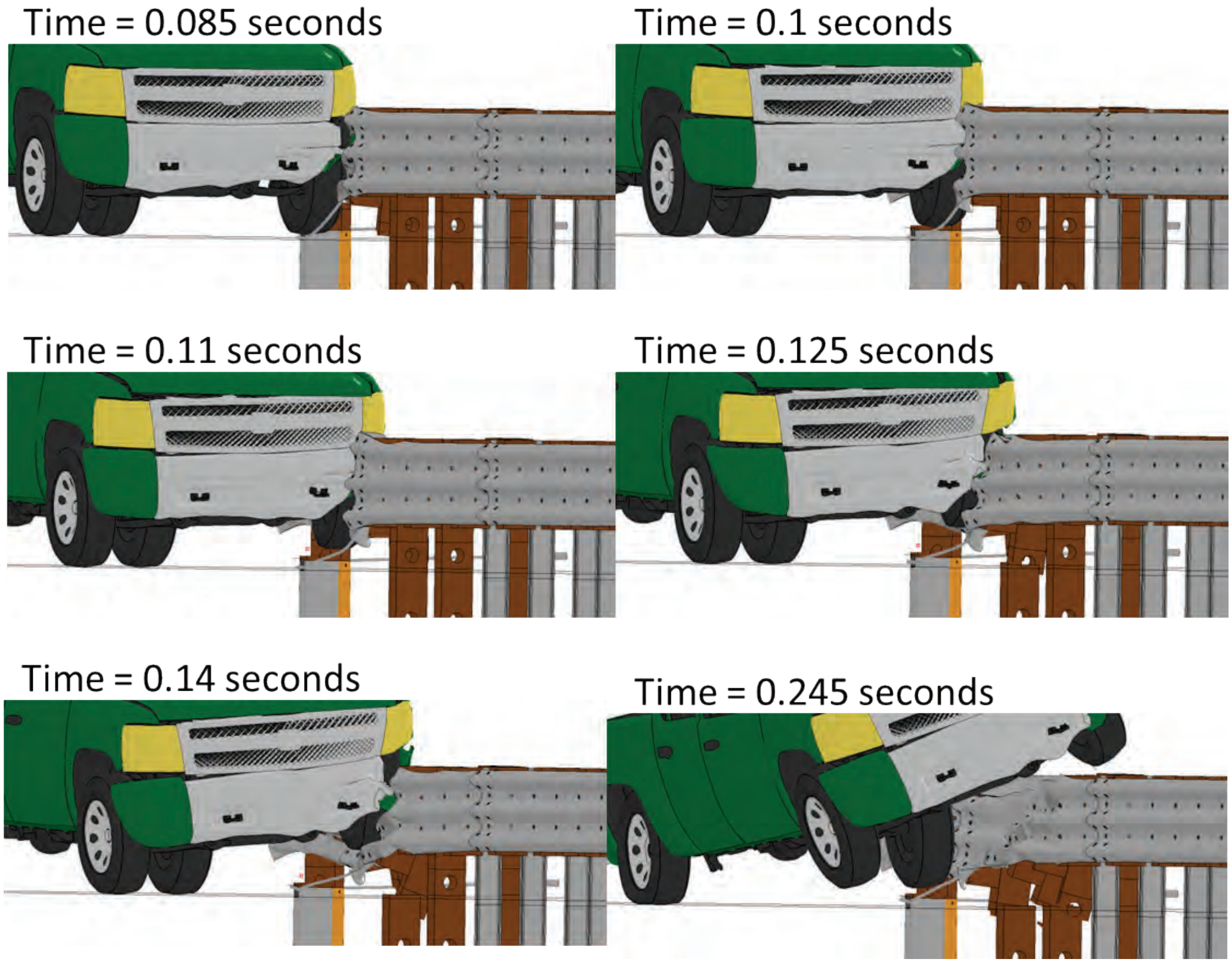


Figure 3.25. Sequential Images of Simulation of Truck, Flare, Spread Out 700-Lb Sand Barrels, and Tension Cable around Post in Radius (Sand Hidden).

Figure 3.26 shows how the front left tire rides up the cable onto the rail and becomes unstable, causing the truck to roll. Figure 3.27 zooms in on the interaction between the tire and the cable. Notice how as the tire pushes the rail into the field side of the system, it begins to ride along the cable. To make them stand out, the cable and cable bracket have been colored lime green and aqua, respectively.

Figure 3.28 shows the velocity of the truck. There was less reduction in velocity in this simulation than the previous simulation. Table 3.5 displays the truck passed the *MASH* impact severity criteria. However, the truck was not stable at the end of the simulation, and therefore, the system did not pass the test.

The next system to be simulated will test a tension cable design that is set farther back into the field side of the short radius system. This will help to attenuate the interaction of the cable with the vehicle's tires while still maintaining the tension in the cable for the redirection test cases.



Time = 0.085 seconds

Time = 0.1 seconds

Time = 0.11 seconds

Time = 0.125 seconds

Time = 0.14 seconds

Time = 0.245 seconds

Figure 3.26. Sequential Images of Tire and Cable Interaction (Sand Hidden).

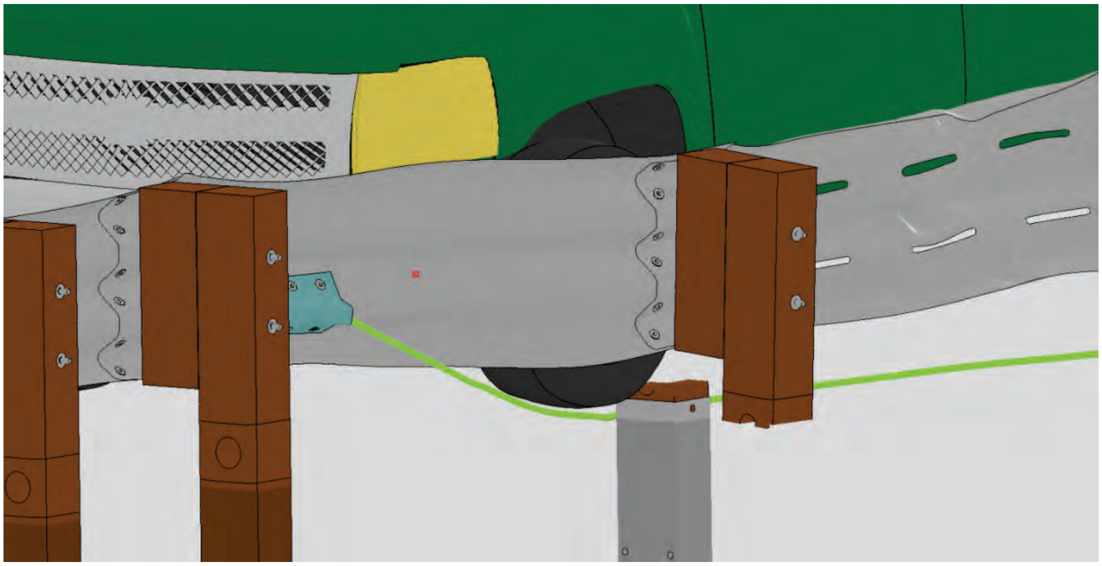


Figure 3.27. Tire and Cable Interaction (Sand Hidden).

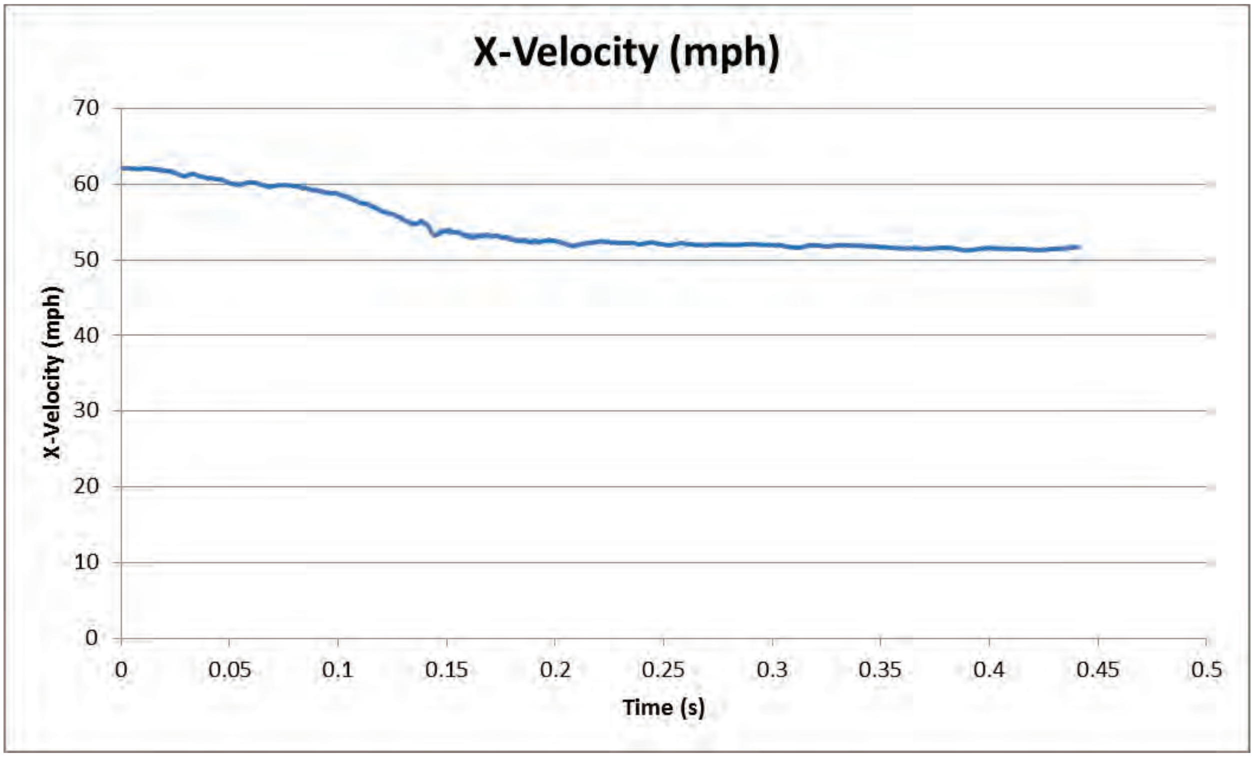


Figure 3.28. X-Velocity in Mph of Simulation of Truck, Flare, Spread Out 700-Lb Sand Barrels, and Tension Cable around Post in Radius.

Table 3.5. TRAP Summary Data for Simulation of Truck, Flare, Spread Out 700-Lb Sand Barrels, and Tension Cable around Post in Radius.

TRAP Results: TL 3-31 (Truck) Flare, Spread Out 700-lb Sand Barrels, and Tension Cable Around Post in Radius	
Impact Velocity, mph	62.2
Impact Angle (degrees)	25
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	14.8
y-direction	8.2
Ridedown Accelerations (Gs)	
x-direction	1.7
y-direction	2.8
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	24.9
Pitch	7.4
Yaw	5.7

3.7. SIMULATION OF *MASH* TEST 3-31 TRUCK IMPACTING SHORT RADIUS WITH FLARE, SPREAD OUT 700-LB SAND BARRELS, AND TENSION CABLE BEHIND POST IN RADIUS

The following simulation includes the promising tension cable design. To help prevent the tire and cable from interacting during the redirection tests, researchers moved the angle to the back of the BCT post on the primary roadway. Now the cable passes from the bottom valley of the thrie beam to underneath the angle that has been moved to the back of the BCT post. From this post, the cable passes along the ground to be captured beneath the angle on the front of the BCT post, which is in the center of the radius. The blockout has been removed from this center post in the radius in order to cause the geometry to allow the cable to bear on all BCT posts. Then the cable continues along the ground to end at the first BCT post on the secondary roadway. The simulation and new cable layout can be seen in Figure 3.29. Figure 3.30 and Figure 3.31 show the tension cable design described above from the back and front of the rail, respectively.

For the TL 3-31 test, the truck was parallel to the primary roadway. The center of the truck was aligned with the traffic face of the concrete parapet at the end of the primary roadway. Figure 3.32 shows the truck's alignment with the system.

Figure 3.33 shows the impact from the front of the rail. The truck remained stable throughout the impact, which was one goal of the new cable design. The sand barrels have been hidden from the following images for clarity.

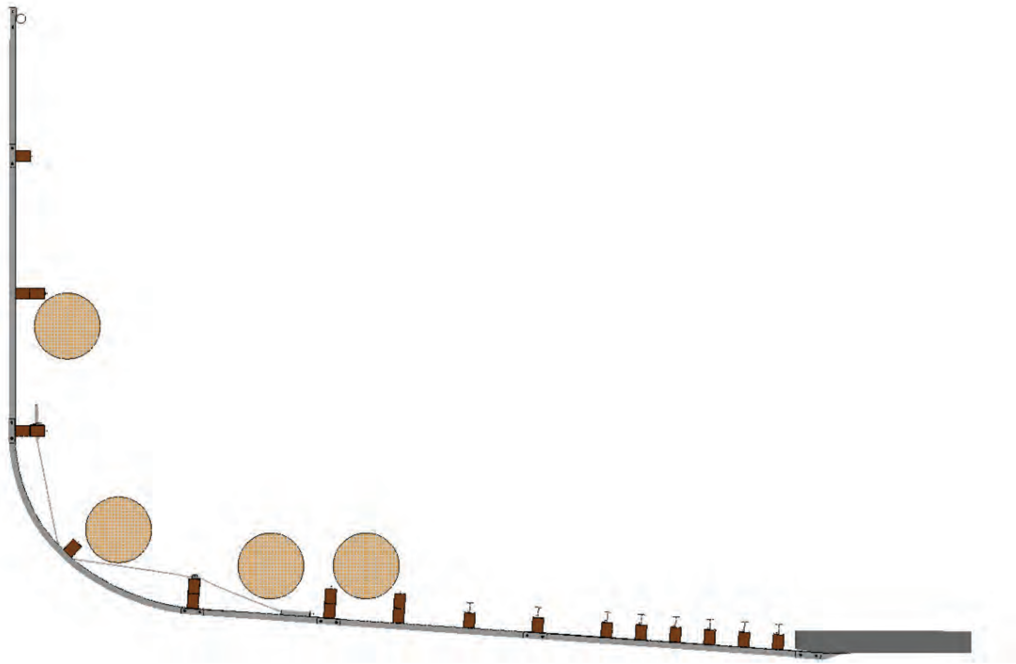


Figure 3.29. Flare, Spread Out 700-Lb Sand Barrels, and Tension Cable behind Post in Radius.

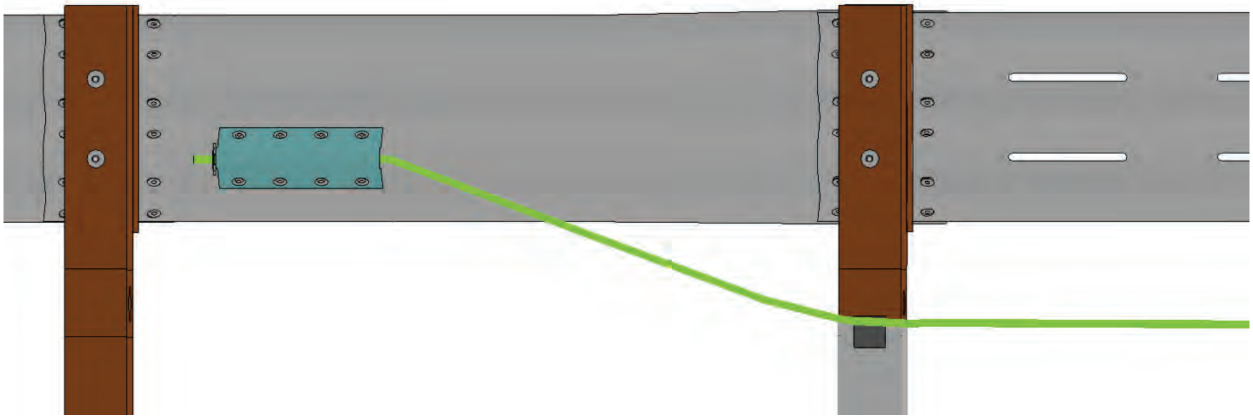


Figure 3.30. Back View of Rail (Sand Hidden).

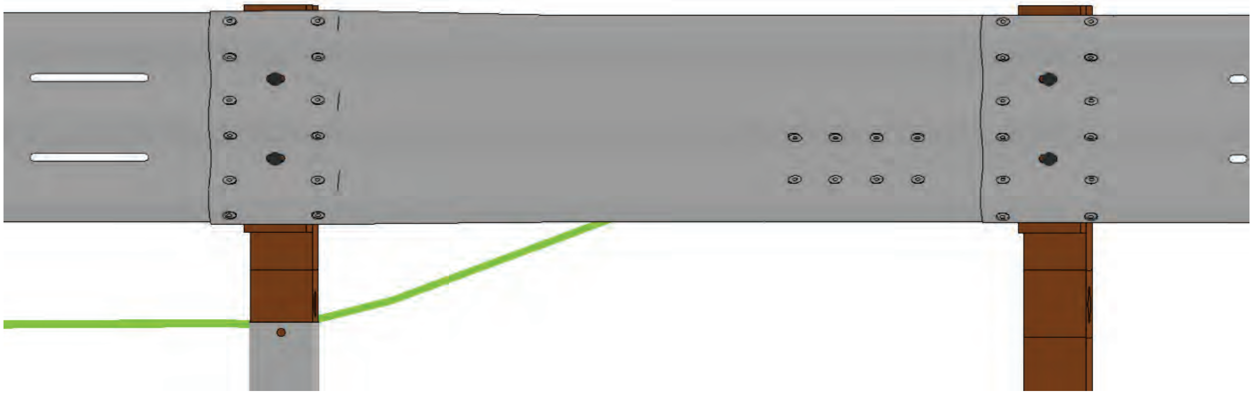


Figure 3.31. Front View of Rail (Sand Hidden).

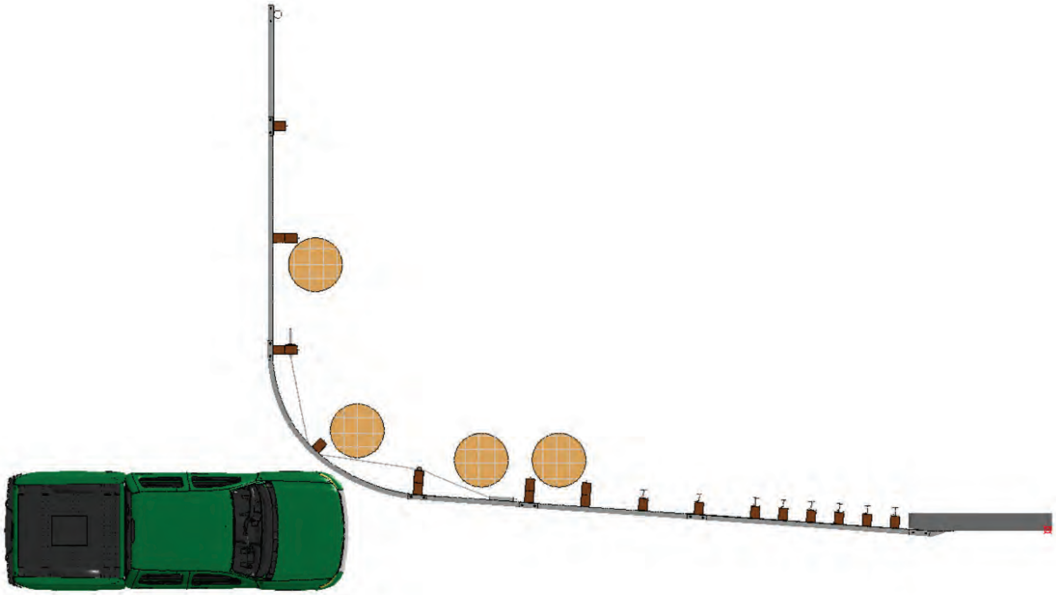


Figure 3.32. Alignment of Truck with System.

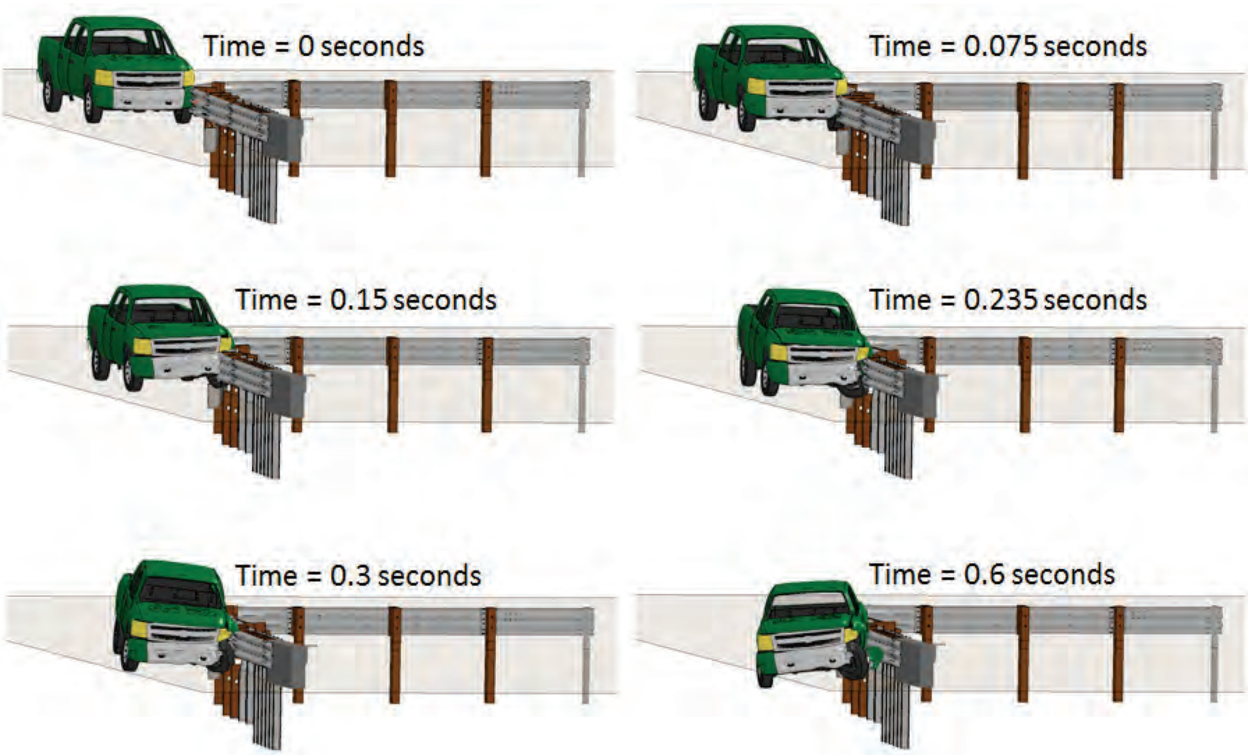


Figure 3.33. Sequential Images of Simulation from Front of Rail (Sand Hidden).

The sequential images in Figure 3.34 show the truck's interaction with the rail from the back of the rail. The sand has been hidden from these images in order to better see the rail and truck interaction.

The sequential images in Figure 3.35 zoom in on the interaction of the tire and the cable. In Figure 3.35, the sand barrels have been hidden and the cable bracket and cable have been colored for clarity. The first BCT on the primary roadway breaks at 0.025 s. At 0.075 s, the front driver side tire passes over the bottom of the broken BCT post on the primary roadway. The cable is still under the angle on the BCT post at this point in the simulation. At 0.13 s, the truck has pushed the rail into the interior of the system and the cable moves out from beneath the angle on the broken BCT post on the primary roadway. The cable maintains tension capacity. At 0.15 s, the BCT post at the center of the radius breaks. The cable still has tension capacity in this design. By 0.4 s, the truck has been redirected and its interaction with the system is complete. At this point in the simulation, the cable is still held under the angle on the BCT post at the center of the radius.

Figure 3.36 zooms in on the tire and cable interaction. As the tire pushes the rail back, the tire does not ride along the cable. The cable and the cable bracket are colored lime green and aqua in the figure to help them stand out.

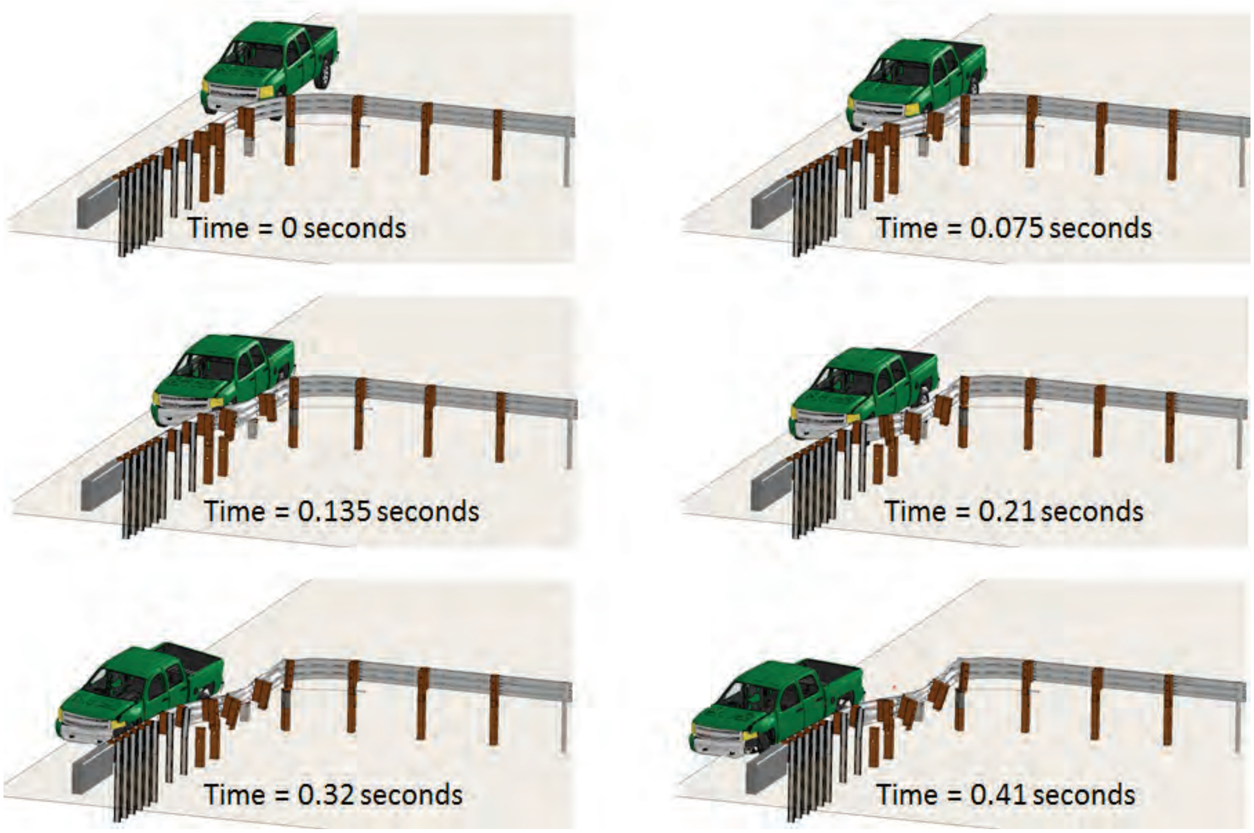


Figure 3.34. Sequential Images of Simulation from Back of Rail (Sand Hidden).

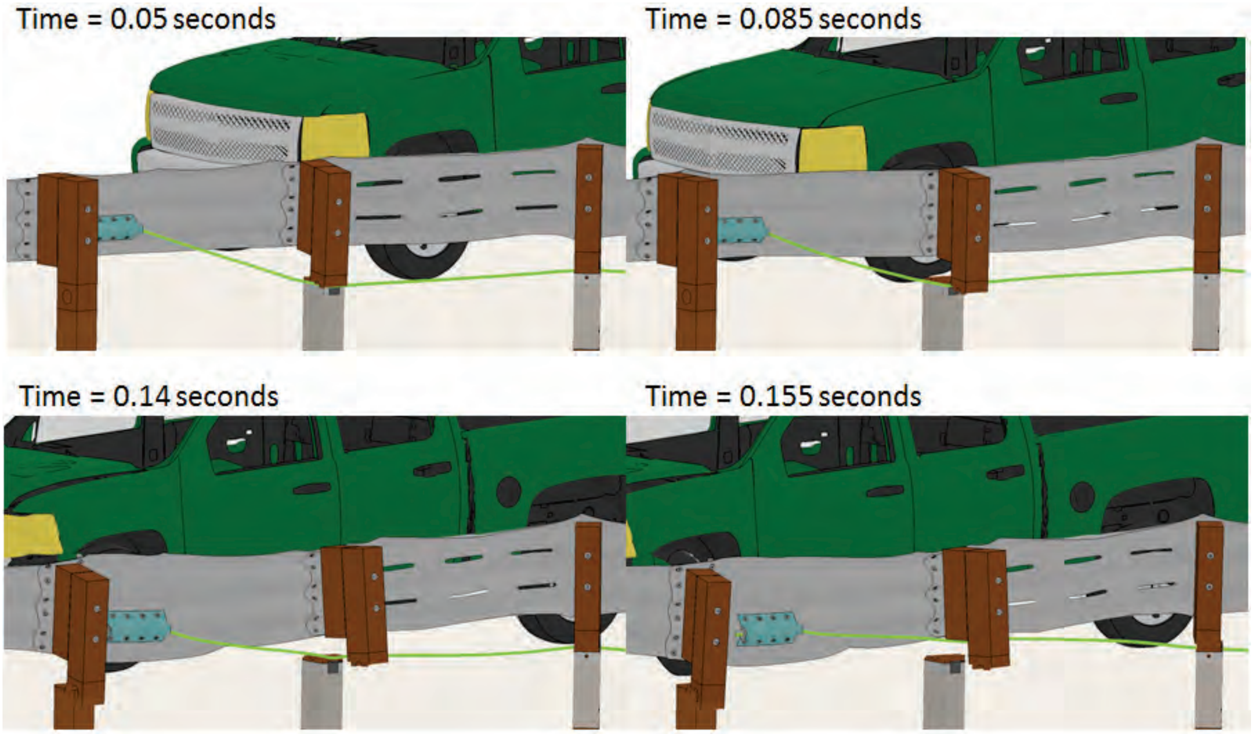


Figure 3.35. Sequential Images of Truck and Cable Interaction (Sand Hidden).

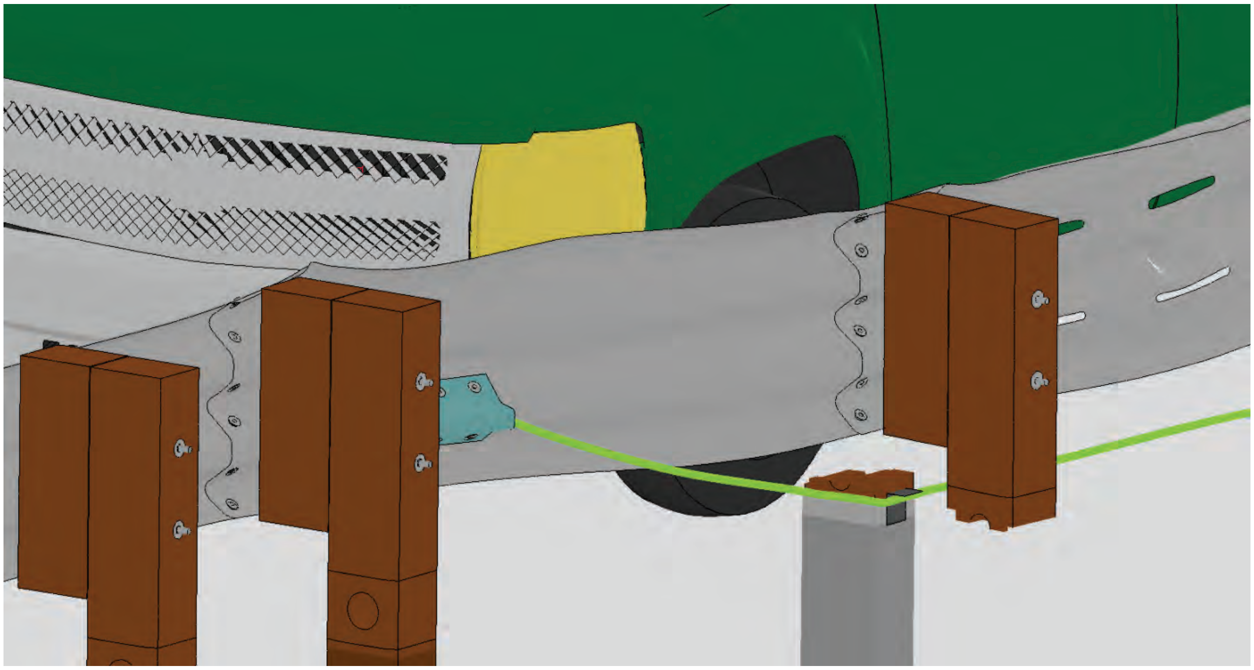


Figure 3.36. Tire and Cable Interaction (Sand Hidden).

Figure 3.37 depicts the final displacement of the vehicle; the sand has been hidden for clarity. Figure 3.38 portrays the velocity of the truck throughout the simulation. The truck is redirected at 25 percent of its initial velocity.

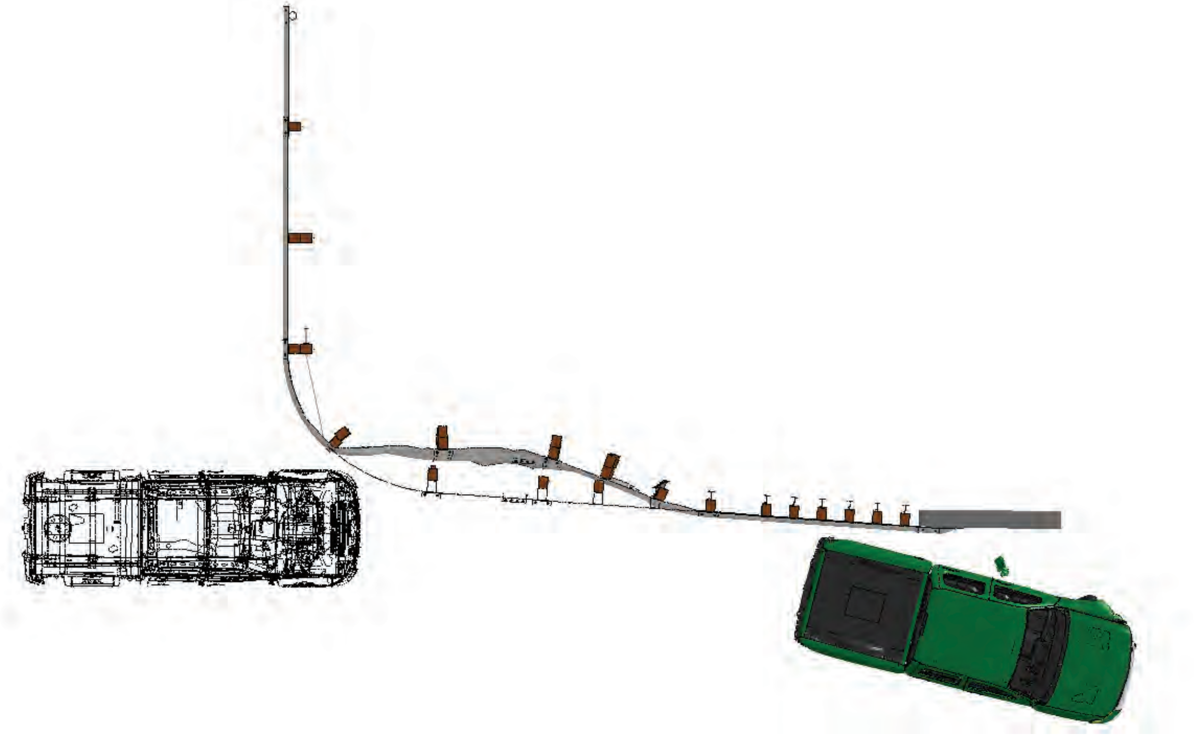


Figure 3.37. Final Displacement of the Truck (Sand Hidden).

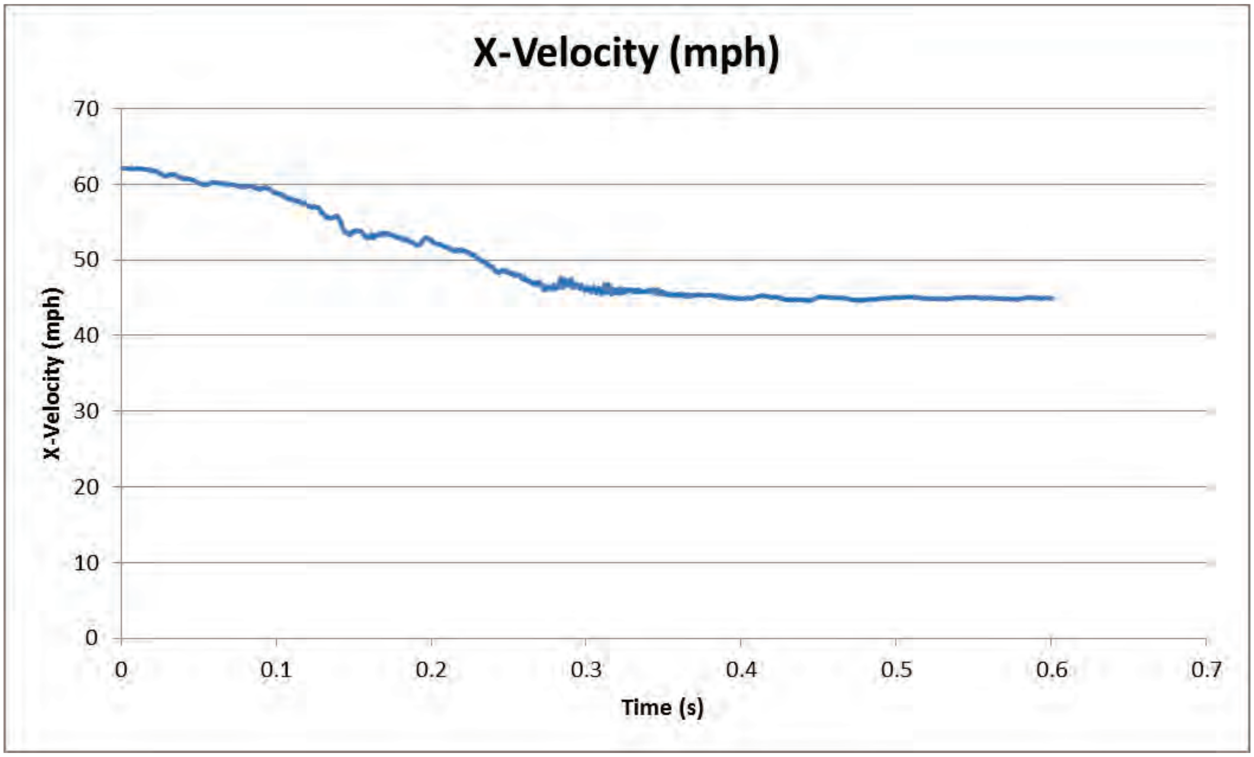


Figure 3.38. X-Velocity in Mph of Simulation with Flare, Spread Out 700-Lb Sand Barrels, and Tension Cable behind Post in Radius.

The truck passed the *MASH* impact severity criteria that can be seen in Table 3.6. Since the truck also remained stable throughout the simulation, the truck passed the TL 3-31 test with this new tension cable design, which passes behind the first BCT post on the primary roadway.

Design checks were done following this phase of simulation in order to check certain aspects of the final short radius system that would be used in the physical crash tests.

Table 3.6. TRAP Summary Data for Simulation with Truck, Flare, Spread Out 700-Lb Sand Barrels, and Tension Cable behind Post in Radius.

TRAP Results: TL 3-31 (Truck) Spread 700-lb Sand Barrel, Flare, and Tension Cable Behind Post	
Impact Velocity, mph	62.2
Impact Angle (degrees)	0
Occupant Risk Factors	
Impact Velocity (ft/s)	
x-direction	15.4
y-direction	10.5
Ridedown Accelerations (Gs)	
x-direction	7.0
y-direction	7.3
Max Roll, Pitch, and Yaw Angles (degrees)	
Roll	−6.2
Pitch	−4.9
Yaw	15.2

CHAPTER 4. CRASH TEST MATRIX

This chapter briefly explains the purpose behind each *MASH* TL-3 tests in the test matrix. The promising short radius system and the respective alignment of the vehicles with the system are also pictured for each case. The following test cases chosen are all originally applied to terminals or crash cushions. They have been modified in accordance with their original intent.

4.1. *MASH* TEST 3-31

MASH Test 3-31 is intended to show whether the system is capable of safely and stably decelerating a 2270P vehicle to a stop. For this system, the 2270P vehicle should be redirected or safely captured when the impact is parallel to one of the sides of the system. In gating systems, like this one, the test will evaluate the occupant impact risk and vehicle trajectory criteria. In this system, the truck was aligned parallel to the primary of the roadway. The centerline of the truck was aligned with the traffic face of the concrete parapet at the end of the system. Figure 4.1 shows the chosen alignment described.

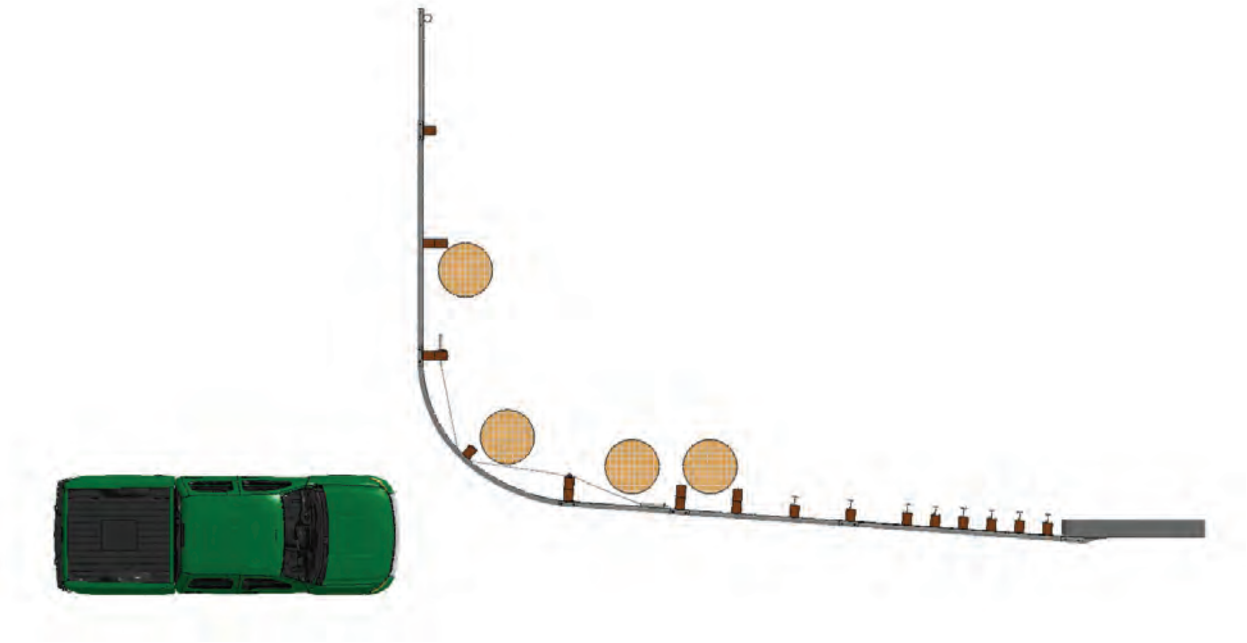


Figure 4.1. Alignment of Truck with System for *MASH* Test 3-31.

4.2. *MASH* TEST 3-32

MASH Test 3-32 examines the behavior of the short radius system during an oblique impact on the nose of the system. Occupant risk and vehicle trajectory are the main concerns with regard to this test. The 1100C vehicle impacts the center of the radius of the system at a 15° angle. Figure 4.2 shows the alignment of the car with the system.

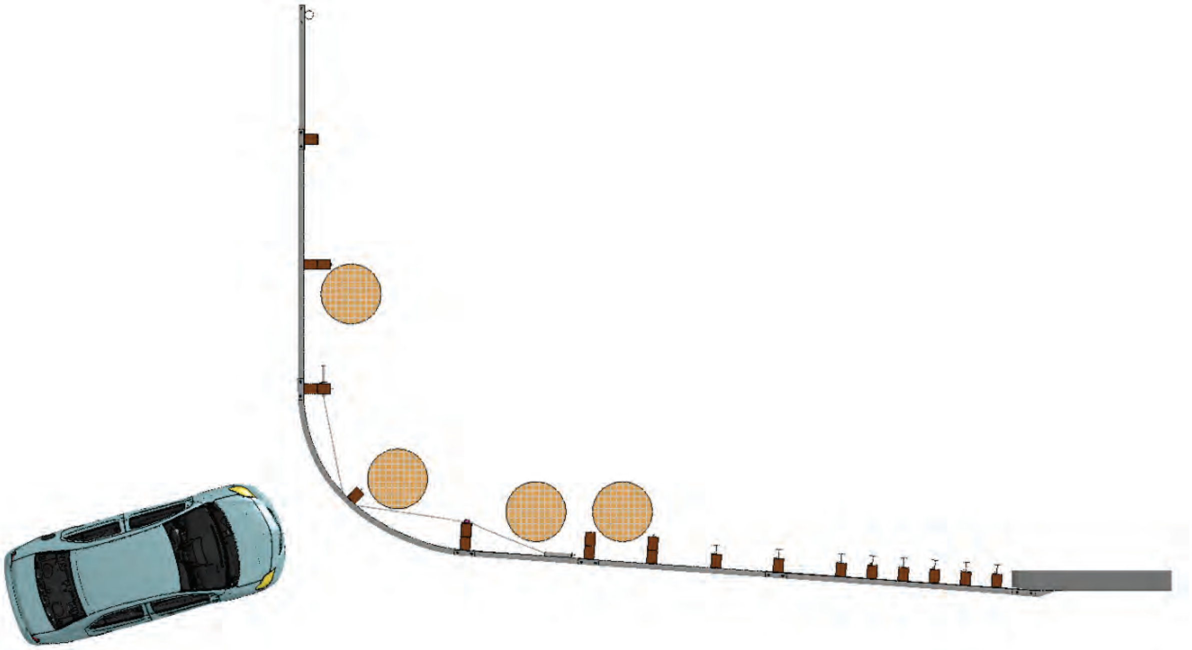


Figure 4.2. Alignment of Car with System for *MASH* Test 3-32.

4.3. *MASH* TEST 3-33

This test examines the behavior of the short radius system during an oblique impact on the nose of the system. Occupant risk and vehicle trajectory are the main concerns with regard to this test. The 2270P vehicle impacts the center of the radius of the system at a 15° angle. Figure 4.3 shows the alignment of the truck with the system.

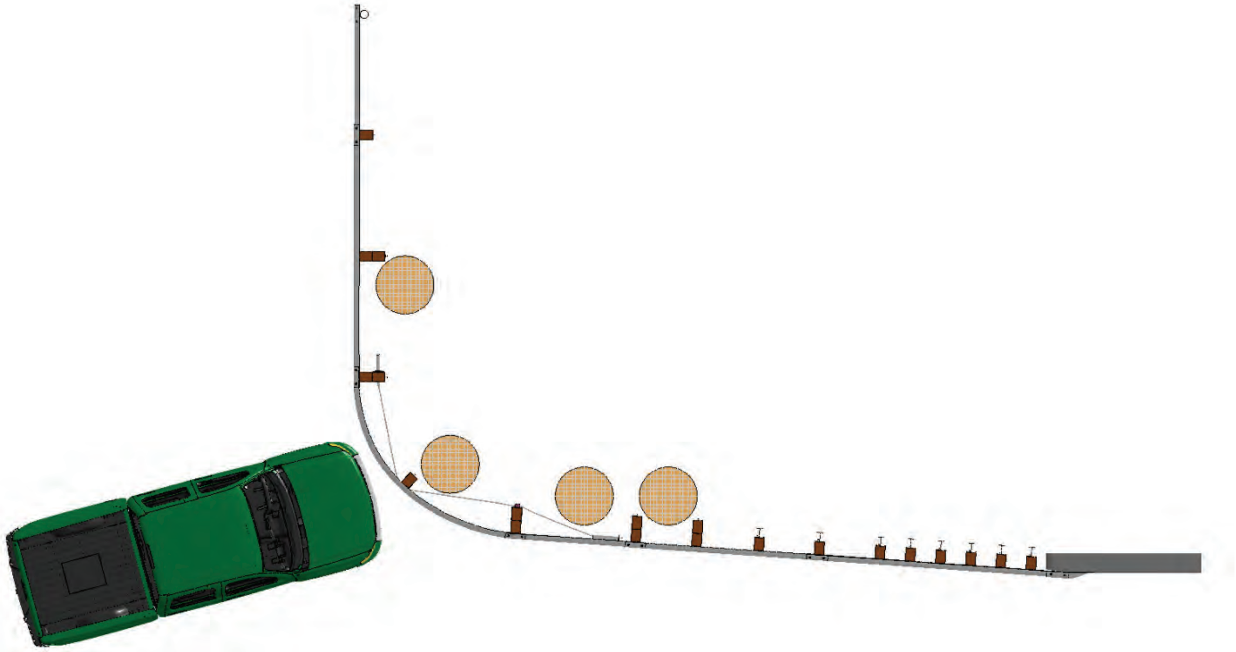


Figure 4.3. Alignment of Truck with System for *MASH* Test 3-33.

4.4. *MASH* TEST 3-35

MASH Test 3-35 case was simulated to determine the rail's capacity for containing or redirecting the truck. The impact location is defined in *MASH* as the beginning of length of need at a 25° angle. The truck impacted the system at a 25° angle in the first section of guardrail along the primary roadway after the radius. This location is near where the rail behavior changes from capturing to redirecting. Figure 4.4 shows the alignment of the truck with the system.

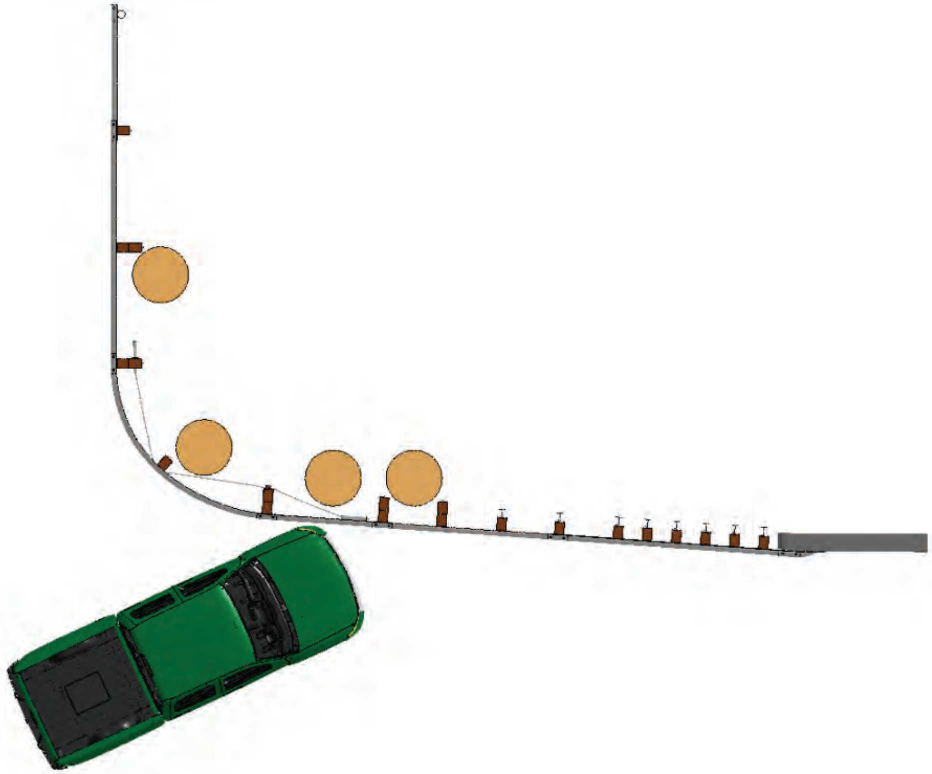


Figure 4.4. Alignment of Truck with System for *MASH* Test 3-35.

CHAPTER 5. SYSTEM DETAILS

5.1. TEST ARTICLE DESIGN AND CONSTRUCTION

5.1.1. Test Installation for Test Nos. 467114-3 through 467114-6

Each test installation consisted of a 31-inch tall, 58-ft 10-inch long, thrie-beam short radius guardrail system constructed with a 27 ft 7¼ 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). 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-roadside thrie-beam was perpendicular to the parapet face tangent. Four sand barrels were strategically placed on the inboard, field side of the installation. The end anchor on the secondary roadway and the modified 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.

The spacing for posts 1 to 2, posts 2 to 3, and posts 3 to 4 was 6 ft 3 inches. Posts 4 to 5 and posts 5 to 6 were spaced at 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 11 were each spaced at 3 ft 1½ inches. Posts 11 to 16 were equally spaced at 1 ft 6¾ inches. Post 16 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 radiused thrie-beam section (RTM02a). Another 75-inch thrie-beam anchor rail spanned between posts 6 and 7. A single 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 16 and the parapet (i.e., two sections of thrie-beam were nested one within the other). At post 10, the upstream single thrie-beam section was attached between the post and 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 (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. Each 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 A, 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 a strut bolt was installed 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 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 and accommodate the strut bolt.

The post 1 tube socket and the post 2 foundation tube were joined at grade level with two (1 field side, 1 traffic side; legs outward) C4×7.25 ASTM A36 channel struts, 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 in a drilled hole with compacted strong 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 a ⅝-inch × 10-inch A307 Grade 5 hex bolt, flat washer, recessed guardrail nut were installed to secure 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 in 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 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 a ⅝-inch × 10-inch A307 Grade 5 hex bolt, flat washer, and recessed guardrail nut were installed to secure the post in the foundation tube. Post 5'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. Additionally, an anchor cable bearing saddle made from half of a 4-inch Schedule 40 pipe (4½ inches OD × 0.2375-inch wall thickness) 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. The guardrail was attached directly to post 5 with two ⅝-inch × 10-inch guardrail bolts (FBB03) and recessed guardrail nuts.

Post 6 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 a ⅝ × 10-inch A307 Grade 5 hex bolt, flat washer, and recessed guardrail nut were installed to secure the post in the foundation tube. Post 6'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 (in the lateral direction) to secure the timber post in the tube as described above. Additionally, an anchor-cable-bearing saddle made from half of a 4-inch Schedule 40 pipe (4½ inches OD × 0.2375-inch wall thickness) was welded (U-side up) to, and protruded 2 inches from, the external field side of the foundation tube. See Appendix B, Sheet 21 for details. The guardrail was attached to post 6 via a thrie-beam timber blockout (PDB02a) and two ⅝ × 18-inch guardrail bolts (FBB04) and recessed guardrail nuts.

Posts 7 and 8 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 thrie-beam timber blockout (PDB02a) and two ⅝-inch × 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 and 10 were W6×8.5 flange guardrail posts (PWE06), 72 inches long. The guardrail was attached to each of posts 9 and 10 via a thrie-beam timber routered blockout (6 inches × 8 inches × 18 inches tall; with a 4½-inch wide × ⅜-inch deep relief, similar ro a

PDB02) and two ⅝-inch × 10-inch guardrail bolts (FBB03) and recessed guardrail nuts. Posts 9 and 10 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 11 through 16 were W6×8.5 wide flange guardrail posts (PWE07), 84 inches long. The guardrail was attached to each of posts 11 through 16 via a thrie-beam timber routed 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 11 through 16 were installed 52 inches deep into a drilled hole with compacted strong soil as per *MASH*. 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 parapet. Five A325 ⅞-inch diameter hex bolts, nuts, and 1¾-inch outside diameter hardened flat washers secured the connector to the parapet: three 14-inch bolts in the upper, wider part of the parapet, and two 12-inch bolts in the lower, narrower part of the parapet. The terminal connector and doubled thrie beam were joined with twelve 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 utilizing 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 was 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.

For this test installation, a reinforced concrete bridge parapet was constructed by adding on to the existing concrete runway apron. The parapet base tapered from 60 inches 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 16 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.

Four 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 outer shell to the back side of the rail at posts 3, 5, 7, and 8 were 15, 10, 10, and 12 inches, respectively. See Attachment A, Sheet 3 of 22 for placement geometry.

Figure 5.1 and Figure 5.2 show the layout and overall details of the Short Radius Guardrail used in Test Nos. 467114-3 through 467114-6, and Figure 5.3 and Figure 5.4 present photographs of the complete installation. Appendix B provides further details.

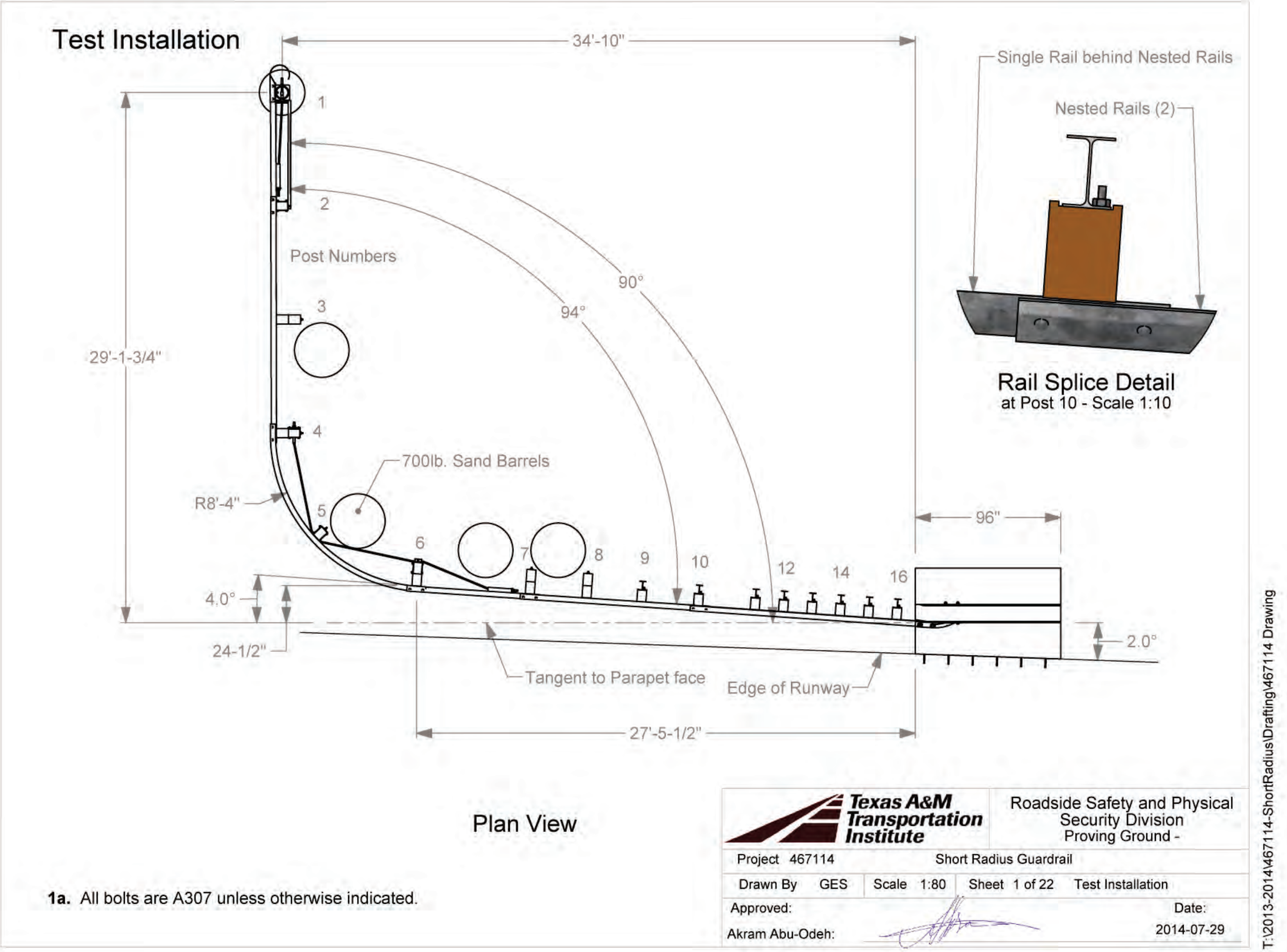


Figure 5.1. Layout of the Short Radius Guardrail for Test Nos. 467114-3 through 467114-6.

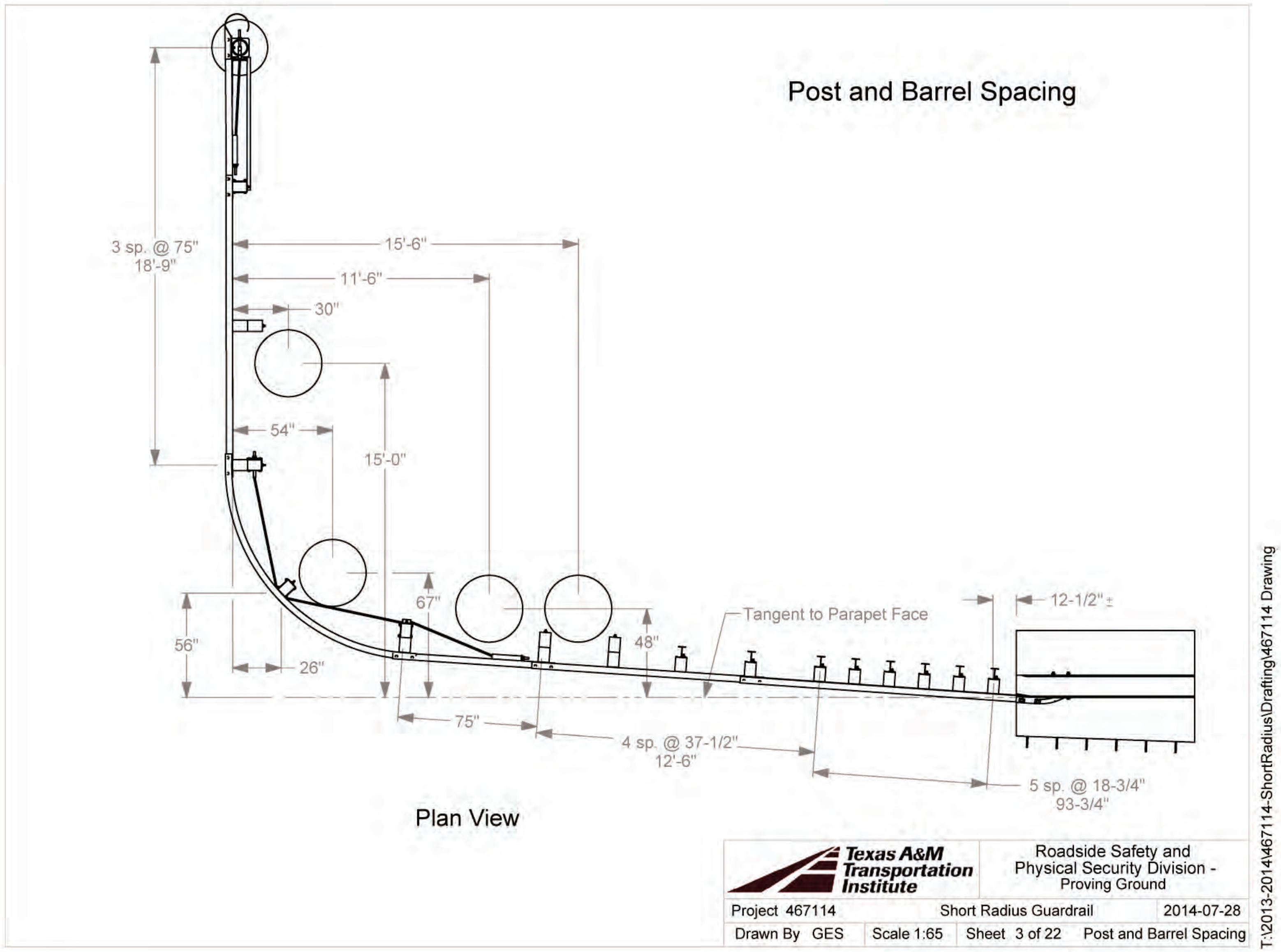


Figure 5.2. Overall Details of the Short Radius Guardrail for Test Nos. 467114-3 through 467114-6.

Figure 5.3. Short Radius Guardrail (Overall, Secondary Road, and Radius) prior to Test Nos. 467114-3 through 467114-6.

Figure 5.4. Short Radius Guardrail (Primary Road) before Test Nos. 467114-3 through 467114-6.

5.1.2. Test Installation for Test No. 467114-7

The test installation for Test No. 467114-7 differed from that for Test Nos. 467114-3 through 467114-6 in that an extra post was added to the thrie-beam section between post 10 and the parapet, resulting in a total of 17 posts for the installation. Furthermore, a shorter blockout (14 inches versus 18 inches) was installed at posts 9, 10, and 11. The following is a summary of the changes for Test No. 467114-7 from Tests 3-4-5-6 as described above:

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 C, Sheet 3 for details. At post 10, the upstream single thrie-beam section was sandwiched between the nested double thrie-beams (as opposed to behind them in Tests Nos. 467114-3 through 467114-6), and all three layers were bolted to post 10.

Posts 9, 10, and 11 were W6×8.5 wide flange guardrail posts (PWE01), 72 inches long. The guardrail was attached to each of posts 9, 10, and 11 via a timber routed blockout (PDB01b) (6 inches × 8 inches × 14 inches tall; with a 4½-inch wide × ⅜-inch deep relief) and one ⅝-inch × 10-inch guardrail bolt (FBB03) and recessed guardrail nut. Posts 9, 10, and 11 were installed 40 inches into a drilled hole with compacted strong soil as per *MASH.* See Appendix C, 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 not attached to posts 12 and 13; however, a thrie-beam timber routed blockout (6 inches × 8 inches × 18 inches tall, with a 4½-inch wide × ⅜-inch deep relief, similar to a PDB02) was attached to each post with two ⅝-inch × 10-inch guardrail bolts (FBB03) and recessed guardrail nuts. The guardrail was attached to each of posts 14 through 17 via a thrie-beam timber routed 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*. See Appendix C, Sheets 5 and 19 for details.

Figure 5.5 and Figure 5.6 show the layout and overall details of the Short Radius Guardrail used in Test No. 467114-7, and Figure 5.7 and Figure 5.8 present photographs of the complete installation. Appendix C provides further details.

5.2. MATERIAL SPECIFICATIONS

The TxDOT Class C specified minimum unconfined compressive strength of the concrete for the parapet was 4000 psi and for the anchor post foundation was 5000 psi. The parapet was poured on July 1, 2014, and the anchor post foundation was poured on July 11, 2014. The compressive strengths of the concrete used for the parapet was 4126 psi (at 16 days age), and for the anchor post foundation measured an average of 5789 psi (at 6 days age).

ASTM A615 Grade 60 rebar with a specified minimum yield strength of 60 ksi that TTI fabricated on site comprised the reinforcement of the base and parapet. Appendix D contains mill certifications sheets and other certification documents for the materials used in the bridge deck test installation.

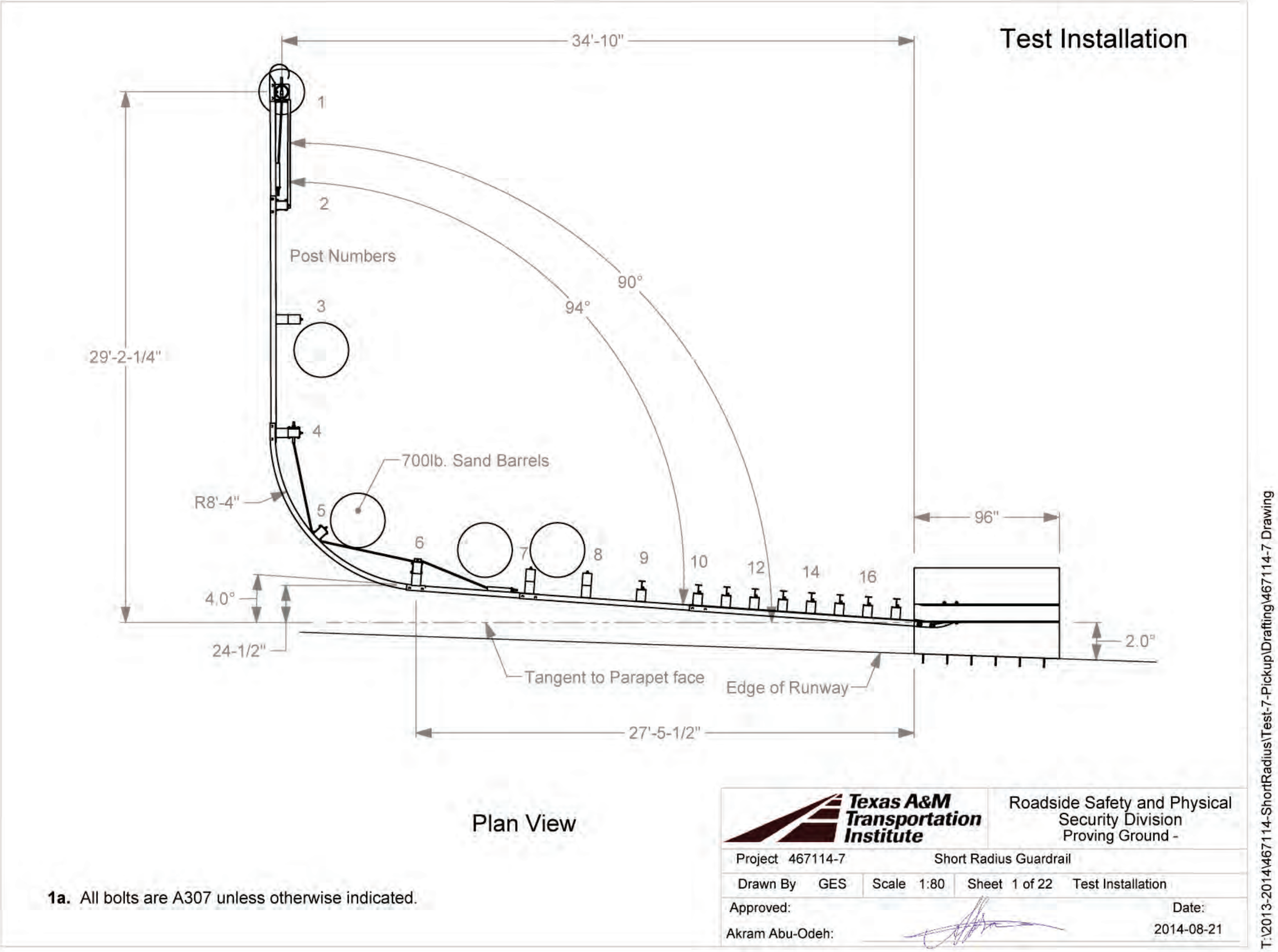


Figure 5.5. Layout of the Short Radius Guardrail for Test No. 467114-7.

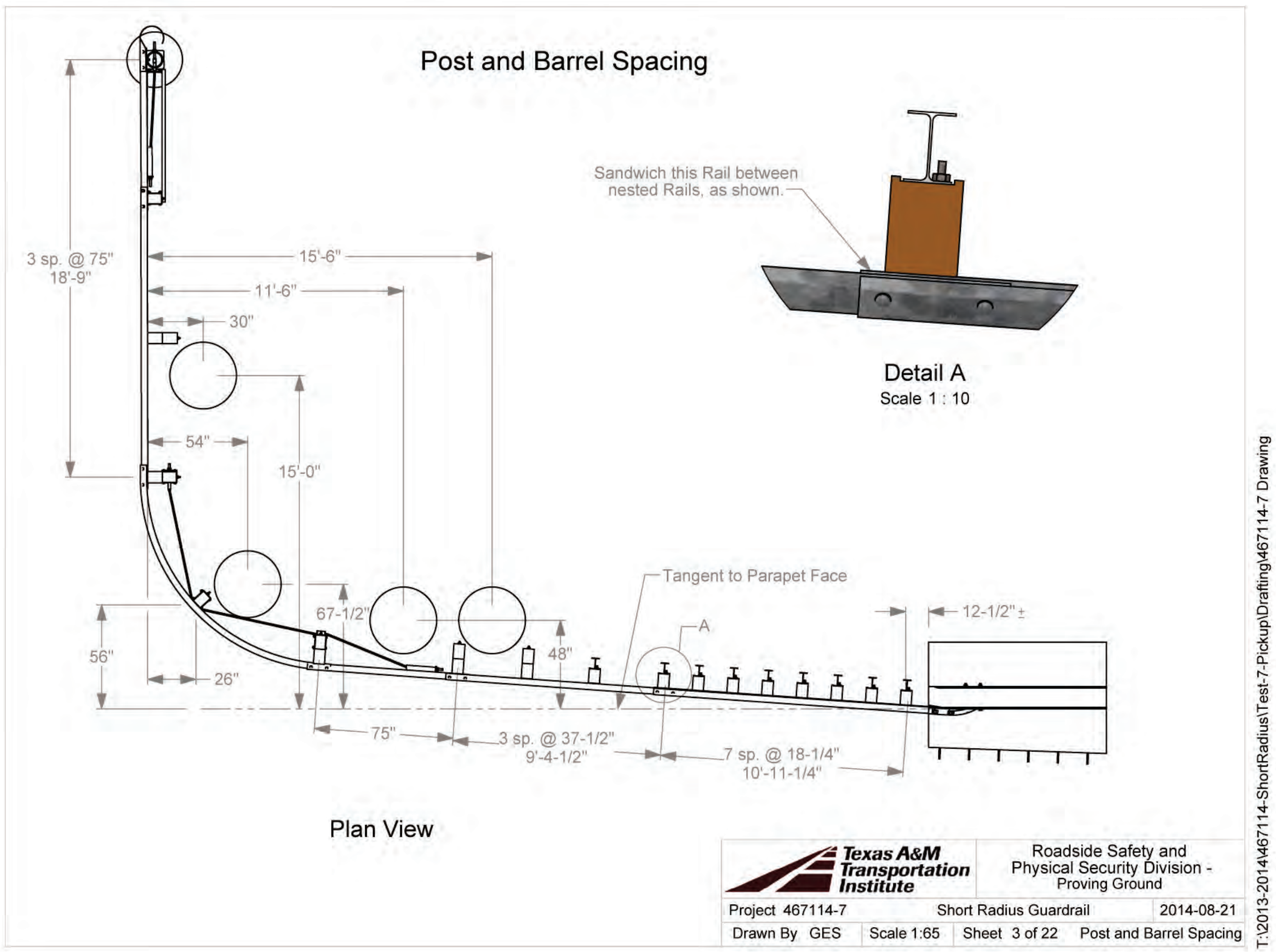


Figure 5.6. Overall Details of the Short Radius Guardrail for Test No. 467114-7.

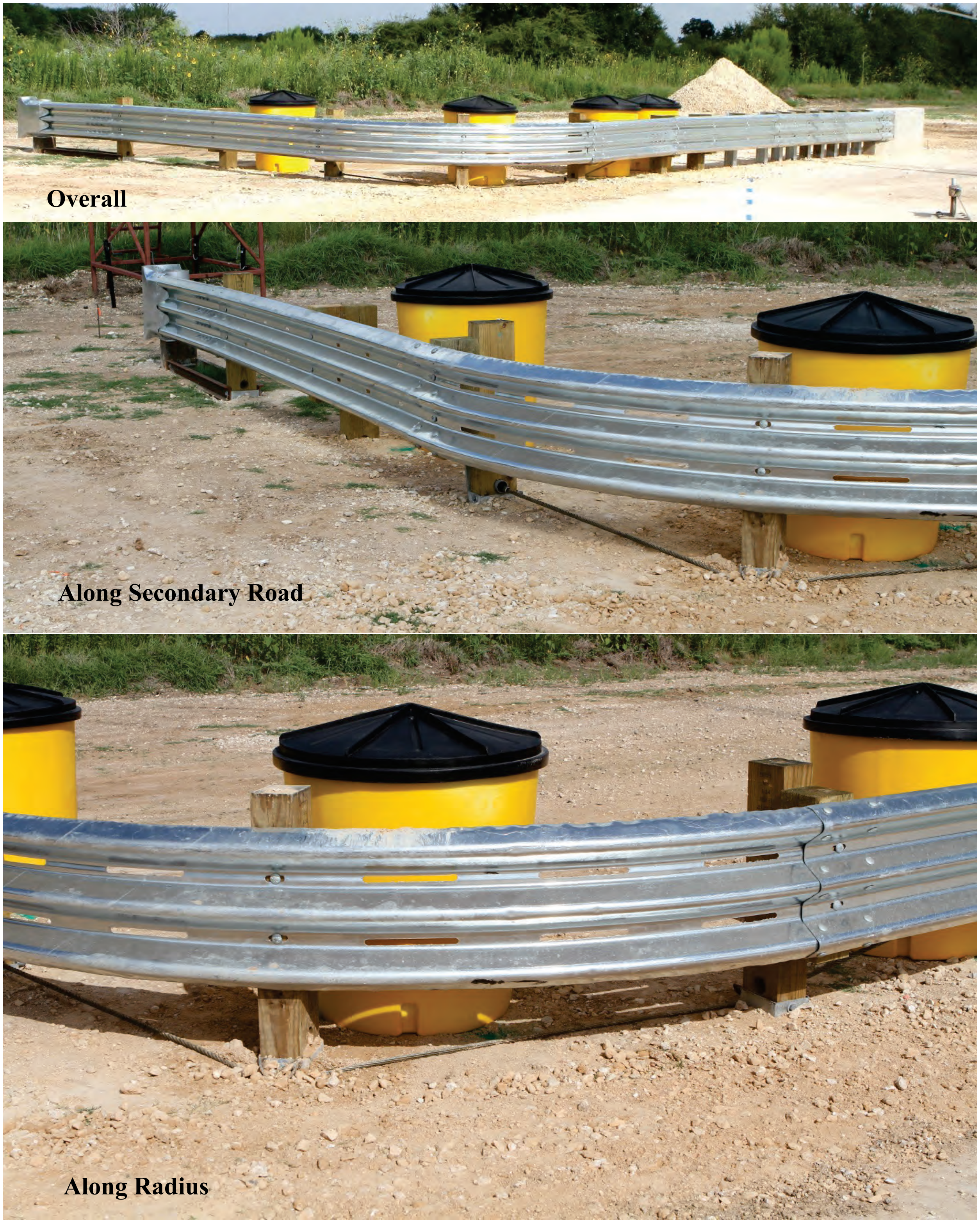


Figure 5.7. Short Radius Guardrail (Overall, Secondary Road, and Radius) prior to Test No. 467114-7.

Figure 5.8. Short Radius Guardrail (Primary Road) before Test No. 467114-7.

5.3. SOIL CONDITIONS

As stated previously, the test installation was set up in standard soil meeting AASHTO standard specifications for “Materials for Aggregate and Sol Aggregate Subbase, Base and Surface Courses,” designated M147-65(2004), grading B.

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the Short Radius Guardrail for full-scale crash testing, two standard W6×16 posts were installed in the immediate vicinity of the Short Radius Guardrail, using the same fill materials and installation procedures in the standard dynamic test.

As determined in the soil strength tests, 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. 467114-5, July 29, 2014, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 11,868 lbf; 11,616 lbf; and 11,212 lbf, respectively. On the day of Test No. 467114-6, August 6, 2014, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 7677 lbf, 7525 lbf, and 7525 lbf, respectively. On the day of Test No. 467114-7, August 22, 2014, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 7626 lbf, 7525 lbf, and 7373 lbf, respectively.

The strength of the backfill material met minimum requirements.

CHAPTER 6. CRASH TEST PROCEDURES

6.1. TEST FACILITY

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

The TTI Proving Ground is a 2000-acre complex of research and training facilities located 10 miles northwest of the main campus of Texas A&M University. The site, formerly a United States Army Air Corps base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for construction and testing of the TxDOT Short Radius Guardrail evaluated under this project was along the edge of an out-of-service apron, which consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches deep. The aprons were constructed in 1942, and the joints have some displacement but are otherwise flat and level.

6.2. VEHICLE TOW AND GUIDANCE PROCEDURES

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

6.3. DATA ACQUISITION SYSTEMS

6.3.1. Vehicle Instrumentation and Data Processing

The test vehicle was instrumented with a self-contained, onboard data acquisition system. The signal conditioning and acquisition system is a 16-channel, Tiny Data Acquisition System (TDAS) Pro that Diversified Technical Systems, Inc. produced. 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 as well as initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop at the test site. The TRAP software then processes the raw data to produce detailed reports of the test results. All TDAS Pro units are returned to the factory annually for complete recalibration. Accelerometers and rate transducers are also calibrated annually with traceability to the National Institute for Standards and Technology. Acceleration data 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 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).

6.3.2. 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 vehicle. The dummy was uninstrumented. Use of a dummy in the 2270P vehicle is optional according to *MASH*, and no dummy was used in the tests with the 2270P vehicle.

6.3.3. Photographic Instrumentation and Data Processing

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

- One overhead with a field of view perpendicular to the ground and directly over the impact point.
- One placed behind the installation at an angle.
- One placed to have a field of view parallel to and aligned with the installation at the downstream end.

A flashbulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The video from these high-speed cameras were analyzed on a computer-linked motion analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital video camera and still cameras recorded and documented conditions of the test vehicle and installation before and after the test.

CHAPTER 7. CRASH TEST RESULTS

7.1. *MASH* TEST 3-33 (CRASH TEST NO. 467114-3)

7.1.1. Test Designation and Actual Impact Conditions

MASH Test 3-33 involves a 2270P vehicle weighing 5000 lb ±110 lb and impacting the test article at an impact speed of 62.2 mph ±2.5 mph and an angle of 15°±1.5° relative to the traffic face of the concrete parapet. The target impact point was the centerline of the vehicle aligned with the nose of the radius. The 2008 Dodge Ram 1500 Quad Cab pickup truck used in the test weighed 5041 lb, and the actual impact speed and angle were 62.8 mph and 14.4°, respectively. The actual impact point was at the nose of the radius. Target impact severity (IS) was 43.0 kip-ft, and actual IS was 41.1 kip-ft (−4 percent).

7.1.2. Test Vehicle

Figure 7.1 shows the 2008 Dodge Ram 1500 Quad Cab pickup truck used for the crash test. Test inertia weight of the vehicle was 5041 lb, and its gross static weight was 5041 lb. The height to the lower edge of the vehicle bumper was 15.25 inches, and it was 26.75 inches to the upper edge of the bumper. The height to the vehicle's center of gravity was 28.38 inches. Tables E1 and E2 in Appendix E give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 7.1. Vehicle/Installation Geometrics before Test No. 467114-3.

7.1.3. Weather Conditions

The test was performed on the morning of July 17, 2014. Weather conditions at the time of testing were as follows:

- Wind speed: 6 mph.
- Wind direction: 183° with respect to the vehicle (vehicle was traveling in a northwesterly direction).
- Temperature: 81°F.
- Relative humidity: 75 percent.

7.1.4. Test Description

The 2008 Dodge Ram pickup truck, traveling at an impact speed of 62.8 mph, impacted the radius of the Short Radius Guardrail at an impact angle of 14.4° (relative to the traffic face of the parapet). At 0.024 s after impact, the front of the vehicle contacted the sand barrel in the center of the radius (barrel no. 2), and at 0.053 s, the vehicle began to yaw counterclockwise. The rail element contacted the sand barrel near post 3 (barrel no. 1) at 0.094 s, and the right front corner of the bumper contacted the sand barrel between posts 6 and 7 (barrel no. 3) at 0.109 s. At 0.110 s, the rail element began to push on barrel no. 1, and at 0.113 s, the barrel began to tear. Barrel no. 3 began to tear at 0.121 s, and the barrel then contacted the sand barrel between post 7 and 8 (barrel no. 4) at 0.161 s. At 0.240 s, barrel no. 4 began to tear open. The vehicle began to roll clockwise at 0.599 s, and reached a maximum roll of 45° at 1.242 s. Brakes on the vehicle were not applied, and the vehicle subsequently came to rest upright. Figure E1 in Appendix E show sequential photographs of the test period. Figure 7.2 shows the vehicle at rest.

Figure 7.2. Vehicle/Installation after Test No. 467114-3.

7.1.5. Damage to Test Installation

Figure 7.3 shows damage to the Short Radius Guardrail installation. Post 1 rotated approximately 50° counterclockwise. Post 2 fractured at ground line and remained attached to the rail element. Post 3 fractured at ground line, and was resting 9 ft toward the field side of the rail and aligned with post 2 initial location. The soil around post 3 had been displaced 6 inches before the post fractured. Post 4 fractured at ground line and had deflected ½-inch. Post 5 fractured at ground line and was resting 16 ft toward the field side and aligned with post 11. The bolt head partially pulled through the sleeve and the sleeve was leaning toward the field side 4°. Post 6 deflected ⅝ inch in the soil, fractured at ground line, and came to rest 25 ft toward the field side of the parapet and 6 ft downstream. Posts 7 and 8 deflected ¼ inch through the soil, fractured at ground line, and were resting 12 ft toward the field side of post 9. The rail element in front of post 8 had a partial tear. Post 9 released from the rail element and was leaning 45° downstream. A partial tear of the rail element was also noted on the radius rail at the downstream splice. All of the sand barrels were torn into several pieces.

Maximum dynamic deflection during the test was 25.0 ft toward the field side of the traffic face of the parapet (‘primary roadway’) and 22.9 ft toward the field side from the ‘secondary roadway’ side. Working width was 25.1 ft relative to the ‘primary road’ and 22.9 ft relative to the ‘secondary roadway.’ Vehicle intrusion was 25.2 ft relative to the ‘primary roadway’ and 23.4 ft relative to the ‘secondary roadway.’ Maximum permanent deformation of the rail element was 19.0 ft relative to the ‘primary roadway’ and 24.0 ft relative to the ‘secondary roadway.’

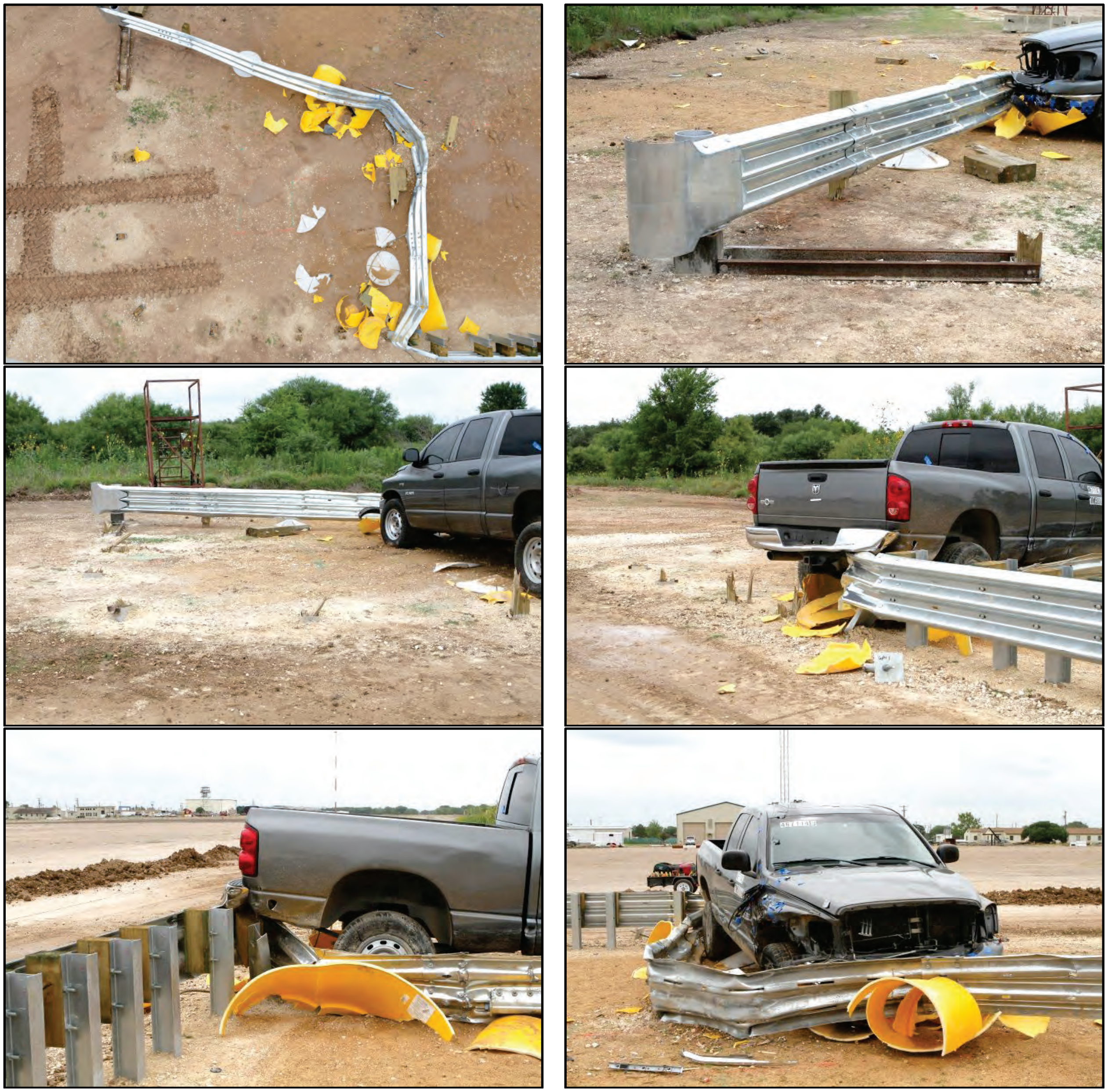


Figure 7.3. Installation after Test No. 467114-3.

7.1.6. Vehicle Damage

Figure 7.4 shows the vehicle after the test. The front bumper, radiator and support, grill, hood, right front tire and wheel rim, right front fender, right front and rear doors, right rear exterior bed, and rear bumper were damaged. Maximum exterior crush to the vehicle was

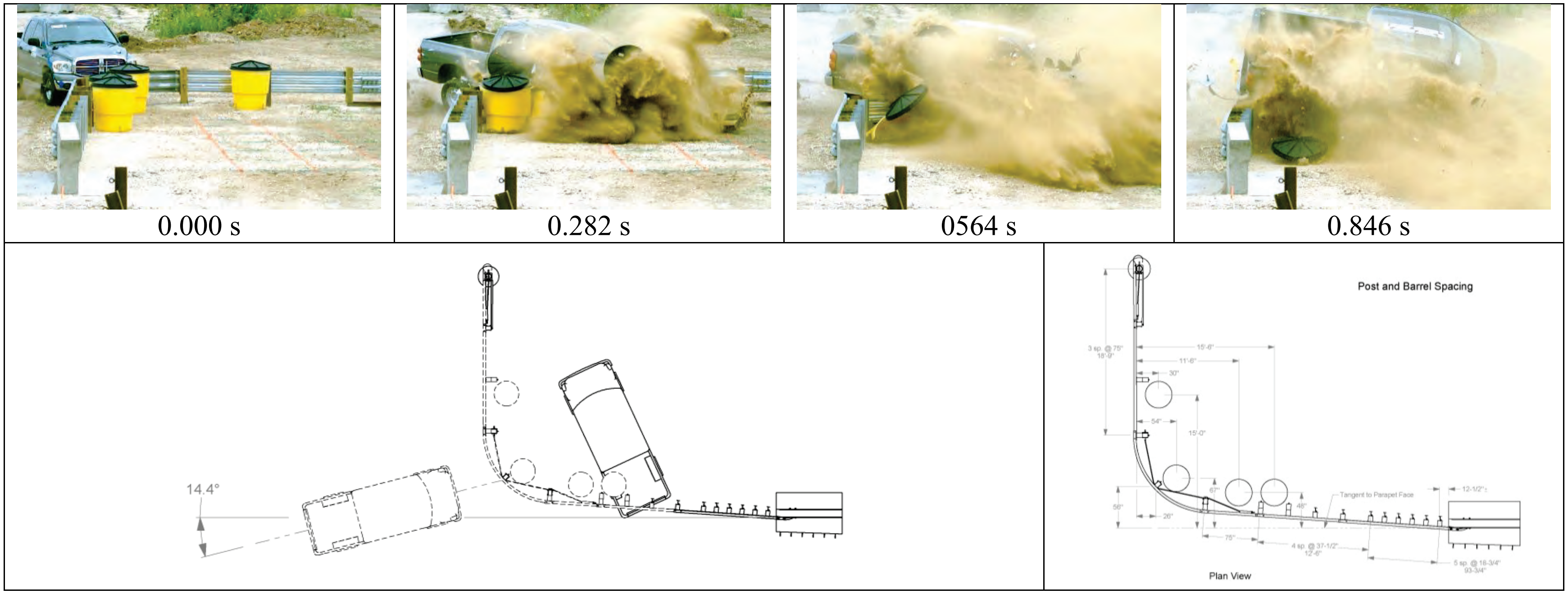
7.75 inches in the front plane at the right front corner of the bumper at bumper height. No occupant compartment deformation was noted. Figure 7.5 shows the impact region of the interior of the vehicle after the test. Exterior crush and occupant compartment measurements are provided in Tables E3 and E4 of Appendix E.

Figure 7.4. Vehicle after Test No. 467114-3.

Figure 7.5. Interior of Vehicle after Test No. 467114-3.

7.1.7. Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 28.5 ft/s at 0.129 s, the highest 0.010-s occupant ridedown acceleration was 8.2 Gs from 0.129 to 0.139 s, and the maximum 0.050-s average acceleration was −9.9 Gs between 0.016 and 0.066 s. In the lateral direction, the occupant impact velocity was 5.9 ft/s at 0.129 s, the highest 0.010-s occupant ridedown acceleration was 10.0 Gs from 0.131 to 0.141 s, and the maximum 0.050-s average was −5.3 Gs between 0.104 and 0.154 s. Theoretical Head Impact Velocity (THIV) was 32.9 km/h or 9.1 m/s at 0.130 s; Post-Impact Head Decelerations (PHD) was 12.6 Gs between 0.130 and 0.140 s; and Acceleration Severity Index (ASI) was 0.86 between 0.041 and 0.091 s. Figure 7.6 summarizes these data and other pertinent information from the test. In Appendix E, Figures E2 through E8 show the vehicle angular displacements and accelerations versus time traces.



0.000 s

0.282 s

0564 s

0.846 s

General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-33
TTI Test No.	467114-3
Test Date	2014-07-17
Test Article	
Type	Guardrail
Name	Short Radius Guardrail
Installation Length	27 ft 5½ inches x 29 ft 1¾ inches
Material or Key Elements	Thrie beam rolled to radius of 8 ft 4½ inches mounted at 31 inches flared 4.25° from parapet face
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type/Designation	2270P
Make and Model	2008 Dodge Ram 1500 pickup
Curb	4933 lb
Test Inertial	5041 lb
Dummy	No dummy
Gross Static	5041 lb

Impact Conditions	
Speed	62.8 mph
Angle	14.4°
Location/Orientation	Center of radius
Impact Severity	−4 percent
Exit Conditions	
Speed	Stopped
Angle	NA
Occupant Risk Values	
Longitudinal OIV	28.5 ft/s
Lateral OIV	5.9 ft/s
Longitudinal Ridedown	8.2 G
Lateral Ridedown	10.0 G
THIV	32.9 km/h
PHD	12.6 G
ASI	0.86
Max. 0.050-s Average	
Longitudinal	−9.9 G
Lateral	−5.3 G
Vertical	−2.5 G

Post-Impact Trajectory	
Stopping Distance	23.2 ft / 25.1 ft.
Vehicle Stability	
Maximum Yaw Angle	76°
Maximum Pitch Angle	10°
Maximum Roll Angle	45°
Vehicle Snagging	No
Vehicle Pocketing	Yes
Test Article Deflections	
Dynamic	25.0 ft / 22.9 ft
Permanent	19.0 ft / 24.0 ft
Working Width	25.1 ft / 22.9 ft
Vehicle Intrusion	25.2 ft / 23.4 ft
Vehicle Damage	
VDS	01RFQ3
CDC	01RFEW3
Max. Exterior Deformation	7.75 inches
OCDI	FS0000000
Max. Occupant Compartment Deformation	None

Figure 7.6. Summary of Results for *MASH* Test 3-33 on the Short Radius Guardrail.

7.1.8. Assessment of Test Results

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

7.1.8.1. Structural Adequacy

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

<u>Results</u>: The Short Radius Guardrail brought the 2270P vehicle to a controlled stop. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 25.0 ft relative to the "primary roadway" and 22.9 ft relative to the "secondary roadway." (PASS)

7.1.8.2. Occupant Risk

D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.
Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 inches).

<u>Results</u>: Some of the posts fractured and separated from the rail, and these and all other debris remained adjacent to the installation. These items did not penetrate, or show potential for penetrating the occupant compartment. The post and other debris traveled relatively close to the ground and remained near the installation, and thereby did not present undue hazard to others in the area. (PASS)
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°.

<u>Results</u>: The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 45° and 10°, respectively. (PASS)

H. Occupant impact velocities should satisfy the following:

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
30 ft/s	*40 ft/s*

Results: Longitudinal occupant impact velocity was 28.5 ft/s, and lateral occupant impact velocity was 5.9 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Maximum longitudinal occupant ridedown acceleration was 8.2 G, and maximum lateral occupant ridedown acceleration was 10.0 G. (PASS)

7.1.8.3. Vehicle Trajectory

For redirective devices, it is desirable that the vehicle be smoothly redirected and exit the barrier within the "exit box" criteria (not less than 32.8 ft), and should be documented. Vehicle rebound distance and velocity should be reported for crash cushions.

Result: The vehicle did not exit the installation. No significant rebound occurred.

7.2. *MASH* TEST 3-32 (CRASH TEST NO. 467114-4)

7.2.1. Test Designation and Actual Impact Conditions

MASH Test 3-32 involves an 1100C vehicle weighing 2420 lb ±55 lb and impacting the test article at an impact speed of 62.2 mph ±2.5 mph and an angle of 15° ±1.5° relative to the traffic face of the concrete parapet. The target impact point was the centerline of the vehicle aligned with the nose of the radius. The 2009 Kia Rio used in the test weighed 2424 lb, and the actual impact speed and angle were 62.1 mph and 14.8°, respectively. The actual impact point was at the nose of the radius. Target IS was 21.0 kip-ft, and actual IS was 20.4 kip-ft (−3 percent).

7.2.2. Test Vehicle

Figure 7.7 shows the 2009 Kia Rio that was used for the crash test. Test inertia weight of the vehicle was 2424 lb, and its gross static weight was 2589 lb. The height to the lower edge of the vehicle bumper was 8.5 inches, and it was 21.5 inches to the upper edge of the bumper. Tables F1 and F2 in Appendix F give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

7.2.3. Weather Conditions

The test was performed on the morning of July 23, 2014. Weather conditions at the time of testing were as follows:

- Wind speed: 3 mph.
- Wind direction: 63° with respect to the vehicle (vehicle was traveling in a northwesterly direction).
- Temperature: 86°F.
- Relative humidity: 71 percent.

Figure 7.7. Vehicle/Installation Geometrics before Test No. 467114-4.

7.2.4. Test Description

The 2009 Kia Rio, traveling at an impact speed of 62.1 mph, impacted the center of the radius of the Short Radius Guardrail at an impact angle of 14.8° (relative to the traffic face of the parapet). At approximately 0.024 s after impact, the vehicle began to yaw counterclockwise, and at 0.034 s, the front of the vehicle contacted the barrel in the center (barrel no. 2) of the radius near post 5. The rail element contacted the side of barrel at post 3 (barrel no. 1) at 0.106 s, and the barrel began to move toward the field side at 0.127 s. At 0.189 s, the rail element contacted the barrel between post 6 and 7 (barrel no. 3), and at 0.230 s, the barrel began to move toward the field side. The side of barrel no. 3 contacted the barrel between posts 7 and 8 (barrel no. 4) at 0.276 s, and the blockout at post 7 contacted barrel no. 4 at 0.366 s. At 0.445 s, barrel no. 4 began to rotate clockwise and move toward the field side, and at 0.495 s, the rear of the vehicle contacted the rail element. Brakes on the vehicle were not applied, and the vehicle came to rest 14.0 ft toward the field side of the parapet (‘primary roadway’) and 14.6 ft toward the field side relative to the traffic face of the rail on the ‘secondary roadway’ side. Figures F1 and F2 in Appendix F show sequential photographs of the test period. Figure 7.8 shows the vehicle at final rest.

Figure 7.8. Vehicle/Installation after Test No. 467114-4.

7.2.5. Damage to Test Installation

Figure 7.9 shows the damage to the Short Radius Guardrail. The anchor plate between post 1 and 2 was pulled downstream 0.12 inch, and post 2 deflected through the soil 2.5 inches. Post 3 fractured at ground line and remained in place, but separated from the rail element. Post 4 fractured at ground line and was resting 32 ft toward the field side. Post 5 and 6 fractured at ground line and were resting at the left front tire and right front tire of the vehicle, respectively. Post 7 fractured at ground line and was resting 31 inches toward the field side. Post 8 displaced 0.25 inch toward the field side. Posts 9 and 10 were disturbed, and no movement was noted at the remaining posts.

Maximum dynamic deflection during the test was 16.3 ft toward the field side of the traffic face of the parapet (‘primary roadway’) and 16.4 ft toward the field side from the ‘secondary road’ side. Working width was 16.3 ft relative to the ‘primary roadway’ and 16.4 ft relative to the ‘secondary road.’ Vehicle intrusion was 15.8 ft relative to the ‘primary roadway’ and 16.1 ft relative to the ‘secondary roadway.’ Maximum permanent deformation of the rail element was 14.1 ft relative to the ‘primary roadway’ and 14.5 ft relative to the ‘secondary roadway.’

7.2.6. Vehicle Damage

Figure 7.10 shows damage sustained by the vehicle. The front bumper, grill, radiator and support, hood, right and left front fenders, and right and left front doors were deformed. The windshield sustained stress fractures. Maximum exterior crush to the vehicle was 10.0 inches in the front plane just left of center front of the vehicle at bumper height. Maximum occupant compartment deformation was 0.5 inch in the right side front passenger door at hip height. Figure 7.11 shows the interior of the vehicle after the test. Exterior crush measurements and occupant compartment deformation are provided in Tables F2 and F3 in Appendix F.

7.2.7. Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 36.4 ft/s at 0.105 s, the highest 0.010-s occupant ridedown acceleration was 12.0 Gs from 0.108

to 0.118 s, and the maximum 0.050-s average acceleration was −13.5 Gs between 0.026 and 0.076 s. In the lateral direction, the occupant impact velocity was 3.6 ft/s at 0.105 s, the highest 0.010-s occupant ridedown acceleration was 6.2 Gs from 0.131 to 0.141 s, and the maximum 0.050-s average was −3.5 Gs between 0.091 and 0.141 s. THIV was 40.6 km/h or 11.3 m/s at 0.105 s; PHD was 13.0 Gs between 0.108 and 0.118 s; and ASI was 1.11 between 0.050 and 0.100 s. Figure 7.12 summarizes these data and other pertinent information from the test. In Appendix F, Figures F3 through F9 show the vehicle angular displacements and accelerations versus time traces.

Figure 7.9. Installation after Test No. 467114-4.

Figure 7.10. Vehicle after Test No. 467114-4.

Figure 7.11. Interior of Vehicle after Test No. 467114-4.

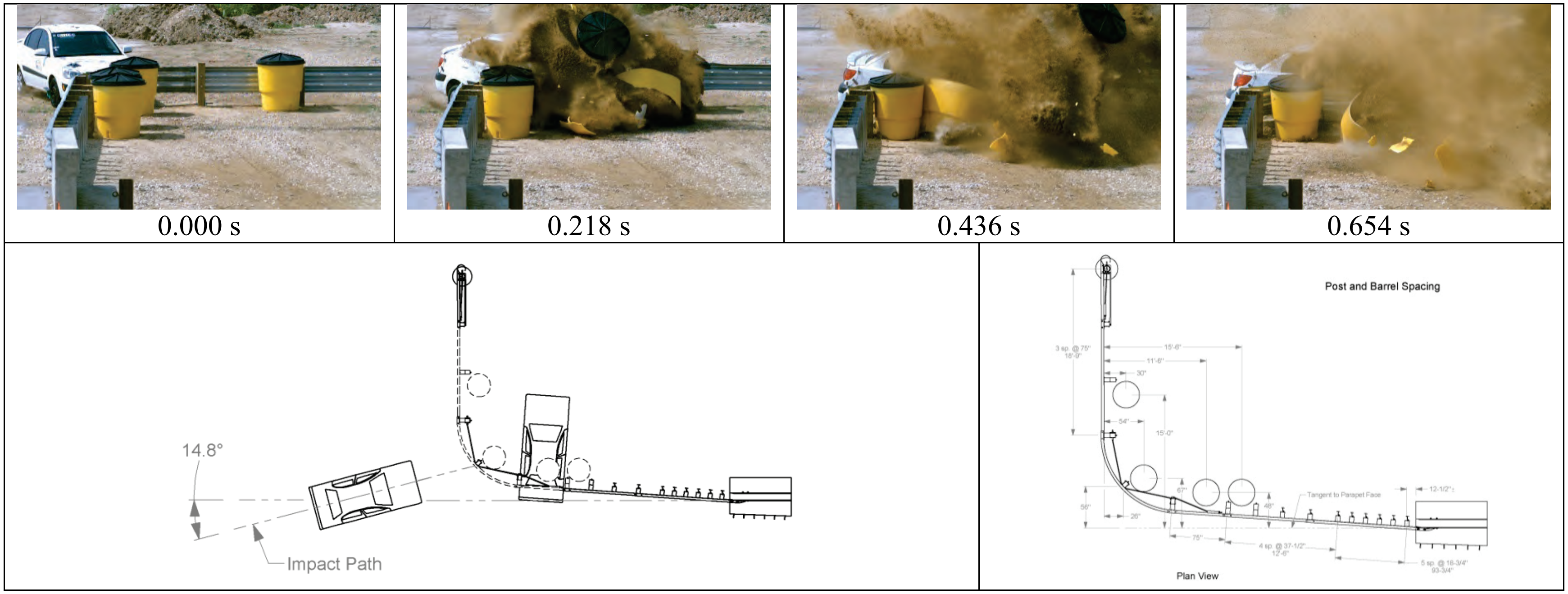
7.2.8. Assessment of Test Results

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

7.2.8.1. Structural Adequacy

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

Results: The Short Radius Guardrail contained the 1100C vehicle and brought it to a controlled stop. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the rail element during the test was 16.3 ft relative to the "primary roadway" and 16.4 ft relative to the "secondary roadway." (PASS)



General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-32
TTI Test No.	467114-4
Test Date	2014-07-23
Test Article	
Type	Guardrail
Name	Short Radius Guardrail
Installation Length	27 ft 5½ inches x 29 ft 1¾ inches
Material or Key Elements	Thrie beam rolled to radius of 8 ft 4½ inches mounted at 31 inches flared 4.25° from parapet face
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type/Designation	1100C
Make and Model	2009 Kia Rio
Curb	2447 lb
Test Inertial	2424 lb
Dummy	165 lb
Gross Static	2589 lb

Impact Conditions	
Speed	62.1 mph
Angle	14.8°
Location/Orientation	Center of Radius
Impact Severity	20.4 kip-ft (-3%)
Exit Conditions	
Speed	Stopped
Angle	NA
Occupant Risk Values	
Longitudinal OIV	36.4 ft/s
Lateral OIV	3.6 ft/s
Longitudinal Ridedown	12.0 G
Lateral Ridedown	6.2 G
THIV	40.6 km/h
PHD	13.0 G
ASI	1.11
Max. 0.050-s Average	
Longitudinal	−13.5 G
Lateral	−3.5 G
Vertical	−1.2 G

Post-Impact Trajectory	
Stopping Distance	14.0 ft primary 14.6 ft secondary
Vehicle Stability	
Maximum Yaw Angle	68°
Maximum Pitch Angle	11°
Maximum Roll Angle	6°
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	16.3 ft / 16.4 ft
Permanent	14.1 ft / 14.5 ft
Working Width	16.3 ft / 16.3 ft
Vehicle Intrusion	15.8 ft / 16.1 ft
Vehicle Damage	
VDS	12FD4
CDC	12FDEW3
Max. Exterior Deformation	10.0 inches
OCDI	RF0000100
Max. Occupant Compartment Deformation	0.5 inch

Figure 7.12. Summary of Results for *MASH* Test 3-32 on the Short Radius Guardrail.

7.2.8.2. *Occupant Risk*

D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.
Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 inches).

Results: All debris remained adjacent to the installation area and did not penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. (PASS)
Maximum occupant compartment deformation was 0.5 inches in the right front passenger area at hip height. (PASS)

F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75°.

Results: The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 6° and 11°, respectively. (PASS)

H. Occupant impact velocities should satisfy the following:

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
30 ft/s	*40 ft/s*

Results: Longitudinal occupant impact velocity was 36.4 ft/s, and lateral occupant impact velocity was 3.6 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Maximum longitudinal occupant ridedown acceleration was 12.0 G, and maximum lateral occupant ridedown acceleration was 6.2 G. (PASS)

7.2.8.3. *Vehicle Trajectory*

For redirective devices, it is desirable that the vehicle be smoothly redirected and exit the barrier within the "exit box" criteria (not less than 32.8 ft), and should be documented. Vehicle rebound distance and velocity should be reported for crash cushions.

Result: The vehicle did not exit the installation. No significant rebound was noted.

7.3. *MASH* TEST 3-31 (CRASH TEST NO. 467114-5)

7.3.1. Test Designation and Actual Impact Conditions

MASH Test 3-31 involves a 2270P vehicle weighing 5000 lb ±110 lb and impacting the test article at an impact speed of 62.2 mph ±2.5 mph and an angle of 0° ±1.5° relative to the traffic face of the concrete parapet. The target impact point was the centerline of the truck aligned with the traffic face of the parapet. The 2008 Dodge Ram 1500 Quad Cab pickup truck used in the test weighed 5023 lb and the actual impact speed and angle were 63.5 mph and 0.2°, respectively. The actual impact point was at the nose of the radius.

7.3.2. Test Vehicle

Figure 7.13 shows a 2008 Dodge Ram 1500 pickup that was used for the crash test. Test inertia weight of the vehicle was 5023 lb, and its gross static weight was 5023 lb. The height to the lower edge of the vehicle bumper was 16.0 inches, and it was 27.0 inches to the upper edge of the bumper. The height to the vehicle's center of gravity was 28.9 inches. Tables G1 and G2 in Appendix G give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 7.13. Vehicle/Installation Geometrics before Test No. 467114-5.

7.3.3. Weather Conditions

The test was performed on the morning of July 29, 2014. Weather conditions at the time of testing were as follows:

- Wind speed: 3 mph.
- Wind direction: 96° with respect to the vehicle (vehicle was traveling in a northerly direction).
- Temperature: 84°F.
- Relative humidity: 69 percent.

7.3.4. Test Description

The 2008 Dodge Ram 1500 pickup, traveling at an impact speed of 63.5 mph, contacted the guardrail 39.7 inches upstream of post 6 at an impact angle of 0° relative to the face of the concrete parapet. At approximately 0.026 s after impact, the vehicle began to yaw clockwise, and at 0.043 s, the left front bumper contacted post 6. The left front tire contacted post 6 at 0.054 s, and the rear of the guardrail contacted barrel 2 at 0.058 s. At 0.067 s, the rear of the guardrail contacted barrel 3, and at 0.069 s, the left front tire snagged on post 6 and blew out. The left front bumper of the vehicle contacted barrel 3 at 0.077 s, and post 7 began to deflect toward the field side at 0.104 s. The left front bumper contacted post 7, 8, and 9 at 0.111 s, 0.152 s, and 0.185 s, respectively. At 0.282 s, the left rear tire snagged on post 7 and blew out; at 0.293 s, the rear of the vehicle contacted the guardrail. The vehicle lost contact with the guardrail at 0.366 s, and was traveling at an exit speed and angle of 54.8 mph and 7.8°. Brakes on the vehicle were applied at 2.1 s after impact, and the vehicle subsequently came to rest 42 ft downstream of impact and 32 ft toward traffic lanes. Figures G1 and G2 in Appendix G show sequential photographs of the test period. Figure 7.14 shows the vehicle at final rest.

Figure 7.14. Vehicle/Installation after Test No. 467114-5.

7.3.5. Damage to Test Installation

Figure 7.15 shows damage to the installation. Post 4 was leaning upstream 6°. Posts 5 and 6 fractured at ground level and were leaning upstream 12°, and toward the field side 8° and 12°, respectively. Posts 7 and 8 fractured below ground level and were leaning toward field side 13° and 5°, respectively. Post 7 had displaced through the soil by 0.75 inch and post 8 by 0.5 inch. The soil around post 9 was disturbed. A small amount of orange paint from post 6 was found on the left front tire, which separated from the vehicle and was resting 90 ft downstream of impact and 40 ft toward traffic lanes. Total length of contact with the rail element on the 'primary roadway' was 20.25 ft. Maximum dynamic deflection of the rail element during the test was 34.1 inches, and maximum permanent deformation of the rail element was 15.0 inches. Maximum working width was 36.0 inches, and maximum vehicle intrusion was 16.0 inches.

Figure 7.15. Installation after Test No. 467114-5.

7.3.6. Vehicle Damage

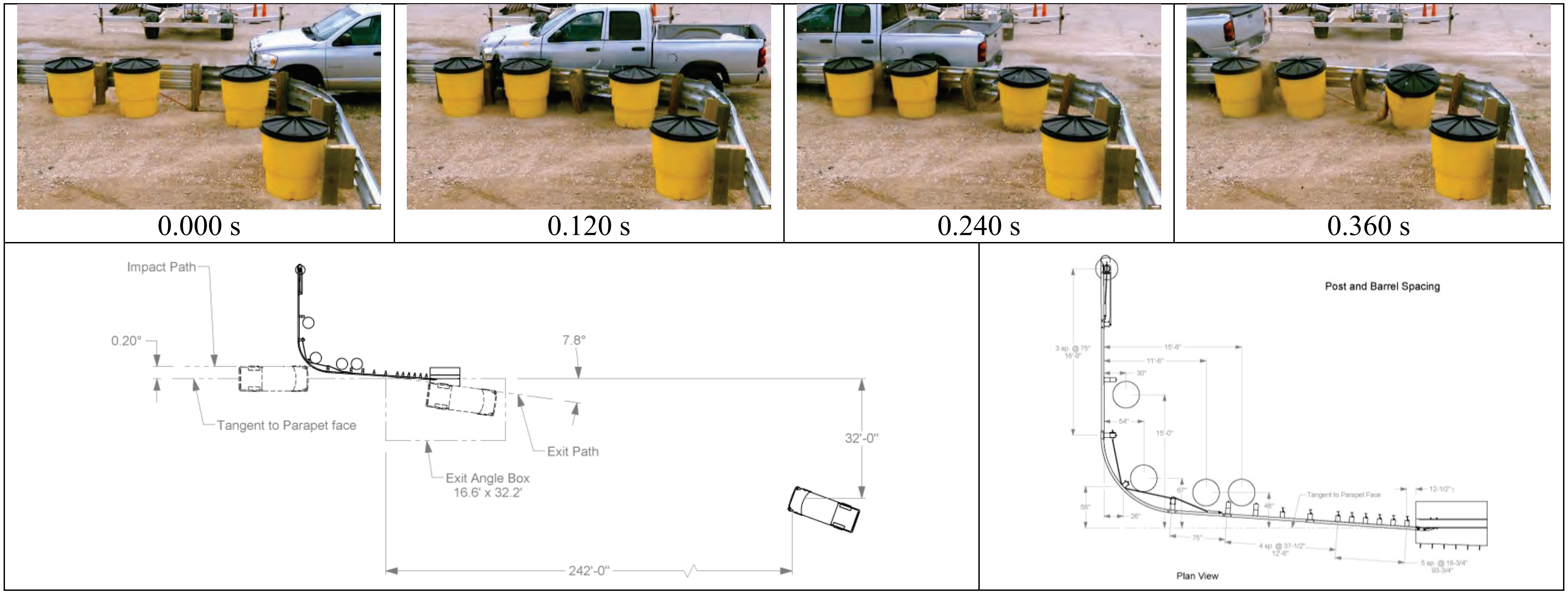
Figure 7.16 shows damage to the vehicle. The left front upper and lower ball joints, left upper and lower A-arms, left tie rod end, left frame rail, left rear U-bolts, and drive shaft were damaged. Also damaged were the front bumper, left front fender, left front and rear doors, left rear exterior bed, left front tire and wheel rim, and left rear tire and wheel rim. Maximum exterior crush to the vehicle was 9.0 inches in the side plane at the left front corner at bumper height. Maximum occupant compartment deformation was 0.5 inch in the left kick panel area near the driver's feet. Figure 7.17 shows the interior damage to the vehicle.

Figure 7.16. Vehicle after Test No. 467114-5.

Figure 7.17. Interior of Vehicle after Test No. 467114-5.

7.3.7. Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 9.2 ft/s at 0.186 s, the highest 0.010-s occupant ridedown acceleration was 5.4 Gs from 0.306 to 0.316 s, and the maximum 0.050-s average acceleration was −3.1 Gs between 0.026 and 0.056 s. In the lateral direction, the occupant impact velocity was 10.5 ft/s at 0.186 s, the highest 0.010-s occupant ridedown acceleration was 4.5 Gs from 0.204 to 0.214 s, and the maximum 0.050-s average was 3.0 Gs between 0.040 and 0.090 s. THIV was 15.0 km/h or 4.2 m/s at 0.179 s; PHD was 6.5 Gs between 0.301 and 0.311 s; and ASI was 0.37 between 0.040 and 0.090 s. Figure 7.18 summarizes these data and other pertinent information from the test. In Appendix G, Figures G3 through G9 show the vehicle angular displacements and accelerations versus time traces.



General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-31
TTI Test No.	467114-5
Test Date	2014-07-29
Test Article	
Type	Guardrail
Name	Short Radius Guardrail
Installation Length	27 ft 5½ inches x 29 ft 1¾ inches
Material or Key Elements	Thrie beam rolled to radius of 8 ft 4½ inches mounted at 31 inches flared 4.25° from parapet face
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type/Designation	2270P
Make and Model	2008 Dodge Ram 1500 Pickup
Curb	4833 lb
Test Inertial	5023 lb
Dummy	No dummy
Gross Static	5023 lb

Impact Conditions	
Speed	63.5 mph
Angle	0.2°
Location/Orientation	Nose of radius
Exit Conditions	
Speed	54.8 mph
Angle	7.8°
Occupant Risk Values	
Longitudinal OIV	9.2 ft/s
Lateral OIV	10.5 ft/s
Longitudinal Ridedown	5.4 G
Lateral Ridedown	4.5 G
THIV	15.0 km/h
PHD	6.5 G
ASI	0.37
Max. 0.050-s Average	
Longitudinal	−3.1 G
Lateral	3.0 G
Vertical	−2.2 G

Post-Impact Trajectory	
Stopping Distance	42 ft dwnstrm 32 ft twd traffic
Vehicle Stability	
Maximum Yaw Angle	82°
Maximum Pitch Angle	12°
Maximum Roll Angle	13°
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	34.1 inches
Permanent	15.0 inches
Working Width	35.9 inches
Vehicle Intrusion	16.0 inches
Vehicle Damage	
VDS	11LFQ3
CDC	11FLEW4
Max. Exterior Deformation	9.0 inches
OCDI	LF0000000
Max. Occupant Compartment Deformation	0.5 inch

Figure 7.18. Summary of Results for *MASH* Test 3-31 on the Short Radius Guardrail.

7.3.8. Assessment of Test Results

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

7.3.8.1. *Structural Adequacy*

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

Results: The Short Radius Guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 34.1 inches. (PASS)

7.3.8.2. *Occupant Risk*

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

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

Results: Several posts fractured, but remained attached to the rail element. No other detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. (PASS)

Maximum occupant compartment deformation was 0.5 inch in the left front kick panel are near the driver's feet. (PASS)

F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75°.*

Results: The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 13° and 12°, respectively. (PASS)

H. *Occupant impact velocities should satisfy the following:*

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
30 ft/s	*40 ft/s*

Results: Longitudinal occupant impact velocity was 9.2 ft/s, and lateral occupant impact velocity was 10.5 ft/s. (PASS)

I. *Occupant ridedown accelerations should satisfy the following:*

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Maximum longitudinal occupant ridedown acceleration was −5.4 G, and maximum lateral occupant ridedown acceleration was 4.5 G. (PASS)

7.3.8.3. Vehicle Trajectory

For redirective devices, it is desirable that the vehicle be smoothly redirected and exit the barrier within the "exit box" criteria (not less than 32.8 ft), and should be documented. Vehicle rebound distance and velocity should be reported for crash cushions.

Result: The 2270P vehicle exited within the exit box criteria.

7.4. *MASH* TEST 3-35 (CRASH TEST NO. 467114-6)

7.4.1. Test Designation and Actual Impact Conditions

MASH Test 3-35 involves a 2270P vehicle weighing 5000 lb ±110 lb and impacting the test article at an impact speed of 62.2 mph ±2.5 mph and an angle of 25° ±1.5° relative to the traffic face of the concrete parapet. The target impact point was post 9. The 2008 Dodge Ram 1500 Quad Cab pickup truck used in the test weighed 5016 lb, and the actual impact speed and angle were 62.6 mph and 25.1°, respectively. The actual impact point was at post 9. Target impact severity (IS) was 115.1 kip-ft, and actual IS was 118.2 kip-ft (+3 percent).

7.4.2. Test Vehicle

Figure 7.19 shows the 2008 Dodge Ram 1500 pickup that was used for the crash test. Test inertia weight of the vehicle was 5016 lb, and its gross static weight was 5016 lb. The height to the lower edge of the vehicle bumper was 15.5 inches, and it was 27.0 inches to the upper edge of the bumper. The height to the vehicle's center of gravity was 28.88 inches. Tables H1 and H2 in Appendix H give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

7.4.3. Weather Conditions

The test was performed on the morning of August 6, 2014. Weather conditions at the time of testing were as follows:

- Wind speed: 6 mph.
- Wind direction: 217° with respect to the vehicle (vehicle was traveling in a northwesterly direction).
- Temperature: 83°F.
- Relative humidity: 71 percent.

Figure 7.19. Vehicle/Installation Geometrics before Test No. 467114-6.

7.4.4. Test Description

The 2008 Dodge Ram 1500 pickup, traveling at an impact speed of 62.6 mph, contacted the Short Radius Guardrail 12 inches upstream of post 9 at an impact angle of 25.1°. At approximately 0.016 s after impact, posts 9 and 10 began to deflect toward the field side; at 0.023 s, the vehicle began to redirect and post 11 began to deflect toward the field side. Post 12 through post 14 began to deflect toward the field side at 0.029 s, and the left front corner of the bumper contacted post 10 at 0.033 s. The bumper reached posts 11 and post 12 at 0.062 s and 0.075 s, respectively. At 0.091 s, the rail element began to buckle at the upstream side of post 15, and the bumper reached post 13 at 0.095 s. At 0.115 s, post 15 began to deflect toward the field side and the bumper reached post 14. The bumper reached post 14 and post 15 at 0.146 s and 0.170 s, respectively. At 0.187 s, the left front corner of the bumper reached the upstream end of the concrete parapet; at 0.194 s, the vehicle was traveling parallel with the parapet. The rear of the vehicle contacted the rail 0.211 s. At 0.410 s, the vehicle began to roll clockwise, rolled three complete revolutions, and came to rest upright 145 ft downstream of impact and 85 ft toward traffic lanes. Figures H1 and H2 in Appendix H show sequential photographs of the test period. Figure 7.20 shows the vehicle at final rest relative to the Short Radius Guardrail.

Figure 7.20. Vehicle/Installation after Test No. 467114-6.

7.4.5. Damage to Test Installation

Figure 7.21 shows damage to the Short Radius Guardrail. Post 7 was pulled downstream 0.25 inch and displaced through the soil toward the field side 0.12 inch. Post 8 was pulled downstream 0.25 inch and displaced through the soil toward the field side 0.5 inch. Post 9 was leaning toward field side 7° and displaced through the soil toward the field side 0.5 inch. Posts 10 through 14 rotated 45° clockwise, leaning downstream 25°, and the top guardrail bolt pulled through the rail element. Post 15 rotated 20° clockwise and leaned downstream 10°. Post 16 was displaced through the soil 0.12 inch toward the field side. Total length of contact of the vehicle with the guardrail was 15 ft. Maximum dynamic deflection during the test was 21.1inches, and maximum permanent deformation was 16.25 inches. Working width was 24.1 inches, and vehicle intrusion was 29.6 inches.

7.4.6. Vehicle Damage

Figure 7.22 shows damage to the vehicle. The front bumper, radiator and support, hood, grill, left front fender, left front tire and wheel rim, left upper and lower ball joints, left rear door, left rear exterior bed, and rear bumper were damaged in the impact with the Short Radius Guardrail. The remaining damage was sustained in the rollover. Maximum exterior crush to the vehicle was 24.0 inches at the left front corner at bumper height. Maximum occupant compartment deformation related to the impact with the Short Radius Guardrail was 3.25 inches in the lateral area across the cab in the driver side kickpanel area. Maximum occupant compartment deformation related to the rollover was 9.5 inches in the floor to roof area in the left rear occupant compartment. Table H3 and Table H4 in Appendix H present the vehicle exterior crush and occupant compartment deformation measurements, respectively.

7.4.7. Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 25.3 ft/s at 0.114 s, the highest 0.010-s occupant ridedown acceleration was 10.8 Gs from 0.142 to 0.152 s, and the maximum 0.050-s average acceleration was −9.8 Gs between 0.079 and 0.129 s. In the lateral direction, the occupant impact velocity was 23.3 ft/s at 0.114 s, the highest 0.010-s occupant ridedown acceleration was 10.0 Gs from 0.142 to 0.152 s, and the maximum 0.050-s average was 9.3 Gs between 0.081 and 0.131 s. THIV was 36.2 km/h or 10.0 m/s at 0.110 s; PHD was 14.7 Gs between 0.142 and 0.152 s; and ASI was 1.28 between 0.086 and 0.136 s. Figure 7.23 summarizes these data and other pertinent information from the test. In Appendix H, Figures H3 through H8 show the vehicle angular displacements and accelerations versus time traces.

Figure 7.21. Installation after Test No. 467114-6.

Figure 7.22. Vehicle after Test No. 467114-6.

7.4.8. Assessment of Test Results

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

7.4.8.1. Structural Adequacy

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

Results: The Short Radius Guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the guardrail was 21.1 inches. (PASS)

7.4.8.2. Occupant Risk

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

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

Results: No detached elements, fragments, or other debris was present to penetrate or to show penetration of the occupant compartment, or to show hazard to others in the area. (PASS)

Maximum occupant compartment deformation related to the impact with the Short Radius Guardrail was 3.25 inches in the lateral area across the cab in the driver side kickpanel area. Maximum occupant compartment deformation related to the rollover was 9.5 inches in the floor to roof area in the left rear occupant compartment. (FAIL)

F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75°.*

Results: The 2270P vehicle rolled three revolutions after exiting the installation. (FAIL)

H. *Occupant impact velocities should satisfy the following:*

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
30 ft/s	*40 ft/s*

Results: Longitudinal occupant impact velocity was 25.3 ft/s, and lateral occupant impact velocity was 23.3 ft/s. (PASS)

I. *Occupant ridedown accelerations should satisfy the following:*

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Maximum longitudinal occupant ridedown acceleration was 10.8 G, and maximum lateral occupant ridedown acceleration as 10.0 G. (PASS)

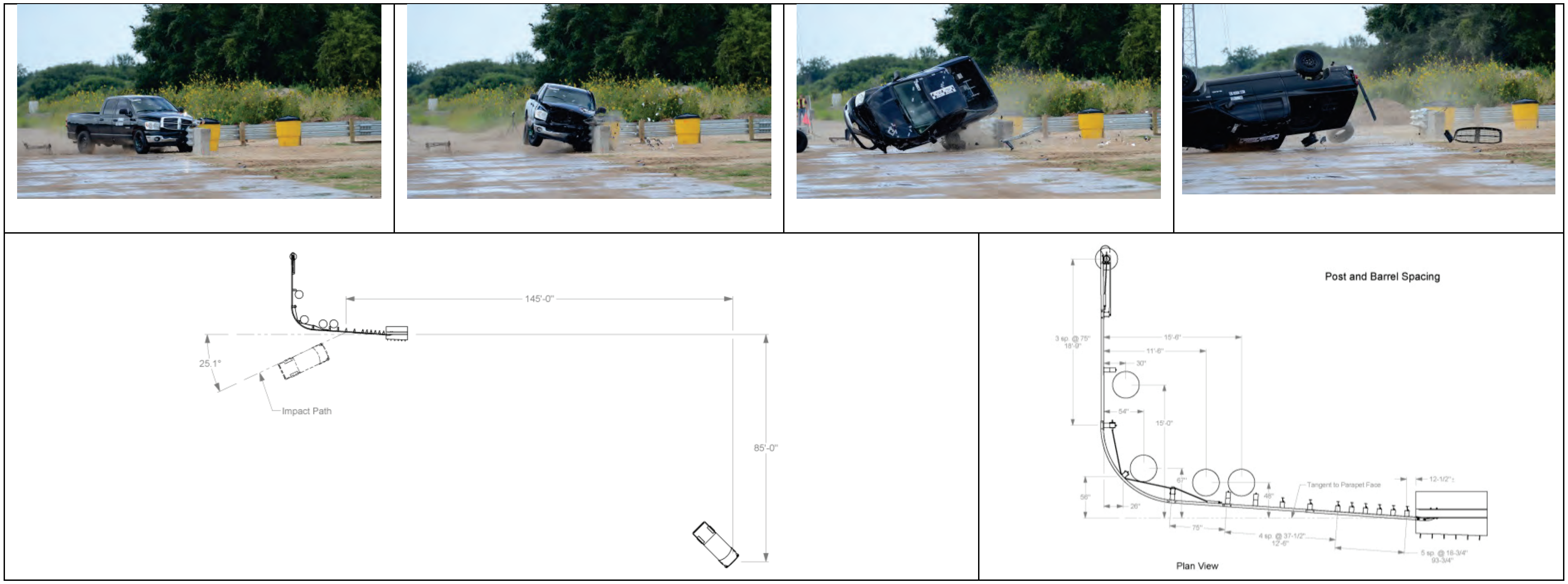
7.4.8.3. Vehicle Trajectory

For redirective devices, it is desirable that the vehicle be smoothly redirected and exit the barrier within the "exit box" criteria (not less than 32.8 ft), and should be documented. Vehicle rebound distance and velocity should be reported for crash cushions.

Result: The vehicle exited the exit box too soon.

7.5. *MASH* TEST 3-35 (CRASH TEST NO. 467114-7)

After the 2270P vehicle rolled in Test No. 467114-6, the test installation was modified and *MASH* Test 3-35 was repeated. The test installation for Test No. 467114-7 differed from that for Test Nos. 467114-3 through 467114-6 most notably in that an extra post was added to the thrie-beam section between post 10 and the parapet, resulting in a total of 17 posts for the installation. At post 10, the upstream thrie-beam section was sandwiched between the nested double thrie-beams, and all three layers were bolted to post 10. Section 6.1.2 and Appendix B provide further details.



General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-35
TTI Test No.	467114-6
Test Date	2014-08-06
Test Article	
Type	Guardrail
Name	Short Radius Guardrail
Installation Length	27 ft 5½ inches x 29 ft 1¾ inches
Material or Key Elements	Thrie beam rolled to radius of 8 ft 4½ inches mounted at 31 inches flared 4.25° from parapet face
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type/Designation	2270P
Make and Model	2008 Dodge Ram 1500 Pickup
Curb	4935 lb
Test Inertial	5016 lb
Dummy	No dummy
Gross Static	5016 lb

Impact Conditions	
Speed	62.6 mph
Angle	25.1°
Location/Orientation	At Post 9
Impact Severity	118.2 kip-ft (+3%).
Exit Conditions	
Speed	Not measurable
Angle	Not measurable
Occupant Risk Values	
Longitudinal OIV	25.3 ft/s
Lateral OIV	23.3 ft/s
Longitudinal Ridedown	10.8 G
Lateral Ridedown	10.0 G
THIV	36.2 km/h
PHD	14.7 G
ASI	1.28
Max. 0.050-s Average	
Longitudinal	−9.8 G
Lateral	9.3 G
Vertical	4.4 G

Post-Impact Trajectory	
Stopping Distance	145 ft dwnstrm 85 twd traffic
Vehicle Stability At 5.0 s	
Maximum Yaw Angle	160°
Maximum Pitch Angle	12°
Maximum Roll Angle	1016°
Vehicle Snagging	Yes
Vehicle Pocketing	Yes
Test Article Deflections	
Dynamic	21.1 inches
Permanent	16.25 inches
Working Width	24.1 inches
Vehicle Intrusion	29.6 inches
Vehicle Damage	
VDS	11FL6
CDC	11FLEW5
Max. Exterior Deformation	24.0 inches
OCDI	LR0300000
Max. Occupant Compartment Deformation	9.5 inches

Figure 7.23. Summary of Results for *MASH* Test 3-35 on the Short Radius Guardrail.

7.5.1. Test Designation and Actual Impact Conditions

MASH Test 3-35 involves a 2270P vehicle weighing 5000 lb ±110 lb and impacting the test article at an impact speed of 62.2 mph ±2.5 mph and an angle of 25° ±1.5° relative to the traffic face of the concrete parapet. The target impact point was post 9. The 2008 Dodge Ram 1500 Quad Cab pickup truck used in the test weighed 5014 lb, and the actual impact speed and angle were 64.5 mph and 25.2°, respectively. The actual impact point was at post 9. Target impact severity (IS) was 115.1 kip-ft, and actual IS was 126.4 kip-ft (+9 percent).

7.5.2. Test Vehicle

Figure 7.24 shows the 2008 Dodge Ram 1500 pickup that was used for the crash test. Test inertia weight of the vehicle was 5014 lb, and its gross static weight was 5041 lb. The height to the lower edge of the vehicle bumper was 15.5 inches, and it was 27.0 inches to the upper edge of the bumper. The height to the vehicle’s center of gravity was 28.0 inches. Tables I1 and I2 in Appendix I give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 7.24. Vehicle/Installation Geometrics for Test No. 467114-7.

7.5.3. Weather Conditions

The test was performed on the morning of August 22, 2014. Weather conditions at the time of testing were as follows:

- Wind speed: 8 mph.
- Wind direction: 182° with respect to the vehicle (vehicle was traveling in a northerly direction).
- Temperature: 91°F.
- Relative humidity: 59 percent.

7.5.4. Test Description

The 2008 Dodge Ram 1500 pickup truck, traveling at an impact speed of 64.5 mph, impacted the Short Radius Guardrail at post 9 at an impact angle of 25.2°. Shortly after impact, post 9 began to deflect toward the field side, and at 0.011 s, post 10 began to deflect toward the field side. Posts 10, 11, and 12 began to deflect toward the field side at 0.011 s, 0.018 s, and 0.026 s, respectively. At 0.032 s, the left front corner of the bumper contacted post 10 and post 13 began to deflect toward the field side. At 0.037 s, the vehicle began to redirect and post 13 began to deflect toward the field side. The bumper contacted post 11 at 0.044 s, and post 14 began to deflect toward the field side at 0.048 s. At 0.057 s, the front bumper contacted post 12, and at 0.071 s, the left front tire and wheel assembly separated from the vehicle. The bumper contacted post 13 at 0.073 s, and post 15 began to deflect toward the field side at 0.077 s. At 0.088 s, the bumper contacted post 14 and post 16 began to deflect toward the field side. The bumper contacted post 15, 16, and 17 at 0.104 s, 0.132 s, and 0.157 s, respectively. The bumper reached the end of the parapet at 0.143 s, and the rear of the vehicle contacted the guardrail at 0.186 s. At 0.208 s, the vehicle was traveling parallel with the parapet, and at 0.423 s, the vehicle began to roll counterclockwise. The vehicle lost contact with the parapet at 0.451 s and was traveling at an exit speed and angle of 40.6 mph and 31.1°. Brakes on the vehicle were applied at 2.5 s after impact, and the vehicle subsequently came to rest upright 160 ft downstream of impact and 58 ft toward traffic lanes from the traffic face of the parapet. Figures I1 and I2 in Appendix I show sequential photographs of the test period. Figure 7.25 shows the vehicle at final rest relative to the Short Radius Guardrail.

Figure 7.25. Vehicle/Installation after Test No. 467114-7.

7.5.5. Damage to Test Installation

Figure 7.26 shows the Short Radius Guardrail after the test. The soil around posts 4 through 7 was disturbed. Post 8 was leaning toward the field side 2° and had deflected through the soil 16 inches. Post 9 was leaning toward the field side 5° and had deflected through the soil 1.5 inches. Posts 10 and 11 were leaning toward field side 15°, and post 11 rotated clockwise 30°. Posts 12 and 13 were leaning toward field side 18° and both rotated clockwise 15°. Post 14 was leaning toward the field side 10° and had deflected through the soil 3 inches. Post 15 was leaning toward the field side 5° and had deflected through the soil 0.5 inch. Post 16 was leaning toward the field side 3°, and the soil around post 17 was disturbed. Total length of contact of the vehicle with the guardrail was 12.5 ft. Maximum dynamic deflection during the test was 14.3 inches, and maximum permanent deformation was 9.0 inches. Working width was 16.9 inches, and vehicle intrusion was 23.7 inches.

Figure 7.26. Installation after Test No. 467114-7.

7.5.6. Vehicle Damage

Figure 7.27 shows the vehicle after the test. The left upper and lower ball joints, left frame rail, and left rear U-bolts were damaged. Also damaged were the front bumper, radiator and support, left front tire and wheel rim, left front and rear doors, left rear exterior bed, left rear tire and wheel rim, rear tailgate, and rear bumper. Maximum exterior crush to the vehicle was

24.0 inches in the front and side planes at the left front corner at bumper height. Maximum occupant compartment deformation was 2.5 inches in the left firewall area near the toe pan.

Figure 7.27. Vehicle after Test No. 467114-7.

7.5.7. Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 25.3 ft/s at 0.107 s, the highest 0.010-s occupant ridedown acceleration was 7.5 Gs from 0.132 to 0.142 s, and the maximum 0.050-s average acceleration was −10.3 Gs between 0.046 and 0.096 s. In the lateral direction, the occupant impact velocity was 26.2 ft/s at 0.107 s, the highest 0.010-s occupant ridedown acceleration was 8.5 Gs from 0.139 to 0.149 s, and the maximum 0.050-s average was 11.4 Gs between 0.051 and 0.101 s. THIV was 38.8 km/h or 10.8 m/s at 0.103 s; PHD was 10.9 Gs between 0.132 and 0.142 s; and ASI was 1.53 between 0.081 and 0.131 s. Figure 7.28 summarizes these data and other pertinent information from the test. In Appendix I, Figures I3 through I9 show the vehicle angular displacements and accelerations versus time traces.

7.5.8. Assessment of Test Results

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

7.5.8.1. Structural Adequacy

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

Results: The Short Radius Guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 14.3 inches. (PASS)

7.5.8.2. *Occupant Risk*

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

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

Results: No detached elements, fragments, or other debris were present to penetrate or show potential to penetrate the occupant compartment, or to present undue hazard to others in the area. (PASS)

Maximum occupant compartment deformation was 2.0 inches in the left side kick panel area near the driver's feet. (PASS)

F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75°.

Results: The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 32° and 11°, respectively. (PASS)

H. Occupant impact velocities should satisfy the following:

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
30 ft/s	*40 ft/s*

Results: Longitudinal occupant impact velocity was 25.3 ft/s, and lateral occupant impact velocity was 26.2 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

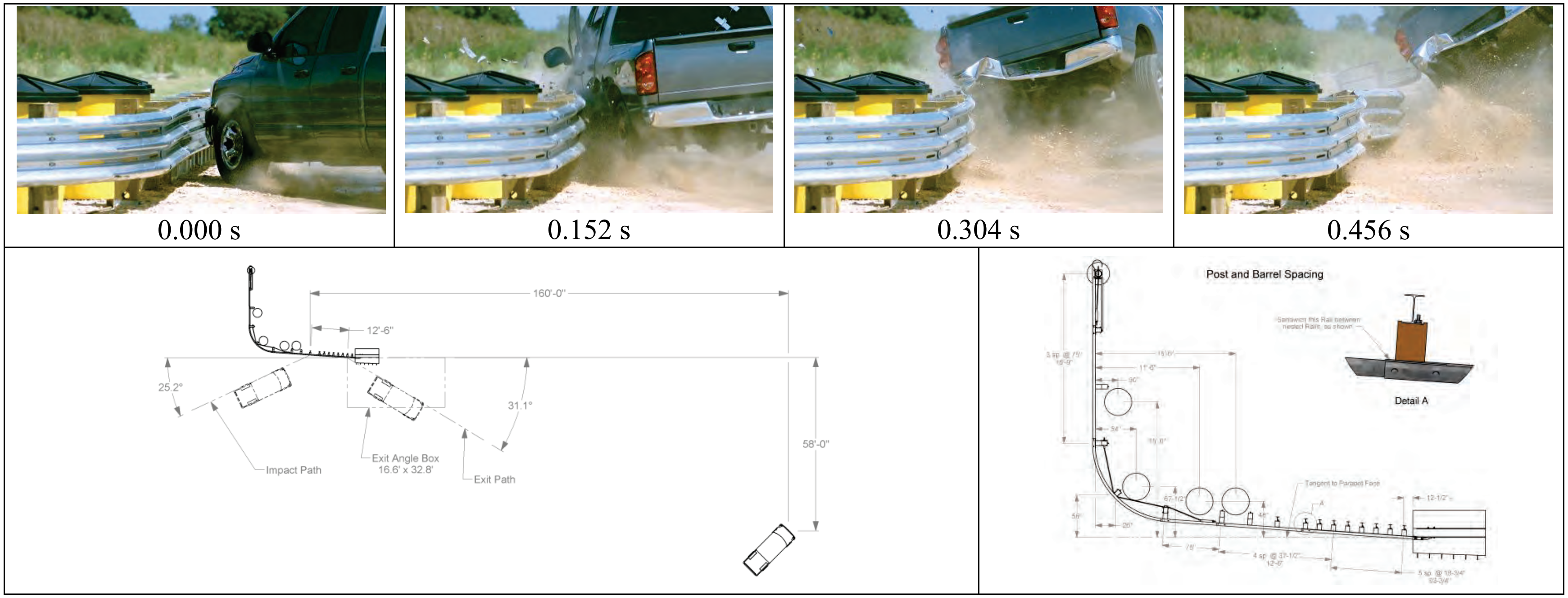
Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Maximum longitudinal occupant ridedown acceleration was 7.5 G, and maximum lateral occupant ridedown acceleration was 8.5 G. (PASS)

7.5.8.3. *Vehicle Trajectory*

For redirective devices, it is desirable that the vehicle be smoothly redirected and exit the barrier within the "exit box" criteria (not less than 32.8 ft), and should be documented. Vehicle rebound distance and velocity should be reported for crash cushions.

Result: The 2270P vehicle exited the exit box too soon.



General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-35
TTI Test No.	467114-7
Test Date	2014-08-22
Test Article	
Type	Guardrail
Name	Short Radius Guardrail
Installation Length	27 ft 5½ inches x 29 ft 1¾ inches
Material or Key Elements	Thrie beam rolled to radius of 8 ft 4½ inches mounted at 31 inches flared 4.25° from parapet face
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type/Designation	2270P
Make and Model	2008 Dodge Ram 1500
Curb	4712 lb
Test Inertial	5014 lb
Dummy	No dummy
Gross Static	5014 lb

Impact Conditions	
Speed	64.5 mph
Angle	25.2°
Location/Orientation	At post 9
Impact Severity	126.4 kip-ft (+9%)
Exit Conditions	
Speed	40.6 mph
Angle	31.0°
Occupant Risk Values	
Longitudinal OIV	25.3 ft/s
Lateral OIV	26.2 ft/s
Longitudinal Ridedown	7.5 G
Lateral Ridedown	8.5 G
THIV	38.8 km/h
PHD	10.8 G
ASI	1.53
Max. 0.050-s Average	
Longitudinal	−10.3 G
Lateral	11.4 G
Vertical	−3.0 G

Post-Impact Trajectory	
Stopping Distance	160 ft dwnstrm 58 ft twd traffic
Vehicle Stability	
Maximum Yaw Angle	84°
Maximum Pitch Angle	11°
Maximum Roll Angle	32°
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	14.3 inches
Permanent	9.0 inches
Working Width	16.9 inches
Vehicle Penetration	23.7 inches
Vehicle Damage	
VDS	11LFQ6
CDC	11FLEW5
Max. Exterior Deformation	24.0 inches
OCDI	LF0000000
Max. Occupant Compartment Deformation	2.0 inches

Figure 7.28. Summary of Results for *MASH* Test 3-35 on the Modified Short Radius Guardrail.

CHAPTER 8. SUMMARY AND CONCLUSIONS

8.1. ASSESSMENT OF TEST RESULTS

8.1.1. *MASH* Test No. 3-33 (Crash Test No. 467114-3)

The Short Radius Guardrail brought the 2270P vehicle to a controlled stop. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 25.0 ft relative to the "primary roadway" and 22.9 ft relative to the "secondary roadway." Some of the posts fractured and separated from the rail, and these and all other debris remained adjacent to the installation. These items did not penetrate, or show potential for penetrating the occupant compartment. The post and other debris traveled relatively close to the ground and remained near the installation, and thereby did not present undue hazard to others in the area. No occupant compartment deformation or intrusion occurred. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 45° and 10°, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The vehicle did not exit the installation. No significant rebound occurred. Table 8.1 gives a summary of the test.

8.1.2. *MASH* Test No. 3-32 (Crash Test No. 467114-4)

The Short Radius Guardrail contained the 1100C vehicle and brought it to a controlled stop. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the rail element during the test was 16.3 ft relative to the 'primary roadway' and 16.4 ft relative to the 'secondary roadway.' All debris remained adjacent to the installation area and did not penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 0.5 inches in the right front passenger area at hip height. The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 6° and 11°, respectively. Occupant risk factors were within the limits specified in *MASH*. The vehicle did not exit the installation. No significant rebound was noted. Table 8.2 gives a summary of the test.

8.1.3. *MASH* Test No. 3-31 (Crash Test No. 467114-5)

The Short Radius Guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 34.1 inches. Several posts fractured, but remained attached to the rail element. No other detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 0.5 inch in the left front kick panel area near the driver's feet. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 13° and 12°, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The 2270P vehicle exited within the exit box criteria. Table 8.3 gives a summary of the test.

8.1.4. *MASH* Test No. 3-35 (Crash Test No. 467114-6)

The Short Radius Guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the guardrail was 21.1 inches. No detached elements, fragments, or other debris were present to penetrate or to show penetration of the occupant compartment, or to show hazard to others in the area. Maximum occupant compartment deformation related to the impact with the Short Radius Guardrail was 3.25 inches in the lateral area across the cab in the driver side kickpanel area. Maximum occupant compartment deformation related to the rollover was 9.5 inches in the floor to roof area in the left rear occupant compartment. The 2270P vehicle rolled three revolutions after exiting the installation. Occupant risk factors were within the limits specified in *MASH*. The vehicle exited the exit box too soon. Table 8.4 gives a summary of the test.

8.1.5. Repeat *MASH* Test No. 3-35 (Crash Test No. 467114-7)

The Short Radius Guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 14.3 inches. No detached elements, fragments, or other debris were present to penetrate or show potential to penetrate the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 2.0 inches in the left side kick panel area near the driver's feet. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 32° and 11°, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. Table 8.5 gives a summary of the test.

8.2. CONCLUSIONS

When a roadway intersects a highway with restrictive features, such as a bridge rail and canal, it becomes difficult to fit a guardrail with the proper length, transitions, and end treatment along the highway. Possible solutions include relocating the constraint blocking the placement of the guardrail, shortening the designed guardrail length, or designing a curved guardrail. Curved, or short radius, guardrails typically present the most viable solution for these areas. However, no previously designed short radius guardrails meet *NCHRP Report 350* TL-3 guidelines. Now, crash testing criteria have been updated by AASHTO *MASH*. The new guidelines supersede *NCHRP Report 350* by increasing the size of test vehicles and changing the test matrices to include more impact conditions. Therefore, meeting new impact standards for short radius guardrails has become more challenging.

During the execution of this project, high fidelity simulations were conducted that accurately predicted the performance of the subsequent full-scale crash tests. The final short radius system that was simulated and crash tested consisted of a thrie beam that is 18 ft 9 inches long placed along the secondary roadway. The radius itself is 8 ft 4 inches and connects to the thrie beam on the primary roadway, which is 27 ft 5 inches long. The primary road rail section includes a transition section to connect the rail to the concrete parapet design. A combination of BCT and CRT wood posts are utilized to provide quick post releases for the capture impacts. A tension cable begins on the primary roadway and runs across the nose section along the ground and anchored on the secondary roadway. This tension cable helps to maintain the tension in the rail for impacts such as *MASH* test 3-35 and *MASH* test 3-31. Frangible sand barrels were spaced behind the rail to help slow the vehicle down without violating OIV and ridedown acceleration thresholds while maintaining a desired stopping distance behind the rail.

The system described above and detailed in the report was successfully crash tested under the *MASH* tests 3-32, 3-33, 3-31, and 3-35 test conditions.

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

Test Agency: Texas A&M Transportation Institute | Test No.: 467114-3 | Test Date: 2014-07-17

MASH Test 3-33 Evaluation Criteria	Test Results	Assessment
Structural Adequacy A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable*	The Short Radius Guardrail brought the 2270P vehicle to a controlled stop. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 25.0 ft relative to the 'primary roadway' and 22.9 ft relative to the 'secondary roadway.'	Pass
Occupant Risk D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	Some of the posts fractured and separated from the rail; these and all other debris remained adjacent to the installation. These items did not penetrate or show potential for penetrating the occupant compartment, and did not present undue hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	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°.*	The 2270P vehicle remained upright during and after the collision event. Maximum roll was 45° and maximum pitch was 10°.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.*	Longitudinal occupant impact velocity was 28.5 ft/s, and lateral occupant impact velocity was 5.9 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.*	Maximum longitudinal occupant ridedown acceleration was 8.2 G, and maximum lateral occupant ridedown acceleration was 10.0 G.	Pass

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

Test Agency: Texas A&M Transportation Institute Test No.: 467114-4 Test Date: 2014-07-23

MASH Test 3-32 Evaluation Criteria	Test Results	Assessment
Structural Adequacy A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable*	The Short Radius Guardrail contained the 1100C vehicle and brought it to a controlled stop. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the rail element during the test was 16.3 ft relative to the 'primary roadway' and 16.4 ft relative to the 'secondary roadway.'	Pass
Occupant Risk D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	All debris remained adjacent to the installation area and did not penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 0.5 inches in the right front passenger area at hip height.	Pass
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75°.*	The 1100C vehicle remained upright during and after the collision event. Maximum roll was 6° and maximum pitch was 11°.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.*	Longitudinal occupant impact velocity was 36.4 ft/s, and lateral occupant impact velocity was 3.6 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.*	Maximum longitudinal occupant ridedown acceleration was 12.0 G, and maximum lateral occupant ridedown acceleration was 6.2 G.	Pass

Table 8.3. Performance Evaluation Summary for *MASH* Test 3-31 on the Short Radius Guardrail.

Test Agency: Texas A&M Transportation Institute Test No.: 467114-5 Test Date: 2014-07-29

***MASH* Test 3-31 Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy *A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable*	The Short Radius Guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 34.1 inches.	Pass
Occupant Risk *D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	Several posts fractured, but remained attached to the rail element. No other detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 0.5 inch in the left front kick panel area near the driver's feet.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75°.	The 2270P vehicle remained upright during and after the collision event. Maximum roll was 13° and maximum pitch was 12°.	Pass
H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.	Longitudinal occupant impact velocity was 9.2 ft/s, and lateral occupant impact velocity was 10.5 ft/s.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.	Maximum longitudinal occupant ridedown acceleration was −5.4 G, and maximum lateral occupant ridedown acceleration was 4.5 G.	Pass

Table 8.4. Performance Evaluation Summary for *MASH* Test 3-35 on the Short Radius Guardrail.

Test Agency: Texas A&M Transportation Institute   Test No.: 467114-6   Test Date: 2014-08-06

MASH Test 3-35 Evaluation Criteria	Test Results	Assessment
Structural Adequacy A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable*	The Short Radius Guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the guardrail was 21.1 inches.	Pass
Occupant Risk D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached element, fragment, or other debris was present to penetrate or to show penetration of the occupant compartment, or to present undue hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation related to the rollover was 9.5 inches in the floor to roof area in the left rear occupant compartment.	Fail
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75°.*	The 2270P vehicle rolled three revolutions after exiting the installation.	Fail
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.*	Longitudinal occupant impact velocity was 25.3 ft/s, and lateral occupant impact velocity was 23.3 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.*	Maximum longitudinal occupant ridedown acceleration was 10.8 G, and maximum lateral occupant ridedown acceleration as 10.0 G.	Pass

Table 8.5. Performance Evaluation Summary for Repeat *MASH* Test 3-35 on the Short Radius Guardrail.

Test Agency: Texas A&M Transportation Institute | Test No.: 467114-7 | Test Date: 2014-08-22

***MASH* Test 3-35 Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy A. *Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable*	The Short Radius Guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 14.3 inches.	Pass
Occupant Risk D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached element, fragment, or other debris was present to penetrate or show potential to penetrate the occupant compartment, or to present undue hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 2.0 inches in the left side kick panel area near the driver's feet.	Pass
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75°.*	The 2270P vehicle remained upright during and after the collision event. Maximum roll was 32° and maximum pitch was 11°.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.*	Longitudinal occupant impact velocity was 25.3 ft/s, and lateral occupant impact velocity was 26.2 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.*	Maximum longitudinal occupant ridedown acceleration was 7.5 G, and maximum lateral occupant ridedown acceleration was 8.5 G.	Pass

CHAPTER 9. IMPLEMENTATION STATEMENT

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 secondary road. This 32-inch tall short radius system is *MASH* TL-3 complaint, and hence can be used on primary roads where TL-3 (or lower) safety features are recommended. It is critical that the primary rail maintain 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. However if TL-2 compliance is needed on the secondary roadway, the system can be configured to accommodate that by removing the rigid anchor and extending the secondary rail with the needed LON and a TL-2 complaint terminal.

The system requires a graded flat ground behind it at a slope of 1V:10H or flatter. However, a steeper slope break can be placed outside a 25-ft × 25-ft square area bordered by both the primary and the secondary rails.

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APPENDIX A. ENGINEERING ANALYSIS OF END ANCHORS AND CABLE BEARING ON BCT

A.1. FOUNDATION OF CONCRETE PARAPET ON THE PRIMARY ROADWAY

The parapet segment is detailed to follow TxDOT standards and it was not designed to withstand any direct load or impact during the crash testing phase. This parapet is a short section with sole function to simulate a bridge parapet end section to connect to the thrie-beam transition. Therefore it was deemed unnecessary to check the parapet with a yield line analysis and cantilever failure action of fully functional bridge parapets. Figure A.1 shows the parapet and foundation.

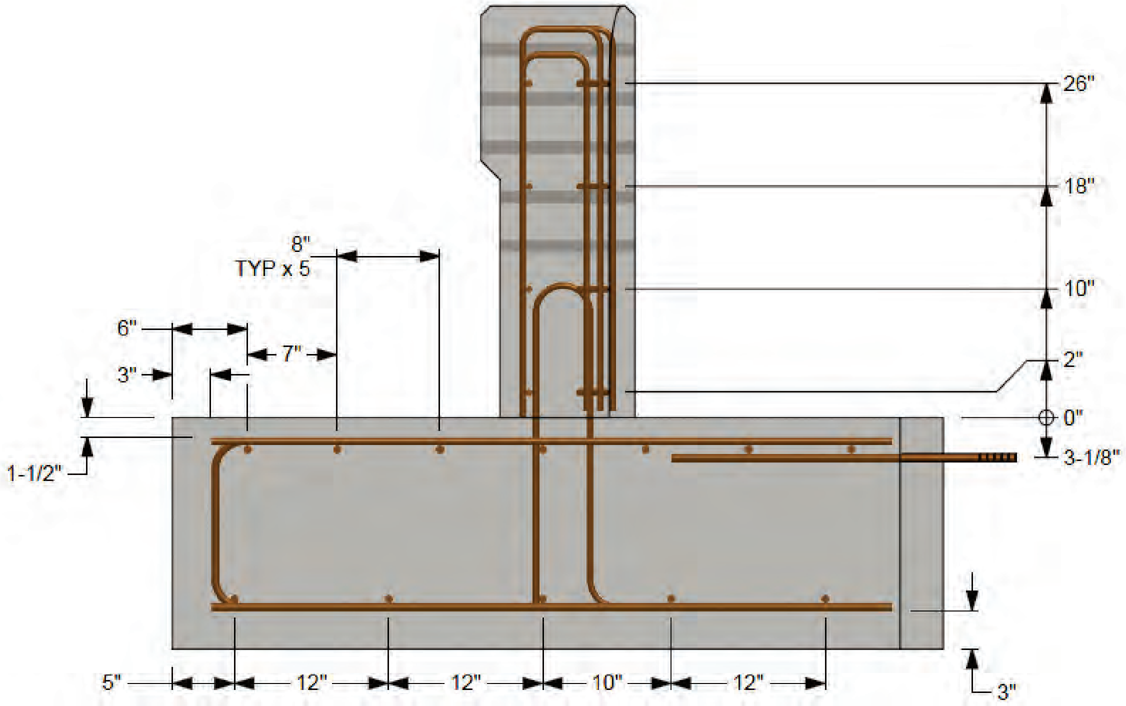


Figure A.1. Parapet and Foundation.

A.2. BCT AND CRT AREA MOMENT OF INERTIA CALCULATIONS

The moments of inertia for the BCT and CRT posts were calculated through the cross section, which contains that complete diameter of the hole. Equation A.1. shows the general equation used to calculate the area moment of inertia.

$$I = \frac{bh^3}{12} \qquad \text{A.1}$$

A.3. WIRE AREA MOMENT OF INERTIAL CALCULATIONS

To better model the behavior of the tension cable passing around the nose, the area moment of inertia was estimated. This was deemed necessary since the cable does have some moment capacity that will affect its interaction with the vehicle if they come into contact.

To get the effective area of steel, the mass of the cable per meter was acquired from the model. The density of steel is known. Researchers used the relationship between mass, density, and volume to calculate the area of steel in the cable. This calculation is shown in Equation A.2.

$$\begin{gathered} mass\ (per\ meter) = density * volume \\ mass\ (per\ meter) = density * length * area \\ mass\ (per\ meter) = density * 1\ meter * area \\ 1.4137\ kg = \left(7.85 * 10^{-9}\frac{kg}{m^3}\right) * 1\ m * A \\ A = 180.089\ mm^2 \end{gathered} \tag{A.2}$$

The effective radius of the steel wire cable was then calculated according to Equation A.3.

$$A = \pi r^2 \tag{A.3}$$

The radius was equal to 7.57 mm and was then used to calculate the polar moment of inertia of the cable cross section. The wire cable used in the system is a ¾-inch diameter 6×19 independent wire rope core (IWRC). This cable is composed of seven groups of smaller wires. For ease of calculation, it was assumed that each of the seven groups of wires had the same effective area of steel. This was calculated by dividing the total effective area of steel above by 7. Therefore, each group of steel had an individual effective area of 25.73 mm^2. The radius of each of the seven groups of wires was estimated by dividing the total radius calculated above by 3. This gave a radius for each of the individual wire groups of 2.52 mm. Figure A.2 depicts the actual wire section used to make these estimations and assumptions on the left. On the right in Figure A.2, the red circles depict the seven approximated areas of steel.

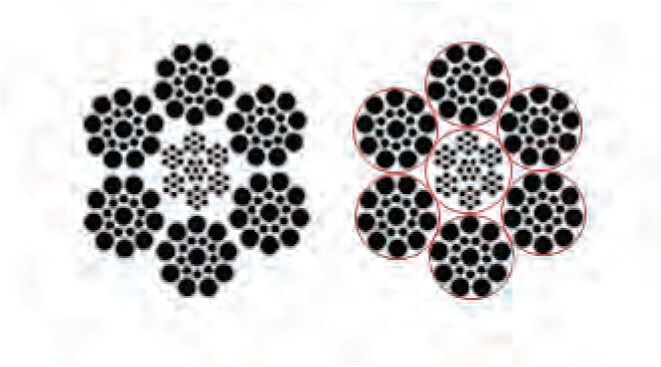


Figure A.2. 6×19 IWRC Steel Wire Cable Section and Approximation.

The individual polar moment of inertia for each of the seven groups of wires was calculated in Equation A.4:

$$J_{ind} = \frac{\pi r^4}{2} \tag{A.4}$$

$$J_{ind} = \frac{\pi * 2.52^4}{2} = 63.35\ mm^4$$

For the six groups of wires surrounding the center group, the parallel axis theorem was applied. The area of each of these individual groups is 25.73 mm^2 and the distance from the center of the whole section to the center of each individual group was calculated as twice the radius, which is equal to 5.04 mm. The total polar moment of inertia for the section is calculated in Equation A.5:

$$J_{tot} = \sum \frac{\pi r^4}{2} + \sum Ad^2 \tag{A.5}$$

$$J_{tot} = 7 * 63.35 + 6 * (25.73 * 5.04^2)$$

$$J_{tot} = 4364.93\ mm^4$$

The estimated polar moment of inertia for the 6×19 IWRC section is 85 percent of the polar moment of inertia for a rod with the same effective radius of steel equal to 7.57 mm. The moments of inertia about the horizontal and vertical axes were calculated by dividing the polar moment of inertia by 2. This reduction in the moment of inertia for the simulated cable will better physically represent actual cable behavior as opposed to rod-like behavior.

A.4. BCT POST CHECK ON PRIMARY ROADWAY

Several components of the BCT post on the primary roadway were checked for adequacy. From calculation and geometry of the model, the vertical forces imparted by the tension in the cable on the half pipe section is 13 kips when the cable has 40 kips of tension and 16.5 kips when the cable has 50 kips of tension. The following components were checked with these forces in mind.

With the half section of pipe welded to the BCT post, failure of the bolt is not a concern since the bolt is not in contact with the cable. Figure A.3 depicts the welded half pipe section on the 6-ft foundation tube.

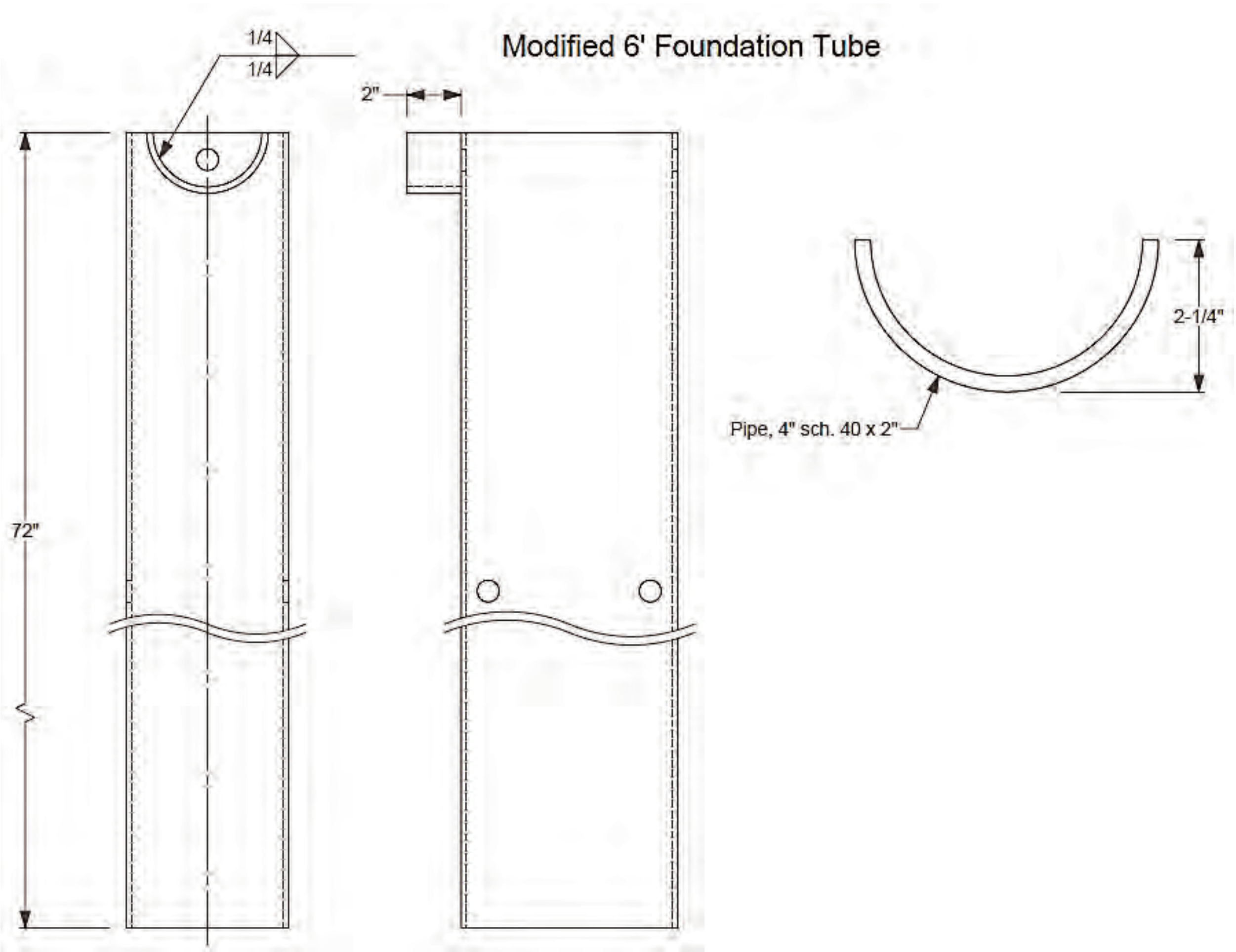


Figure A.3. Modified 6-Ft Foundation Tube.

A.5. CHECK BENDING CAPACITY OF PIPE SECTION

The bending capacity for the half section of a 4-inch diameter schedule 40 pipe is calculated. The moment of inertia of the half section of pipe about the x-axis passing through what would be the center of the full pipe section is calculated in Equation A.6:

$$\begin{gathered} I_{section} = I_R - I_r \\ I_{section} = \left(\frac{\pi}{8} - \frac{8}{9\pi}\right) * (R^4 - r^4) \\ I_{section} = \left(\frac{\pi}{8} - \frac{8}{9\pi}\right) * (2.25^4 - 2.013^4) \\ I_{section} = 1.01 \end{gathered} \qquad \textbf{A.6}$$

The maximum stress will occur at the outermost fiber of the pipe section. The distance from the horizontal axis about which the moment of inertia was taken to the outermost fiber is 2.25 inches. The elastic section modulus is calculated in Equation A.7:

$$S = \frac{I}{c} \quad \textbf{A.7}$$

$$S = \frac{1.01}{2.25} = 0.449\ inch^3$$

Assuming that the yield strength of the pipe section is 36 ksi, the moment capacity of the half pipe section is calculated in Equation A.8:

$$M = f_y * S \quad \textbf{A.8}$$

$$M = 36\ ksi * 0.449\ inch^3 = 16.2\ k * inch$$

Assuming that the moment arm is half of the length of the 2-inch half pipe section, the vertical force the pipe can withstand is 16.2 kips. This is very close to the force exerted on the half pipe section when the cable has 50 kips of tension. According to the geometry of the cable, a more realistic moment arm is 0.55 inch. At this lever arm, the pipe section can resist a force of 29 kips, which is well under the force that the cable exerted in 50 kips of tension.

Equation A.9 computes the moment capacity when the yield strength of the pipe is 35 ksi:

$$M = f_y * S \quad \textbf{A.9}$$

$$M = 35\ ksi * 0.449\ inch^3 = 15.7\ k * inch$$

With a 1-inch lever arm, this half pipe section will not be adequate if the tension force in the cable is equal to 50 kips. At the more realistic lever arm of 0.55 inches, the force that the section can withstand is 28.5 kips. Therefore, the section is adequate at the more realistic moment arm.

A.6. CHECK CAPACITY OF WELD

The weld was checked for its shear capacity. The strength of the weld was matched to the pipe having a yield strength of 36 ksi. This means that the strength of the weld material can be either 60 ksi or 70 ksi. To be conservative, researchers used a strength of 60 ksi in the calculations. It was assumed that the weld would have equal length legs. Equation A.10 calculated the effective throat of the weld:

$$t_e = 0.707a \quad \textbf{A.10}$$

$$t_e = 0.707 * 0.25 = 0.177\ inch$$

The fillet weld runs the entire perimeter, along both sides, of the half pipe section. The length of the weld is calculated in Equation A.11:

$$L_w = P_{outer} + P_{inner} + 2t \quad \textbf{A.11}$$

$$L_w = \frac{\pi * 4.5}{2} + \frac{\pi * 4.026}{2} + 2 * 0.237$$

$$L_w = 13.87\ inches$$

The strength of the weld is calculated in Equation A.12:

$$F = F_w A_w$$
$$F = (0.6 * 60\ ksi) * (0.177\ inch * 13.87\ inches) \qquad \textbf{A.12}$$
$$F = 88.4\ kips$$

This force is well over the 16.5 kips that the tension cable will exert on the half pipe section. Therefore, the weld is adequate.

A.7. ANCHOR POST ON SECONDARY ROADWAY

The anchor at the end of the secondary roadway was checked for adequacy. Figure A.4 shows this anchor post assembly. This check was done by making sure each component could withstand an 80-kip force individually. However, it is highly unlikely that the components will have to individually withstand the entire 80-kip load. The components in the anchor assembly that were checked include:

- The thrie beam.
- The cables.
- The tubular section of the anchor post.

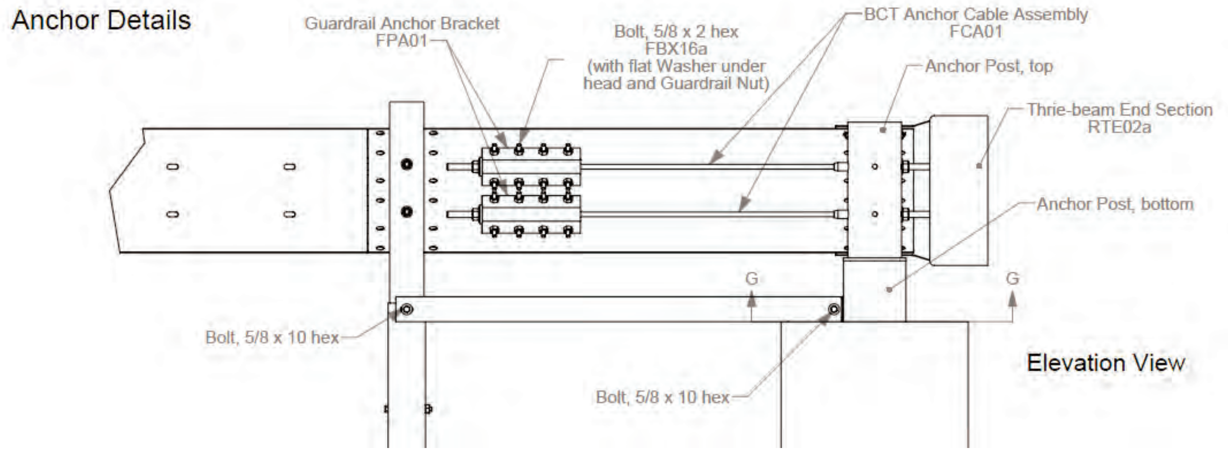


Figure A.4. Anchor Post System on Secondary Roadway.

A.8. TENSILE CAPACITY OF THRIE BEAM

The capacity of the thrie beam was calculated in the following manner. The total cross-sectional area of the 12-gauge thrie beam is 2000 mm^2. The thickness of the thrie beam is 2.77 mm. The capacity calculation was determined at the cross section containing the six splice bolt holes. The height of these holes is 24 mm. The nominal area is calculated in Equation A.13 for the capacity of the rail.

$$A_{nom} = A_{total} - A_{holes}$$
$$A_{nom} = 2000 - 6 * (24 * 2.77) \qquad \textbf{A.13}$$
$$A_{nom} = 1601\ mm^2$$

The capacity of the rail was calculated in Equation A.14. A yield strength of 50 ksi was assumed for a lower end yield strength that would provide a conservative estimate. The nominal area in square inches is equal to 2.48.

$$F_{rail} = A_{nom} * f_y$$
$$F_{rail} = 2.48 * 50 \qquad \textbf{A.14}$$
$$F_{rail} = 124\ kips$$

Assuming that the impact will cause a load of 80 kips on the system; the rail has the capacity to take the load.

A.9. CAPACITY OF THE TWO CABLES

The next check was for the two cables used in the anchor system. The ¾-inch diameter 6×19 IWRC has a capacity of 29.4 tons, which is 58.8 kips. The two cables have a total capacity of 117.6 kips, and therefore, have enough capacity to withstand the 80-kip load by themselves.

A.10. MOMENT CAPACITY OF PIPE SECTION

The tubular section's bending capacity was checked next. Figure A.5 depicts the pipe referred to in this section.

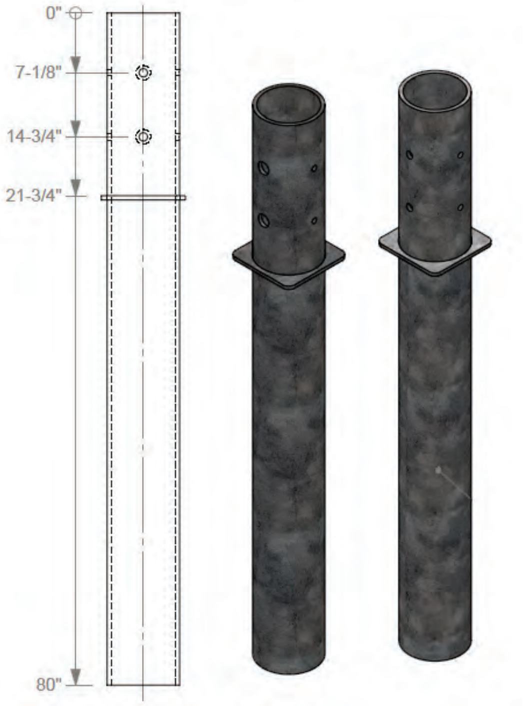


Figure A.5. Anchor Post.

The pipe is schedule 80. The area moment of inertia of the 8-inch diameter tubular section is equal to 106 in^4. The maximum moment will occur at the extreme fiber of the pipe cross section. Therefore, c is equal to the diameter divided by 2. This makes c equal to 4.31 inches. Equation A.15 calculates the moment capacity of the section. It was assumed that the tubular section's yield strength was 50 ksi.

$$\sigma = \frac{Mc}{I}$$
$$M = \frac{\sigma I}{c} \tag{A.15}$$
$$M = \frac{50 * 106}{4.31}$$
$$M = 1229\ k * inches$$

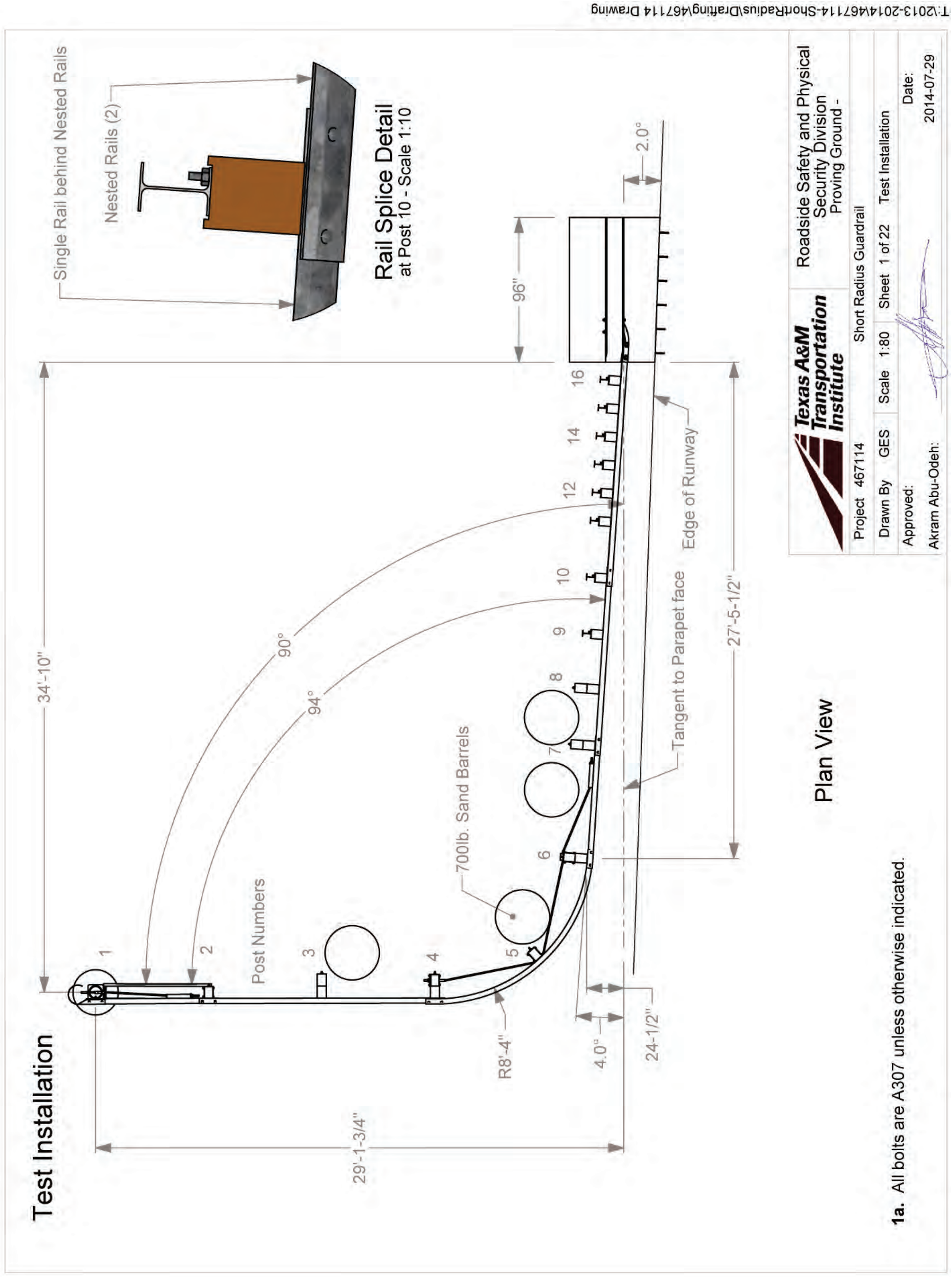
If one force of 80 kips is located at half the height of the tubular section above the ground, the moment arm is 11 inches. Dividing the moment capacity calculated above by the moment arm gives the force, which the tubular section can withstand. This force is equal to 111 kips, which is greater than 80 kips. Therefore, the section can withstand a single force of 80 kips applied at half of the post's height above the ground.

The tubular section's capacity was also checked with two 40-kip forces applied at the height of the bolt holes on the tubular post. Equation A.16 shows the calculation of this moment:

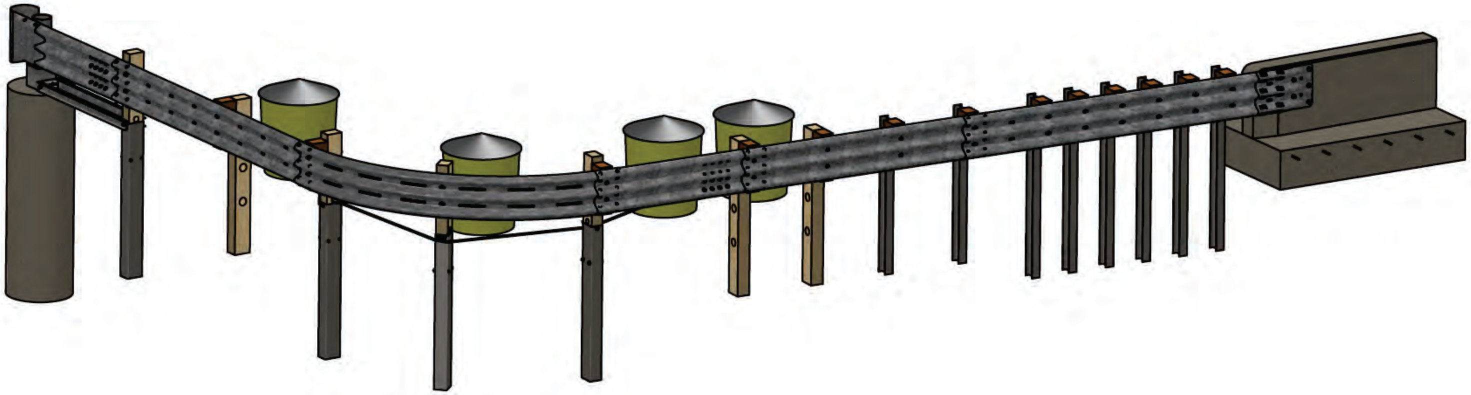
$$M_{2Forces} = 40\ kips * 7\ inches + 40\ kips * 14.625\ inches \tag{A.16}$$
$$M_{2Forces} = 865\ k * inches$$

Therefore, the tubular section has the capacity to withstand two 40-kip forces located at the bolt holes of the tubular section as well. Furthermore, The A307 bolt and the hex nut are chosen to match or exceed the expected load.

APPENDIX B. DETAILS OF THE TEST ARTICLE FOR TEST NOS. 467114-3 THROUGH 467114-6.



Isometric View



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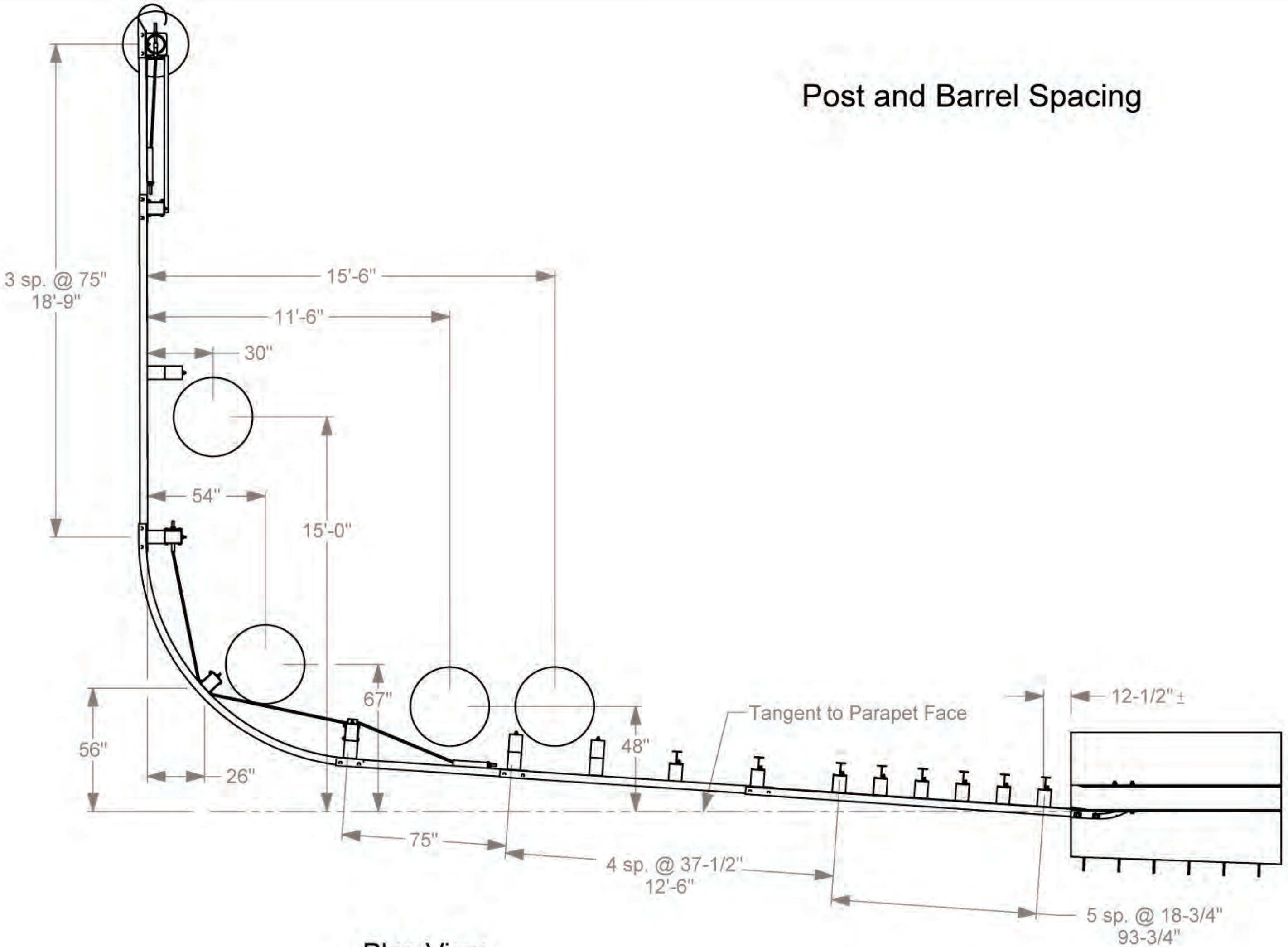
Post and Barrel Spacing



Plan View

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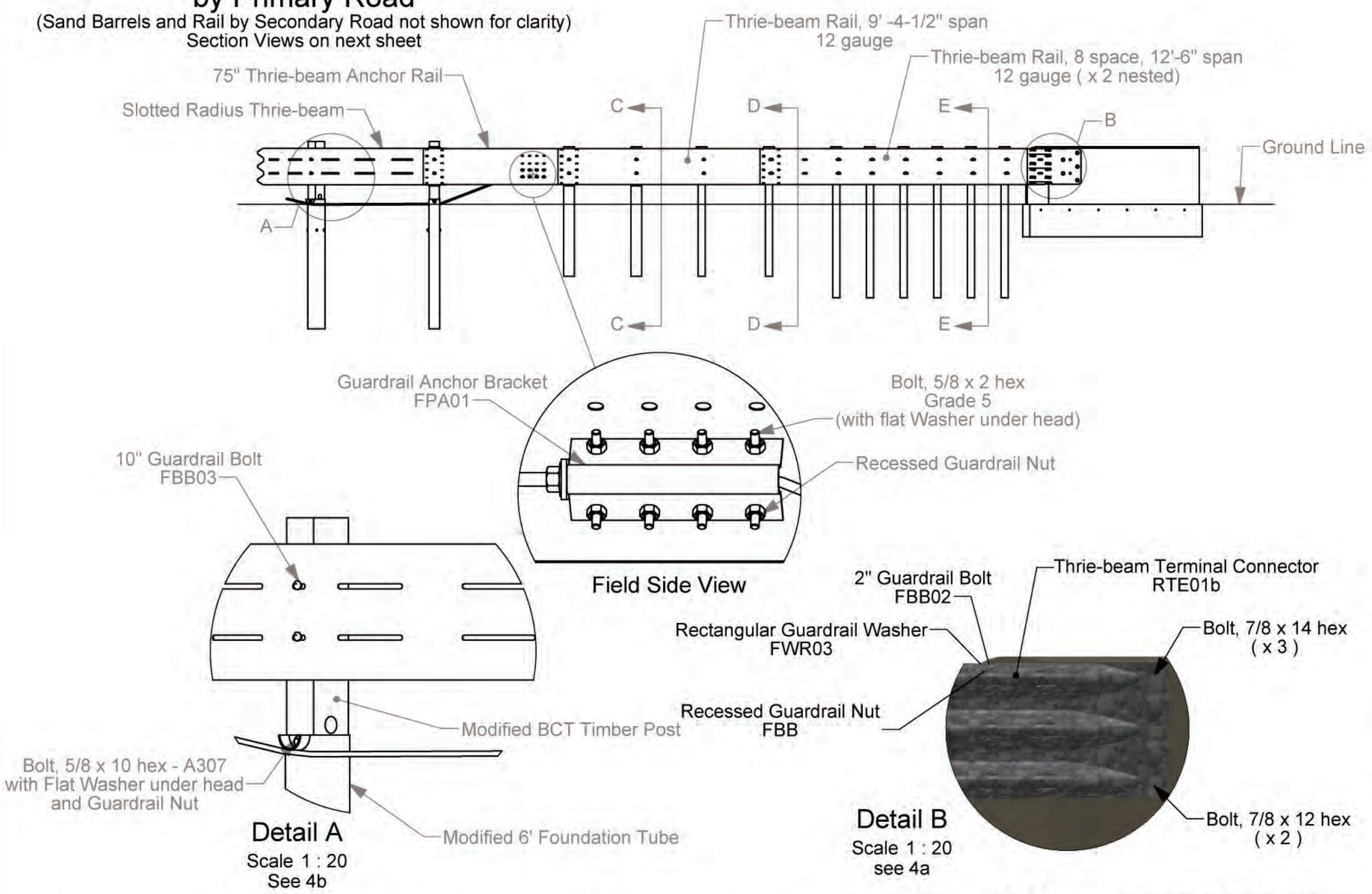
by Primary Road

(Sand Barrels and Rail by Secondary Road not shown for clarity)
Section Views on next sheet



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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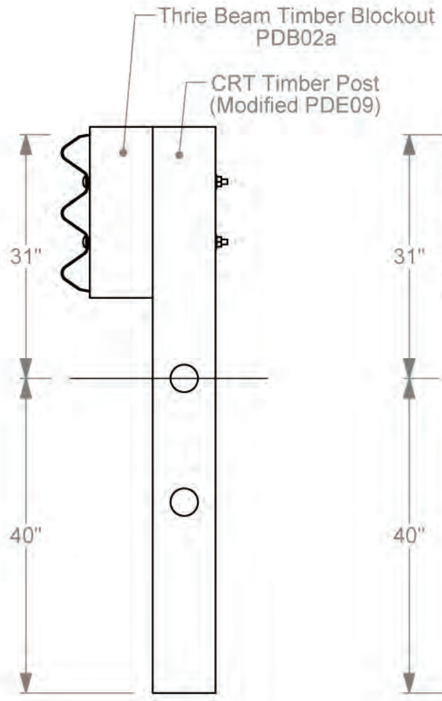
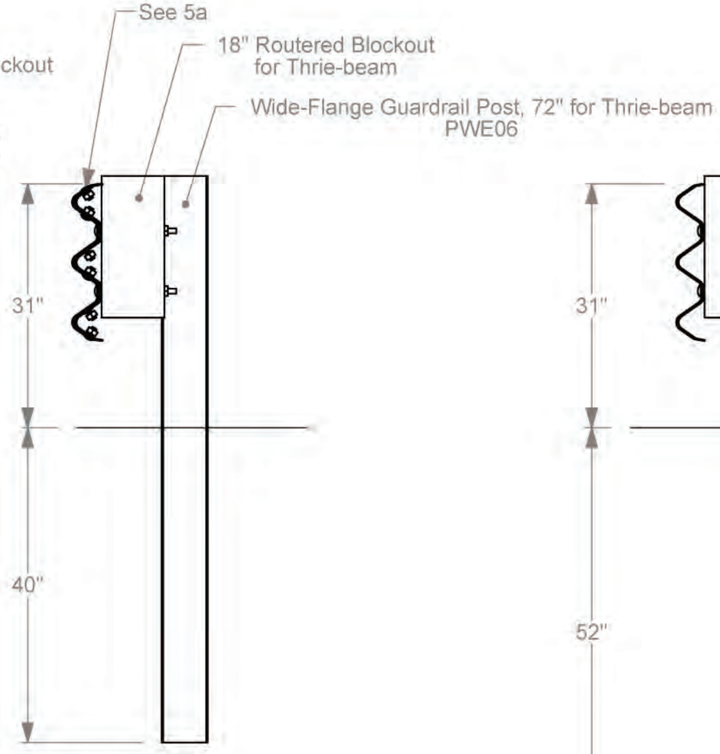


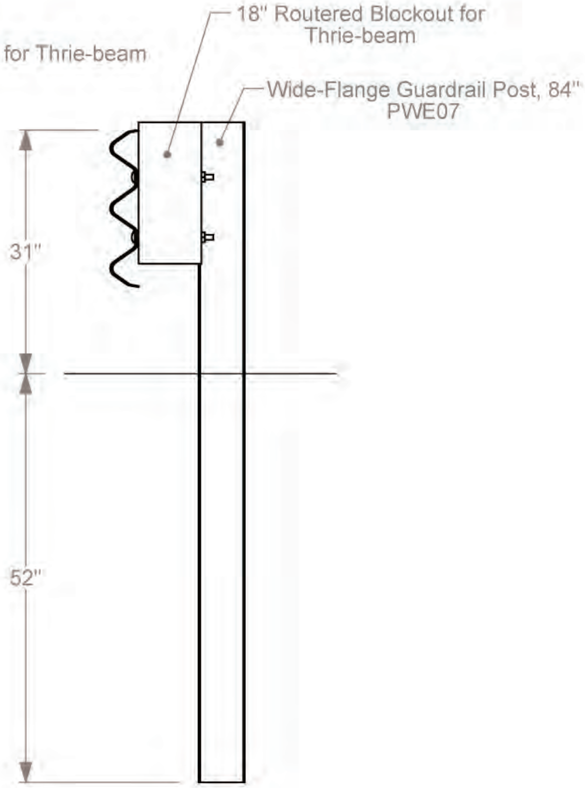
Section C-C

Scale 1 : 20
TYP at Posts 3 and 7 - 8



Section D-D

Scale 1 : 20
TYP at Posts 9 - 10



Section E-E

Scale 1 : 20
TYP at Posts 11 - 16

5a. Button-head Guardrail Bolts and Recessed Nuts (FBB) at all post and rail splice connections unless otherwise indicated.

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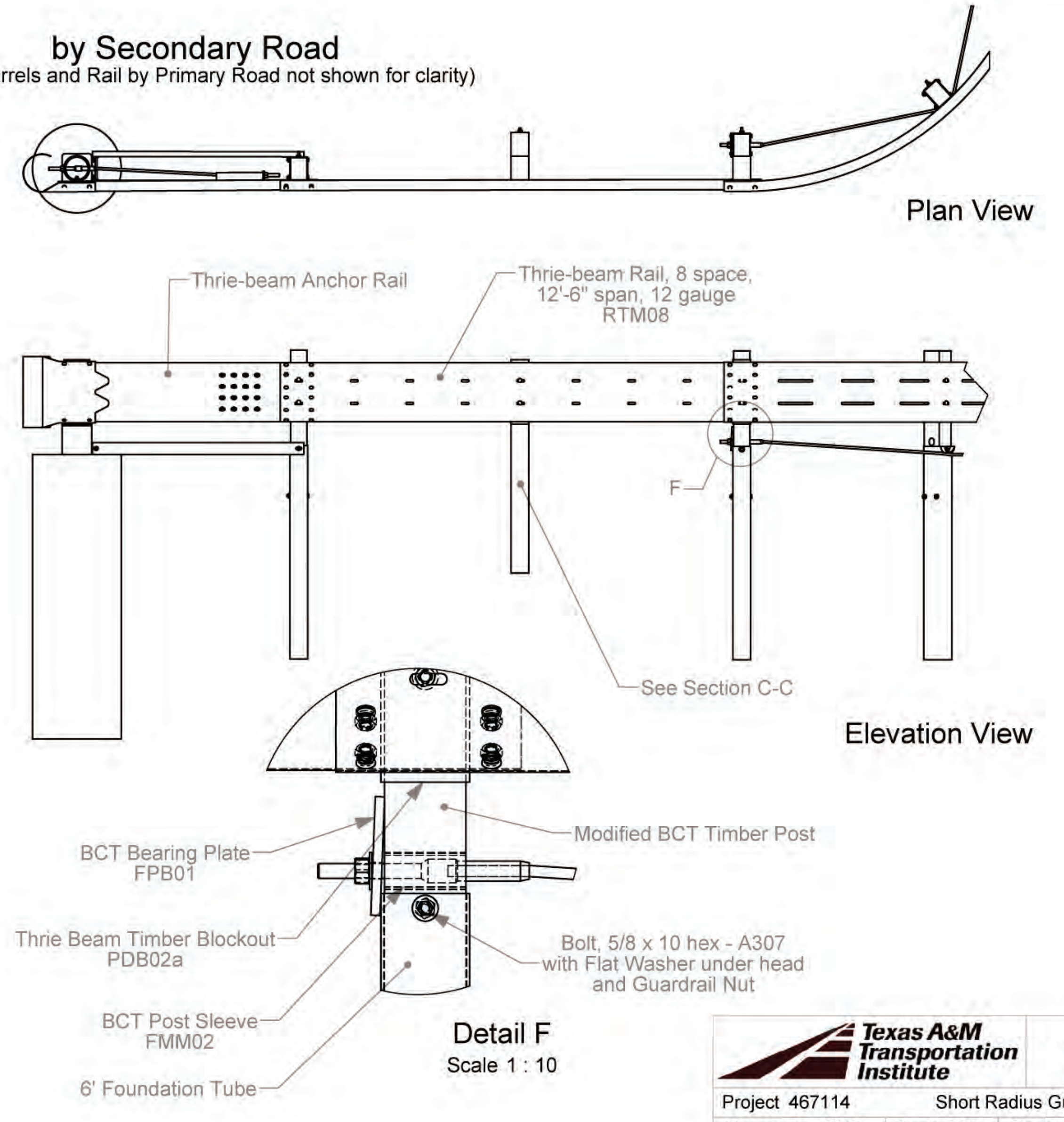
by Secondary Road

(Sand Barrels and Rail by Primary Road not shown for clarity)



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Drawn By GES | Scale 1:50 | Sheet 6 of 22 | by Secondary Road

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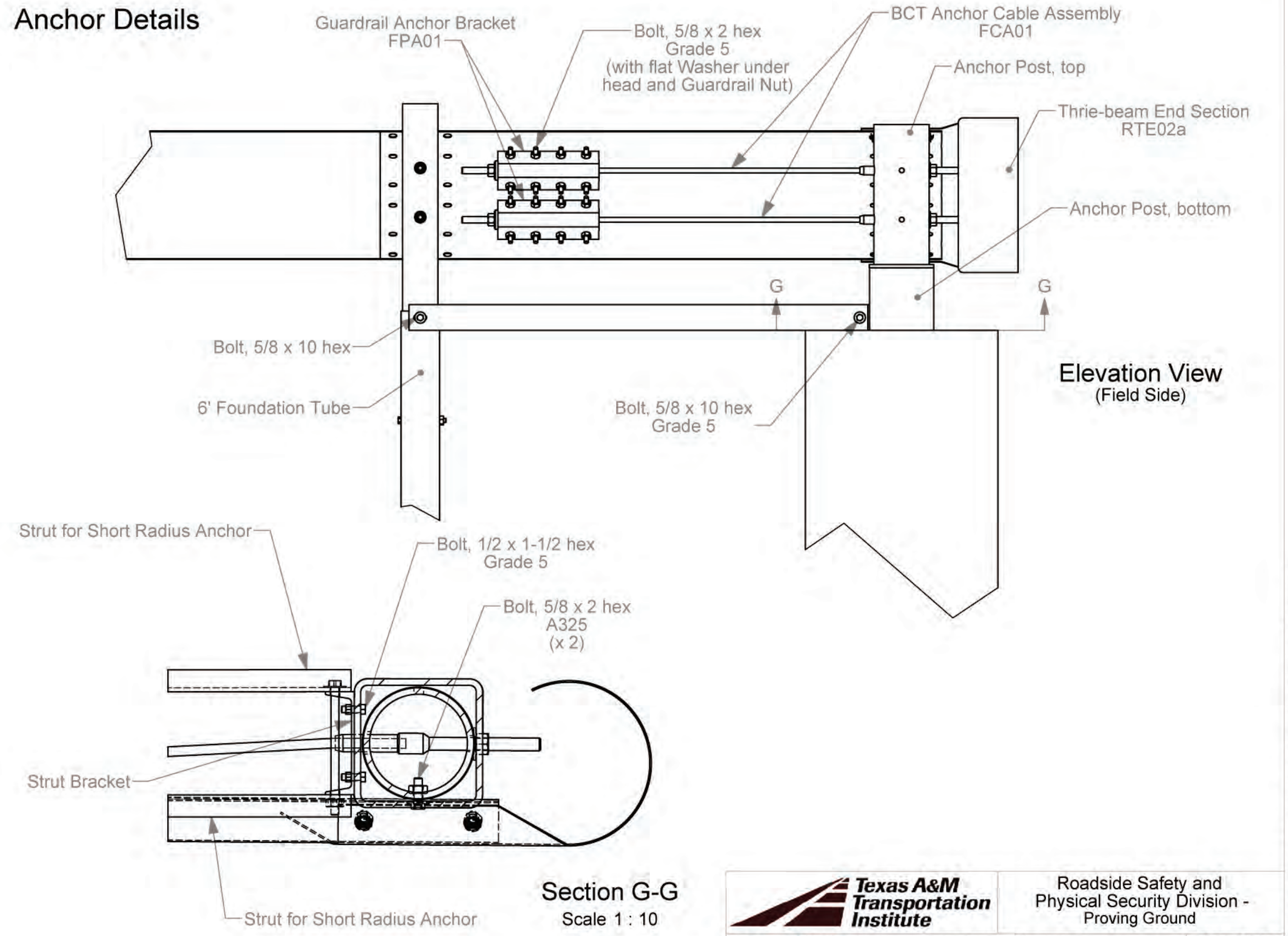
Anchor Details



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Drawn By GES | Scale 1:20 | Sheet 7 of 22 | Anchor Details

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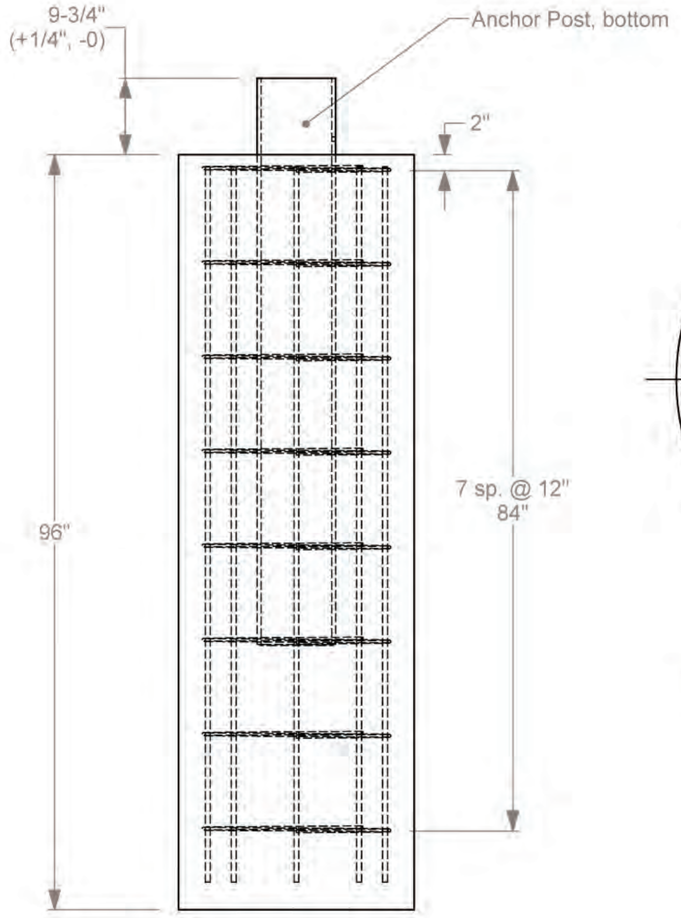
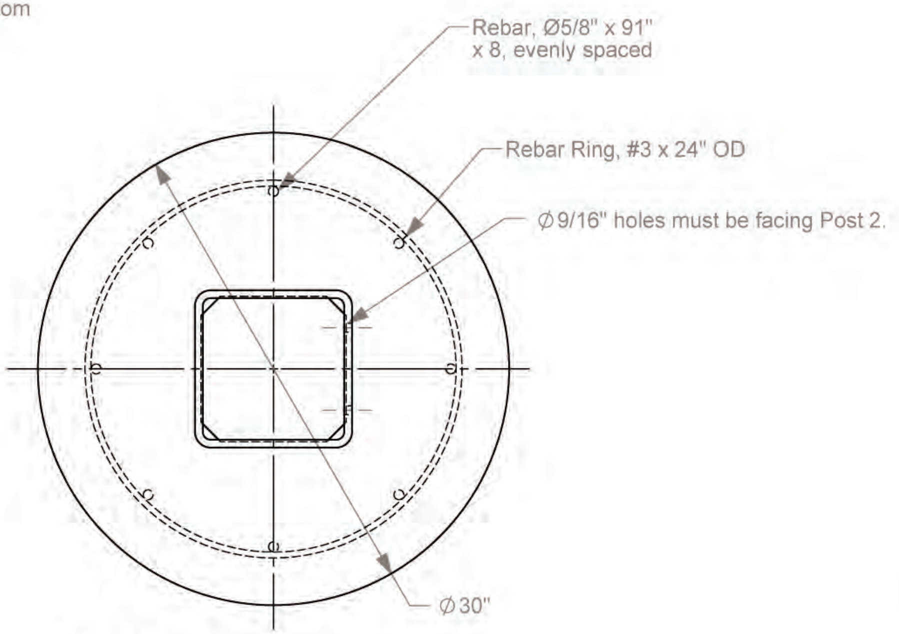
Post 1 Foundation



Elevation View



Plan View
Scale 1:10

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

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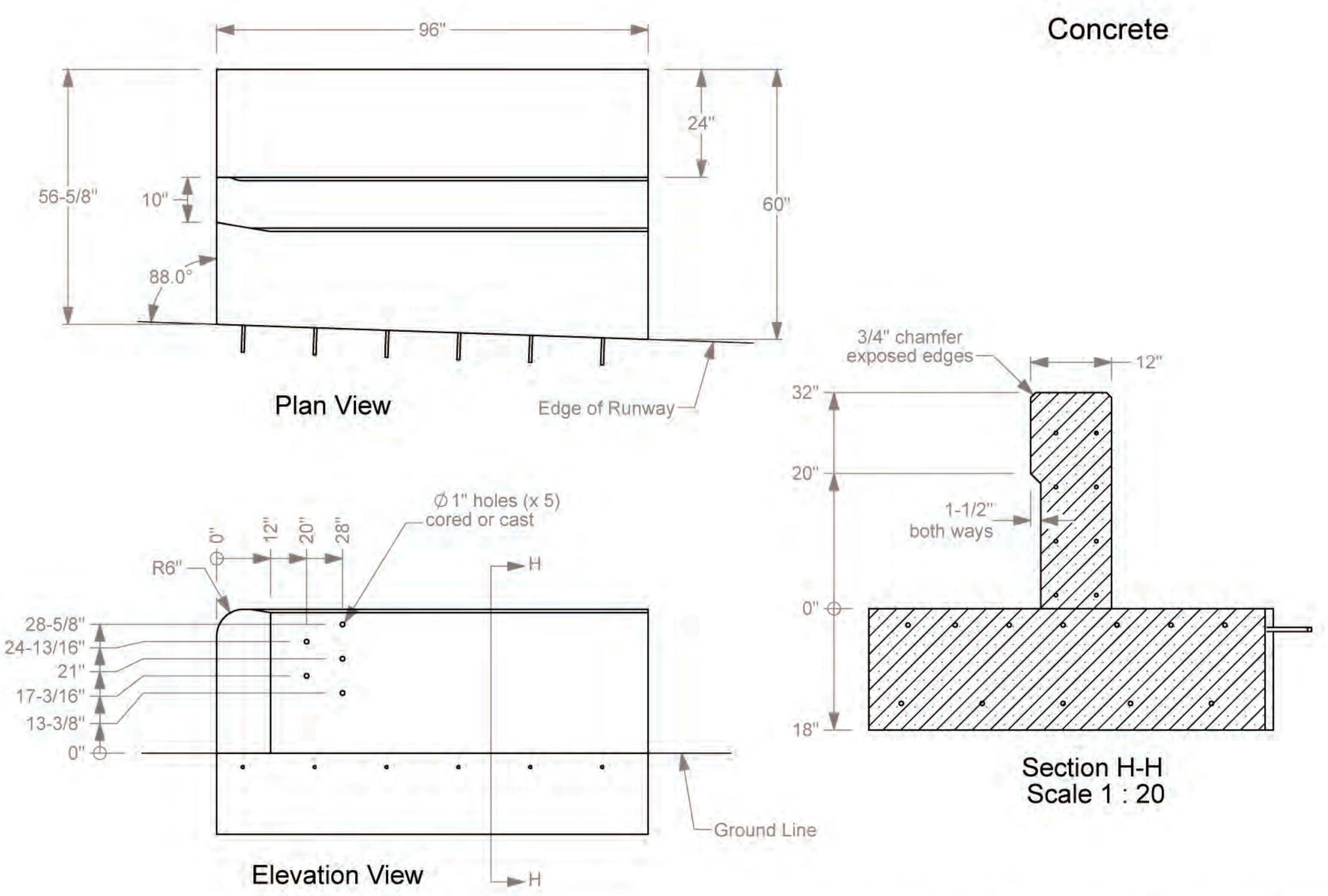

9a. Concrete is TxDOT Class C (3600 psi).

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Drawn By GES	Scale 1:30	Sheet 9 of 22	Concrete

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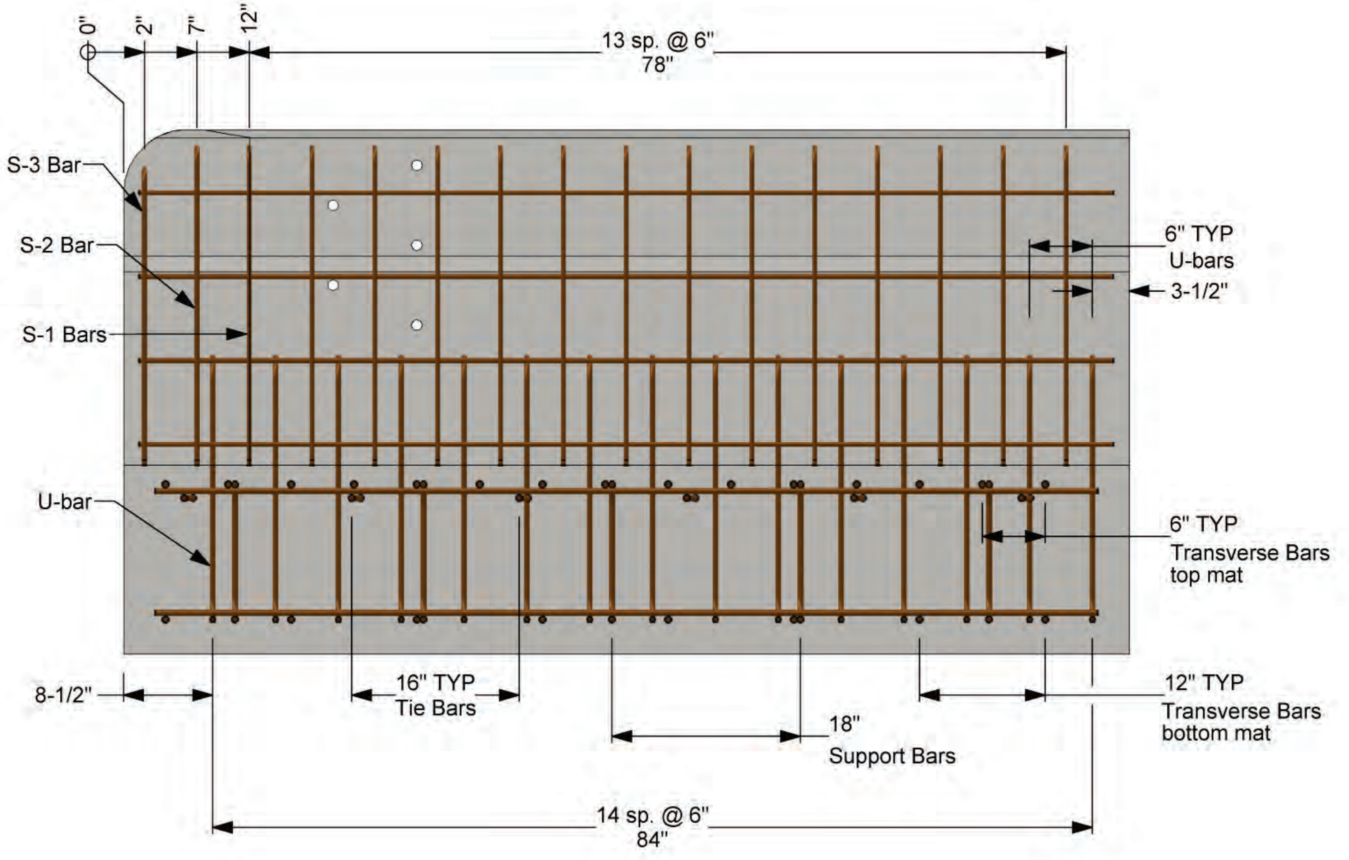
Rebar Details-1

(Elevation View)



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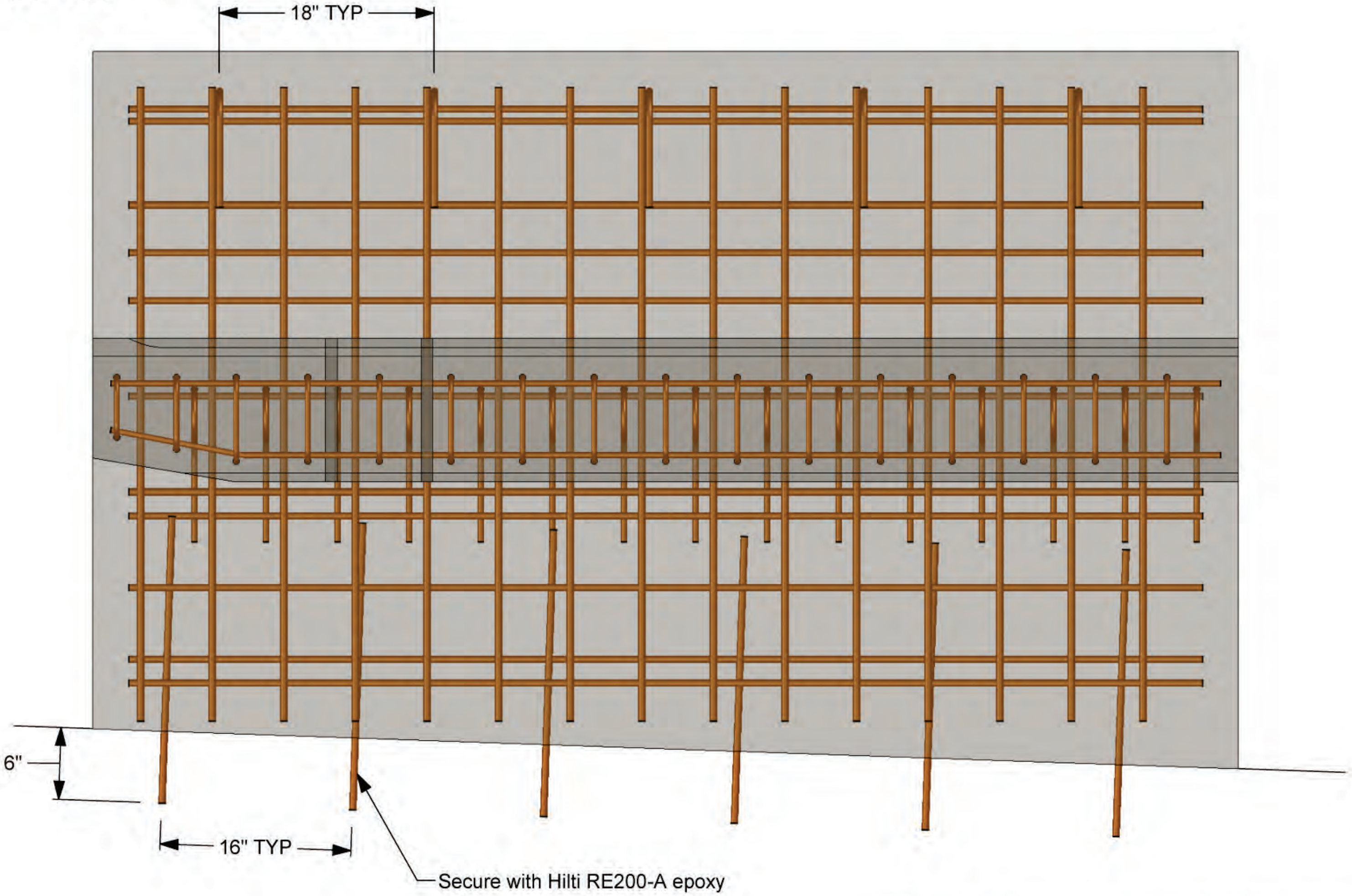
Drawn By GES	Scale 1:15	Sheet 10 of 22	Rebar Details-1

T:\2013-2014\467114-ShortRadius\Drafting\467114 Drawing

Rebar Details-2

(Plan View)



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Drawn By GES	Scale 1:12	Sheet 11 of 22	Rebar Details-2

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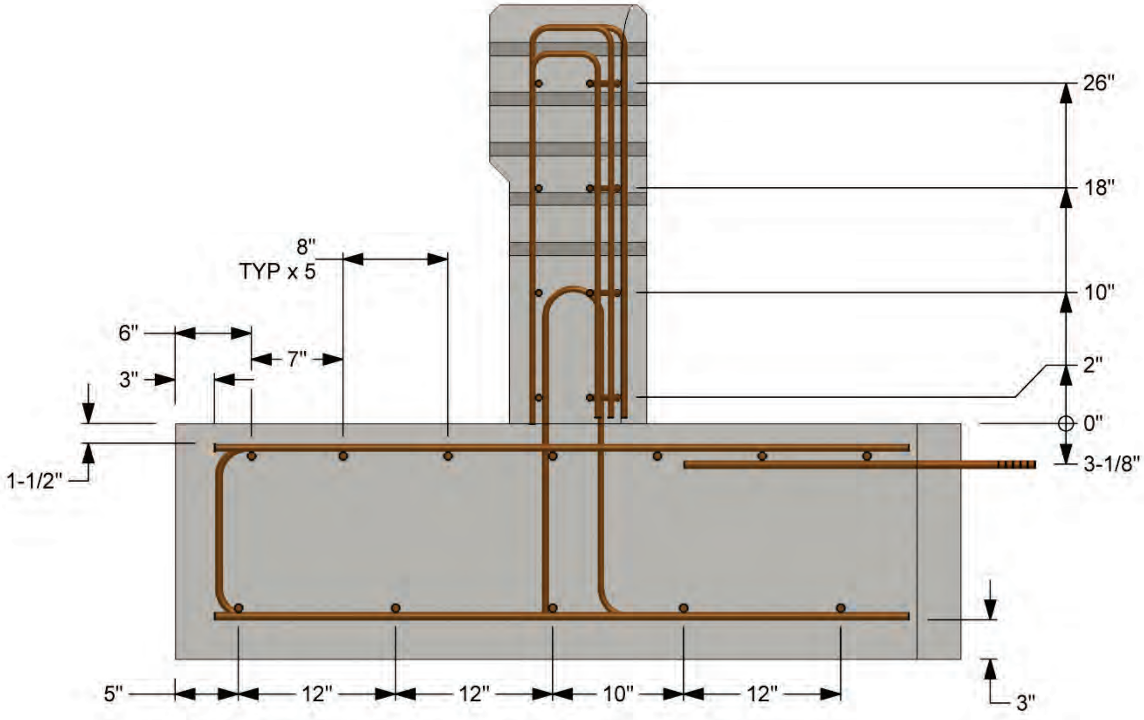
Rebar Details-3

(End View)



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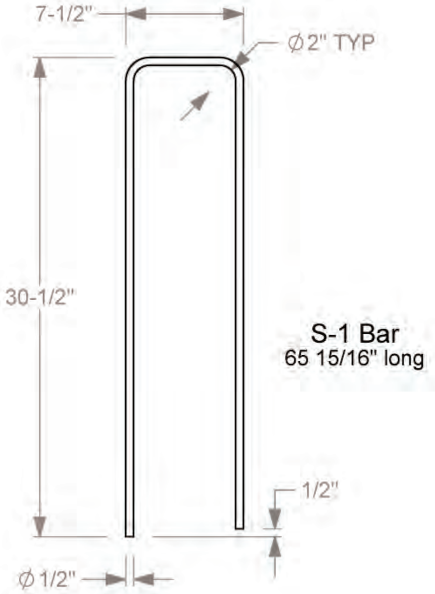
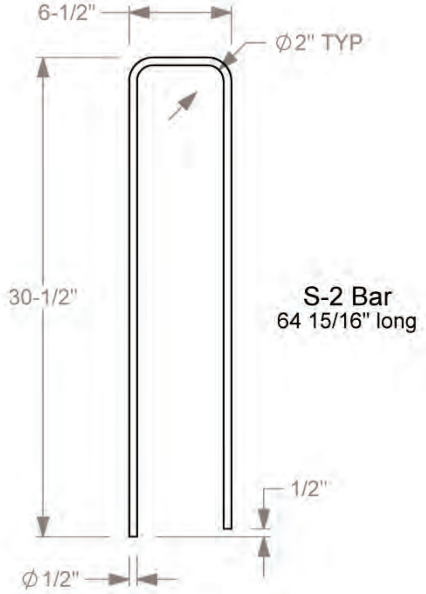
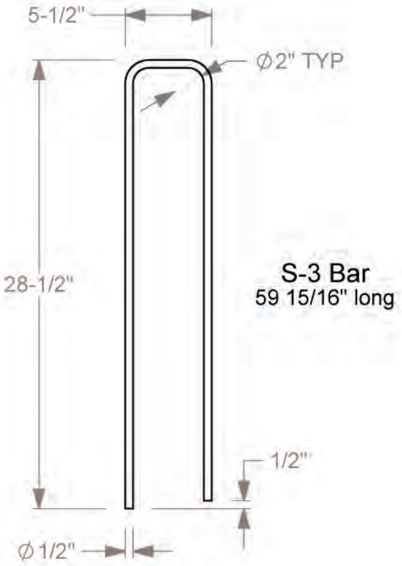
Drawn By GES Scale 1:12 Sheet 12 of 22 Rebar Details-3

T:\2013-2014\467114-ShortRadius\Drafting\467114 Drawing

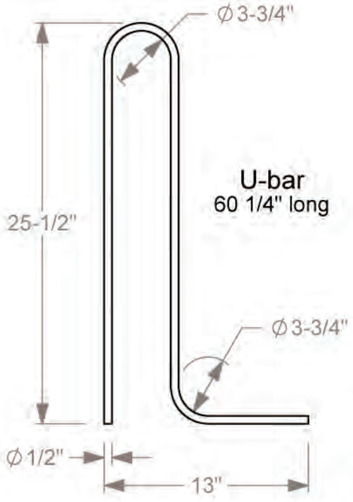


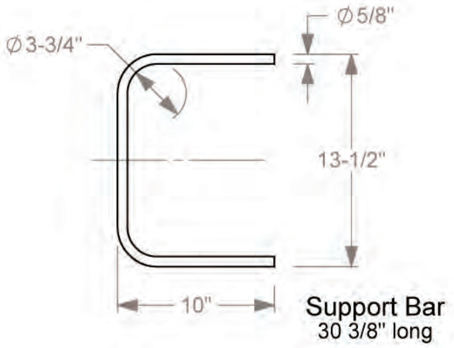




PARTS	
Part Name	QTY.
S-3 Bar	1
S-2 Bar	1
S-1 Bar	14
U-bar	15
Bent Bar	4
Longitudinal Bar, Parapet	4
Longitudinal Bar, Deck	12
Transverse Bar	23
Tie Bar	6
Support Bar	5

13a. All rebar is grade 60.





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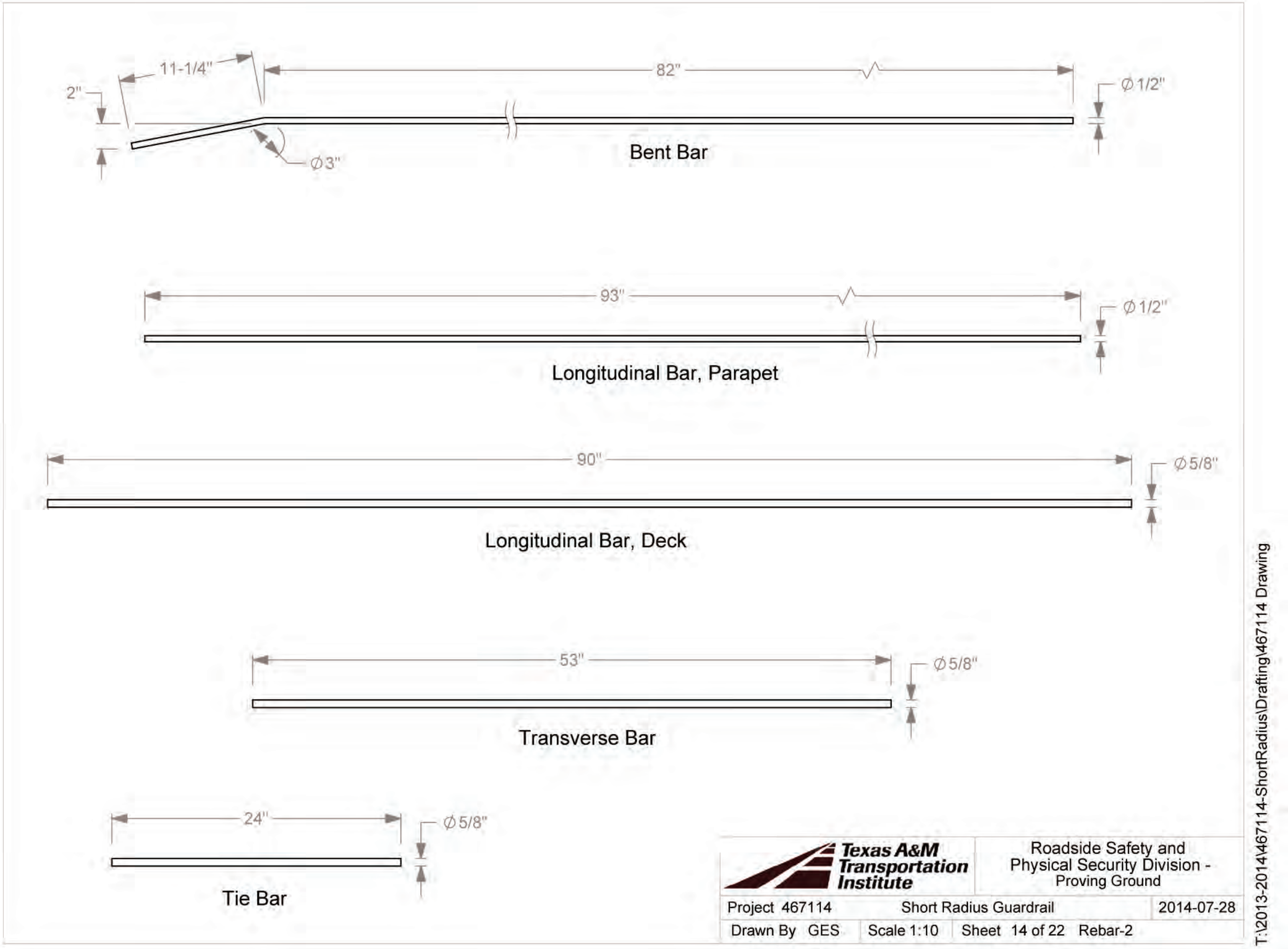

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Rebar-2

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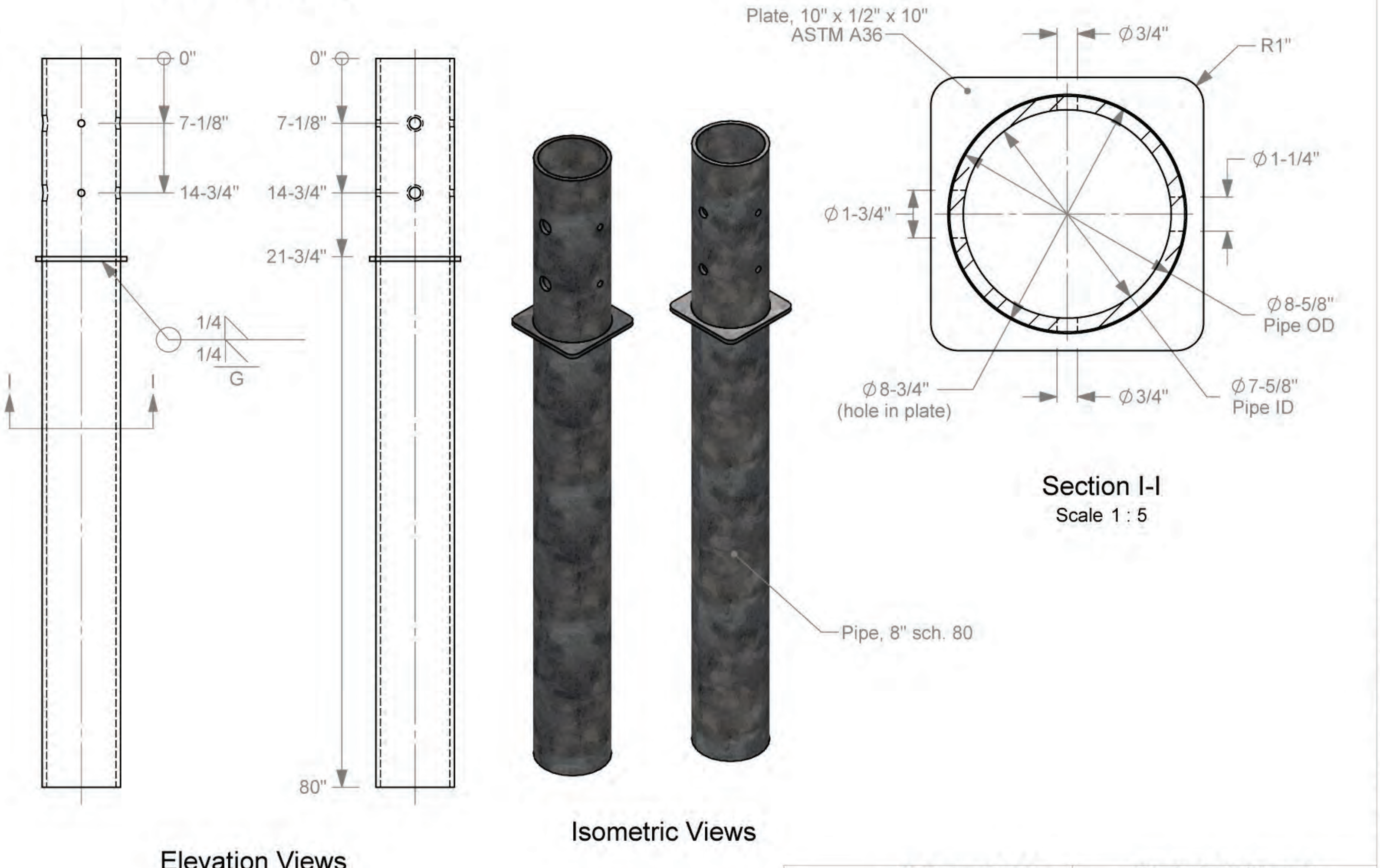
Anchor Post, top



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Drawn By GES | Scale 1:15 | Sheet 15 of 22 | Anchor Post

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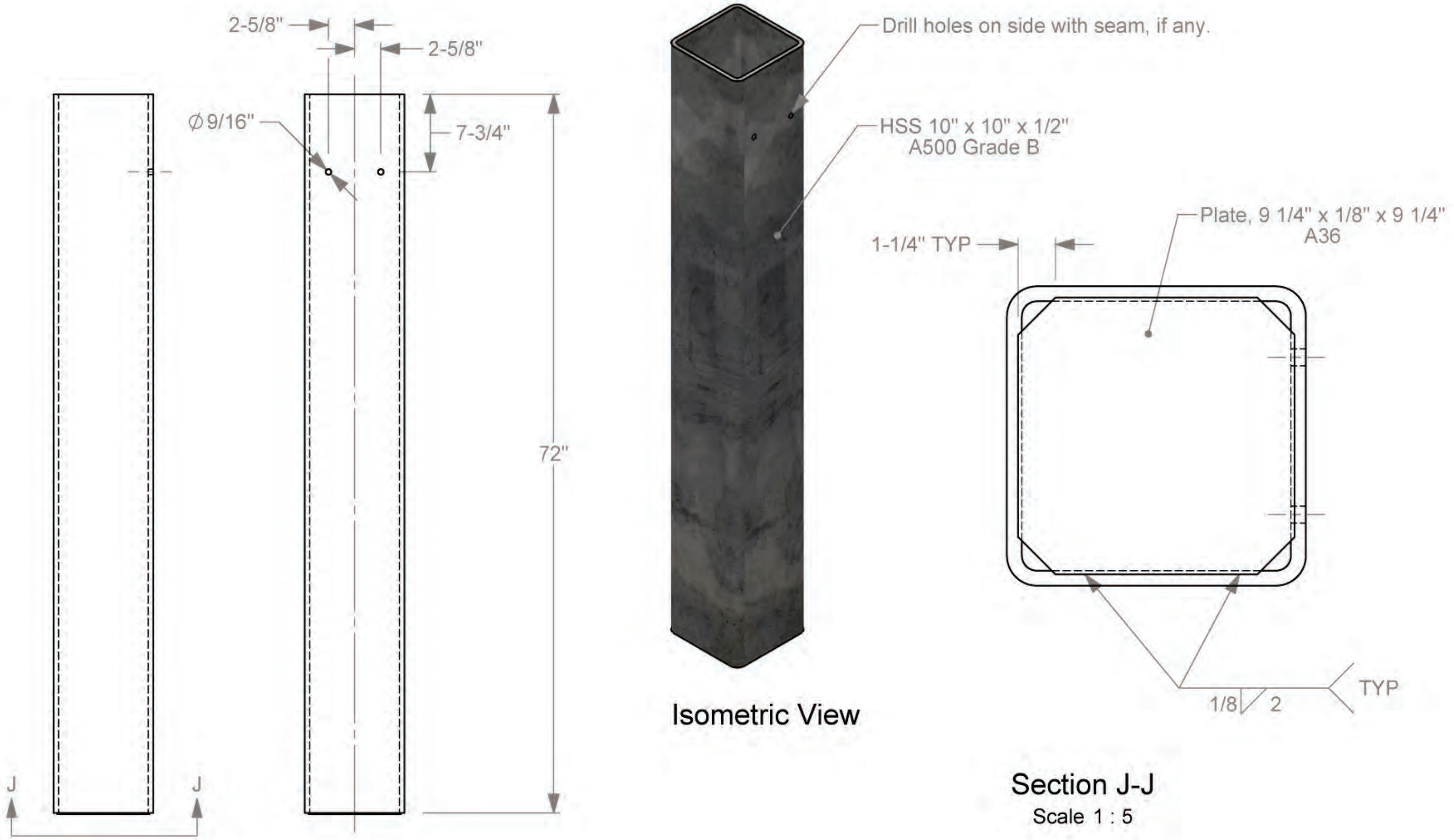
Anchor Post, bottom



Elevation Views

Isometric View

Section J-J
Scale 1 : 5

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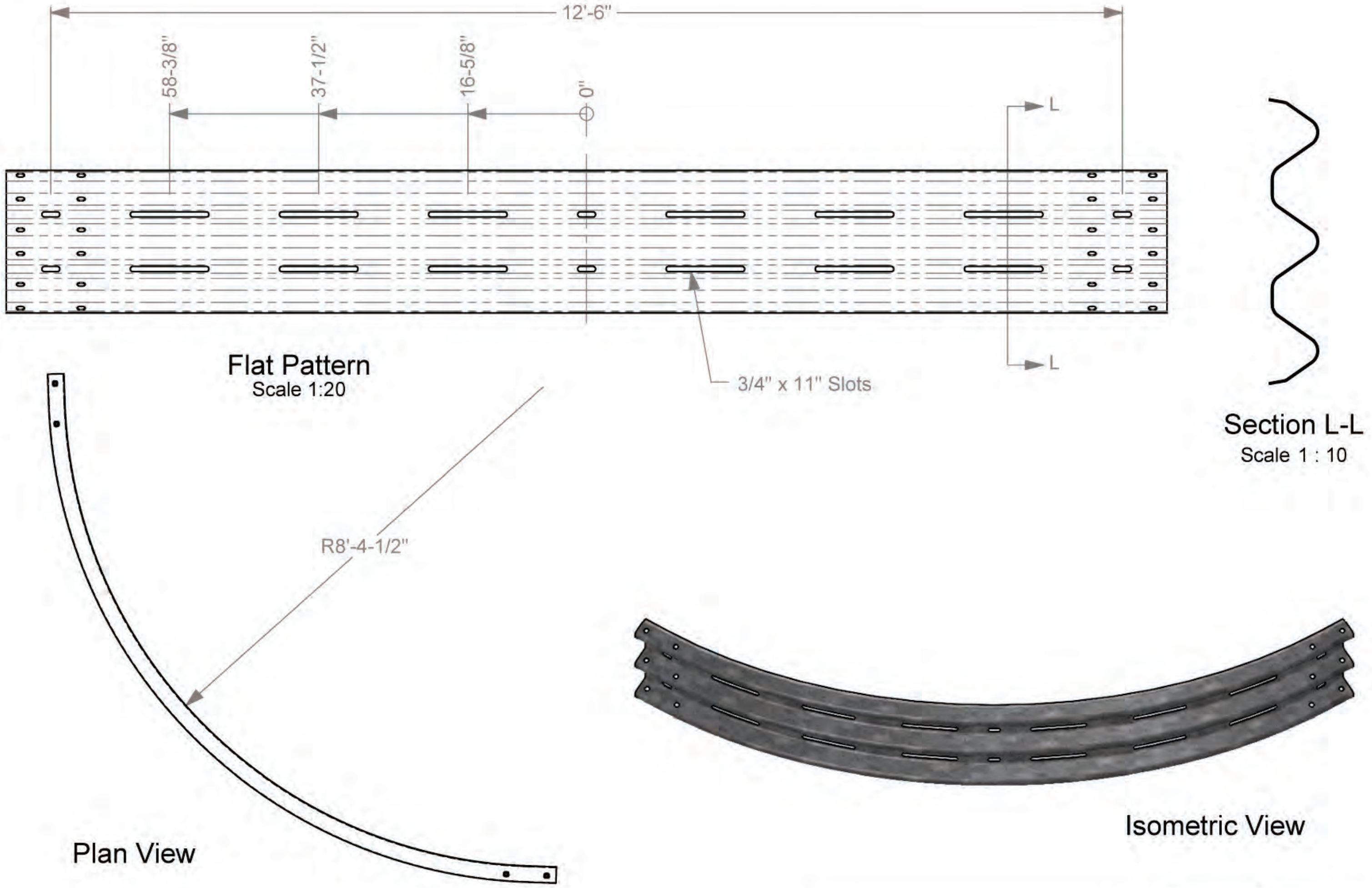
Radius Rail



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

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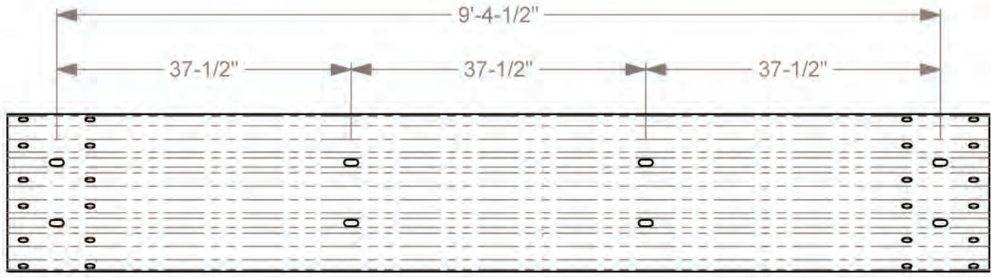
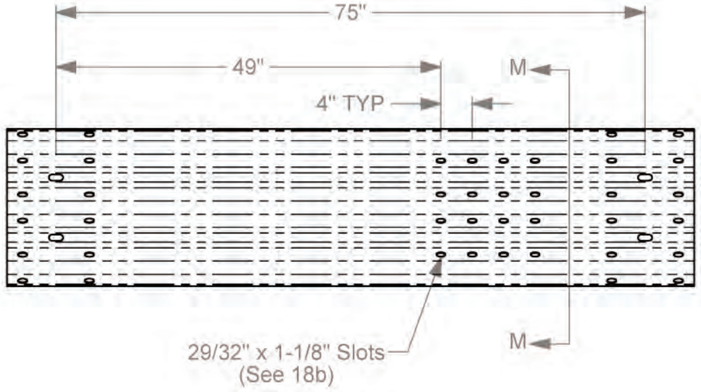
9'-4-1/2" Thrie-beam, 37-1/2" spacing



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).

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Drawn By GES | Scale 1:20 | Sheet 18 of 22 | Thrie-beam Rails

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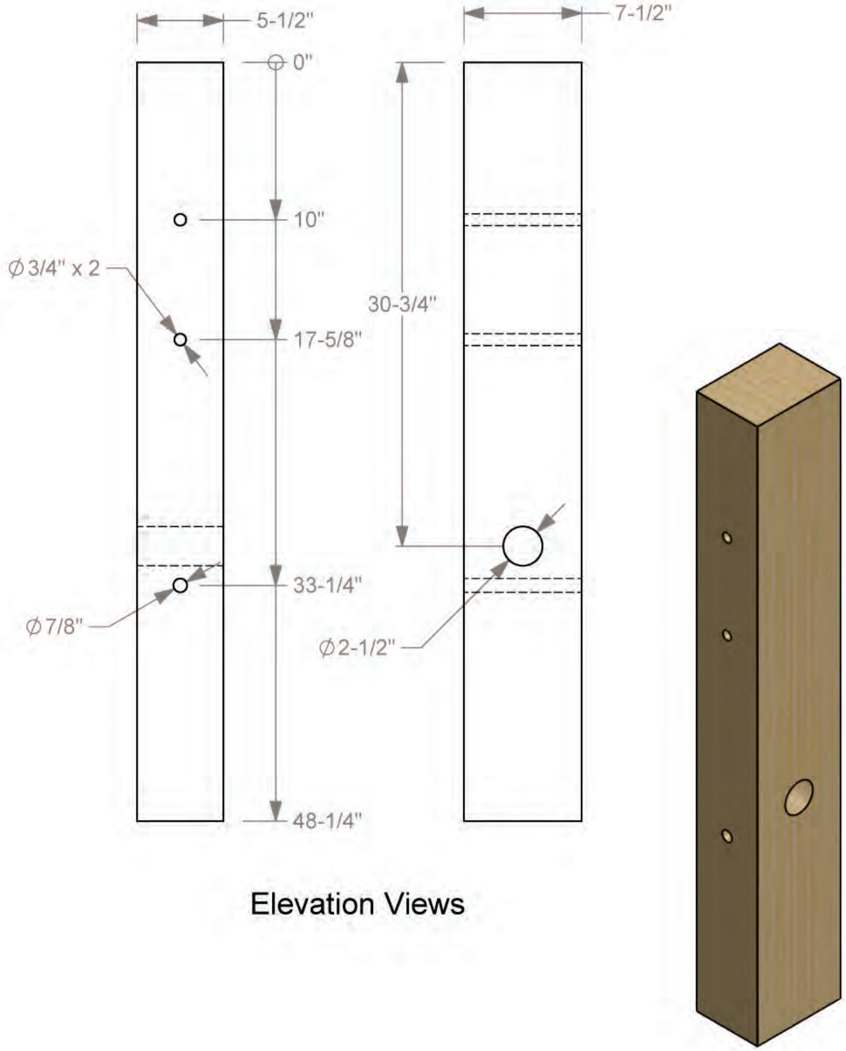
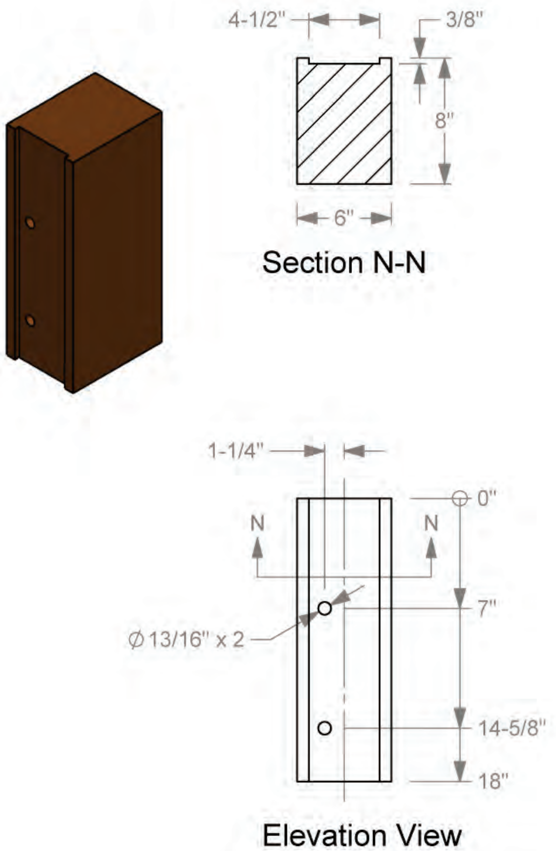
Modified BCT Timber Post



18" Routered Blockout for Thrie-beam



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Drawn By GES Scale 1:10 Sheet 19 of 22 Parts-1

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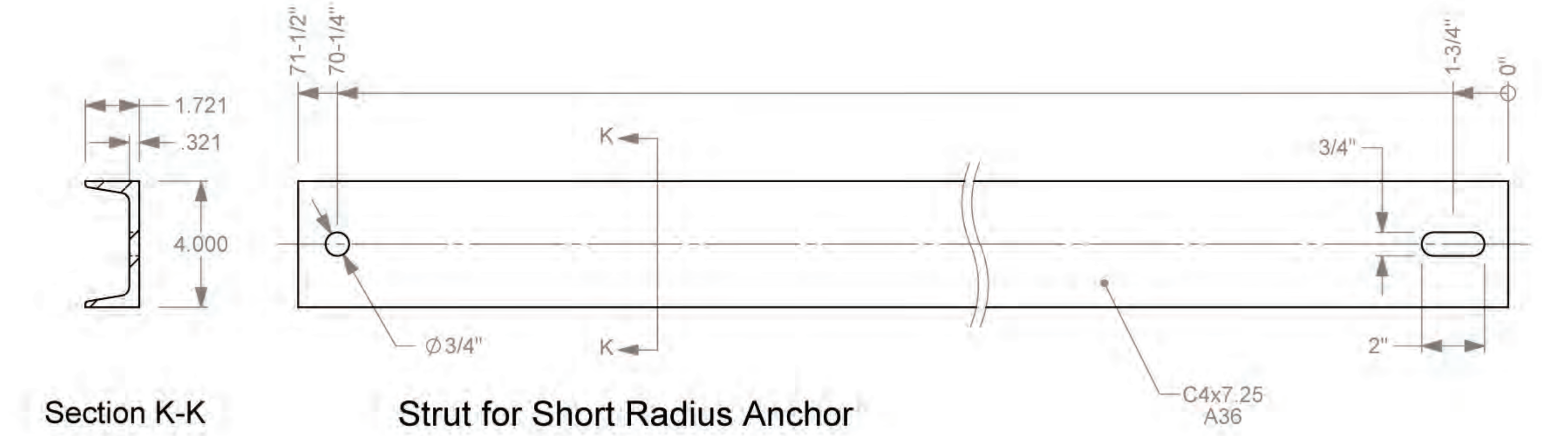
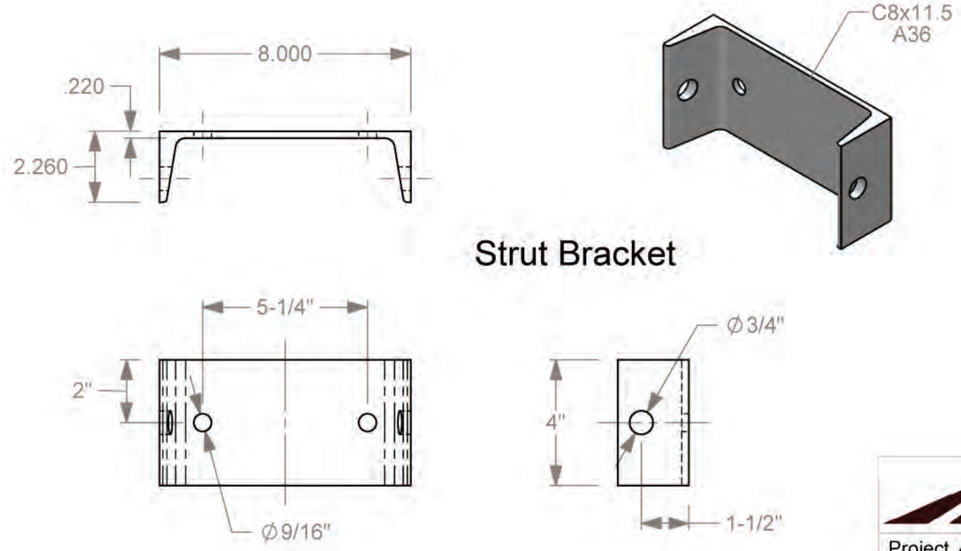


Section K-K

Strut for Short Radius Anchor



Strut Bracket

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Drawn By GES | Scale 1:5 | Sheet 20 of 22 Parts-2

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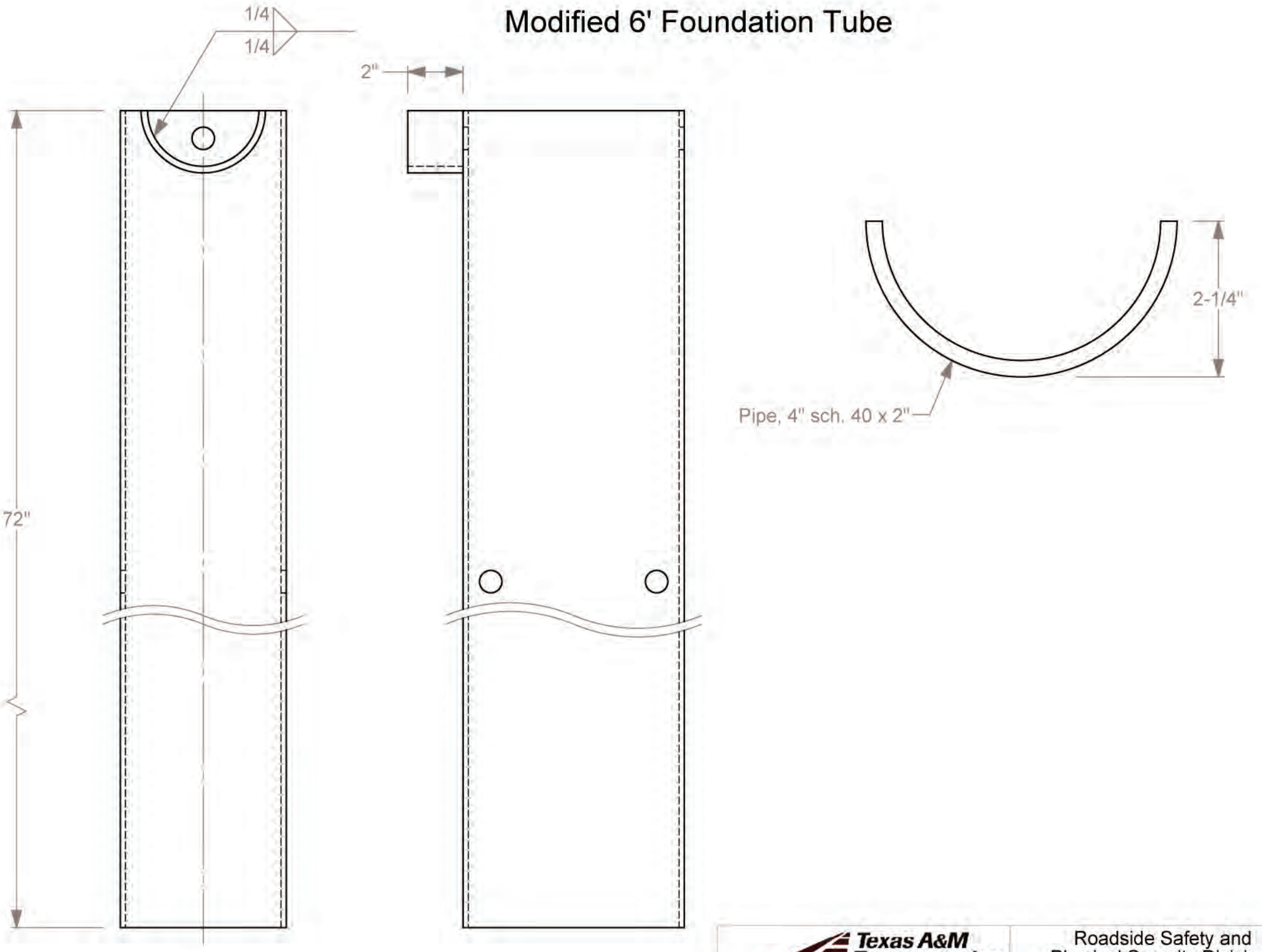
Modified 6' Foundation Tube



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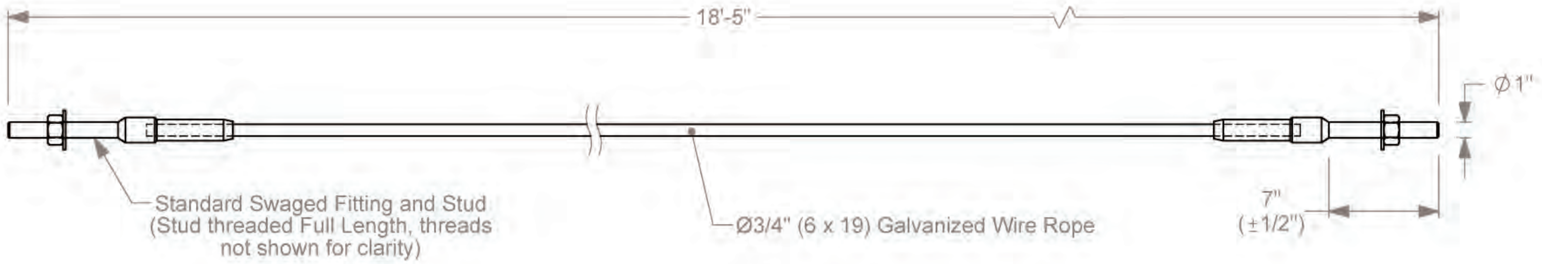
Drawn By GES | Scale 1:5 | Sheet 21 of 22 | Tube Sleeve

T:\2013-2014\467114-ShortRadius\Drafting\467114 Drawing

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

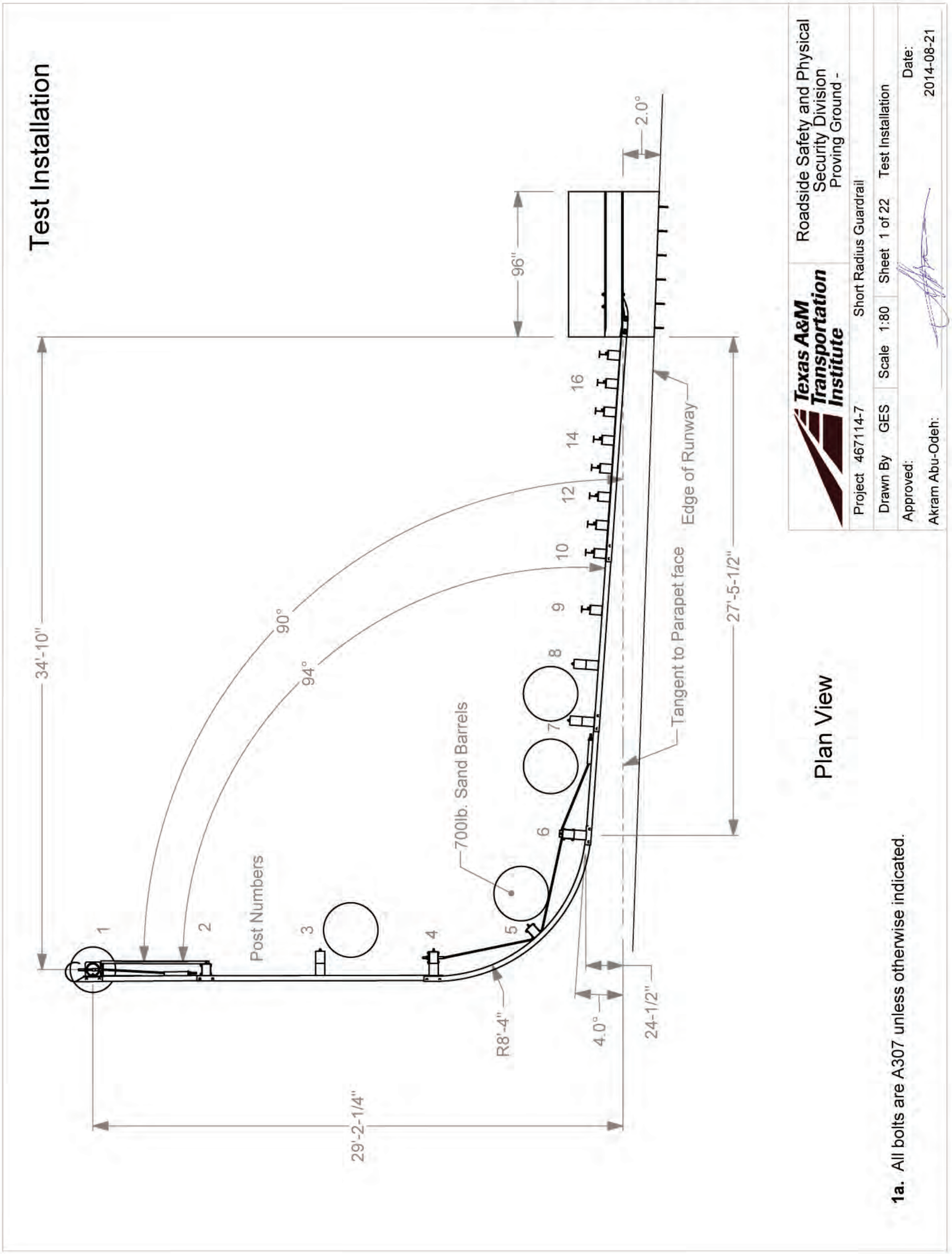
Roadside Safety and
Physical Security Division -
Proving Ground

Project 467114
Short Radius Guardrail
2014-07-28
Drawn By GES
Scale 1:10
Sheet 22 of 22
Anchor Cable

T:\2013-2014\467114-ShortRadius\Drafting\467114 Drawing

APPENDIX C. DETAILS OF THE TEST ARTICLE FOR TEST NO. 467114-7.

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing



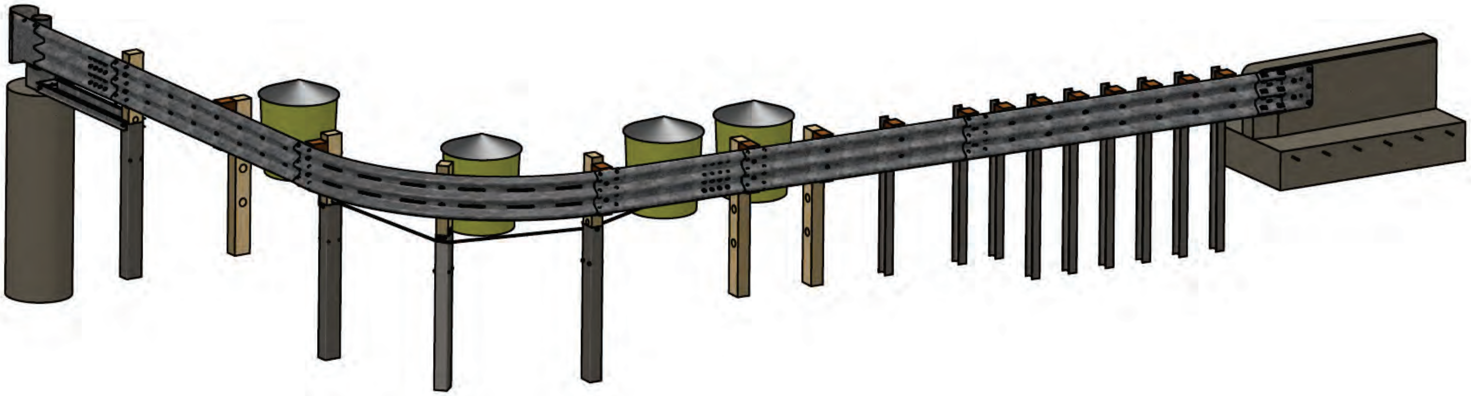
1a. All bolts are A307 unless otherwise indicated.

Texas A&M Transportation Institute

Roadside Safety and Physical Security Division
Proving Ground -

Project 467114-7
Short Radius Guardrail
Drawn By GES
Scale 1:80
Sheet 1 of 22
Test Installation
Approved:
Akram Abu-Odeh:
Date:
2014-08-21

Isometric View



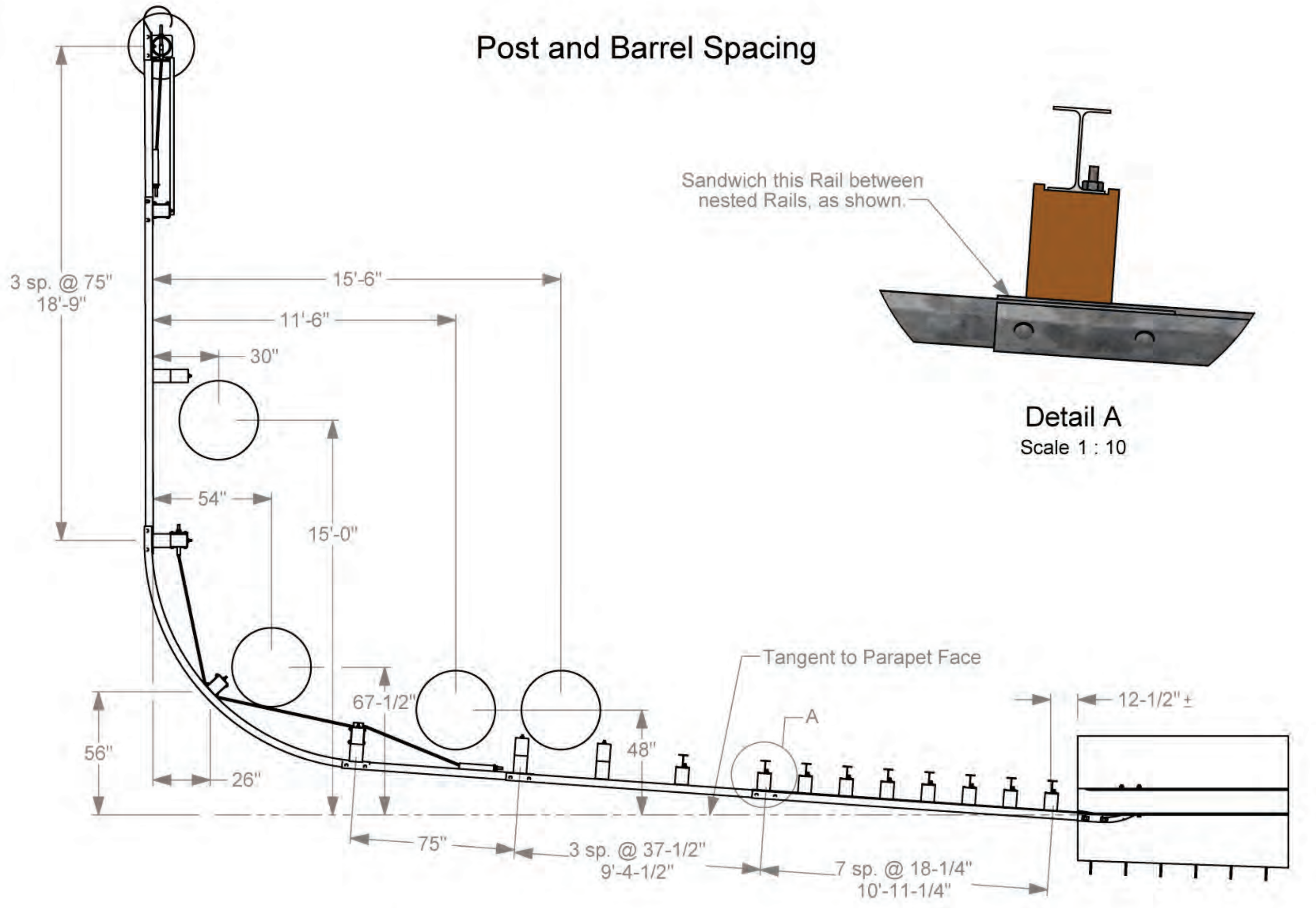
Texas A&M Transportation Institute

Roadside Safety and
Physical Security Division -
Proving Ground

Project 467114-7	Short Radius Guardrail		2014-08-21
Drawn By GES	Scale 1:70	Sheet 2 of 22	Isometric View

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

Post and Barrel Spacing



Detail A
Scale 1 : 10

Plan View

Texas A&M Transportation Institute

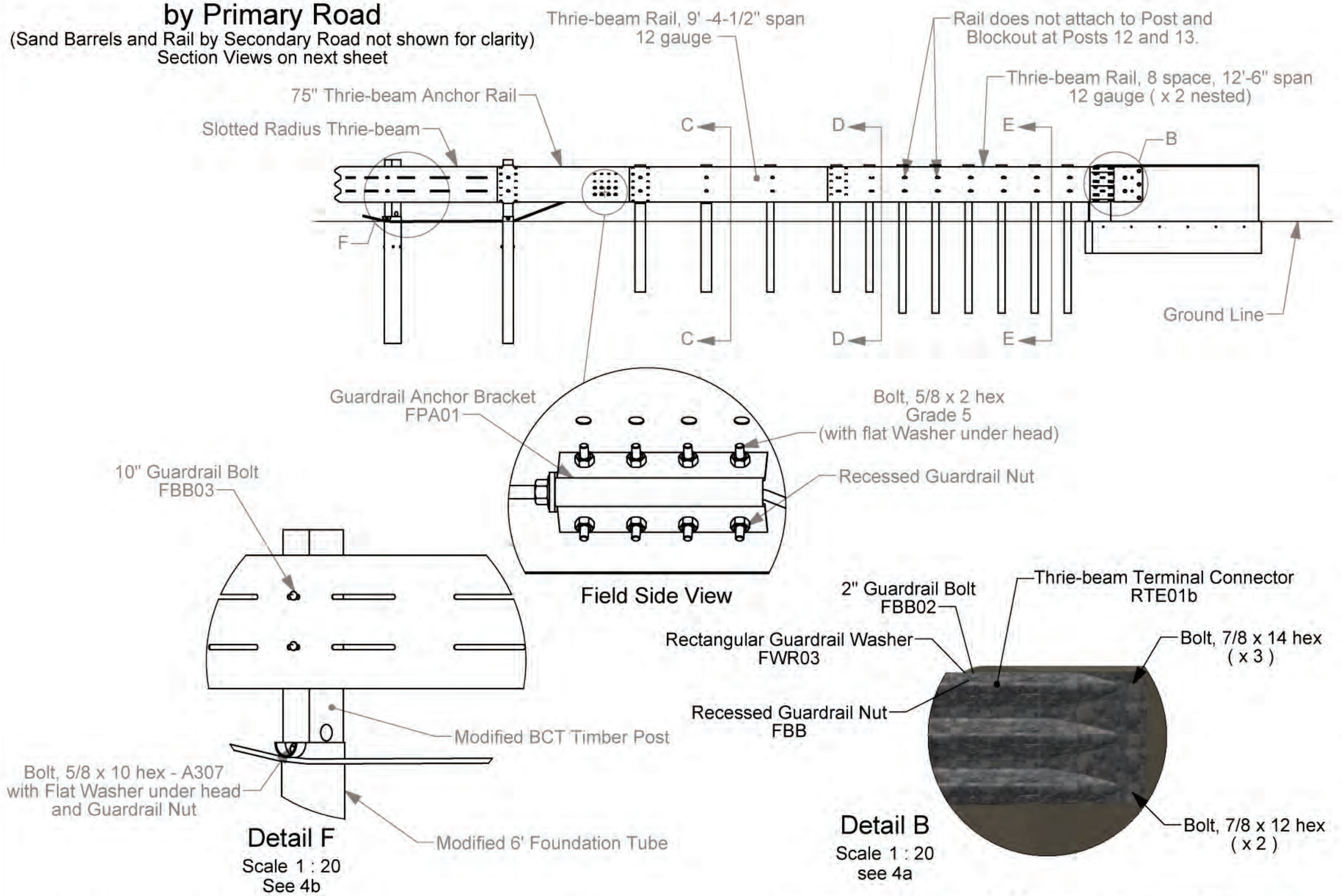
Roadside Safety and Physical Security Division - Proving Ground

Project 467114-7	Short Radius Guardrail		2014-08-21
Drawn By GES	Scale 1:65	Sheet 3 of 22	Post and Barrel Spacing

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

by Primary Road

(Sand Barrels and Rail by Secondary Road not shown for clarity)
Section Views on next sheet

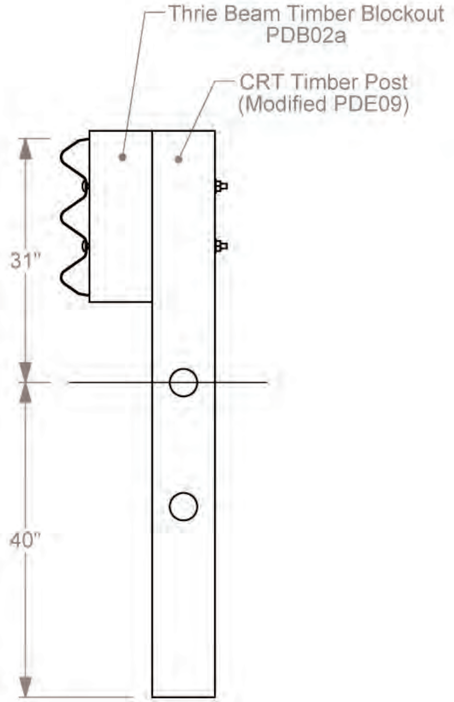


4a. A325 bolts with 1-3/4" OD (hardened) flat Washer under each Bolt head and Nut attaching Terminal Connector to Parapet.

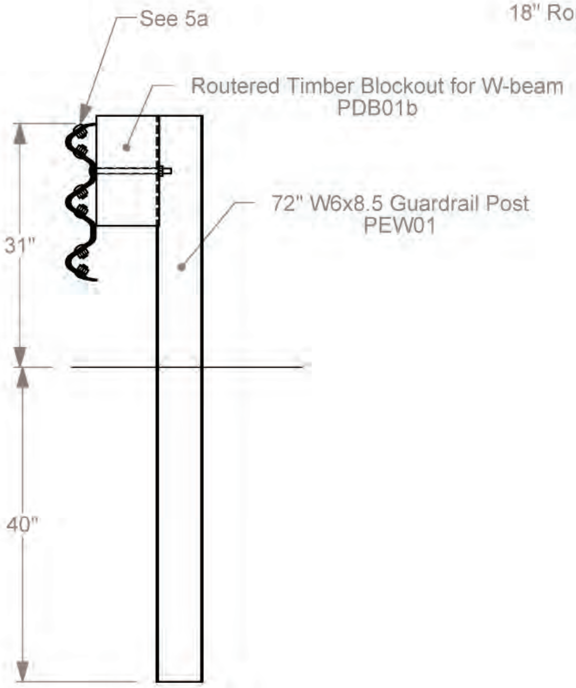
4b. Detail A shows Post 5. Post 6 is similar, but with Blockout and 18" Guardrail Bolts, Modified Tube Post rotated 180° (so Pipe Section welded to Foundation Tube will be on Field Side), and Anchor Cable on Field Side (see Sheets 1 and 3).

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project 467114-7	Short Radius Guardrail		2014-08-21
Drawn By GES	Scale 1:75	Sheet 4 of 22	by Primary Road

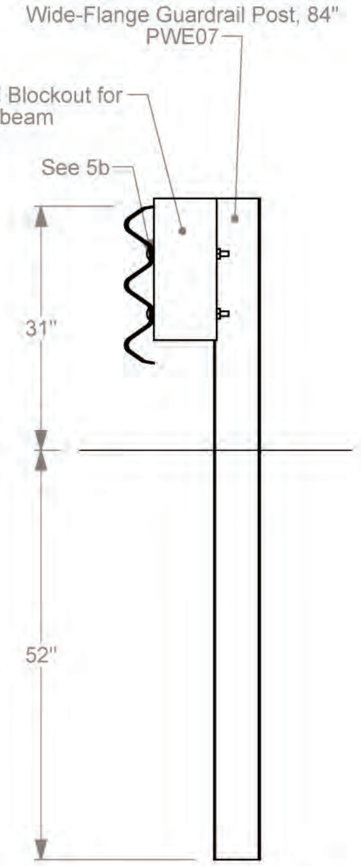
T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing



Section C-C
TYP at Posts 3 and 7 - 8



Section D-D
TYP at Posts 9 - 11



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.

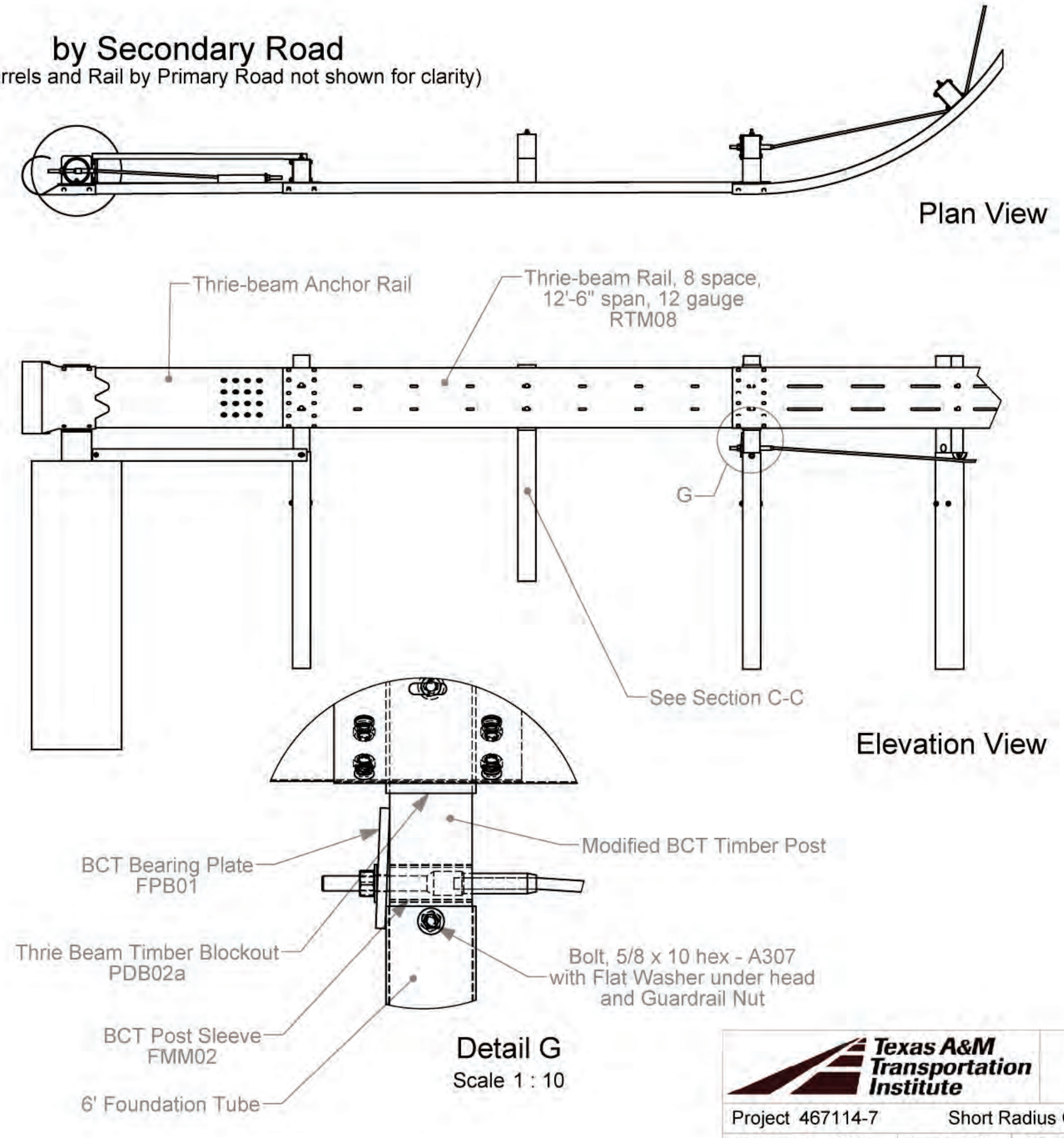
5b. Rail does not attach to Post and Blockout at Posts 12 and 13.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
Project 467114-7	Short Radius Guardrail		2014-08-21
Drawn By GES	Scale 1:20	Sheet 5 of 22	Section Views

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

by Secondary Road

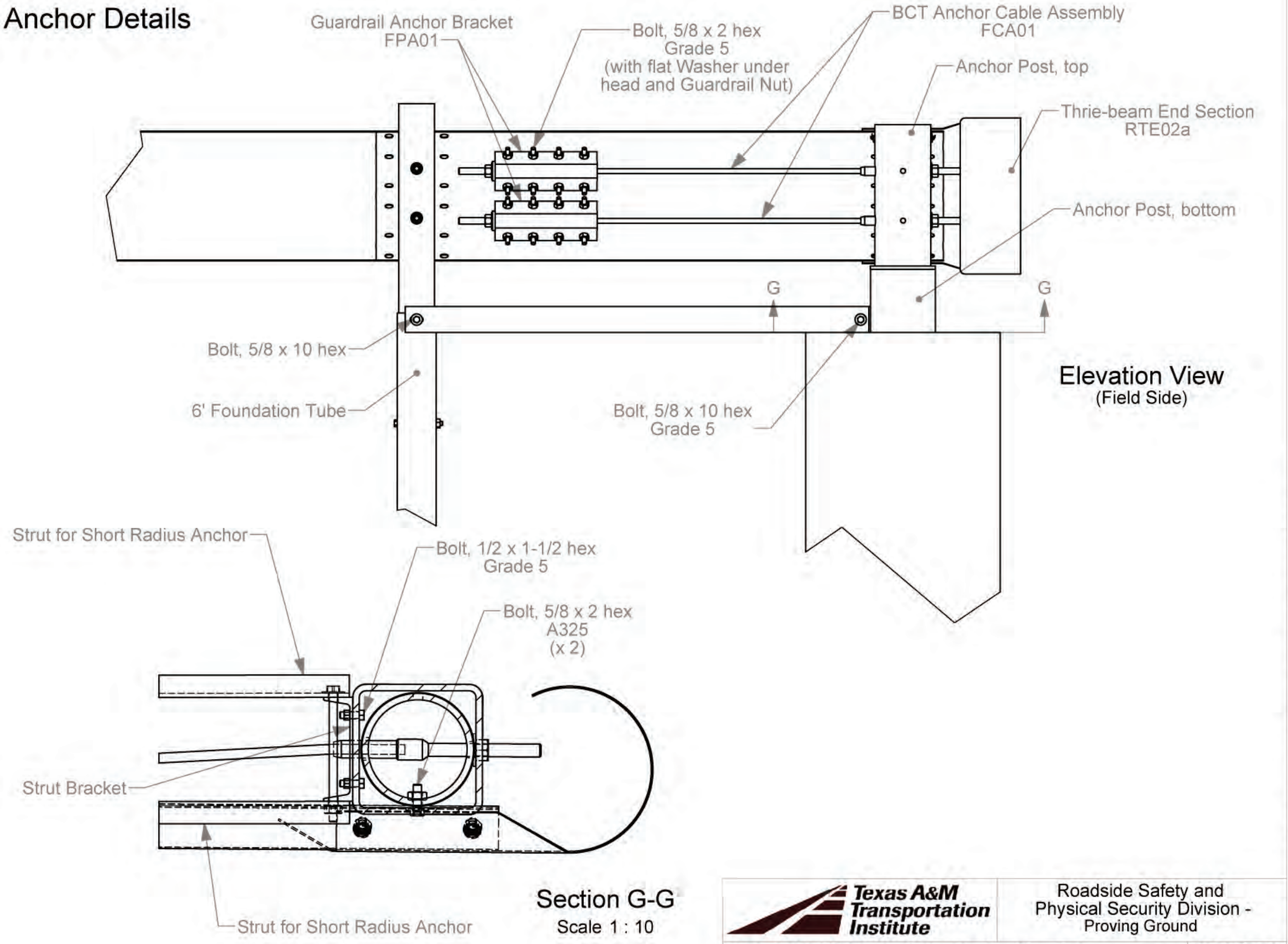
(Sand Barrels and Rail by Primary Road not shown for clarity)



Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project 467114-7	Short Radius Guardrail		2014-08-21
Drawn By GES	Scale 1:50	Sheet 6 of 22	by Secondary Road

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

Anchor Details



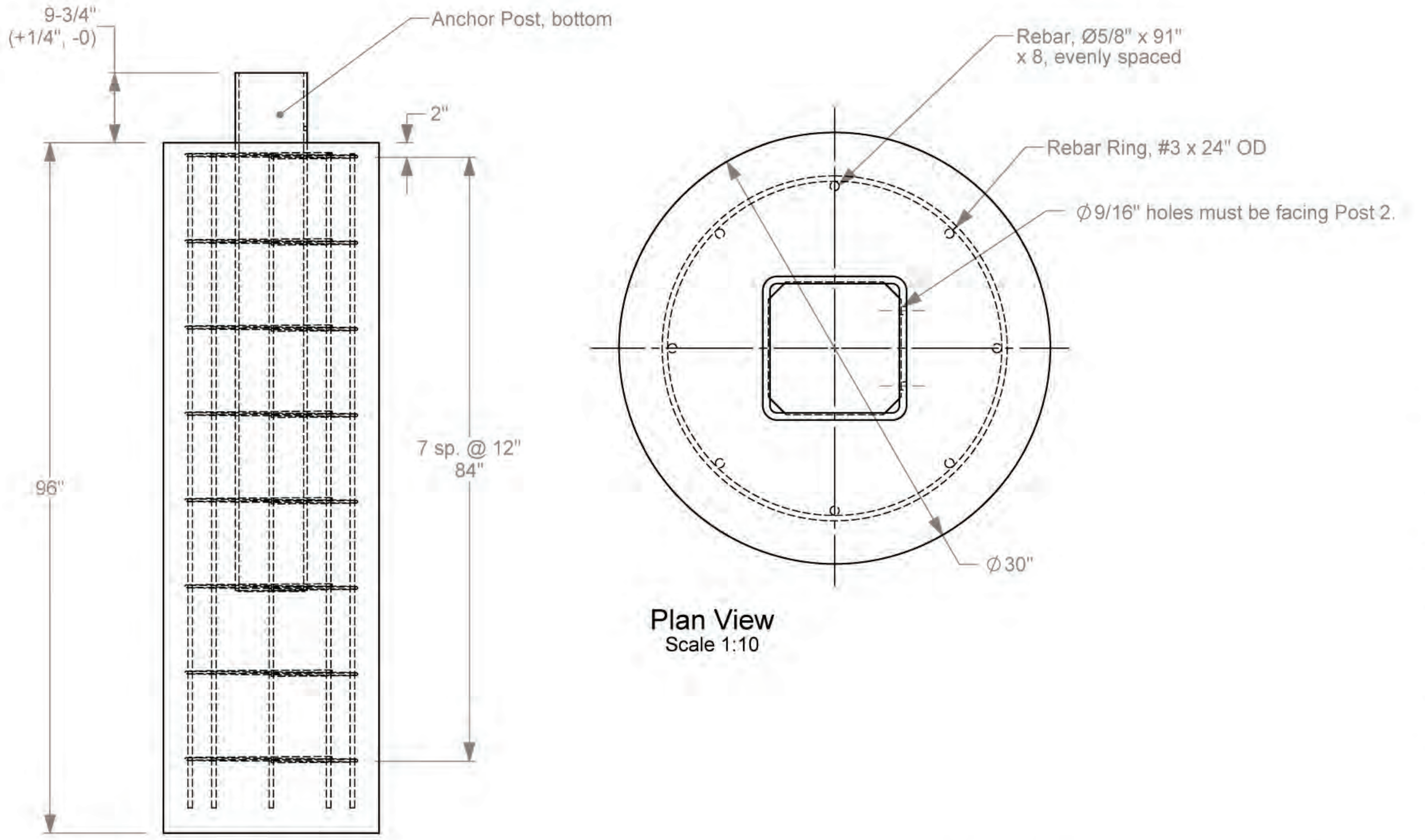
Elevation View
(Field Side)

Section G-G
Scale 1 : 10

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project 467114-7	Short Radius Guardrail		2014-08-21
Drawn By GES	Scale 1:20	Sheet 7 of 22	Anchor Details

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

Post 1 Foundation



Elevation View

Plan View
Scale 1:10

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

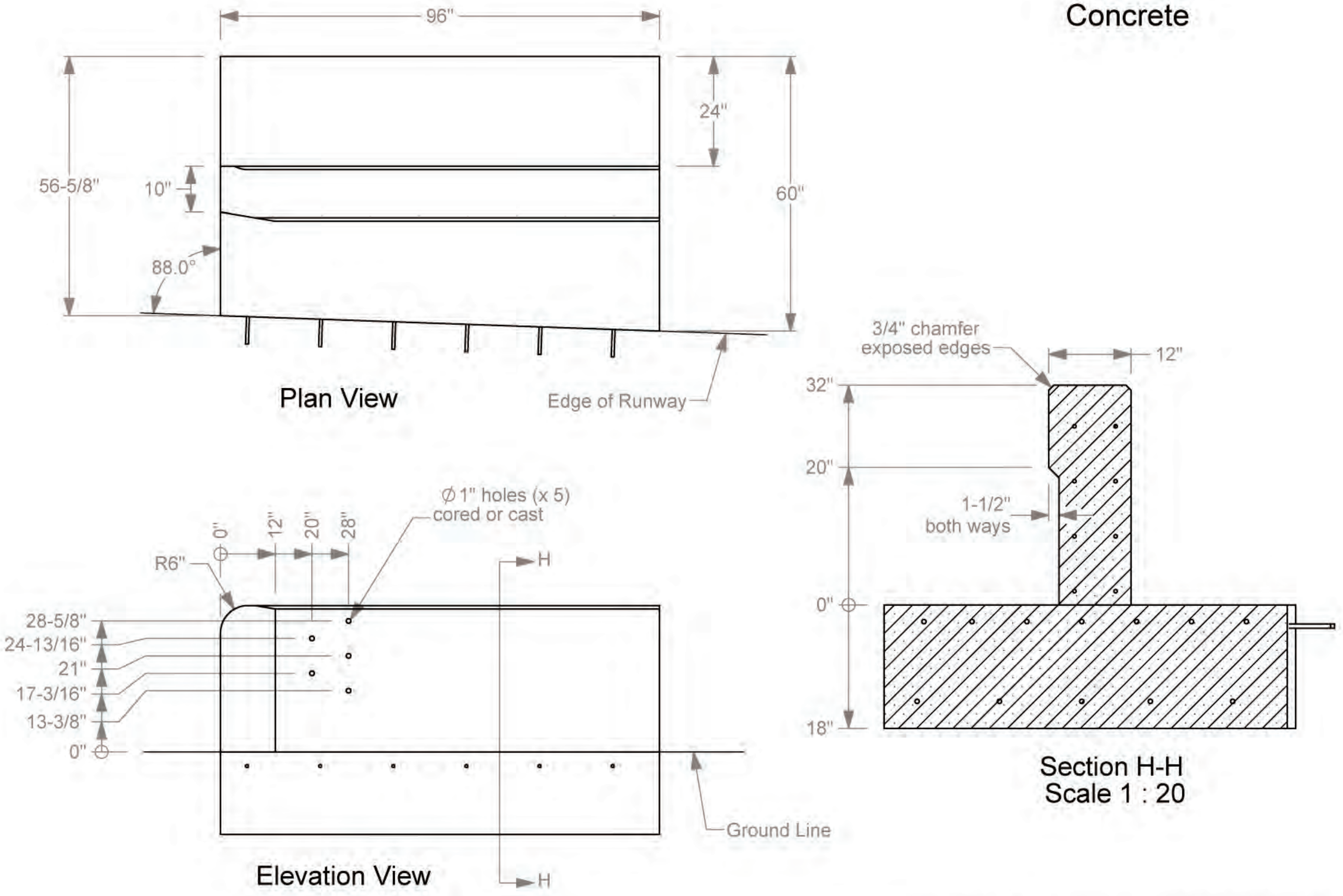
Texas A&M Transportation Institute

Roadside Safety and
Physical Security Division -
Proving Ground

Project 467114-7	Short Radius Guardrail		2014-08-21
Drawn By GES	Scale 1:20	Sheet 8 of 22	Post 1 Foundation

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

Concrete



9a. Concrete is TxDOT Class C (3600 psi).

Texas A&M Transportation Institute

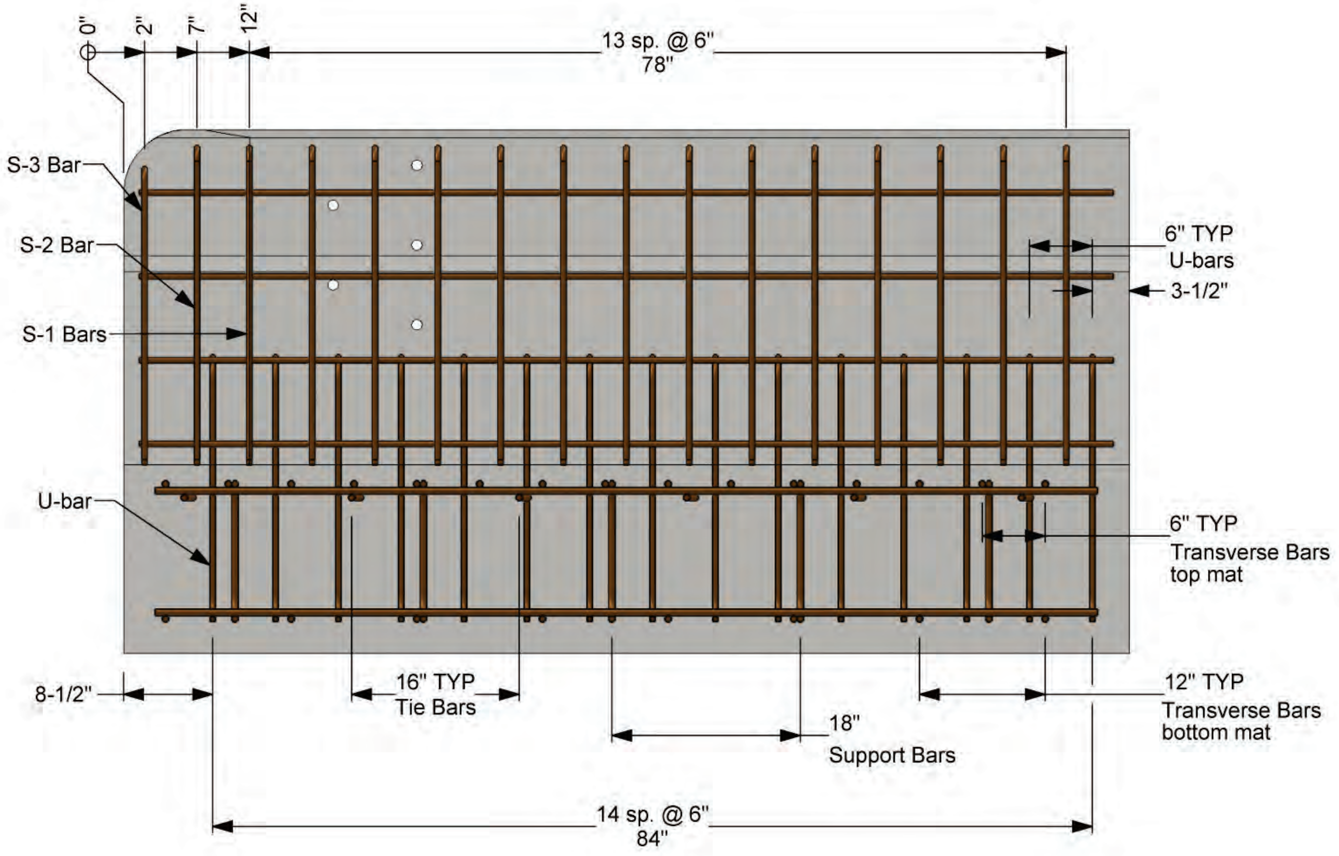
Roadside Safety and Physical Security Division - Proving Ground

Project 467114-7	Short Radius Guardrail	2014-08-21
Drawn By GES	Scale 1:30	Sheet 9 of 22 Concrete

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

Rebar Details-1

(Elevation View)



Texas A&M Transportation Institute

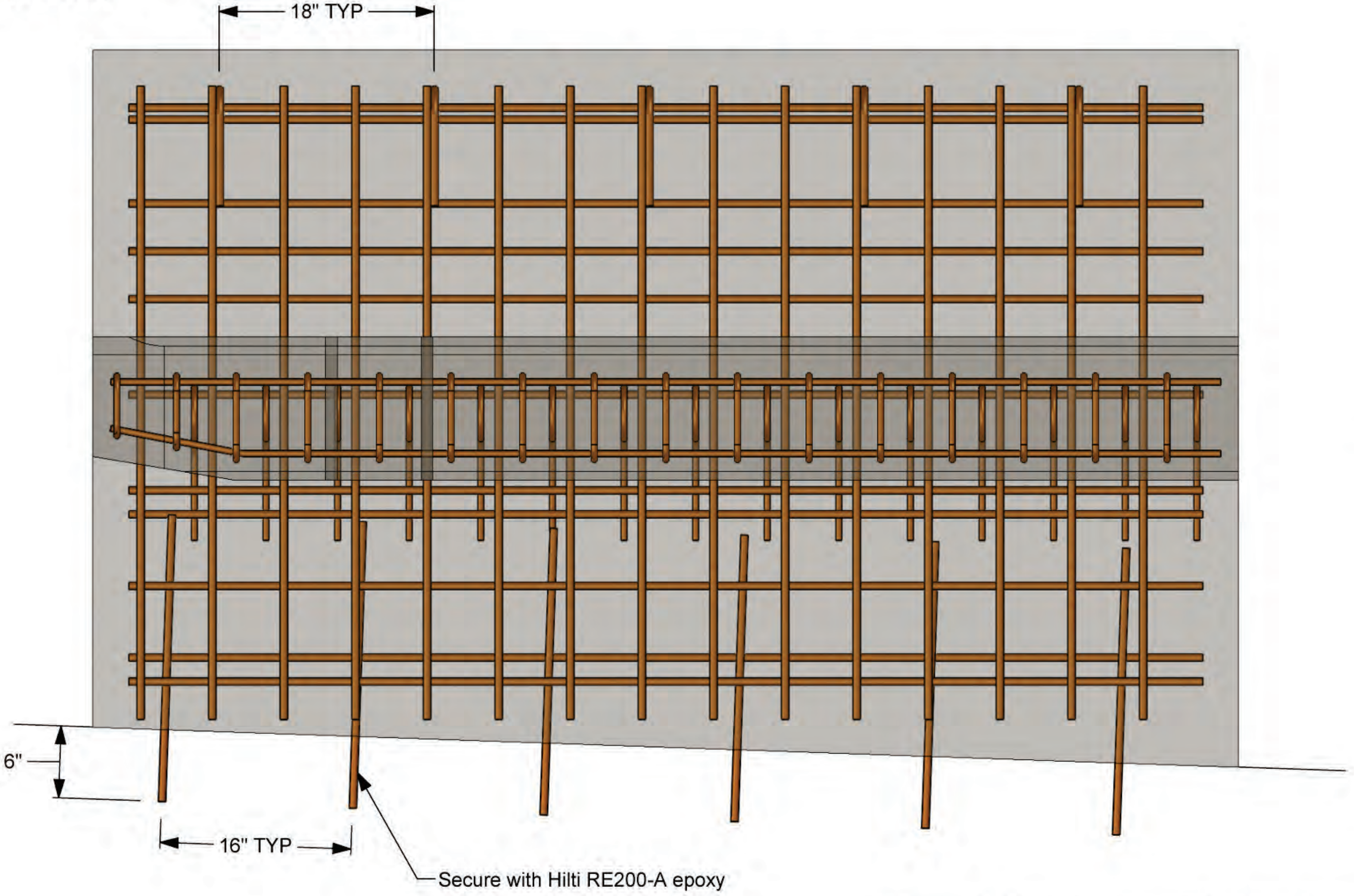
Roadside Safety and
Physical Security Division -
Proving Ground

Project 467114-7	Short Radius Guardrail	2014-08-21
Drawn By GES	Scale 1:15	Sheet 10 of 22 Rebar Details-1

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

Rebar Details-2

(Plan View)



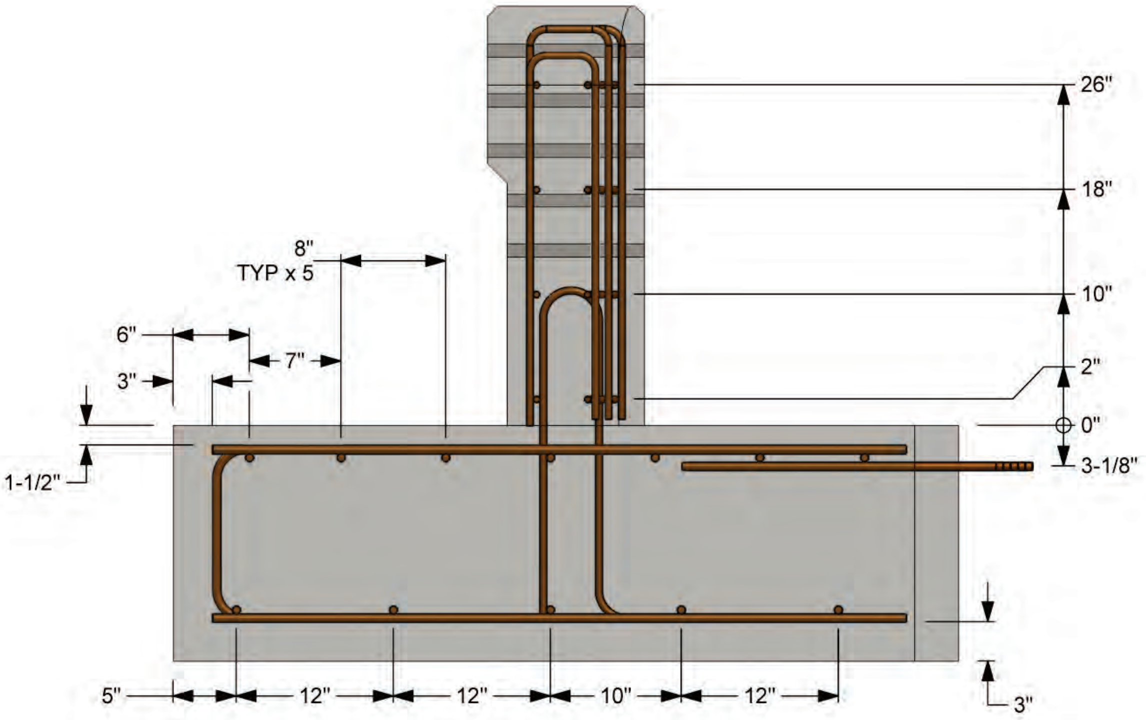
Texas A&M Transportation Institute

Roadside Safety and
Physical Security Division -
Proving Ground

Project 467114-7	Short Radius Guardrail	2014-08-21
Drawn By GES	Scale 1:12	Sheet 11 of 22 Rebar Details-2

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

Rebar Details-3
(End View)



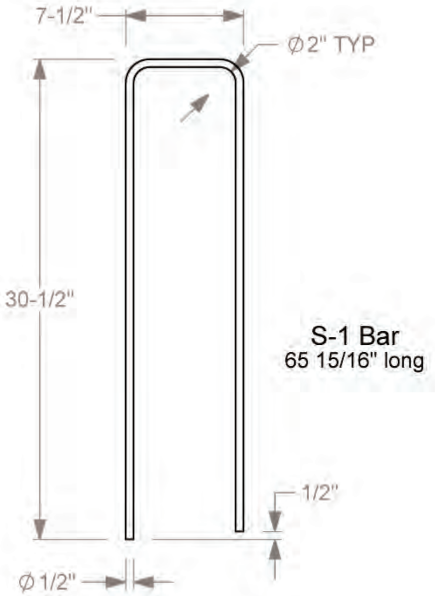
Texas A&M Transportation Institute

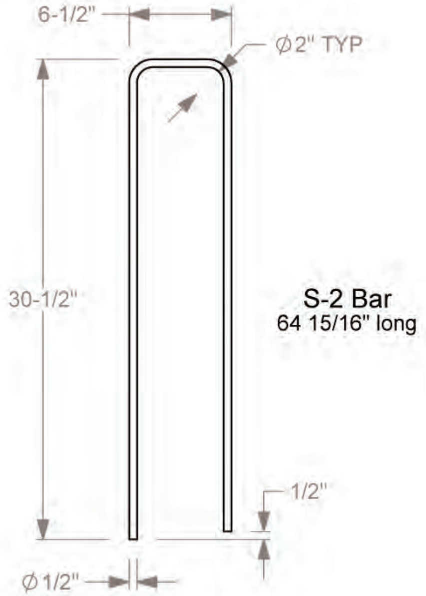
Roadside Safety and Physical Security Division - Proving Ground

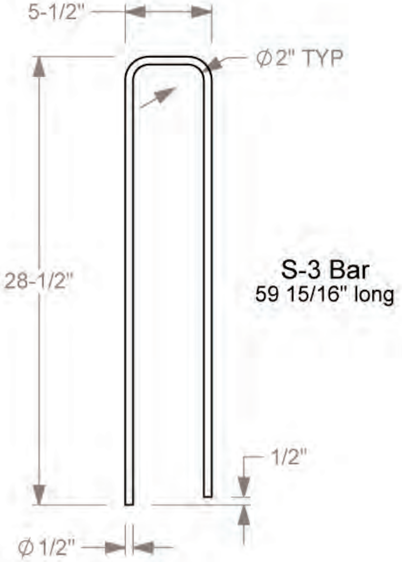
Project 467114-7 | Short Radius Guardrail | 2014-08-21

Drawn By GES | Scale 1:12 | Sheet 12 of 22 | Rebar Details-3

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

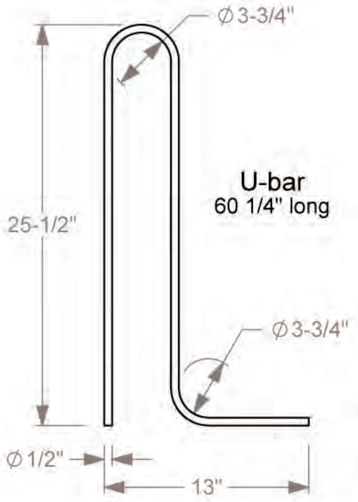


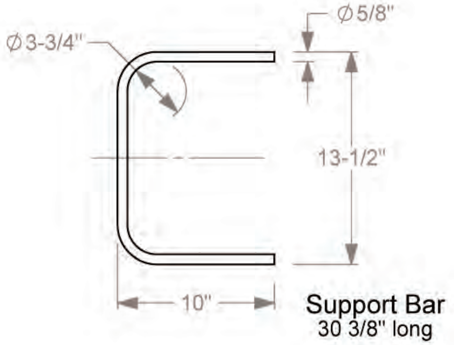




PARTS	
Part Name	QTY.
S-3 Bar	1
S-2 Bar	1
S-1 Bar	14
U-bar	15
Bent Bar	4
Longitudinal Bar, Parapet	4
Longitudinal Bar, Deck	12
Transverse Bar	23
Tie Bar	6
Support Bar	5

13a. All rebar is grade 60.



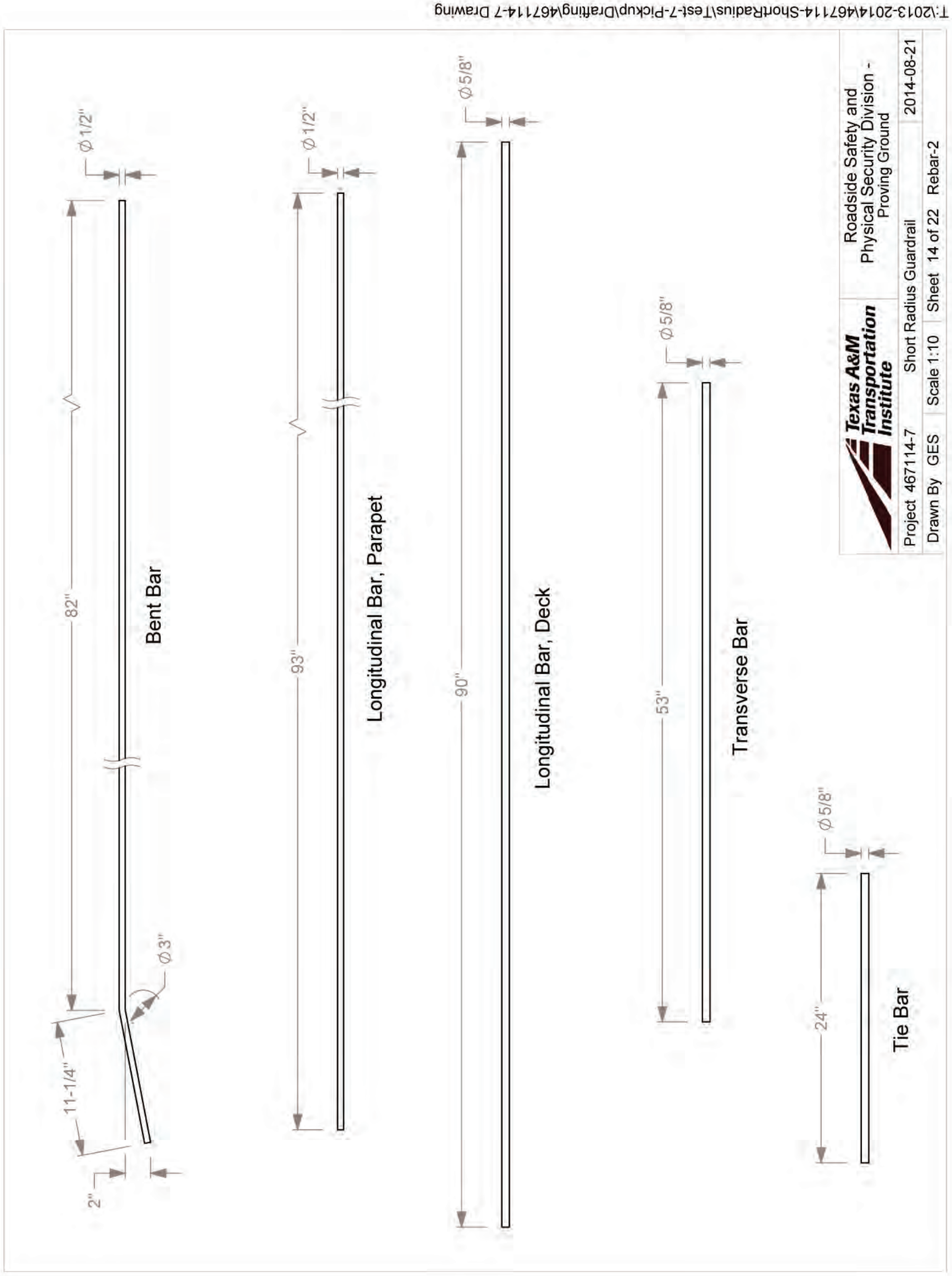


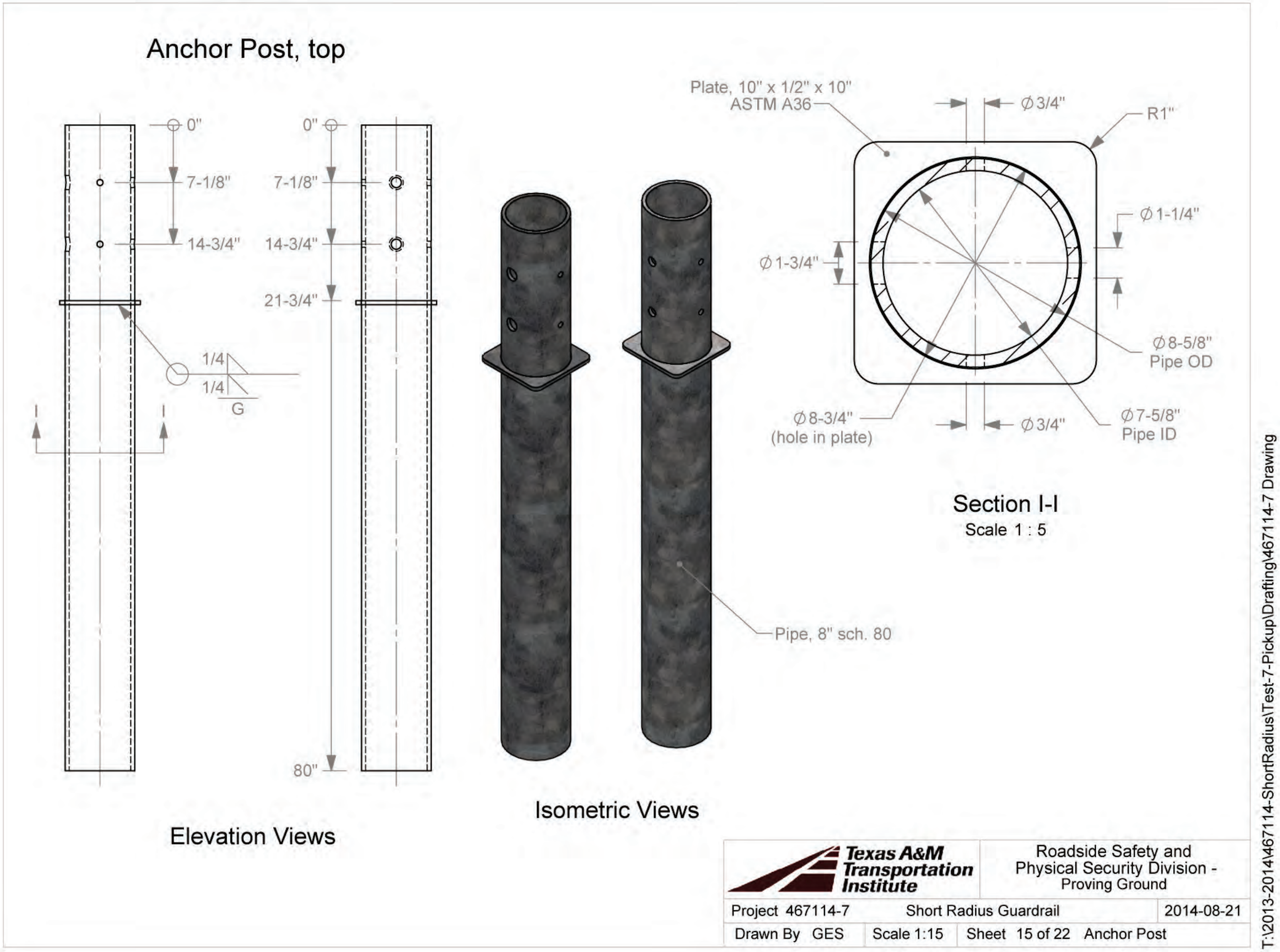
Texas A&M Transportation Institute

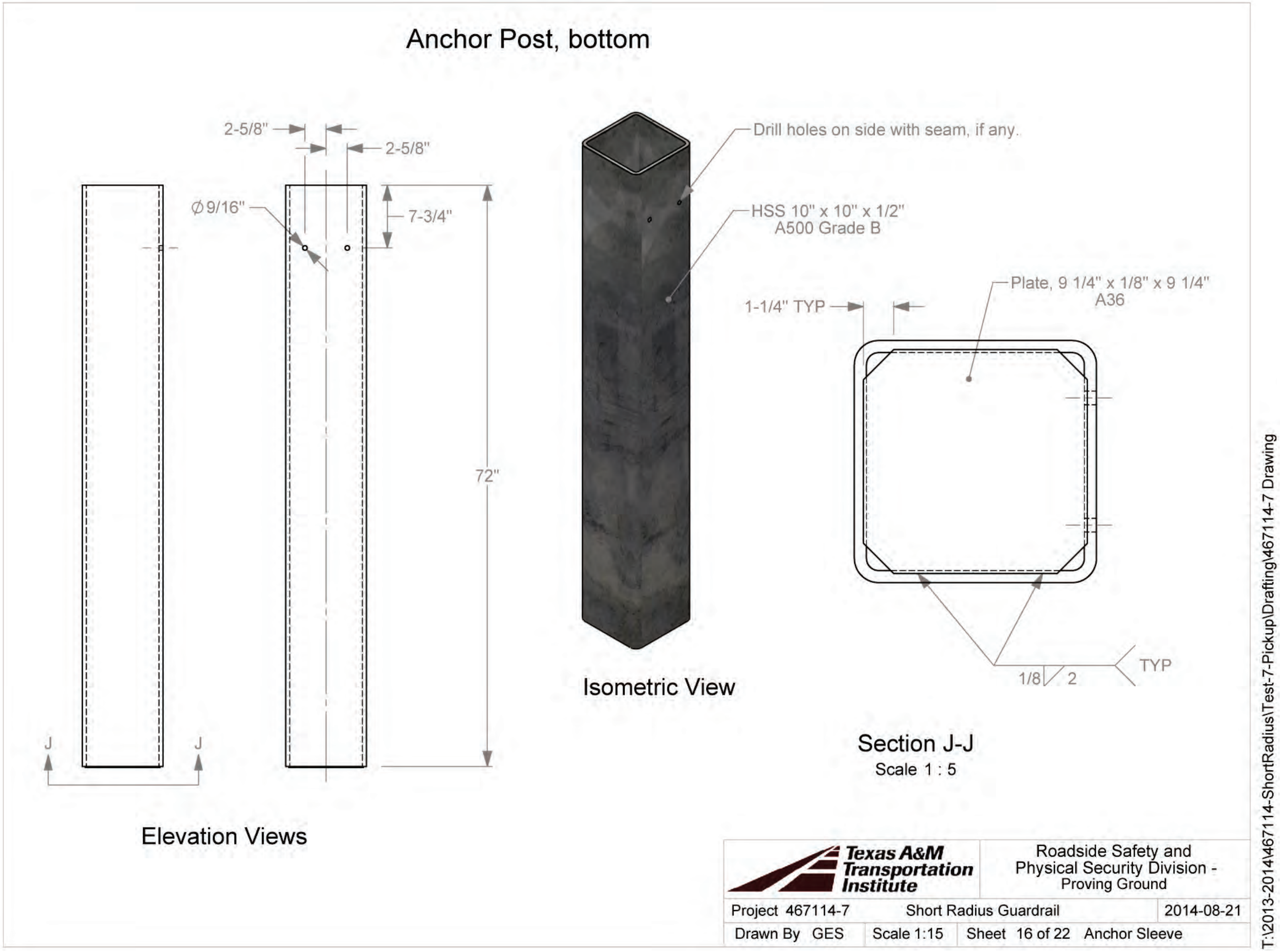
Roadside Safety and
Physical Security Division -
Proving Ground

Project 467114-7	Short Radius Guardrail		2014-08-21
Drawn By GES	Scale 1:10	Sheet 13 of 22	Rebar-1

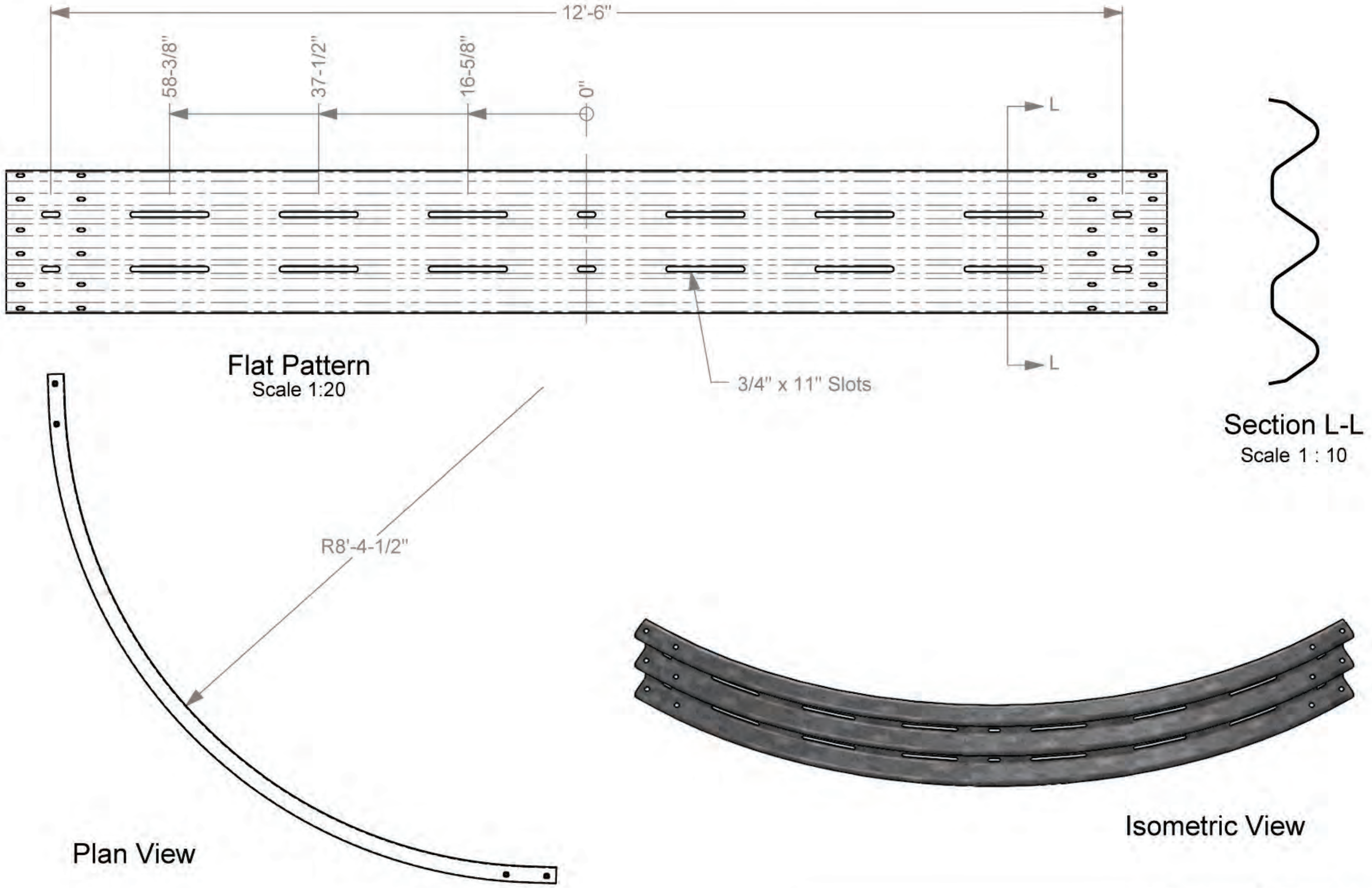
T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing


T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing
Bent Bar
Ø1/2"
82"
11-1/4"
2"
Ø3"
Longitudinal Bar, Parapet
Ø1/2"
93"
Longitudinal Bar, Deck
Ø5/8"
90"
Transverse Bar
Ø5/8"
53"
Tie Bar
Ø5/8"
24"
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project 467114-7
Short Radius Guardrail
2014-08-21
Drawn By GES
Scale 1:10
Sheet 14 of 22
Rebar-2


Anchor Post, top
0"
7-1/8"
14-3/4"
1/4
1/4
G
0"
7-1/8"
14-3/4"
21-3/4"
80"
Elevation Views
Isometric Views
Pipe, 8" sch. 80
Plate, 10" x 1/2" x 10"
ASTM A36
Ø 3/4"
R1"
Ø 1-1/4"
Ø 1-3/4"
Ø 8-5/8"
Pipe OD
Ø 8-3/4"
(hole in plate)
Ø 3/4"
Ø 7-5/8"
Pipe ID
Section I-I
Scale 1 : 5
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project 467114-7
Short Radius Guardrail
2014-08-21
Drawn By GES
Scale 1:15
Sheet 15 of 22
Anchor Post
T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing


Anchor Post, bottom
2-5/8"
2-5/8"
Ø9/16"
7-3/4"
72"
J
J
Elevation Views
Drill holes on side with seam, if any.
HSS 10" x 10" x 1/2"
A500 Grade B
Isometric View
Plate, 9 1/4" x 1/8" x 9 1/4"
A36
1-1/4" TYP
1/8
2
TYP
Section J-J
Scale 1 : 5
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project 467114-7
Short Radius Guardrail
2014-08-21
Drawn By GES
Scale 1:15
Sheet 16 of 22
Anchor Sleeve
T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

Radius Rail



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

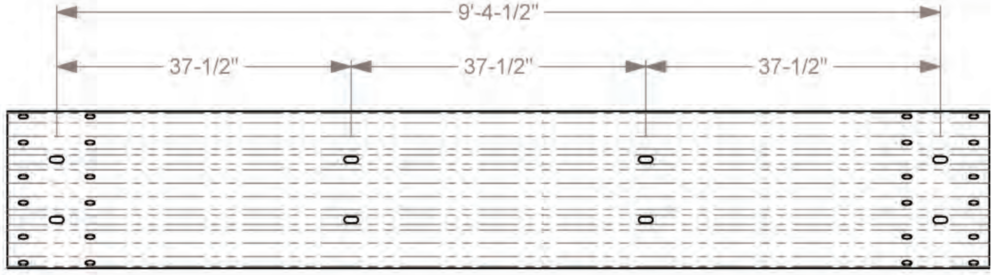
Institute

Roadside Safety and
Physical Security Division -
Proving Ground

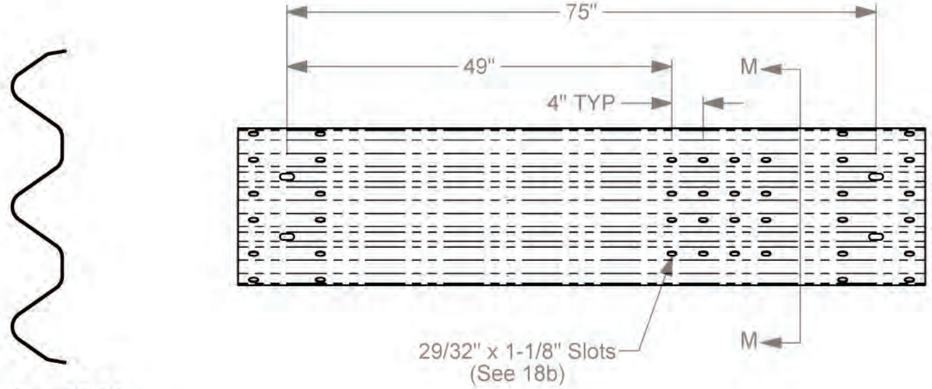
Project 467114-7	Short Radius Guardrail		2014-08-21
Drawn By GES	Scale 1:30	Sheet 17 of 22	Radius Rail

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

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).

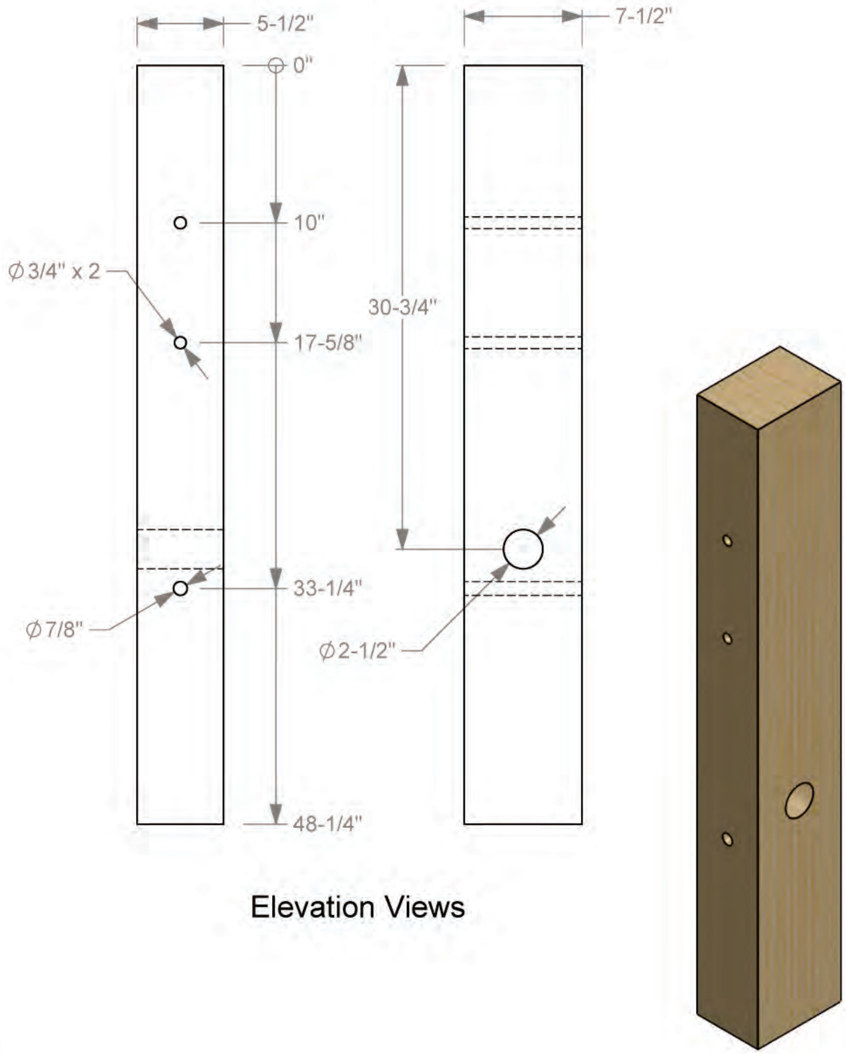
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

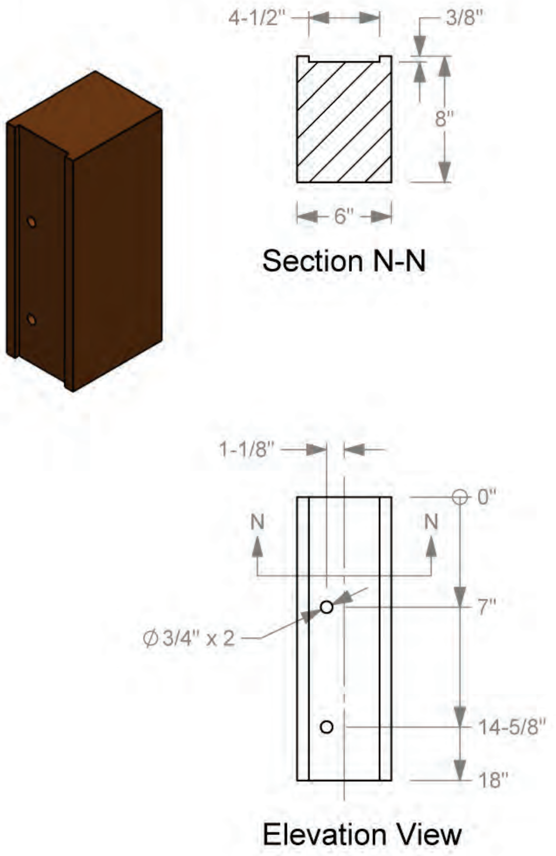
Project 467114-7	Short Radius Guardrail		2014-08-21
Drawn By GES	Scale 1:20	Sheet 18 of 22	Thrie-beam Rails

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

Modified BCT Timber Post

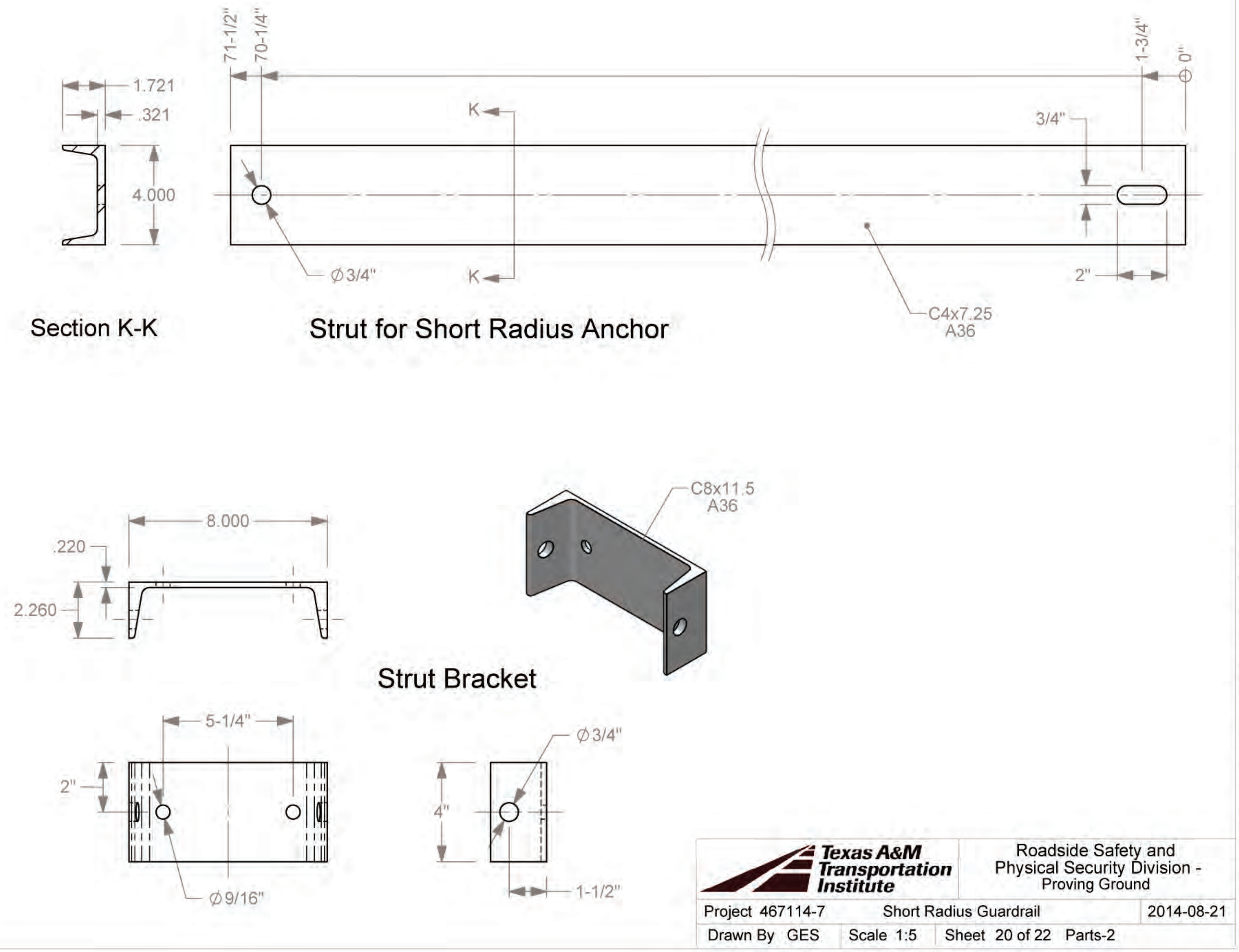


18" Routered Blockout for Thrie-beam



Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project 467114-7	Short Radius Guardrail		2014-08-21
Drawn By GES	Scale 1:10	Sheet 19 of 22	Parts-1

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing



Section K-K

Strut for Short Radius Anchor

Strut Bracket

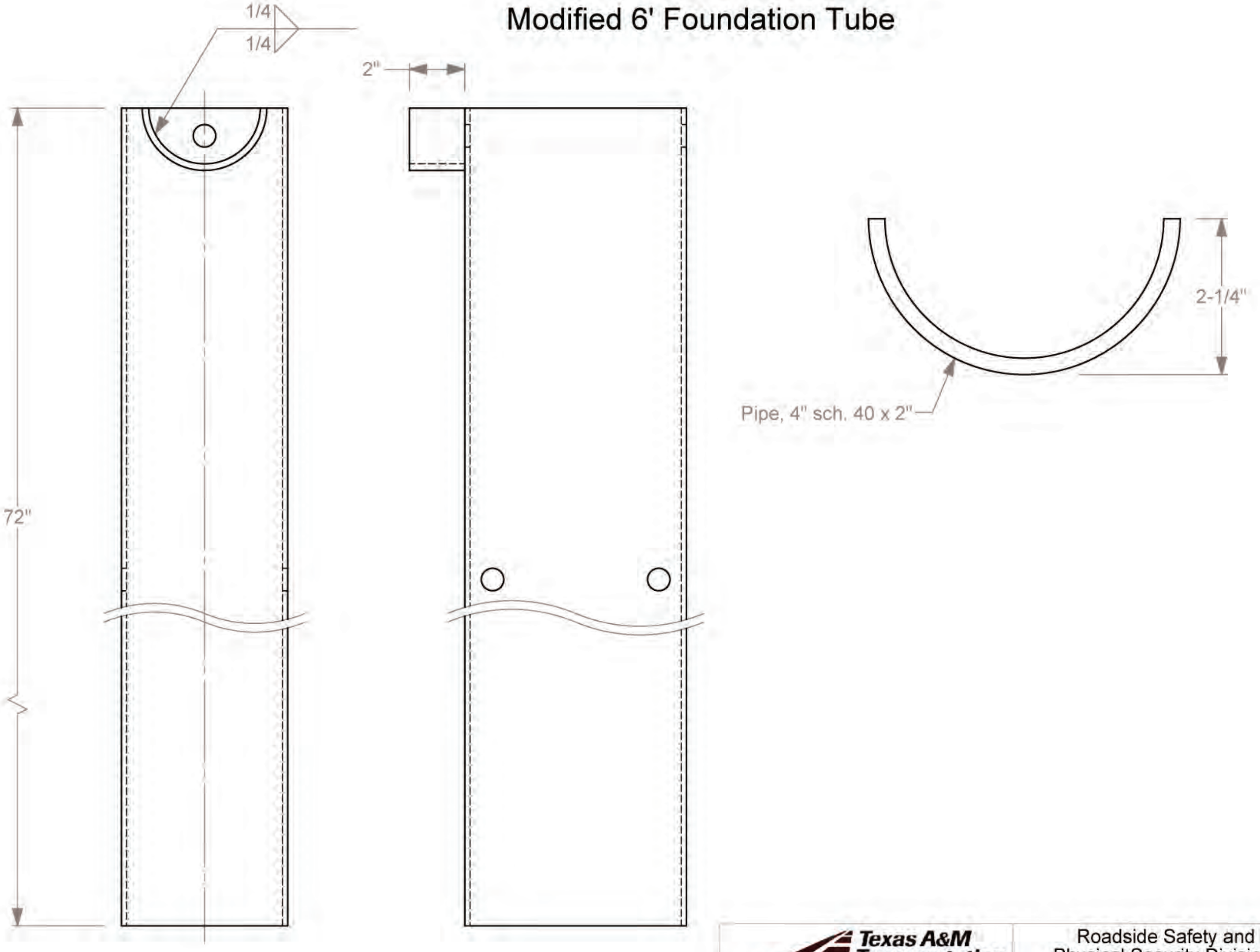
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project 467114-7
Short Radius Guardrail
2014-08-21
Drawn By GES
Scale 1:5
Sheet 20 of 22
Parts-2

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

Modified 6' Foundation Tube



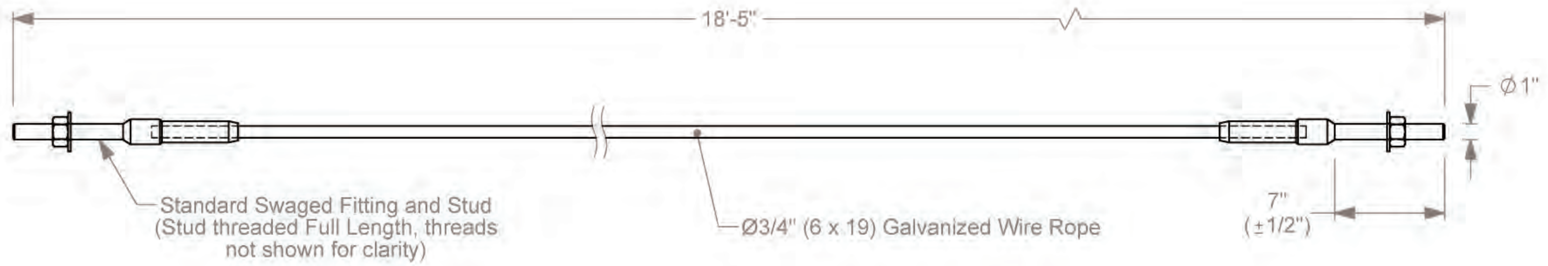
Texas A&M Transportation Institute

Roadside Safety and
Physical Security Division -
Proving Ground

Project 467114-7	Short Radius Guardrail	2014-08-21
Drawn By GES	Scale 1:5	Sheet 21 of 22 Tube Sleeve

T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

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 467114-7
Short Radius Guardrail
2014-08-21
Drawn By GES
Scale 1:10
Sheet 22 of 22
Anchor Cable

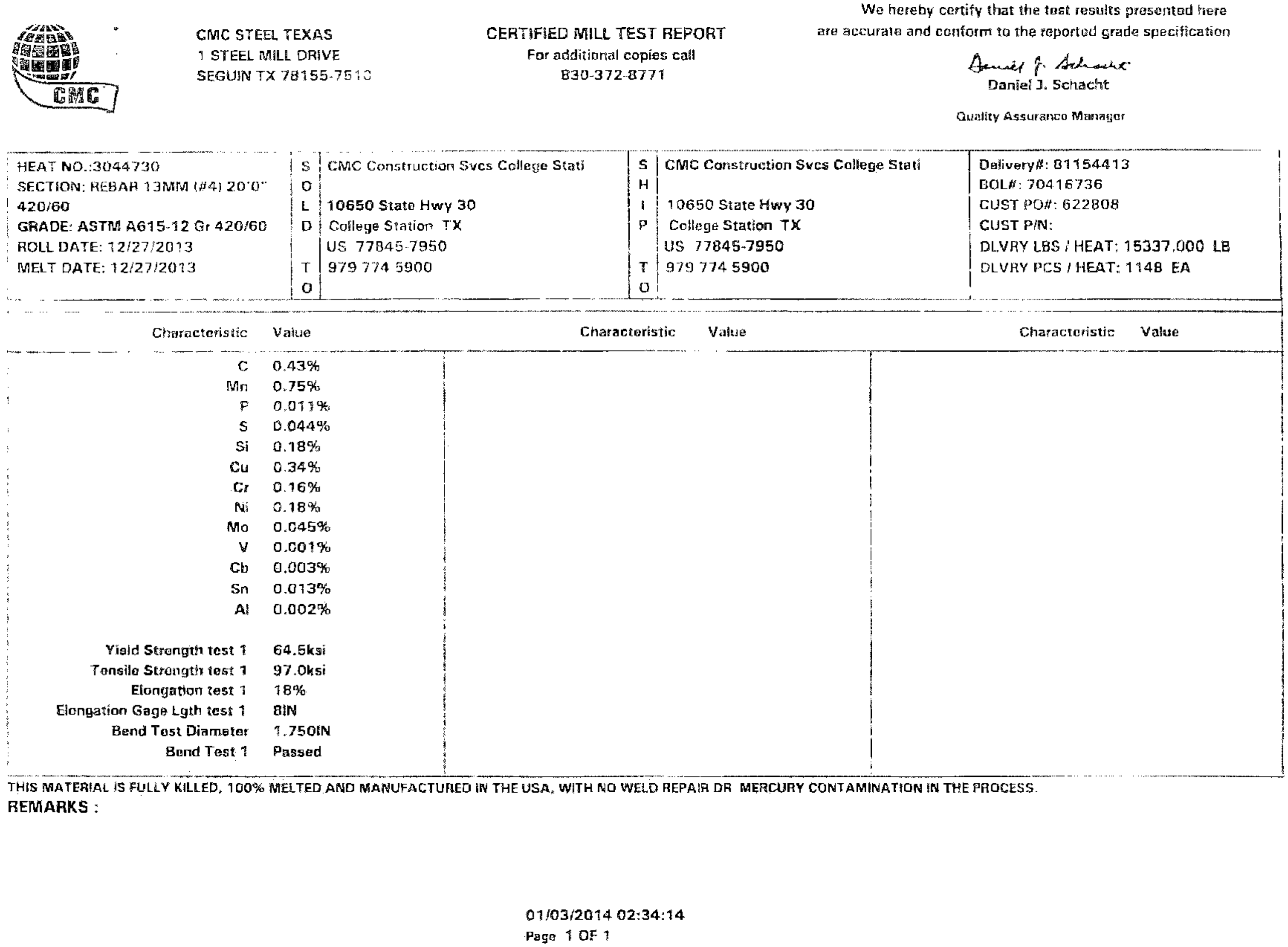
T:\2013-2014\467114-ShortRadius\Test-7-Pickup\Drafting\467114-7 Drawing

APPENDIX D. CERTIFICATION DOCUMENTATION

MATERIAL USED

TEST NUMBER	467114-3
TEST NAME	Short Radius Guardrail
DATE	2014-07-17

#	DATE RECEIVED	DESCRIPTION	GRADE	YIELD	TENSILE	SUPPLIER
13-040	2013-10-11	Barrels	plastic, w/cones, etc	N/A	N/A	Trinity Industries
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
13-166	2014-06-16	Anchor Cables		see file		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



CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7513

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

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

Daniel J. Schacht
Daniel J. Schacht
Quality Assurance Manager

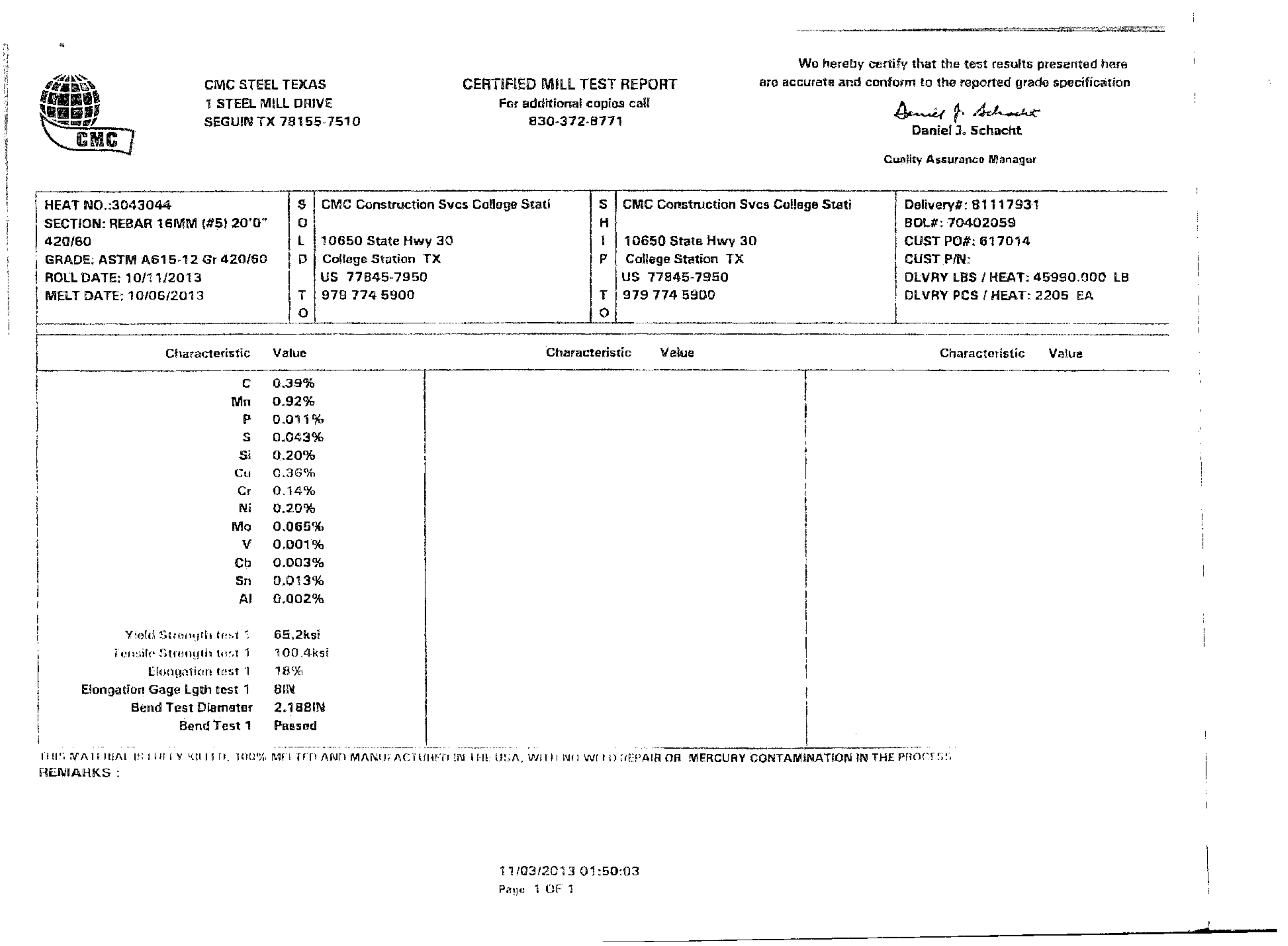
HEAT NO.:3044730 SECTION: REBAR 13MM (#4) 20'0" 420/60 GRADE: ASTM A615-12 Gr 420/60 ROLL DATE: 12/27/2013 MELT DATE: 12/27/2013	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 81154413 BOL#: 70416736 CUST PO#: 622808 CUST P/N: DLVRY LBS / HEAT: 15337.000 LB DLVRY PCS / HEAT: 1148 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.43%				
Mn	0.75%				
P	0.011%				
S	0.044%				
Si	0.18%				
Cu	0.34%				
Cr	0.16%				
Ni	0.18%				
Mo	0.045%				
V	0.001%				
Cb	0.003%				
Sn	0.013%				
Al	0.002%				
Yield Strength test 1	64.5ksi				
Tensile Strength test 1	97.0ksi				
Elongation test 1	18%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	1.750IN				
Bend Test 1	Passed				

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

REMARKS :

01/03/2014 02:34:14
Page 1 OF 1



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

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

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

Daniel J. Schacht
Daniel J. Schacht
Quality Assurance Manager

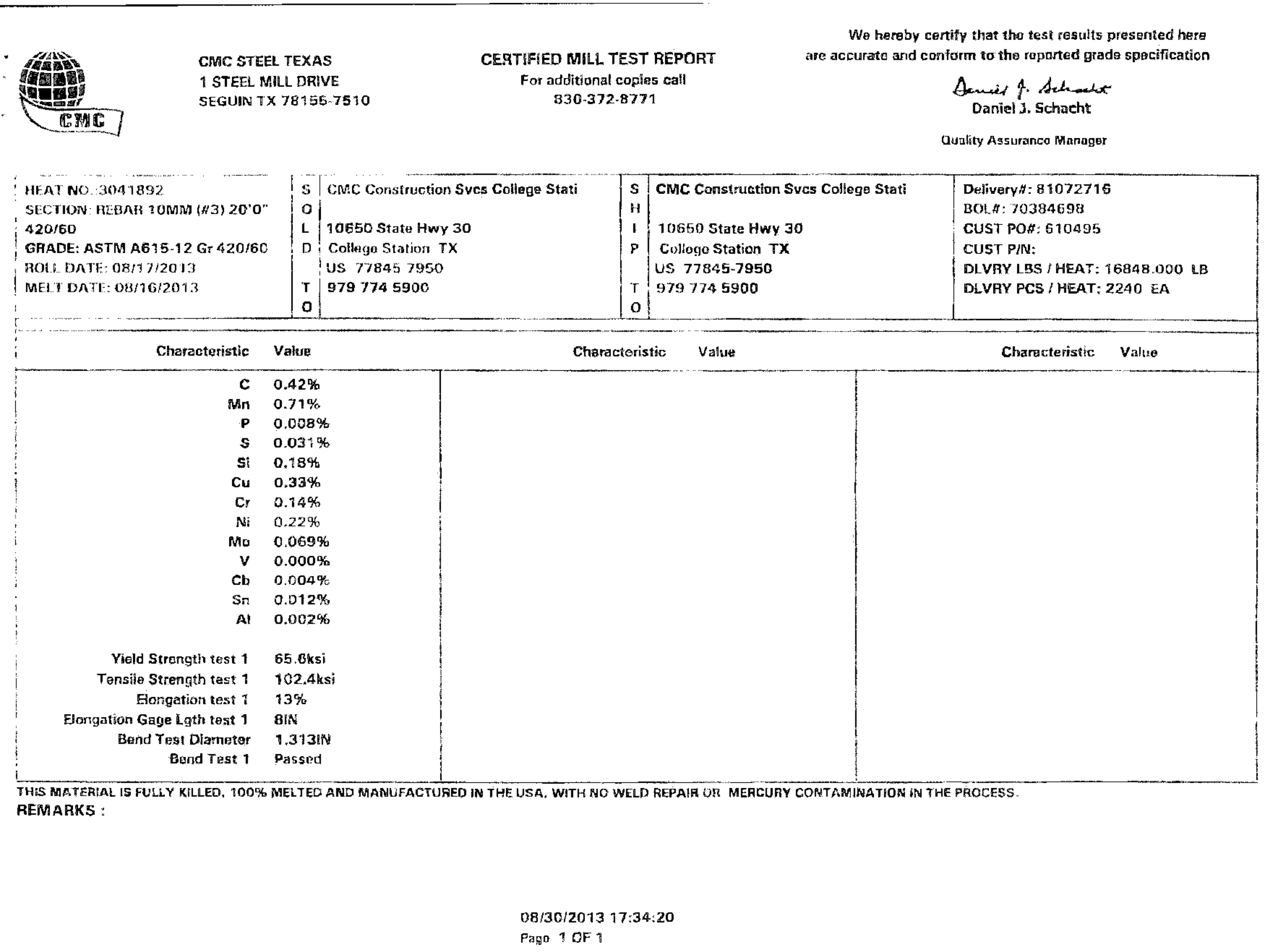
HEAT NO.:3043044 SECTION: REBAR 16MM (#5) 20'0" 420/60 GRADE: ASTM A615-12 Gr 420/60 ROLL DATE: 10/11/2013 MELT DATE: 10/06/2013	S O L D T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	S H I P T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 81117931 BOL#: 70402059 CUST PO#: 617014 CUST P/N: DLVRY LBS / HEAT: 45990.000 LB DLVRY PCS / HEAT: 2205 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.39%				
Mn	0.92%				
P	0.011%				
S	0.043%				
Si	0.20%				
Cu	0.36%				
Cr	0.14%				
Ni	0.20%				
Mo	0.065%				
V	0.001%				
Cb	0.003%				
Sn	0.013%				
Al	0.002%				
Yield Strength test 1	65.2ksi				
Tensile Strength test 1	100.4ksi				
Elongation test 1	18%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	2.188IN				
Bend Test 1	Passed				

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

REMARKS :

11/03/2013 01:50:03
Page 1 OF 1



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

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

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

Daniel J. Schacht
Daniel J. Schacht
Quality Assurance Manager

HEAT NO: 3041892 SECTION: REBAR 10MM (#3) 20'0" 420/60 GRADE: ASTM A615-12 Gr 420/60 ROLL DATE: 08/17/2013 MELT DATE: 08/16/2013	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845 7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 81072716 BOL#: 70384698 CUST PO#: 610495 CUST P/N: DLVRY LBS / HEAT: 16848.000 LB DLVRY PCS / HEAT: 2240 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.42%				
Mn	0.71%				
P	0.008%				
S	0.031%				
Si	0.18%				
Cu	0.33%				
Cr	0.14%				
Ni	0.22%				
Mo	0.069%				
V	0.000%				
Cb	0.004%				
Sn	0.012%				
Al	0.002%				
Yield Strength test 1	65.6ksi				
Tensile Strength test 1	102.4ksi				
Elongation test 1	13%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	1.313IN				
Bend Test 1	Passed				

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

REMARKS :

08/30/2013 17:34:20
Page 1 OF 1

This Memorandum is an acknowledgement that a Bill of Lading has been issued and is not the original Bill of Lading, nor a copy or duplicate, covering the property named herein, and is intended solely for filing or record.

Carrier

Shipper's No. 16-52531

S/O No. 1220084

RECEIVED, subject to the classifications and tariffs in effect on the date of receipt by the carrier of the property described in the Original Bill of Lading,

at Ft Worth, TX 5/16/ 20, 14 from Trinity Highway Products LLC

the property described below, in apparent good order, except as noted (contents and condition of contents of packages unknown) marked, consigned and destined as shown below, which said company (the word company being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its own railroad, water line, highway route or routes, or within the territory of its highway operations, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the conditions not prohibited by law, whether printed or written, herein contained, including the conditions on back hereof, which are hereby agreed to by the shipper and accepted for himself and his assigns.

Subject to Section 7 of Conditions of applicable Bill of Lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.

TRINITY HIGHWAY PRODUCTS, LLC

Per ______________________
(Signature of Consignor)

If charges are to be prepaid, write or stamp here, "To be Prepaid."

Received $ ______________________
to apply in prepayment of the charges on the property described hereon.

Agent or Cashier

Per ______________________
(The signature here acknowledges only the amount prepaid.)
Charges advanced:

Consigned to: SAMPLES,TESTING,TRAINING MTRLS Cust. P.O. TXDOT SHORT RAD Load No.: [illegible]
Destination: [illegible] ATTN GARY GERKE [illegible]
[illegible]
Total Weight: 9,542 16
City: BRYAN State: TX Zip: 77807
Ship: 5/16/14
Arrive: 5/13/14 8:00:00AM
Contact: GARY GERKE Phone: [illegible]-4061
Delivering Carrier: FedEx PRIORITY Vehicle or Car Initial: ______ No. ______

Collect On Delivery:
$ ______ **and remit to:** ______
______ **Street** ______ **City** ______ **State**

C.O.D. charge to be paid by **Shipper** ☐ **Consignee** ☐

[illegible] all materials [illegible] to Trinity Highway Products, LLC [illegible]
[illegible] TxDOT [illegible]
[illegible] Comments

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
	6	[illegible]			
	4	[illegible]			
	12	[illegible] CAB ANC [illegible]			
	4	[illegible] 2" ID X 6' PIPE			
	16	[illegible]			
	6	[illegible] 5/8" [illegible]			
	6	[illegible]			
	3	[illegible] 1/2" [illegible] HEX NUT A563 DH			
	100	[illegible] WASHER [illegible]			
	44	[illegible] XL [illegible] WASHER			
	100	[illegible] HEX NUT			
	244	[illegible] GR BOLT			
	44	[illegible] 5/8"X2" GR BOLT			
	100	[illegible] 5/8"X2" HEX BOLT A325			
	72	[illegible] 10" GR BOLT A307			
	18	[illegible] X18" GR BOLT A307			
	40	372[illegible] ROUND WASHER F436			
	20	[illegible] HEX NUT A563 DH			
	[illegible]	[illegible] 14" HEX BOLT A307			
	12	[illegible] WD [illegible] POST [illegible]			
	16	[illegible] WD [illegible] 25 POST 5.5X7.5			
		[illegible] 2 ET 3[illegible] BOL[illegible]			
	12	[illegible] HEX BOLT A325			

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
	4	[illegible] HEX BOLT [illegible]			
	24	[illegible] L [illegible]			
	4	[illegible]			
	12	[illegible]			
	4	[illegible]			
	9	[illegible] TRI-[illegible] TERMINAL [illegible]			
	10	[illegible] U [illegible] CABLE SOCKET [illegible]			

3 - PALLETS
1 - CRATE
1 - BUNDLE

GUARDRAIL HWY STEEL
NMFC ITEM 105460
CLASS 50

16-52531

SPECIAL INSTRUCTIONS:

SHIPPER LOAD - CONSIGNEE UNLOAD

Total Weight
9,542
③

*If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is "carrier's or shipper's weight."
NOTE - Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property.
The agreed or declared value of the property is hereby specifically stated by the shipper to be not exceeding ______ per ______

ORIGIN
SHIPPER OR AGENT — I hereby authorize this shipment and make the declaration of values (if any) and agree to the contract terms and conditions hereof.
SIGN HERE Dawn Bullock DATE 5/16/14
AGENT OR DRIVER — This shipment received subject to exceptions as noted and according to the terms and conditions hereof.
(SIGN HERE) DATE

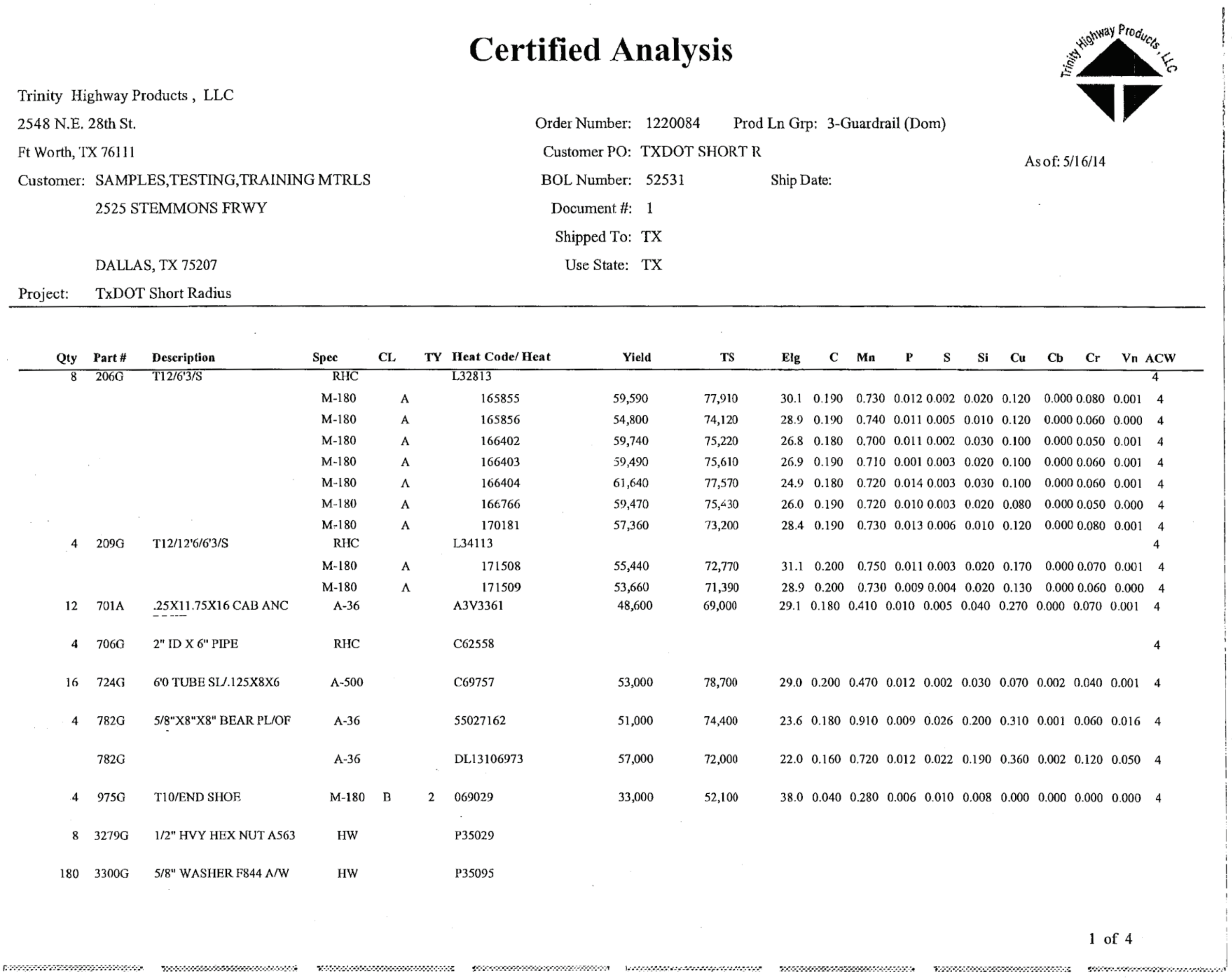
DESTINATION
CONSIGNEE OR AGENT — Received the above described property in good condition except as noted on the back hereof and agree to the foregoing contract terms and conditions.
SIGN HERE / / DATE A.M. P.M. TIME
DRIVER NO

Permanent post-office address of shipper,

TRI 609-RF (R 10/93)

(This Bill of Lading is to be signed by the shipper and agent of the carrier issuing same.)

CONSIGNEE/CUSTOMER COPY



Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111
Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

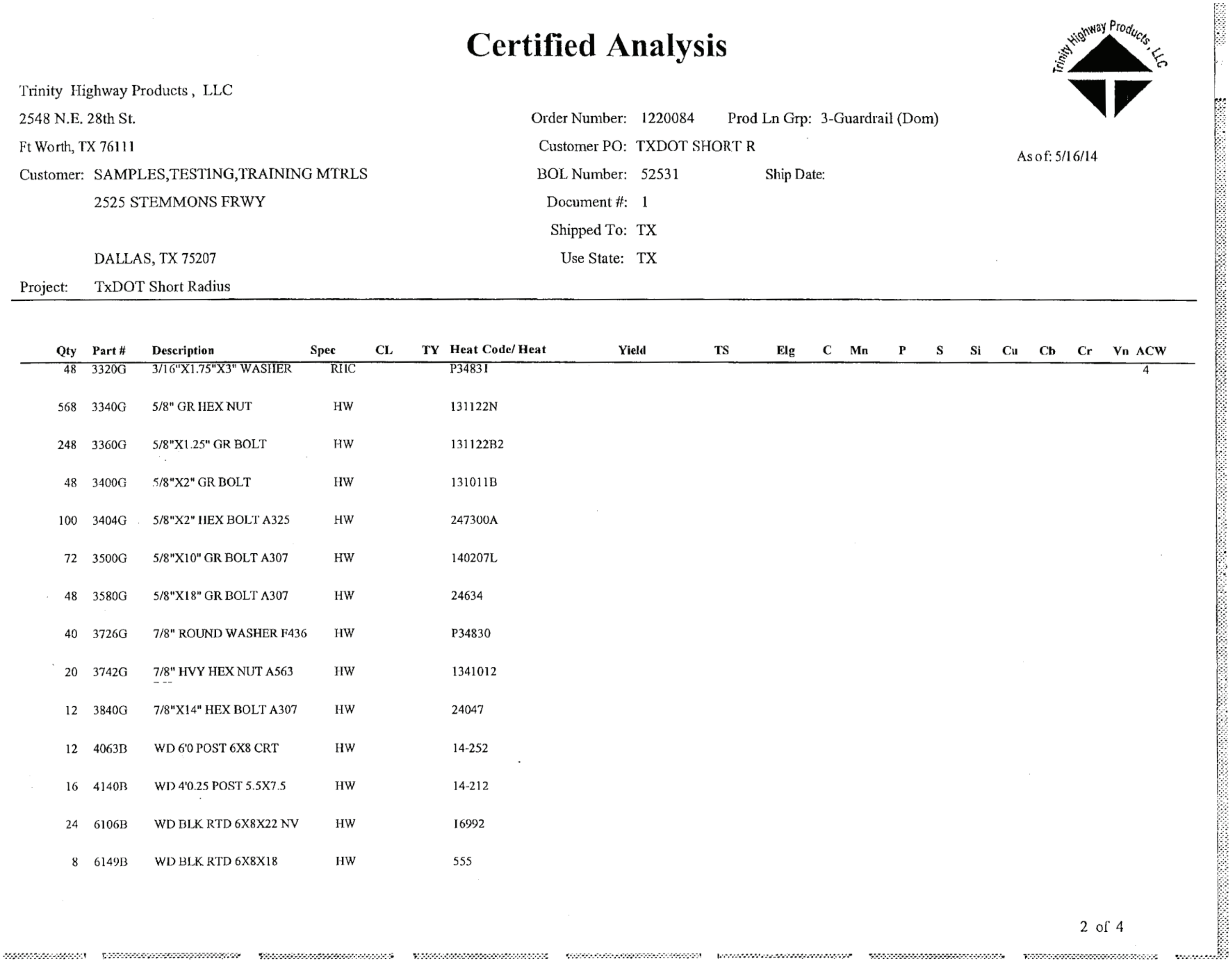
DALLAS, TX 75207
Project: TxDOT Short Radius

Order Number: 1220084 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: TXDOT SHORT R
BOL Number: 52531 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 5/16/14

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
8	206G	T12/6'3/S	RHC			L32813													4
			M-180	A		165855	59,590	77,910	30.1	0.190	0.730	0.012	0.002	0.020	0.120	0.000	0.080	0.001	4
			M-180	A		165856	54,800	74,120	28.9	0.190	0.740	0.011	0.005	0.010	0.120	0.000	0.060	0.000	4
			M-180	A		166402	59,740	75,220	26.8	0.180	0.700	0.011	0.002	0.030	0.100	0.000	0.050	0.001	4
			M-180	A		166403	59,490	75,610	26.9	0.190	0.710	0.001	0.003	0.020	0.100	0.000	0.060	0.001	4
			M-180	A		166404	61,640	77,570	24.9	0.180	0.720	0.014	0.003	0.030	0.100	0.000	0.060	0.001	4
			M-180	A		166766	59,470	75,430	26.0	0.190	0.720	0.010	0.003	0.020	0.080	0.000	0.050	0.000	4
			M-180	A		170181	57,360	73,200	28.4	0.190	0.730	0.013	0.006	0.010	0.120	0.000	0.080	0.001	4
4	209G	T12/12'6/6'3/S	RHC			L34113													4
			M-180	A		171508	55,440	72,770	31.1	0.200	0.750	0.011	0.003	0.020	0.170	0.000	0.070	0.001	4
			M-180	A		171509	53,660	71,390	28.9	0.200	0.730	0.009	0.004	0.020	0.130	0.000	0.060	0.000	4
12	701A	.25X11.75X16 CAB ANC	A-36			A3V3361	48,600	69,000	29.1	0.180	0.410	0.010	0.005	0.040	0.270	0.000	0.070	0.001	4
4	706G	2" ID X 6" PIPE	RHC			C62558													4
16	724G	6'0 TUBE SL/.125X8X6	A-500			C69757	53,000	78,700	29.0	0.200	0.470	0.012	0.002	0.030	0.070	0.002	0.040	0.001	4
4	782G	5/8"X8"X8" BEAR PL/OF	A-36			55027162	51,000	74,400	23.6	0.180	0.910	0.009	0.026	0.200	0.310	0.001	0.060	0.016	4
	782G		A-36			DL13106973	57,000	72,000	22.0	0.160	0.720	0.012	0.022	0.190	0.360	0.002	0.120	0.050	4
4	975G	T10/END SHOE	M-180	B	2	069029	33,000	52,100	38.0	0.040	0.280	0.006	0.010	0.008	0.000	0.000	0.000	0.000	4
8	3279G	1/2" HVY HEX NUT A563	HW			P35029													
180	3300G	5/8" WASHER F844 A/W	HW			P35095													

1 of 4



Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111
Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207
Project: TxDOT Short Radius

Order Number: 1220084 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: TXDOT SHORT R
BOL Number: 52531 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 5/16/14

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
48	3320G	3/16"X1.75"X3" WASHER	RHC			P34831													4
568	3340G	5/8" GR HEX NUT	HW			131122N													
248	3360G	5/8"X1.25" GR BOLT	HW			131122B2													
48	3400G	5/8"X2" GR BOLT	HW			131011B													
100	3404G	5/8"X2" HEX BOLT A325	HW			247300A													
72	3500G	5/8"X10" GR BOLT A307	HW			140207L													
48	3580G	5/8"X18" GR BOLT A307	HW			24634													
40	3726G	7/8" ROUND WASHER F436	HW			P34830													
20	3742G	7/8" HVY HEX NUT A563	HW			1341012													
12	3840G	7/8"X14" HEX BOLT A307	HW			24047													
12	4063B	WD 6'0 POST 6X8 CRT	HW			14-252													
16	4140B	WD 4'0.25 POST 5.5X7.5	HW			14-212													
24	6106B	WD BLK RTD 6X8X22 NV	HW			16992													
8	6149B	WD BLK RTD 6X8X18	HW			555													

2 of 4

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111
Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207
Project: TxDOT Short Radius

Order Number: 1220084 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: TXDOT SHORT R
BOL Number: 52531 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 5/16/14

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
12	12365G	T12/12'6/8@1'6.75/S	RHC			L32913													4
			M-180	A		165151	58,820	76,850	27.7	0.180	0.720	0.009	0.003	0.010	0.090	0.000	0.050	0.000	4
			M-180	A		165851	56,370	73,630	30.6	0.190	0.720	0.013	0.002	0.020	0.120	0.000	0.080	0.001	4
			M-180	A		165853	60,570	76,880	28.1	0.190	0.730	0.012	0.002	0.020	0.120	0.000	0.080	0.001	4
			M-180	A		165855	59,590	77,910	30.1	0.190	0.730	0.012	0.002	0.020	0.120	0.000	0.080	0.001	4
			M-180	A		165856	54,800	74,120	28.9	0.190	0.740	0.011	0.005	0.010	0.120	0.000	0.060	0.000	4
			M-180	A		166402	59,740	75,220	26.8	0.180	0.700	0.011	0.002	0.030	0.100	0.000	0.050	0.001	4
			M-180	A		166403	59,490	75,610	26.9	0.190	0.710	0.001	0.003	0.020	0.100	0.000	0.060	0.001	4
			M-180	A		166766	59,470	75,430	26.0	0.190	0.720	0.010	0.003	0.020	0.080	0.000	0.050	0.000	4
			M-180	A		171509	53,660	71,390	28.9	0.200	0.730	0.009	0.004	0.020	0.130	0.000	0.060	0.000	4
24	14784G	7'0 POST/8.5#/3HI TX	A-36			58016753	45,800	65,300	25.1	0.090	0.820	0.013	0.026	0.210	0.250	0.000	0.140	0.001	4
4	35200G	TRI-GARD TERMINAL	A-36			C42965	51,120	68,750	35.0	0.070	0.460	0.010	0.000	0.030	0.080	0.028	0.000	0.000	4
10	400010B	NU-CABLE,SOCKET (PVC)	HW			C06H881906P													

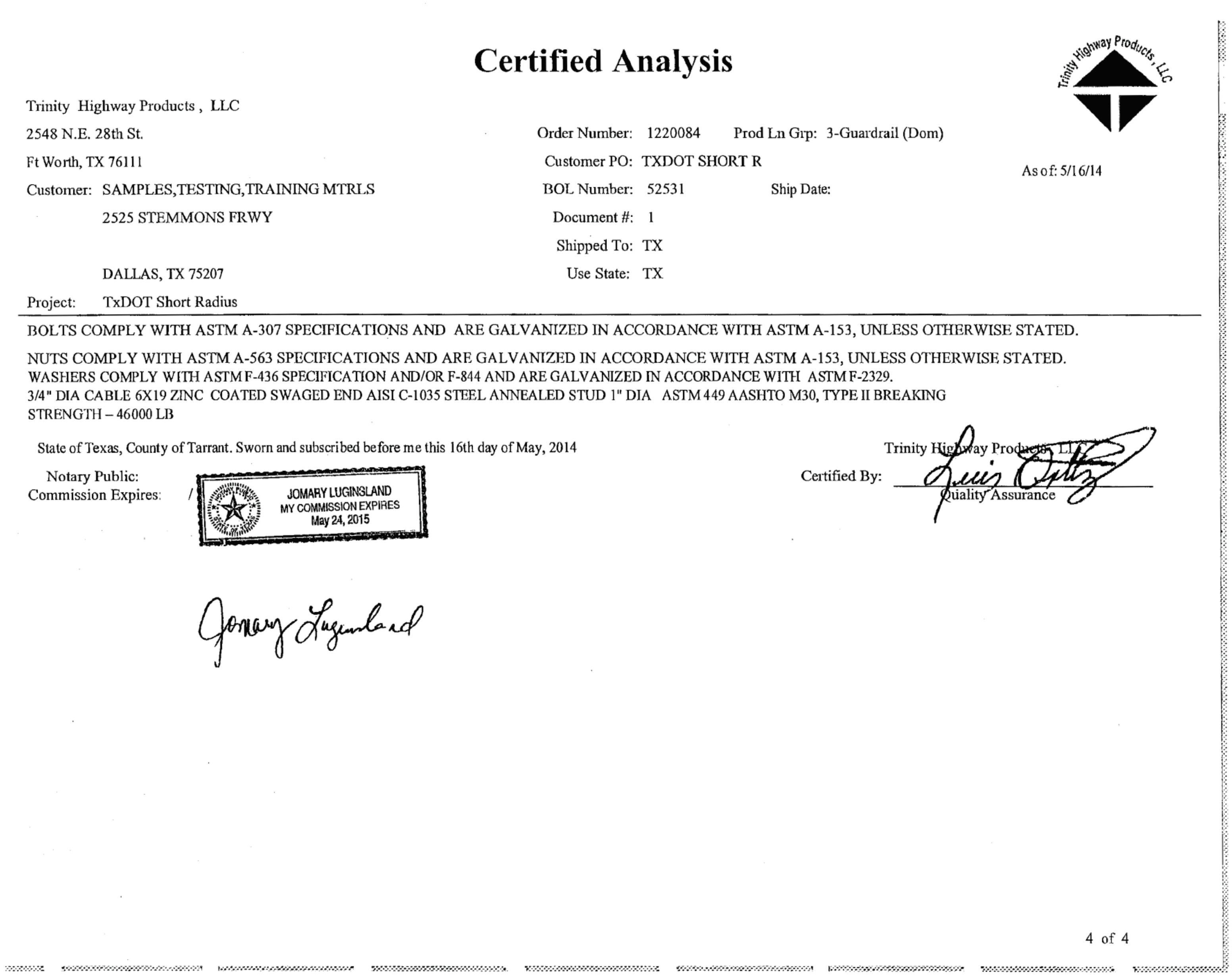
TL -3 or TL-4 COMPLIANT when installed according to manufactures specifications

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

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED



Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111

Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207

Project: TxDOT Short Radius

Order Number: 1220084 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: TXDOT SHORT R
BOL Number: 52531 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 5/16/14

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

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 16th day of May, 2014

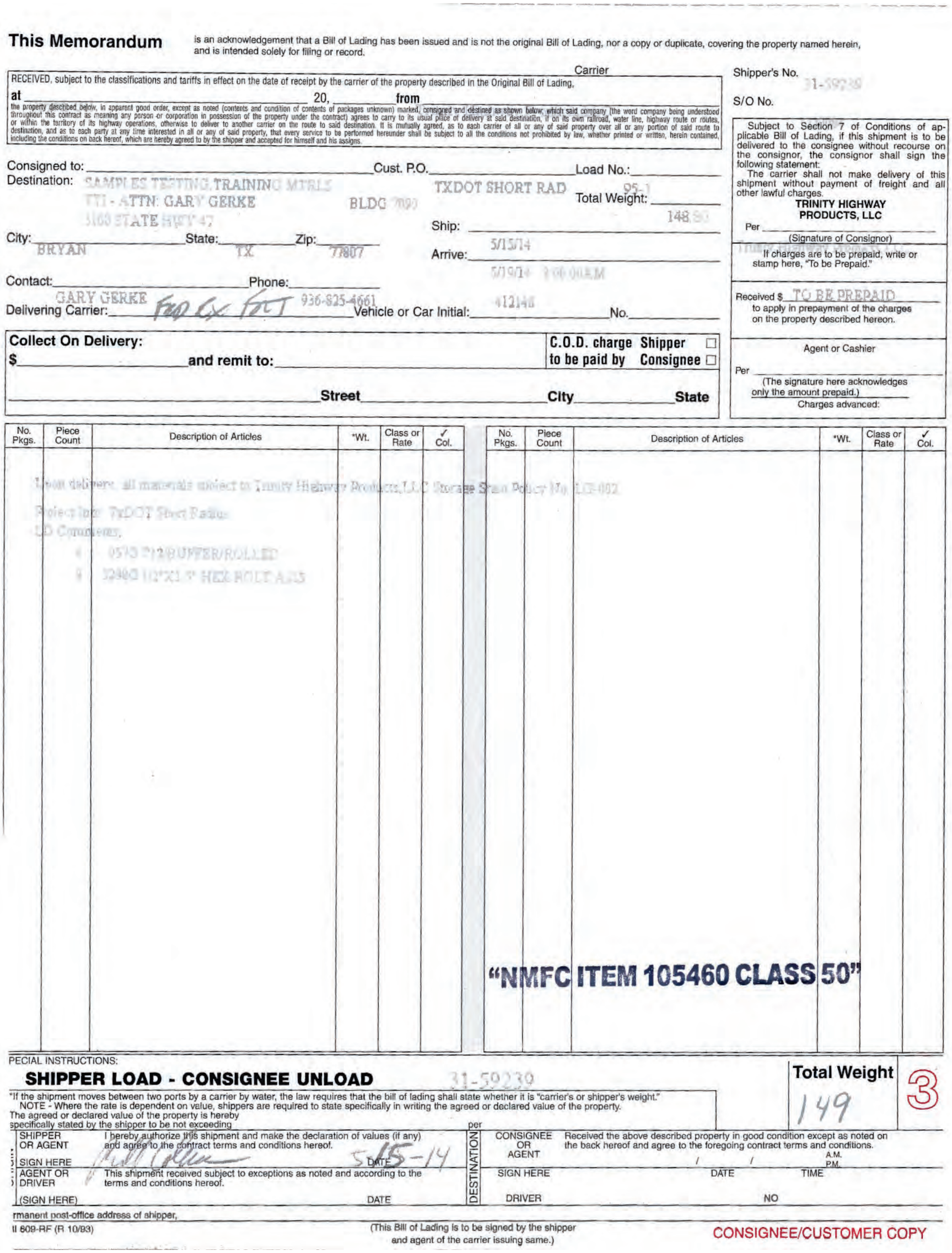
Notary Public:
Commission Expires: /

JOMARY LUGINSLAND
MY COMMISSION EXPIRES
May 24, 2015

Jomary Luginsland

Trinity Highway Products, LLC
Certified By: Luis Ortiz
Quality Assurance

4 of 4



This Memorandum is an acknowledgement that a Bill of Lading has been issued and is not the original Bill of Lading, nor a copy or duplicate, covering the property named herein, and is intended solely for filing or record.

Carrier

RECEIVED, subject to the classifications and tariffs in effect on the date of receipt by the carrier of the property described in the Original Bill of Lading,

at ______ 20, ______ **from** ______

the property described below, in apparent good order, except as noted (contents and condition of contents of packages unknown) marked, consigned and destined as shown below, which said company (the word company being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its own railroad, water line, highway route or routes, or within the territory of its highway operations, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the conditions not prohibited by law, whether printed or written, herein contained, including the conditions on back hereof, which are hereby agreed to by the shipper and accepted for himself and his assigns.

Shipper's No. 31-59230

S/O No.

Consigned to: ______ Cust. P.O. TXDOT SHORT RAD Load No.: 95-1

Destination: SAMPLES TESTING.TRAINING MTRLS
TTI - ATTN: GARY GERKE BLDG 7090
3100 STATE HWY 47

Total Weight: 148.90

City: BRYAN State: TX Zip: 77807

Ship: 5/15/14

Arrive: 5/19/14 9:00:00A.M

Contact: GARY GERKE Phone: 936-825-4661

Delivering Carrier: Fed Ex FRT Vehicle or Car Initial: 412148 No. ______

Subject to Section 7 of Conditions of applicable Bill of Lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.

TRINITY HIGHWAY PRODUCTS, LLC

Per ______
(Signature of Consignor)
Trinity Highway Products, LLC

If charges are to be prepaid, write or stamp here, "To be Prepaid."

Received $ TO BE PREPAID
to apply in prepayment of the charges on the property described hereon.

Agent or Cashier

Per ______
(The signature here acknowledges only the amount prepaid.)
Charges advanced:

Collect On Delivery:
$ ______ **and remit to:** ______
______ **Street** ______ **City** ______ **State**

C.O.D. charge to be paid by **Shipper** ☐ **Consignee** ☐

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
		Upon delivery, all materials subject to Trinity Highway Products,LLC Storage Stain Policy No. LEG-002			
		Project Info: TxDOT Short Radius			
		LD Comments:			
	4	0573 7'12/BUFFER/ROLLED			
	8	3340G 1/2"X1.5" HEX BOLT A325			

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
		"NMFC ITEM 105460 CLASS 50"			

PECIAL INSTRUCTIONS:

SHIPPER LOAD - CONSIGNEE UNLOAD 31-59230

Total Weight 149

3

*If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is "carrier's or shipper's weight."
NOTE - Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property.
The agreed or declared value of the property is hereby specifically stated by the shipper to be not exceeding ______ per ______

SHIPPER OR AGENT — I hereby authorize this shipment and make the declaration of values (if any) and agree to the contract terms and conditions hereof.
SIGN HERE ______ DATE 5-15-14

AGENT OR DRIVER — This shipment received subject to exceptions as noted and according to the terms and conditions hereof.
(SIGN HERE) ______ DATE ______

DESTINATION

CONSIGNEE OR AGENT — Received the above described property in good condition except as noted on the back hereof and agree to the foregoing contract terms and conditions.
SIGN HERE ______ DATE / / TIME A.M. P.M.
DRIVER ______ NO ______

rmanent post-office address of shipper,

ll 609-RF (R 10/93)

(This Bill of Lading is to be signed by the shipper and agent of the carrier issuing same.)

CONSIGNEE/CUSTOMER COPY

Certified Analysis

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

DALLAS, TX 75207
Project: TxDOT Short Radius

Order Number: 1220084 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: TXDOT SHORT R
BOL Number: 59239 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 5/15/14

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
4	957G	T12/BUFFER/ROLLED	M-180	A	2	4145361	56,100	71,000	32.0	0.210	0.400	0.007	0.003	0.020	0.030	0.000	0.030	0.000	4

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

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.
ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH - 46000 LB

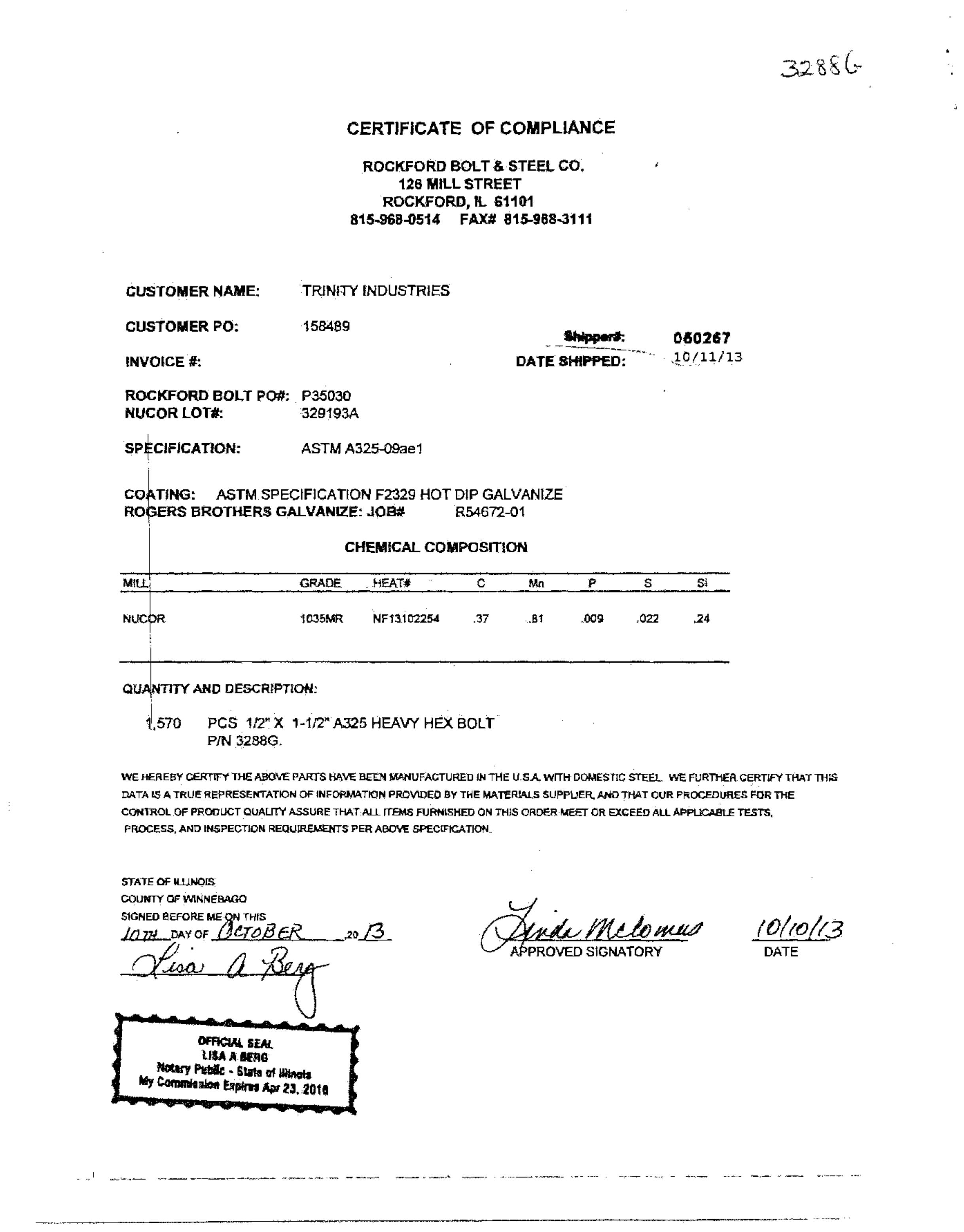
State of Ohio, County of Trumbull. Sworn and subscribed before me this 15th day of May, 2014

Notary Public:
Commission Expi

MARY ANN SKOVRAN
NOTARY PUBLIC - OHIO
MY COMMISSION EXPIRES JANUARY 16, 2017

Trinity Highway Products , LLC
Certified By:
Quality Assurance

1 of 1



3288G

CERTIFICATE OF COMPLIANCE

ROCKFORD BOLT & STEEL CO.
126 MILL STREET
ROCKFORD, IL 61101
815-968-0514 FAX# 815-968-3111

CUSTOMER NAME: TRINITY INDUSTRIES

CUSTOMER PO: 158489

Shipper#: 060267

INVOICE #:

DATE SHIPPED: 10/11/13

ROCKFORD BOLT PO#: P35030
NUCOR LOT#: 329193A

SPECIFICATION: ASTM A325-09ae1

COATING: ASTM SPECIFICATION F2329 HOT DIP GALVANIZE
ROGERS BROTHERS GALVANIZE: JOB# R54672-01

CHEMICAL COMPOSITION

MILL	GRADE	HEAT#	C	Mn	P	S	Si
NUCOR	1035MR	NF13102254	.37	.81	.009	.022	.24

QUANTITY AND DESCRIPTION:

1,570 PCS 1/2" X 1-1/2" A325 HEAVY HEX BOLT
P/N 3288G.

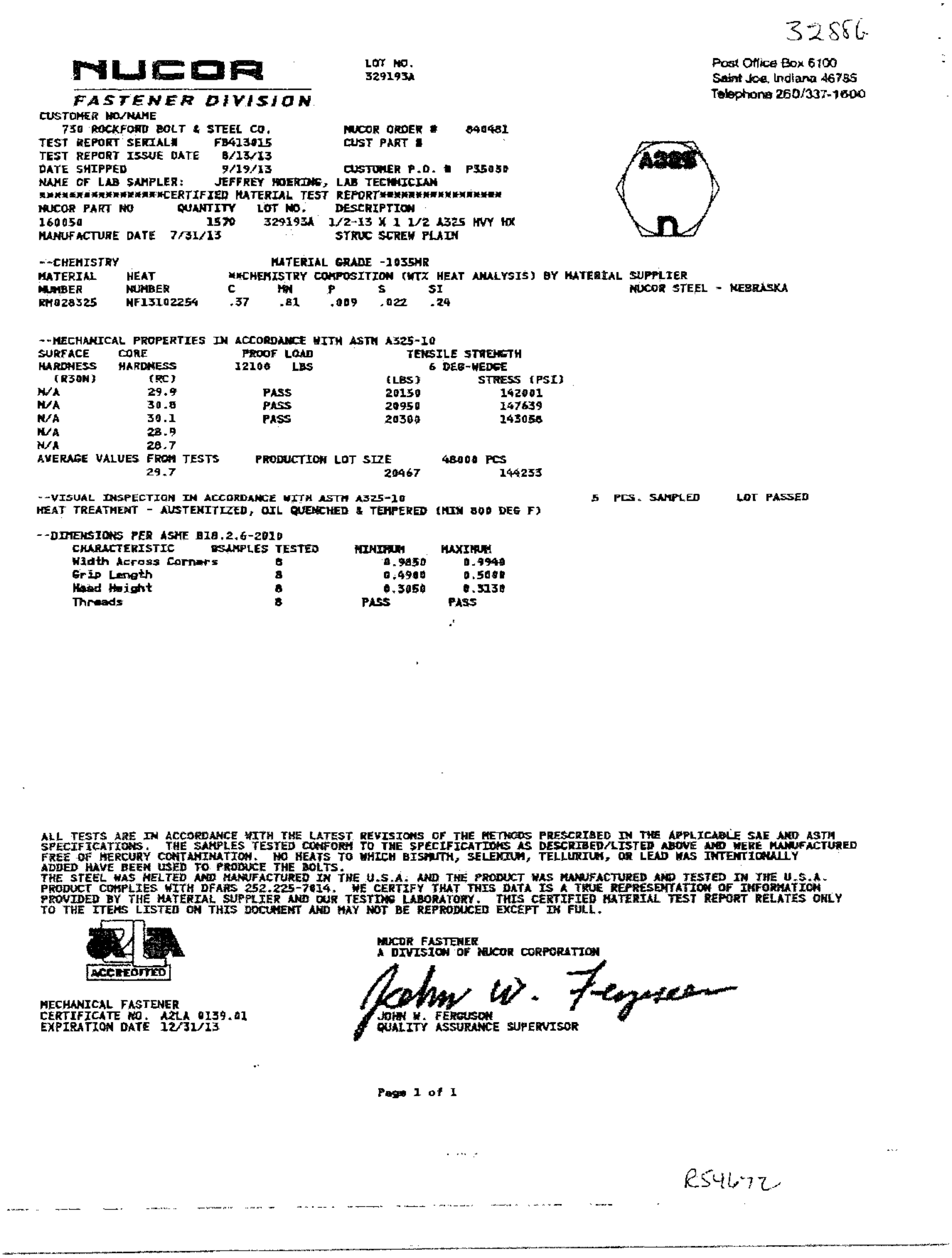
WE HEREBY CERTIFY THE ABOVE PARTS HAVE BEEN MANUFACTURED IN THE U.S.A. WITH DOMESTIC STEEL. WE FURTHER CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENTS PER ABOVE SPECIFICATION.

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS
10TH DAY OF OCTOBER 20 13
Lisa A Berg

OFFICIAL SEAL
LISA A BERG
Notary Public - State of Illinois
My Commission Expires Apr 23, 2016

Linda Melomus
APPROVED SIGNATORY

10/10/13
DATE



32886

NUCOR
FASTENER DIVISION

LOT NO.
329193A

Post Office Box 6100
Saint Joe, Indiana 46785
Telephone 260/337-1600

CUSTOMER NO/NAME
730 ROCKFORD BOLT & STEEL CO.
NUCOR ORDER # 840481
TEST REPORT SERIAL# FB413015
CUST PART #
TEST REPORT ISSUE DATE 8/13/13
DATE SHIPPED 9/19/13
CUSTOMER P.O. # P35050
NAME OF LAB SAMPLER: JEFFREY HOERING, LAB TECHNICIAN

*****************CERTIFIED MATERIAL TEST REPORT*****************

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
160050	1570	329193A	1/2-13 X 1 1/2 A325 HVY HX STRUC SCREW PLAIN

MANUFACTURE DATE 7/31/13

A325

--CHEMISTRY MATERIAL GRADE -1035MR

**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER NUCOR STEEL - NEBRASKA

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI
RM028325	NF13102254	.37	.81	.009	.022	.24

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A325-10

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 12100 LBS	TENSILE STRENGTH 6 DEG-WEDGE (LBS)	STRESS (PSI)
N/A	29.9	PASS	20150	142001
N/A	30.8	PASS	20950	147639
N/A	30.1	PASS	20300	143056
N/A	28.9			
N/A	28.7			
AVERAGE VALUES FROM TESTS	29.7		20467	144233

PRODUCTION LOT SIZE 48000 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A325-10 5 PCS. SAMPLED LOT PASSED
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2010

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	0.9850	0.9940
Grip Length	8	0.4900	0.5000
Head Height	8	0.3050	0.3130
Threads	8	PASS	PASS

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION. NO HEATS TO WHICH BISMUTH, SELENIUM, TELLURIUM, OR LEAD WAS INTENTIONALLY ADDED HAVE BEEN USED TO PRODUCE THE BOLTS.
THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A. PRODUCT COMPLIES WITH DFARS 252.225-7014. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL.

A2LA
ACCREDITED

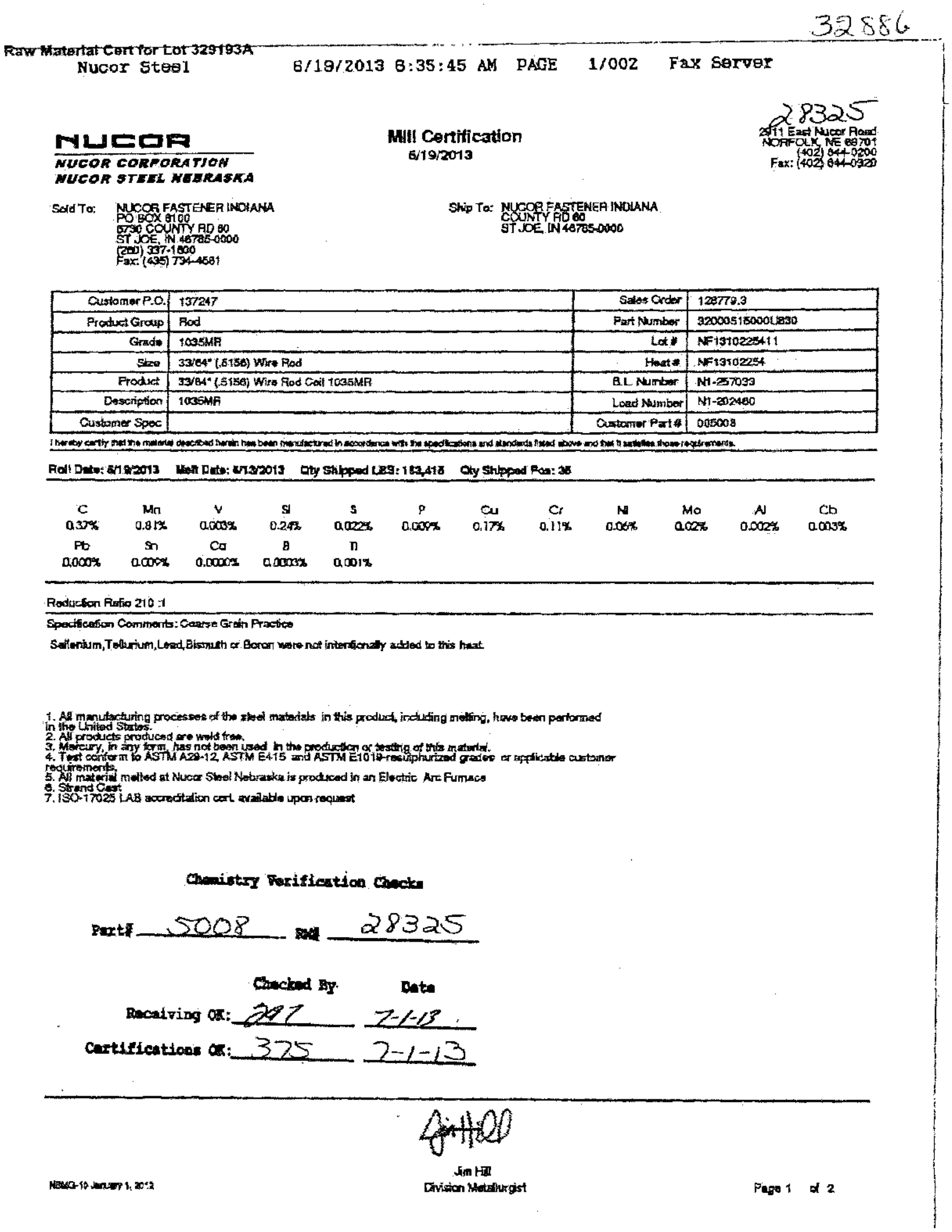
MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 12/31/13

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

John W. Ferguson
JOHN W. FERGUSON
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

R54672



32886

Raw Material Cert for Lot 329193A

Nucor Steel 6/19/2013 6:35:45 AM PAGE 1/002 Fax Server

28325

NUCOR
NUCOR CORPORATION
NUCOR STEEL NEBRASKA

Mill Certification

6/19/2013

2911 East Nucor Road
NORFOLK, NE 68701
(402) 644-0200
Fax: (402) 644-0320

Sold To:
NUCOR FASTENER INDIANA
PO BOX 6100
6730 COUNTY RD 60
ST JOE, IN 46785-0000
(260) 337-1800
Fax: (435) 734-4581

Ship To:
NUCOR FASTENER INDIANA
COUNTY RD 60
ST JOE, IN 46785-0000

Customer P.O.	137247	Sales Order	128779.3
Product Group	Rod	Part Number	32000515000U830
Grade	1035MR	Lot #	NF1310225411
Size	33/64" (.5156) Wire Rod	Heat #	NF13102254
Product	33/64" (.5156) Wire Rod Coil 1035MR	B.L. Number	N1-257033
Description	1035MR	Load Number	N1-202460
Customer Spec		Customer Part #	005008

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.

Roll Date: 6/19/2013 Melt Date: 6/13/2013 Qty Shipped LBS: 183,418 Qty Shipped Pcs: 38

C	Mn	V	Si	S	P	Cu	Cr	Ni	Mo	Al	Cb
0.37%	0.81%	0.003%	0.24%	0.022%	0.009%	0.17%	0.11%	0.06%	0.02%	0.002%	0.003%
Pb	**Sn**	**Ca**	**B**	**Ti**							
0.000%	0.009%	0.0000%	0.0003%	0.001%							

Reduction Ratio 210 :1

Specification Comments: Coarse Grain Practice

Sellenium,Tellurium,Lead,Bismuth or Boron were not intentionally added to this heat.

1. All manufacturing processes of the steel materials in this product, including melting, have been performed in the United States.
2. All products produced are weld free.
3. Mercury, in any form, has not been used in the production or testing of this material.
4. Test conform to ASTM A29-12, ASTM E415 and ASTM E1019-resulphurized grades or applicable customer requirements.
5. All material melted at Nucor Steel Nebraska is produced in an Electric Arc Furnace
6. Strand Cast
7. ISO-17025 LAB accreditation cert. available upon request

Chemistry Verification Checks

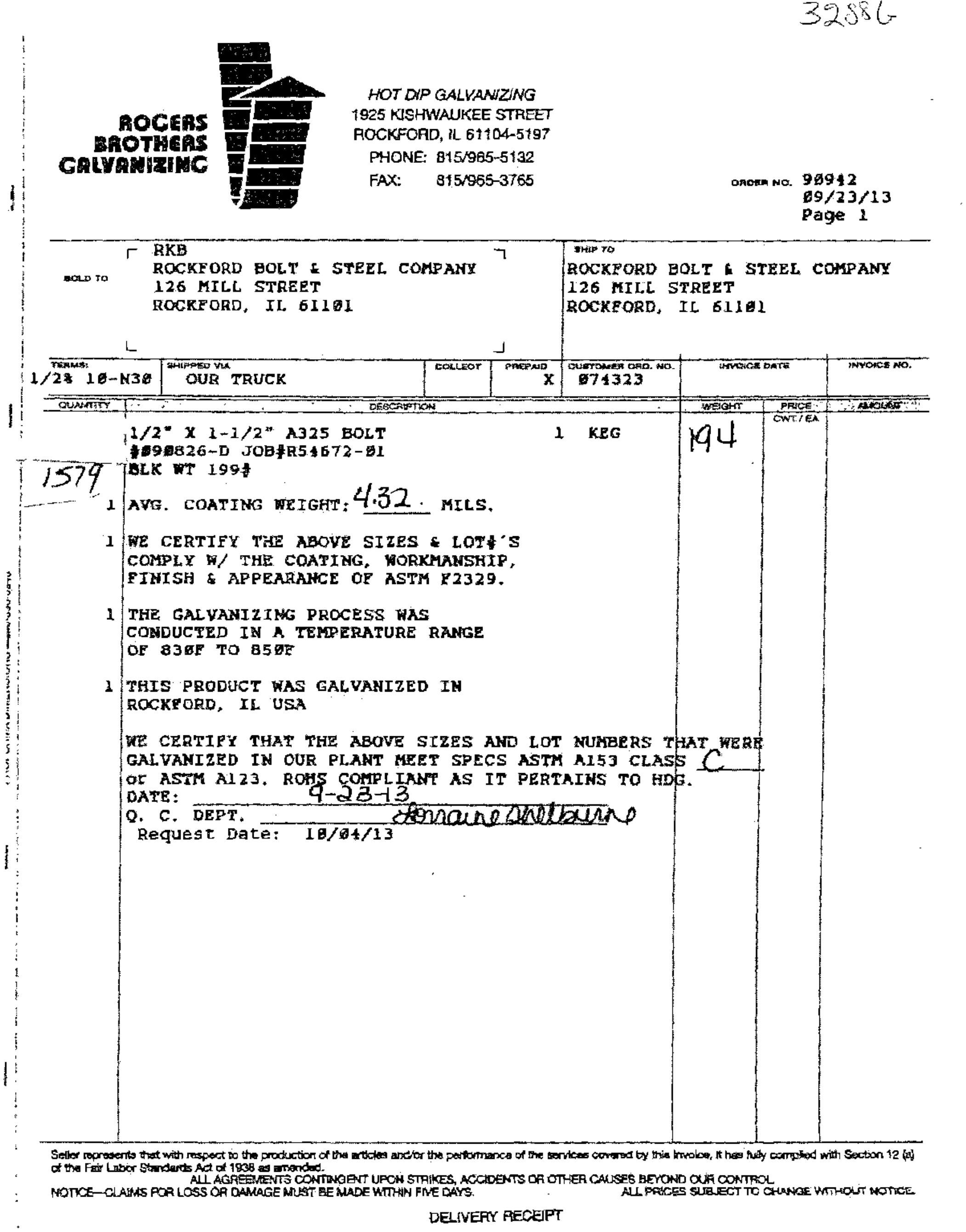
Part# 5008 RM# 28325

	Checked By	Date
Receiving OK:	297	7-1-13
Certifications OK:	325	7-1-13

Jim Hill
Division Metallurgist

NBMG-10 January 1, 2012

Page 1 of 2



32886

ROGERS BROTHERS GALVANIZING

HOT DIP GALVANIZING
1925 KISHWAUKEE STREET
ROCKFORD, IL 61104-5197
PHONE: 815/965-5132
FAX: 815/965-3765

ORDER NO. 90942
09/23/13
Page 1

SOLD TO
RKB
ROCKFORD BOLT & STEEL COMPANY
126 MILL STREET
ROCKFORD, IL 61101

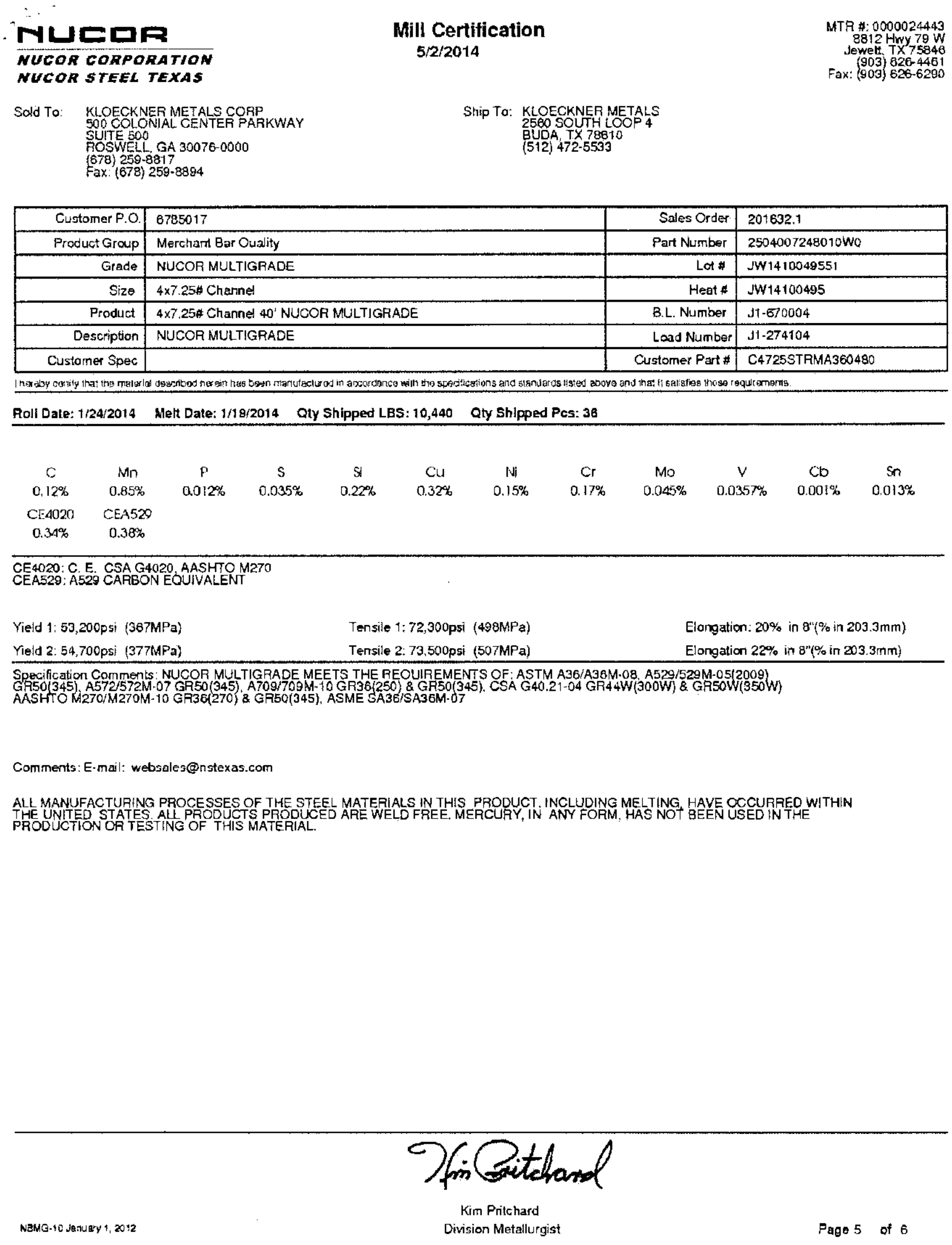
SHIP TO
ROCKFORD BOLT & STEEL COMPANY
126 MILL STREET
ROCKFORD, IL 61101

TERMS:	SHIPPED VIA	COLLECT	PREPAID	CUSTOMER ORD. NO.	INVOICE DATE	INVOICE NO.
1/2% 10-N30	OUR TRUCK		X	074323		

QUANTITY	DESCRIPTION	WEIGHT	PRICE CWT/EA	AMOUNT
	1/2" X 1-1/2" A325 BOLT 1 KEG #090826-D JOB#R54672-01 BLK WT 199#	194		
1579				
1	AVG. COATING WEIGHT: 4.32 MILS.			
1	WE CERTIFY THE ABOVE SIZES & LOT#'S COMPLY W/ THE COATING, WORKMANSHIP, FINISH & APPEARANCE OF ASTM F2329.			
1	THE GALVANIZING PROCESS WAS CONDUCTED IN A TEMPERATURE RANGE OF 830F TO 850F			
1	THIS PRODUCT WAS GALVANIZED IN ROCKFORD, IL USA			
	WE CERTIFY THAT THE ABOVE SIZES AND LOT NUMBERS THAT WERE GALVANIZED IN OUR PLANT MEET SPECS ASTM A153 CLASS C or ASTM A123. ROHS COMPLIANT AS IT PERTAINS TO HDG. DATE: 9-23-13 Q. C. DEPT. Request Date: 10/04/13			

Seller represents that with respect to the production of the articles and/or the performance of the services covered by this invoice, it has fully complied with Section 12 (a) of the Fair Labor Standards Act of 1938 as amended.
ALL AGREEMENTS CONTINGENT UPON STRIKES, ACCIDENTS OR OTHER CAUSES BEYOND OUR CONTROL.
NOTICE—CLAIMS FOR LOSS OR DAMAGE MUST BE MADE WITHIN FIVE DAYS. ALL PRICES SUBJECT TO CHANGE WITHOUT NOTICE.

DELIVERY RECEIPT



NUCOR

NUCOR CORPORATION

NUCOR STEEL TEXAS

Mill Certification

5/2/2014

MTR #: 0000024443
8812 Hwy 79 W
Jewett, TX 75846
(903) 626-4461
Fax: (903) 626-6290

Sold To:
KLOECKNER METALS CORP
500 COLONIAL CENTER PARKWAY
SUITE 500
ROSWELL, GA 30076-0000
(678) 259-8817
Fax: (678) 259-8894

Ship To:
KLOECKNER METALS
2560 SOUTH LOOP 4
BUDA, TX 78610
(512) 472-5533

Customer P.O.	6785017	Sales Order	201632.1
Product Group	Merchant Bar Quality	Part Number	2504007248010W0
Grade	NUCOR MULTIGRADE	Lot #	JW1410049551
Size	4x7.25# Channel	Heat #	JW14100495
Product	4x7.25# Channel 40' NUCOR MULTIGRADE	B.L. Number	J1-670004
Description	NUCOR MULTIGRADE	Load Number	J1-274104
Customer Spec		Customer Part #	C4725STRMA360480

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.

Roll Date: 1/24/2014 Melt Date: 1/19/2014 Qty Shipped LBS: 10,440 Qty Shipped Pcs: 36

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Sn
0.12%	0.85%	0.012%	0.035%	0.22%	0.32%	0.15%	0.17%	0.045%	0.0357%	0.001%	0.013%

CE4020	CEA529
0.34%	0.38%

CE4020: C. E. CSA G4020, AASHTO M270
CEA529: A529 CARBON EQUIVALENT

Yield 1: 53,200psi (367MPa)	Tensile 1: 72,300psi (498MPa)	Elongation: 20% in 8"(% in 203.3mm)
Yield 2: 54,700psi (377MPa)	Tensile 2: 73,500psi (507MPa)	Elongation 22% in 8"(% in 203.3mm)

Specification Comments: NUCOR MULTIGRADE MEETS THE REQUIREMENTS OF: ASTM A36/A36M-08, A529/529M-05(2009) GR50(345), A572/572M-07 GR50(345), A709/709M-10 GR36(250) & GR50(345), CSA G40.21-04 GR44W(300W) & GR50W(350W) AASHTO M270/M270M-10 GR36(270) & GR50(345), ASME SA36/SA36M-07

Comments: E-mail: websales@nstexas.com

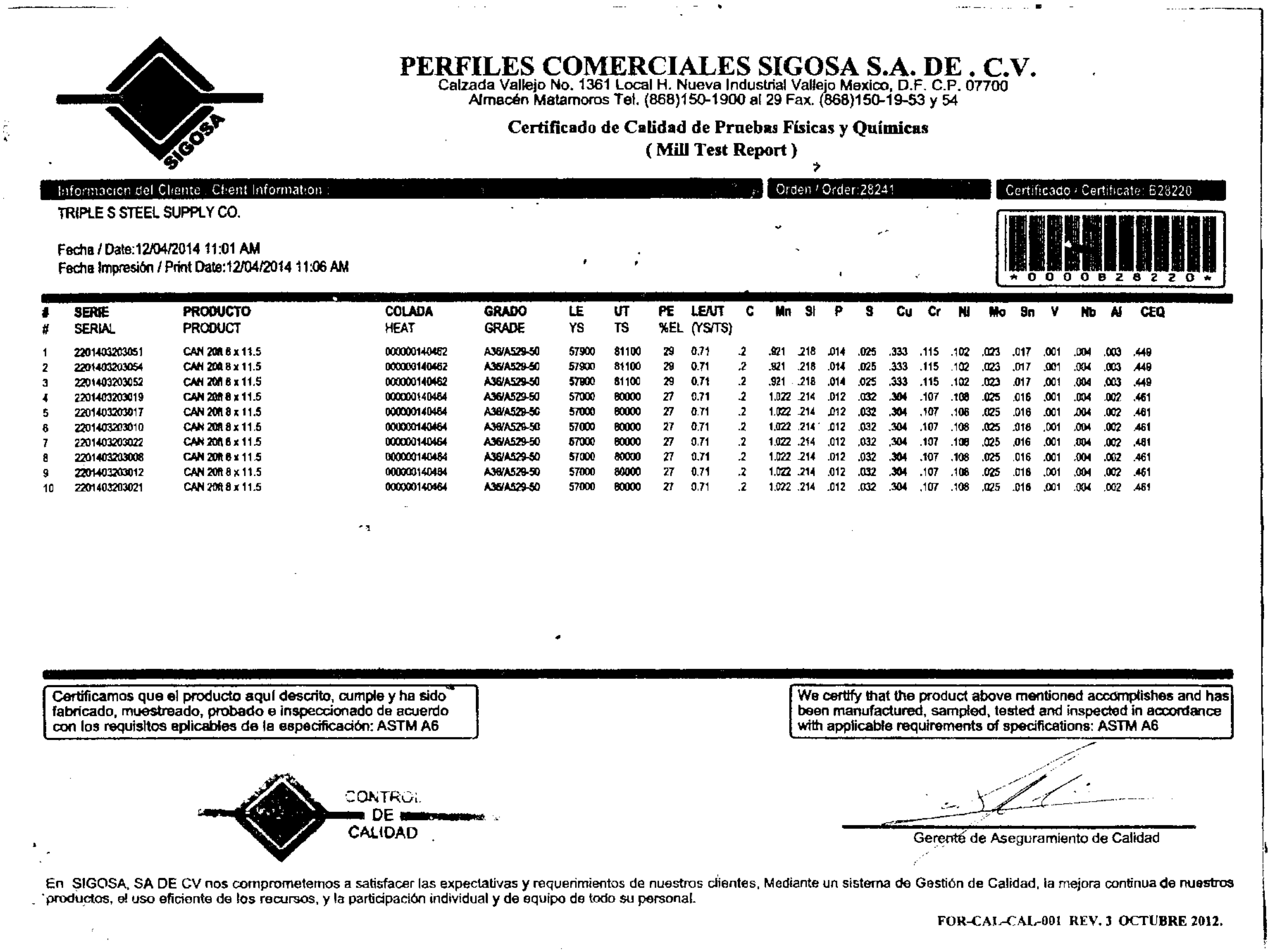
ALL MANUFACTURING PROCESSES OF THE STEEL MATERIALS IN THIS PRODUCT, INCLUDING MELTING, HAVE OCCURRED WITHIN THE UNITED STATES. ALL PRODUCTS PRODUCED ARE WELD FREE. MERCURY, IN ANY FORM, HAS NOT BEEN USED IN THE PRODUCTION OR TESTING OF THIS MATERIAL.

Kim Pritchard

Kim Pritchard
Division Metallurgist

NBMG-10 January 1, 2012

Page 5 of 6



PERFILES COMERCIALES SIGOSA S.A. DE . C.V.

Calzada Vallejo No. 1361 Local H. Nueva Industrial Vallejo Mexico, D.F. C.P. 07700
Almacén Matamoros Tel. (868)150-1900 al 29 Fax. (868)150-19-53 y 54

Certificado de Calidad de Pruebas Físicas y Químicas
(Mill Test Report)

Informacion del Cliente . Client Information :

Orden / Order:28241

Certificado / Certificate: B28220

TRIPLE S STEEL SUPPLY CO.

Fecha / Date:12/04/2014 11:01 AM
Fecha Impresión / Print Date:12/04/2014 11:06 AM

* 0 0 0 0 B 2 8 2 2 0 *

# #	SERIE SERIAL	PRODUCTO PRODUCT	COLADA HEAT	GRADO GRADE	LE YS	UT TS	PE %EL	LE/UT (YS/TS)	C	Mn	Si	P	S	Cu	Cr	Ni	Mo	Sn	V	Nb	Al	CEQ
1	2201403203051	CAN 20ft 8 x 11.5	000000140462	A36/A529-50	57900	81100	29	0.71	.2	.921	.218	.014	.025	.333	.115	.102	.023	.017	.001	.004	.003	.449
2	2201403203054	CAN 20ft 8 x 11.5	000000140462	A36/A529-50	57900	81100	29	0.71	.2	.921	.218	.014	.025	.333	.115	.102	.023	.017	.001	.004	.003	.449
3	2201403203052	CAN 20ft 8 x 11.5	000000140462	A36/A529-50	57900	81100	29	0.71	.2	.921	.218	.014	.025	.333	.115	.102	.023	.017	.001	.004	.003	.449
4	2201403203019	CAN 20ft 8 x 11.5	000000140464	A36/A529-50	57000	80000	27	0.71	.2	1.022	.214	.012	.032	.304	.107	.108	.025	.016	.001	.004	.002	.461
5	2201403203017	CAN 20ft 8 x 11.5	000000140464	A36/A529-50	57000	80000	27	0.71	.2	1.022	.214	.012	.032	.304	.107	.108	.025	.016	.001	.004	.002	.461
6	2201403203010	CAN 20ft 8 x 11.5	000000140464	A36/A529-50	57000	80000	27	0.71	.2	1.022	.214	.012	.032	.304	.107	.108	.025	.016	.001	.004	.002	.461
7	2201403203022	CAN 20ft 8 x 11.5	000000140464	A36/A529-50	57000	80000	27	0.71	.2	1.022	.214	.012	.032	.304	.107	.108	.025	.016	.001	.004	.002	.461
8	2201403203008	CAN 20ft 8 x 11.5	000000140464	A36/A529-50	57000	80000	27	0.71	.2	1.022	.214	.012	.032	.304	.107	.108	.025	.016	.001	.004	.002	.461
9	2201403203012	CAN 20ft 8 x 11.5	000000140464	A36/A529-50	57000	80000	27	0.71	.2	1.022	.214	.012	.032	.304	.107	.108	.025	.016	.001	.004	.002	.461
10	2201403203021	CAN 20ft 8 x 11.5	000000140464	A36/A529-50	57000	80000	27	0.71	.2	1.022	.214	.012	.032	.304	.107	.108	.025	.016	.001	.004	.002	.461

Certificamos que el producto aquí descrito, cumple y ha sido fabricado, muestreado, probado e inspeccionado de acuerdo con los requisitos aplicables de la especificación: ASTM A6

We certify that the product above mentioned accomplishes and has been manufactured, sampled, tested and inspected in accordance with applicable requirements of specifications: ASTM A6

CONTROL
DE
CALIDAD

Gerente de Aseguramiento de Calidad

En SIGOSA, SA DE CV nos comprometemos a satisfacer las expectativas y requerimientos de nuestros clientes, Mediante un sistema de Gestión de Calidad, la mejora continua de nuestros productos, el uso eficiente de los recursos, y la participación individual y de equipo de todo su personal.

FOR-CAL-CAL-001 REV. 3 OCTUBRE 2012.

05/19/2014 From: To:
PO #: Heat #: SO #:
Item #: NMSC#:
Desc:

PAGE : 1 / 1

증명서번호
CERTIFICATE NO. : PE201402-0211-000484(5010943)

제 품 명
COMMODITY : H.F.W STEEL PIPE

제 품 규 격
SPECIFICATION : API 5LX42 PSL1/5LB(45th)/ASTM A53B(2012)/ASME SA53B(2010)

INSPECTION CERTIFICATE

SeAH SeAH Steel Corp.

(주)세아제강

HEAD OFFICE: SEAH TOWER, 45 YANGHWA-RO, MAPO-GU, SEOUL, KOREA
POHANG PLANT : 136, GOEDONG-RO, NAM-GU, POHANG

발급일자
DATE OF ISSUE : 2014.02.24

계약서번호
L/C No. (P/O No.) : 141-1037(702074)

수요가
CUSTOMER : MERFISH SUPPLY

주문자
SHIPPER : SEAH STEEL AMERICA INC.

NO.	HEAT NO. (BATCH NO.)	판단 TYPE *1	주문치수 ORDER SIZE	수량 QUANTITY 본수 PCS	총길이 TOTAL LENGTH	중량(FT/T) WEIGHT	비고 REMARK
1	SQ28391 (SH02151080)	BBE	8,5/8 " X 0,500 " X 42,000 FT	35	1,470,000 FT	28.959	
2	SQ28391 (SH02152030)	BBE	8,5/8 " X 0,500 " X 21,000 FT	53	1,113,000 FT	21,926	

NO.	HEAT NO. (BATCH NO.)	HYDROSTATIC TEST 5 Sec. psi	RESULT	N-D-T U *2	VISUAL & DIMENSION	FLATTENING	SHOCK	COMPRESSION	RESIDUAL MAGNETISM GAUSS	BENDING *3	DRIFT	CRUSH	FLARING	FLANGE	REVERSE FLATTENING	ZINC COATING TEST WEIGHT OF ZINC COATING	균일성 C.S *4	알칼리 ALK *5
기준 SPEC									30				-					
1	SQ28391 (SH02151080)	2970	G	G	G	G			G									
2	SQ28391 (SH02152030)	2970	G	G	G	G			G									

NO.	DESIG *6	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Nb	Ti		CEQ *8	DIR *9	TENSILE STRENGTH psi	YIELD STRENGTH psi	E.L % *10	IMPACT TEST (℃) ENERGY Joule	SHEAR AREA %	HARDNESS TEST	HEAT TREATMENT SN *11
		2			3		2	2	2	2	3	3	3										
		*7																					
기준 SPEC	MAX	26		120	30	30	40	40	40	15	80												
	MIN																60200	42100					
1	H	18	1	76	12	5																	
	P	17	2	76	14	7	2	1	2	TR	1	1	1			T	70190	46840	39				G
	P	17	1	77	13	6	2	1	2	TR	1	1	1			W	75850						
2	H	18	1	76	12	5																	
	P	17	1	76	13	5	2	1	1	TR	2	1	1			T	69610	48290	38				G
	P	17	2	75	13	6	2	1	1	TR	1	1	1			W	76720						

NOTE *1 - *11: Refer To Others

OTHERS
*1-BBE:Black Beveled End(30°) *G:GOOD *Tr:Trace
*2-U:Weld Seam Ultrasonic Test
*6-H:Heat(Ladle) Analysis, P:Product Analysis *7-2:X100, 3:X1000, 4:X10000
*9-T:Base Metal Transverse, W:Weld Part Transverse *10-E.L:Elongation *11-S.N:Seam Normalizing

* THIS CERTIFICATE IS ISSUED ACCORDING TO EN 10204 3.1 (ISO 10474 3.1.B)

Surveyor :

· 본 제품은 관련 규격에 정한 시험 및 검사에 합격하였음을 증명합니다.
(WE HEREBY CERTIFY THAT THE MATERIAL HEREIN HAS BEEN MADE AND TESTED IN ACCORDANCE WITH ABOVE SPECIFICATION AND THE RESULTS OF ALL TEST ARE ACCEPTABLE.)

· 본 검사 증명서에 명기된 규격용도외 사용시 안전상 또는 재산상의 문제가 발생할 수 있으며, 검사증명서 위.변조시 사문서 위조(형법 231조)로 불이익을 당하실 수 있습니다.

Manager of Q.M Dept.

N. J. Baek

Independence Tube

6226 W. 74th St
Chicago, IL 60638
708-496-0380
Fax: 708-563-1950

independencetube.com
itctube.com

Certificate Number: MAR 117562

Sold By:
INDEPENDENCE TUBE CORPORATION
6226 W. 74th St.
Chicago, IL 60638
Tel: 708-496-0380
Fax: 708-563-1950

Purchase Order No: 6756003
Sales Order No: MAR 253617 - 2
Bill of Lading No: MAR 147919 - 2
Invoice No:

Shipped: 1/7/2014
Invoiced:

Sold To:
144 - KLOECKNER METALS CORPORATION
500 COLONIAL PARKWAY
SUITE 500
ROSWELL, GA 30076

Ship To:
21 - KLOECKNER METALS-BUDA
2560 SOUTH LOOP 4
BUDA, TX 78610

CERTIFICATE of ANALYSIS and TESTS

Customer Part No: 002

Certificate No: MAR 117562
Test Date: 1/3/2014

TUBING A500 GRADE B(C)
10" SQ X 5/8" X 40'

Total Pieces	Total Weight
1	3,053

Heat #: U61800 Yield: 53,840 psi Tensile: 65,790 psi Elongation: 37.2 % Y/T Ratio: 0.8184 Carbon Eq: 0.3303

C	Mn	P	S	Si	Al	Cu	Cr	Mo	V	Ni
0.2000	0.7100	0.0060	0.0130	0.0150	0.0340	0.0200	0.0400	0.0090	0.0010	0.0100

Bundle Tag	Pieces	Weight
794466	1	3,053

T/R FAX

Test Report Clerk
MELTED IN U.S.A.

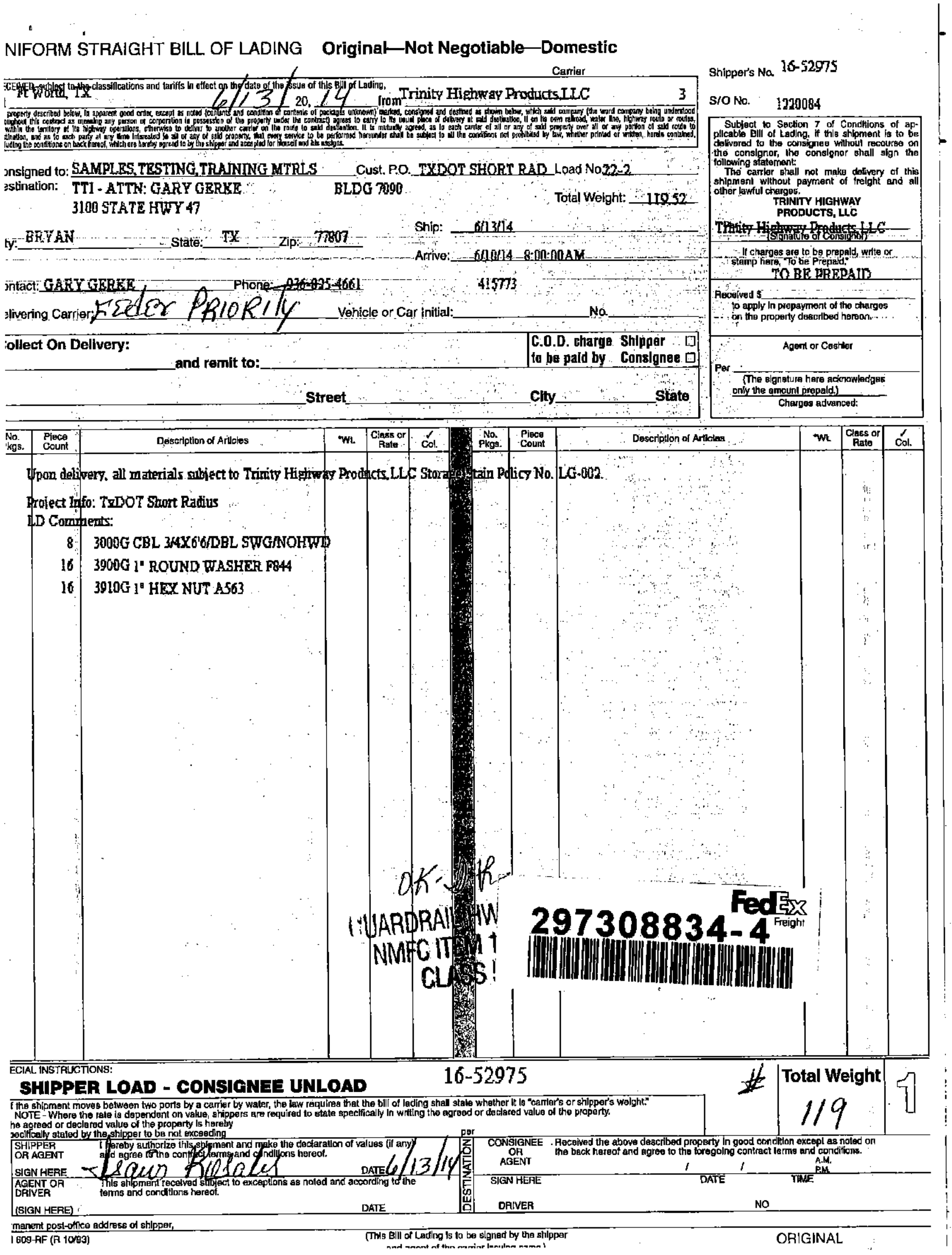
Certification:

I certify that the above results are a true and correct copy of records prepared and maintained by Independence Tube Corporation. Sworn this day, 1/3/2014

WE PROUDLY MANUFACTURE ALL OF OUR HSS IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED,
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.
****

CURRENT STANDARDS:
...............................A500/A500M-10a
...............................A513-07
...............................A252-98 (2002)
...............................A847/A847M-11

Jose Martinez, QMS Manager



NIFORM STRAIGHT BILL OF LADING **Original—Not Negotiable—Domestic**

Carrier

Shipper's No. 16-52975

S/O No. 1220084

CEIVED, subject to the classifications and tariffs in effect on the date of the issue of this Bill of Lading, Ft Worth, TX 6/13/ 20, 14 from Trinity Highway Products,LLC 3

property described below, in apparent good order, except as noted (contents and condition of contents of packages unknown) marked, consigned and destined as shown below, which said company (the word company being understood oughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its own railroad, water line, highway route or routes, within the territory of its highway operations, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to stination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the conditions not prohibited by law, whether printed or written, herein contained, luding the conditions on back hereof, which are hereby agreed to by the shipper and accepted for himself and his assigns.

onsigned to: SAMPLES,TESTING,TRAINING MTRLS Cust. P.O. TXDOT SHORT RAD Load No 22-2

estination: TTI - ATTN: GARY GERKE BLDG 7090

3100 STATE HWY 47

Total Weight: 119.52

ty: BRYAN State: TX Zip: 77807

Ship: 6/13/14

Arrive: 6/10/14 8:00:00AM

ontact: GARY GERKE Phone: 936-835-4661

415773

elivering Carrier: FEDEX PRIORITY Vehicle or Car Initial: No.

ollect On Delivery:

and remit to:

Street City State

C.O.D. charge to be paid by Shipper ☐ Consignee ☐

Subject to Section 7 of Conditions of applicable Bill of Lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:

The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.

TRINITY HIGHWAY PRODUCTS, LLC

Trinity Highway Products,LLC

(Signature of Consignor)

If charges are to be prepaid, write or stamp here, "To be Prepaid."

TO BE PREPAID

Received $

to apply in prepayment of the charges on the property described hereon.

Agent or Cashier

Per

(The signature here acknowledges only the amount prepaid.)

Charges advanced:

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.	No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
		Upon delivery, all materials subject to Trinity Highway Products,LLC Storage/Stain Policy No. LG-002.									
		Project Info: TxDOT Short Radius									
		LD Comments:									
	8	3000G CBL 3/4X6'6/DBL SWG/NOHWD									
	16	3900G 1" ROUND WASHER F844									
	16	3910G 1" HEX NUT A563									

OK

GUARDRAIL HW

NMFC ITEM 1

CLASS

297308834-4

FedEx Freight

ECIAL INSTRUCTIONS:

SHIPPER LOAD - CONSIGNEE UNLOAD

16-52975

Total Weight	
119	1

f the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is "carrier's or shipper's weight."

NOTE - Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property.

he agreed or declared value of the property is hereby pecifically stated by the shipper to be not exceeding per

SHIPPER OR AGENT: I hereby authorize this shipment and make the declaration of values (if any) and agree to the contract terms and conditions hereof.

SIGN HERE Shaun Robalis DATE 6/13/14

AGENT OR DRIVER: This shipment received subject to exceptions as noted and according to the terms and conditions hereof.

(SIGN HERE) DATE

DESTINATION

CONSIGNEE OR AGENT: Received the above described property in good condition except as noted on the back hereof and agree to the foregoing contract terms and conditions.

SIGN HERE DATE / / TIME A.M. P.M.

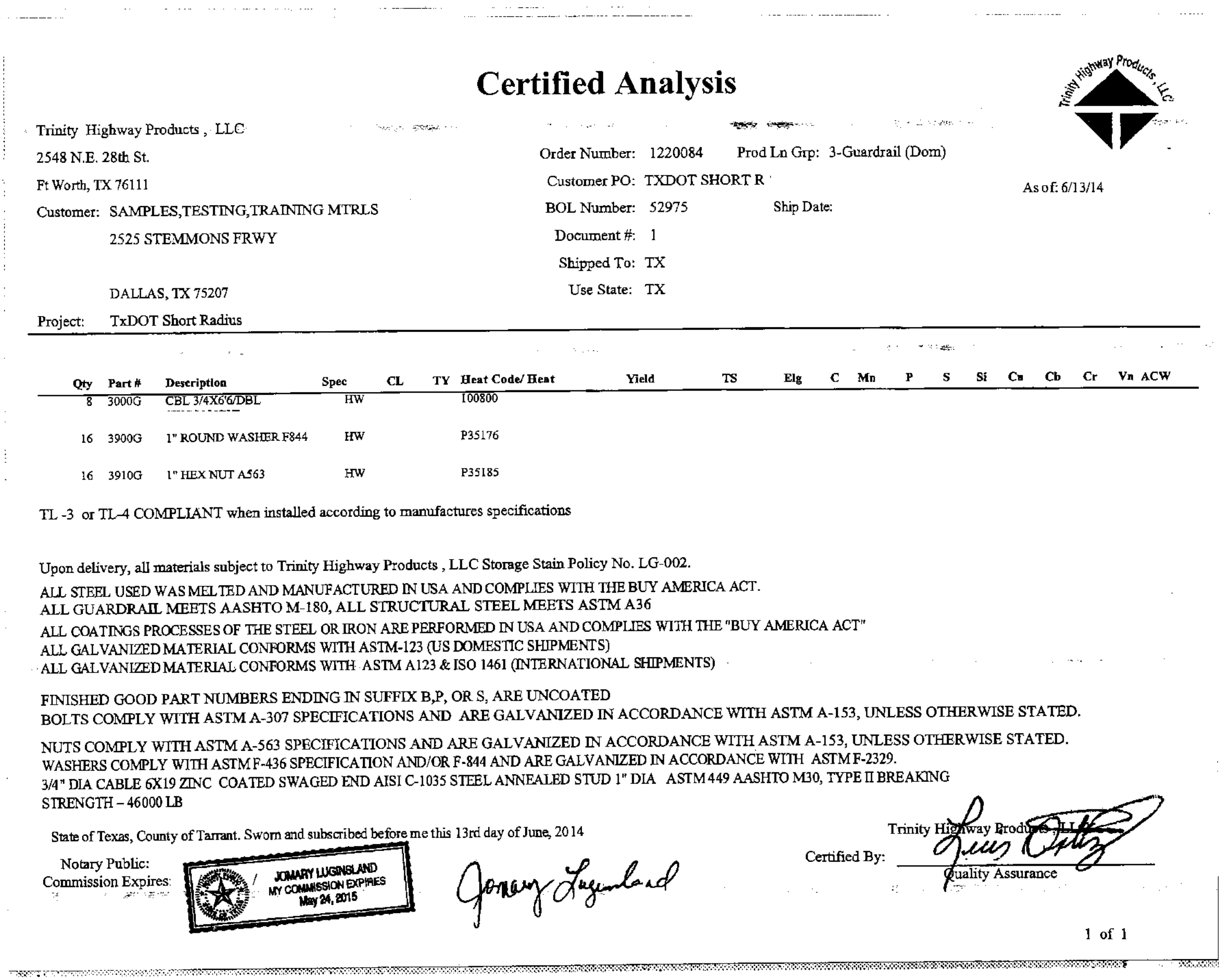
DRIVER NO

manent post-office address of shipper,

I 609-RF (R 10/93)

(This Bill of Lading is to be signed by the shipper and agent of the carrier issuing same.)

ORIGINAL



Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111

Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207

Project: TxDOT Short Radius

Order Number: 1220084 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: TXDOT SHORT R
BOL Number: 52975 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 6/13/14

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
8	3000G	CBL 3/4X6'6/DBL	HW			100800													
16	3900G	1" ROUND WASHER F844	HW			P35176													
16	3910G	1" HEX NUT A563	HW			P35185													

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

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

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 13rd day of June, 2014

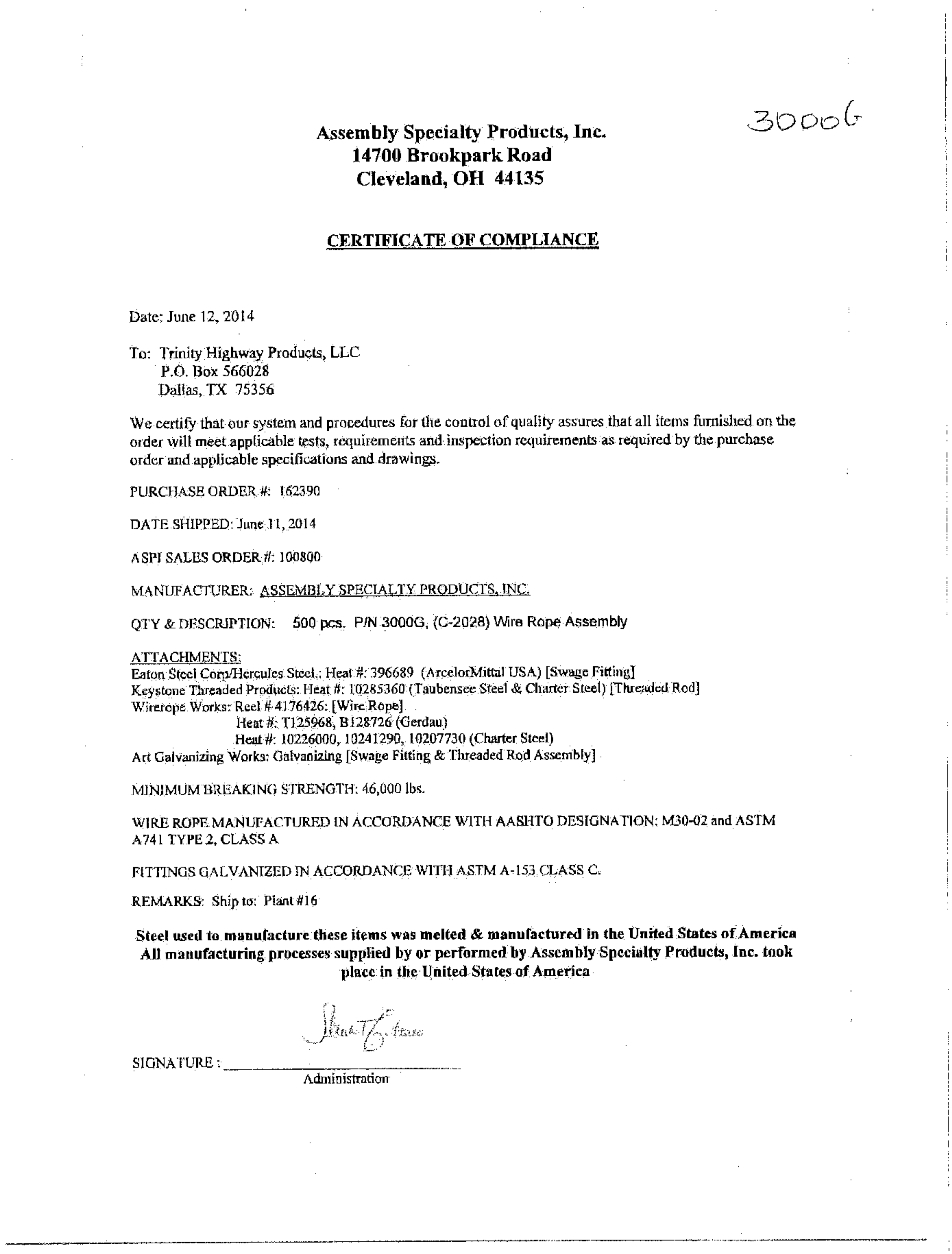
Notary Public:
Commission Expires:

JOMARY LUGINSLAND
MY COMMISSION EXPIRES
May 24, 2015

Jomary Luginsland

Trinity Highway Products, LLC
Certified By:
Quality Assurance

1 of 1



3000G

Assembly Specialty Products, Inc.
14700 Brookpark Road
Cleveland, OH 44135

CERTIFICATE OF COMPLIANCE

Date: June 12, 2014

To: Trinity Highway Products, LLC
P.O. Box 566028
Dallas, TX 75356

We certify that our system and procedures for the control of quality assures that all items furnished on the order will meet applicable tests, requirements and inspection requirements as required by the purchase order and applicable specifications and drawings.

PURCHASE ORDER #: 162390

DATE SHIPPED: June 11, 2014

ASPI SALES ORDER #: 100800

MANUFACTURER: ASSEMBLY SPECIALTY PRODUCTS, INC.

QTY & DESCRIPTION: 500 pcs. P/N 3000G, (C-2028) Wire Rope Assembly

ATTACHMENTS:
Eaton Steel Corp/Hercules Steel,: Heat #: 396689 (ArcelorMittal USA) [Swage Fitting]
Keystone Threaded Products: Heat #: 10285360 (Taubensee Steel & Charter Steel) [Threaded Rod]
Wirerope Works: Reel # 4176426: [Wire Rope]
Heat #: T125968, B128726 (Gerdau)
Heat #: 10226000, 10241290, 10207730 (Charter Steel)
Art Galvanizing Works: Galvanizing [Swage Fitting & Threaded Rod Assembly]

MINIMUM BREAKING STRENGTH: 46,000 lbs.

WIRE ROPE MANUFACTURED IN ACCORDANCE WITH AASHTO DESIGNATION: M30-02 and ASTM A741 TYPE 2, CLASS A

FITTINGS GALVANIZED IN ACCORDANCE WITH ASTM A-153 CLASS C.

REMARKS: Ship to: Plant #16

Steel used to manufacture these items was melted & manufactured in the United States of America All manufacturing processes supplied by or performed by Assembly Specialty Products, Inc. took place in the United States of America

SIGNATURE : ______________________
Administration

3006

PACKING LIST

DELIVERY NUMBER: 105151

DOCUMENT DATE:
Wednesday, June 11, 2014

SHIPPED FROM:
Assembly Specialty Products, Inc.
14700 Brookpark Rd.
Cleveland, OH 44135-5166
Phone #: (216) 676-5600
Fax #: (216) 676-6761

SHIPPED TO:
Trinity Highway Products, Ft. Worth
Plant # 16, Attn: Luis Ortiz
817-665-1499
2548 N.E. 28th Street
Fort Worth, TX 76111-1701

PO LINE #	QTY SHIPPED	QTY ORDERED	ITEM #	CUSTOMER ITEM #	MATERIAL DESCRIPTION
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] Cable Assembly

PASSED & CERTIFIED
JUN 12 2014
Trinity Highway Products, LLC
Dallas, Texas Plant 99

Tracking Number(s)
2962597923

NO RETURNS AFTER 30 DAYS. ALL RETURNS MUST BE AUTHORIZED AND MAY BE SUBJECT TO A RESTOCKING CHARGE.

aspi

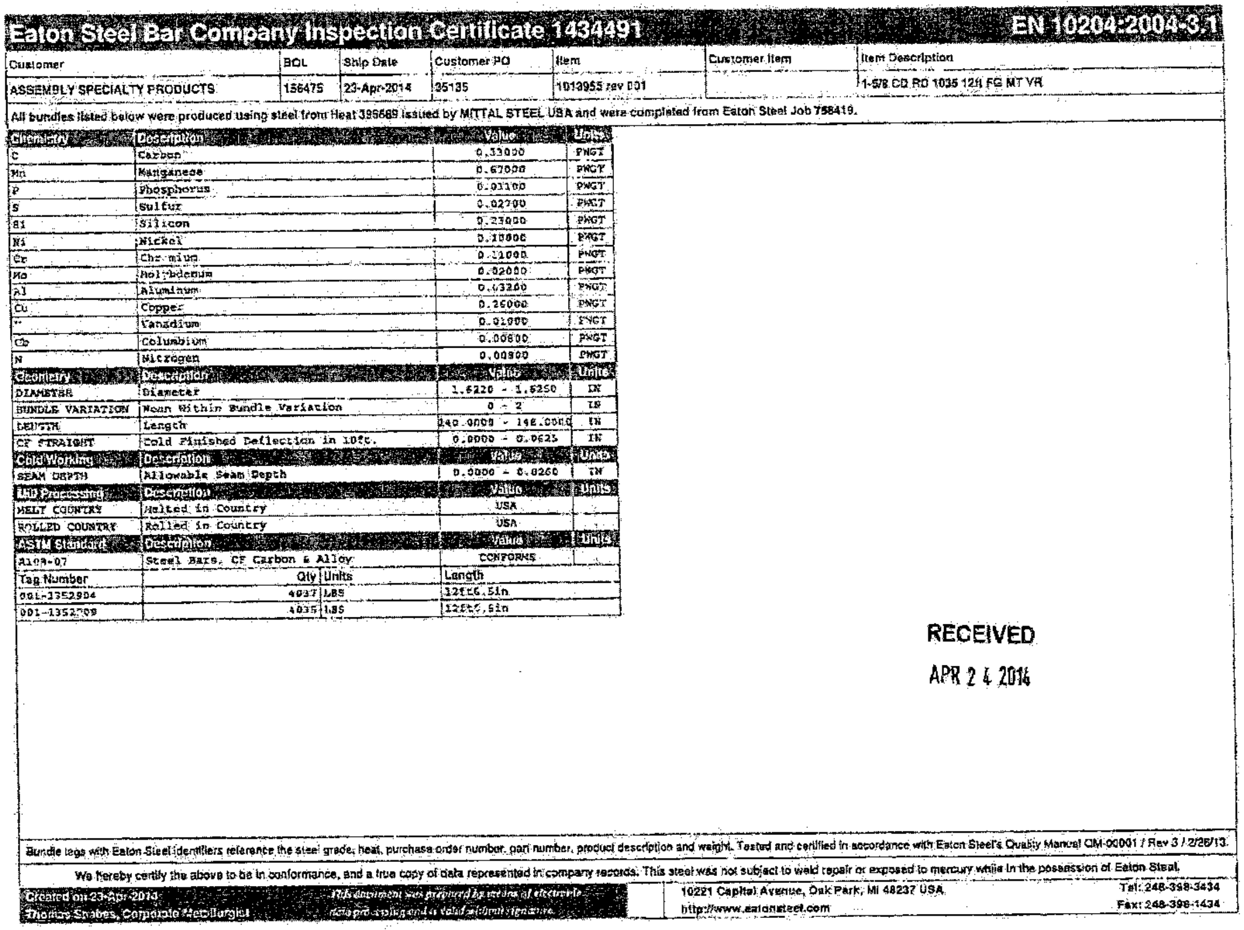
Like us on Facebook @ www.facebook.com/ASPICleveland

ISO 9001:2008 REGISTERED

THANK YOU FOR YOUR ORDER!

Page 1 of 1

30006



Eaton Steel Bar Company Inspection Certificate 1434491 EN 10204:2004-3.1

Customer	BOL	Ship Date	Customer PO	Item	Customer Item	Item Description
ASSEMBLY SPECIALTY PRODUCTS	156475	23-Apr-2014	35135	1013955 rev 001		1-5/8 CD RD 1035 12ft FG MT VR

All bundles listed below were produced using steel from Heat 395689 issued by MITTAL STEEL USA and were completed from Eaton Steel Job 758419.

Chemistry	Description	Value	Units
C	Carbon	0.33000	PNGT
Mn	Manganese	0.67000	PNGT
P	Phosphorus	0.03100	PNGT
S	Sulfur	0.02700	PNGT
Si	Silicon	0.23000	PNGT
Ni	Nickel	0.10000	PNGT
Cr	Chromium	0.11000	PNGT
Mo	Molybdenum	0.02000	PNGT
Al	Aluminum	0.03200	PNGT
Cu	Copper	0.26000	PNGT
"	Vanadium	0.01000	PNGT
Cb	Columbium	0.00600	PNGT
N	Nitrogen	0.00900	PNGT
Geometry	**Description**	**Value**	**Units**
DIAMETER	Diameter	1.6220 - 1.6250	IN
BUNDLE VARIATION	Mean Within Bundle Variation	0 - 2	IN
LENGTH	Length	140.0000 - 148.0000	IN
CF STRAIGHT	Cold Finished Deflection in 10ft.	0.0000 - 0.0625	IN
Cold Working	**Description**	**Value**	**Units**
SEAM DEPTH	Allowable Seam Depth	0.0000 - 0.0260	IN
Mill Processing	**Description**	**Value**	**Units**
MELT COUNTRY	Melted in Country	USA	
ROLLED COUNTRY	Rolled in Country	USA	
ASTM Standard	**Description**	**Value**	**Units**
A108-07	Steel Bars, CF Carbon & Alloy	CONFORMS	

Tag Number	Qty	Units	Length
001-1352904	4037	LBS	12ft6.5in
001-1352709	4035	LBS	12ft6.5in

RECEIVED
APR 24 2014

Bundle tags with Eaton Steel identifiers reference the steel grade, heat, purchase order number, part number, product description and weight. Tested and certified in accordance with Eaton Steel's Quality Manual QM-00001 / Rev 3 / 2/26/13.

We hereby certify the above to be in conformance, and a true copy of data represented in company records. This steel was not subject to weld repair or exposed to mercury while in the possession of Eaton Steel.

Created on 23-Apr-2014
Thomas Snabes, Corporate Metallurgist

This document was prepared by means of electronic data processing and is valid without signature.

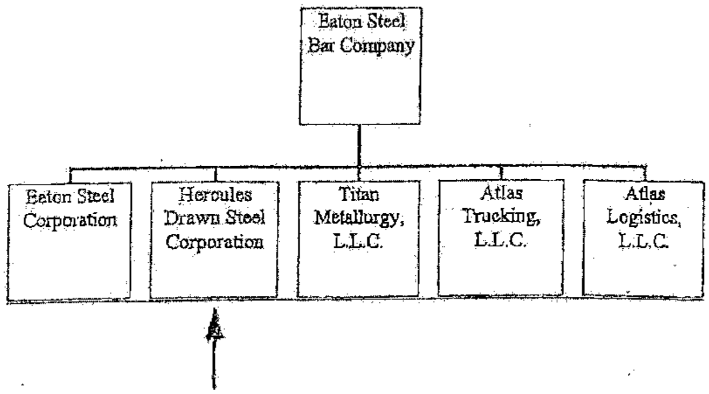
10221 Capital Avenue, Oak Park, MI 48237 USA
http://www.eatonsteel.com
Tel: 248-398-3434
Fax: 248-398-1434

30006

EATON
STEEL BAR COMPANY

Quality System Registrar QS 9000 ISO 9002

Eaton Steel Bar Company Corporate Hierarchy



3006

TEST REPORT

REQ., JOB, CONTRACT NO	PURCHASE ORDER NO 124346
SHIPPER'S NO	MILL ORDER NO 286094
REPORT DATE 10/26/2013	

VENDOR
ArcelorMittal USA Inc.
INDIANA HARBOR LONG CARBON
3300 DICKEY ROAD
EAST CHICAGO, INDIANA 46312-1644

TEST REPORT TO:
HERCULES DRAWN STEEL CORP

10221 CAPITAL AVE

OAK PARK MI 48237

SHIP TO:
HERCULES DRAWN STEEL

38901 AMRHEIN RD

LIVONIA MI, 48151

CMS (REG TM) SQ HOT ROLLED ROUNDS SAE 1035 /ESM8-1035 09/25/96 / FINE GRAIN/
/ASTM A576-90b (Reapproved 2012)/RESTRICTED MAX INCIDENTAL ELEMENTS/MRR FOR SPEC
SURF, SND & CLEAN/ASTM A29/

RND 1.6875 IN X 23 FT 7 IN TO 35 FT

```
HEAT: 396689  C : 0.33   Mn: 0.67   P : .011   S : .027   Si: 0.23
              Cu: .26    Ni: 0.10   Cr: 0.11   Mo: .02    Al: .032
              Cb: <.008  V : .010   N : .008   Ti: .002

              R.RATIO: 21.9:1       DI VALUE: 1.00
```

PART NUMBER: 1005437

MATERIAL IS FREE FROM SURFACE MERCURY CONTAMINATION AS OF THE TIME OF
SHIPMENT BASED ON PRESENT METHODS & EQUIPMENT FOR DETECTION OF THIS
KIND OF CONTAMINATION.
THIS MATERIAL HAS RECEIVED NO WELD REPAIR.
MATERIAL MEETS AUSTENITIC GRAIN SIZE REQUIREMENT OF 5 OR FINER
THIS STEEL IS WARRANTED TO MEET OR EXCEED MACRO/RATING OF " S4 R4 C4"
THIS STEEL IS WARRANTED TO MEET OR EXCEED MICROCLEANLINESS/ RATING OF "85-05"
PRODUCT WAS ROLLED AT ARCELORMITTAL EAST CHICAGO, INDIANA, USA
FROM CONTINUOUSLY BILLET CAST, ELECTRIC ARC FURNACE STEEL
MELTED AT ARCELORMITTAL EAST CHICAGO, INDIANA, USA.

Unless otherwise stated, the steel described herein was manufactured, inspected and tested in accordance with the requirements of the contract or purchase order and conform to those requirements. This steel is compliant with European Union Directive 2002/95/EC. No mercury, radium or alpha source materials were used in the production of this steel. This steel has not been welded nor repair welded. Heat analyses are reported in weight percent. Heat analyses and test results marked with an asterisk (*) were reported by a ArcelorMittal USA Inc., Indiana Harbor Long Carbon approved third party. The "+" sign at the beginning of any line indicates an amendment to that line from a previously issued report for the same heat/order. All tests were performed by ArcelorMittal USA Inc., Indiana Harbor Long Carbon, in accordance with the following, unless otherwise specified: Chemistry per ASTM E415 & E1019; Hardenability per ASTM A255 and SAE J406; Macrostructure per ASTM E381 & E1180; Mechanical Properties per ASTM A370, E8 & E23; Hardness per ASTM E10-Type A, E18 & SAE J417; Cleanliness per SAE J421; Microstructure/Microcleanliness per ASTM E3, E45, E112, E1077, J419, J422 & JIS G0555; Rounding per ASTM E29. Tested per most recent standard, unless otherwise noted. Measurement uncertainty was determined and is available upon request. We hereby certify that the heat and/or test results in this report are applicable only to the items described herein, and are correct as contained in the records of the Company. This document shall not be reproduced except in full.

The management system governing the manufacturing processes of this product, at ArcelorMittal USA Inc., Indiana Harbor Long Carbon, is ISO/TS 16949:2009 certified, Certificate No. 41526; ISO 14001:2004 certified, Certificate No. 38274 and A2LA accredited in the fields of Chemical, Mechanical and Environmental Testing-Certificate Nos. 111.01, 111.02 and 111.03

Kenneth B. Kolodziej
Manager - Quality & Technical Services

Rev 10/5/10

Page 1 of 1

30006

KEYSTONE
THREADED PRODUCTS

MATERIAL CERTIFICATION

7600 HUB PARKWAY
VALLEY VIEW, OHIO 44125

Sold To:			
Sold To:	ASSEMBLY SPECIALTY PRODUCTS INC.	Order Date	1/14/14
	14700 BROOKPARK ROAD	Order No.	34900
	CLEVELAND, OHIO 44135	Shipped Date	3/31/14
		Invoice No.	69622-01

SPECIAL STUDS - ROLLED THREAD

9673 Pcs. 1"-8 X 8-3/4"

PART NO. C-1681

MATERIAL DESCRIPTION

Weight	Size	Length	Shape	Grade	Type
15,902 LBS.	0.9080 / 0.9080	168.00	RND	1045	CD

Heat No.	Order No.	Rec. Date	Code
10285360	0023168	3/11/14	TSW

SPECIFICATIONS

ASTM A108-07 SAE J403

CHEMICALS

ELEMENTS:	C	MN	P	S	SI	NI	CR
AMOUNTS	0.4800	0.8600	0.0110	0.0250	0.2700	0.0500	0.0600

ELEMENTS:	MO	CU	SN	V	AL	N	B
AMOUNTS	0.0100	0.0800	0.0060	0.0020	0.0340	0.0060	0.0001

ELEMENTS:	TI	NB
AMOUNTS	0.0010	0.0010

STEEL MELTED AND MANUFACTURED IN THE U.S.A.

ASSEMBLY SPECIALTY PRODUCTS, INC
14700 BROOKPARK ROAD
CLEVELAND, OH 44135

ROSE YOVICH
Notary Public, State of Ohio
My Commission Expires

State of Ohio
County of Cuyahoga

Sworn to and subscribed before me
This 28th Day of march 2014

We certify the foregoing a true and accurate report as represented by our suppliers.

30006

TAUBENSEE STEEL & WIRE COMPANY
600 DIENS DRIVE WHEELING, IL 60090
(847) 459-5100

PAGE 1

MATERIAL ANALYSIS CERTIFICATION

SOLD TO: KEYSTONE THREADED PROD. (B)
P.O. BOX 31059
INDEPENDENCE OH 441310059

CUST P.O. #: 0023168
TSW ORDER #: 3310040
TSW INVOICE #:

THE FOLLOWING TEST CONFORMS TO THE REQUIREMENTS OF THE GRADE SPECIFICATION ORDERED AND LISTED BELOW:

MATERIAL DESCRIPTION:

1000 SERIES(CARBON .29-.55%) COLD DRAW ROUND BARS TO ASTM A108-07 & SAE J403.
"STEEL MELTED & MANUFACTURED IN USA"

PART NUMBER # 104509100-002

HEAT	SIZE	GRADE	LENGTH	WEIGHT	AVG TENSILE
10285360	.91	1045	168	15902	

HEAT:	CHEMICAL ANALYSIS:				
10285360	C 0.480	Mn 0.860	P 0.011	S 0.025	Si 0.270
	Ni 0.050	Cr 0.060	Mo 0.010	Al 0.034	Sn 0.0001
	V 0.002	N 0.006	Nb 0.001	Ti 0.001	Cu 0.080
	Pb .000/.000				

MECHANICAL PROPERTIES:
THE FOLLOWING MECHANICAL PROPERTIES SHOULD REPORT TYPICAL TO ASTM A108-95:
TENSILE, YIELD, ELONGATION, REDUCTION OF AREA, HARDNESS & HARDENABILITY

WE CERTIFY THAT THE INFORMATION SHOWN ABOVE IS TRUE AND EXACT AS CONTAINED IN THE PERMANENT ELECTRONIC RECORDS OF TAUBENSEE STEEL & WIRE CO.

STATE OF ILLINOIS
COUNTY OF COOK

Authorized Electronic Signature
Chuck Hrycko

Quality Technician

ASSEMBLY SPECIALTY PRODUCTS, INC
14700 BROOKPARK ROAD
CLEVELAND, OH 44135

3000

TAUBENSEE STEEL & WIRE COMPANY
600 DIENS DRIVE WHEELING, IL 60090
(847) 459-5100

PAGE 2

MATERIAL ANALYSIS CERTIFICATION

SOLD TO: KEYSTONE THREADED PROD. (B)

P.O. BOX 31059
INDEPENDENCE OH 441310059

CUST P.O. #: 0023168
TSW ORDER #: 3310040
TSW INVOICE #:

THE FOLLOWING TEST CONFORMS TO THE REQUIREMENTS OF THE GRADE SPECIFICATION ORDERED AND LISTED BELOW:

Subscribed and sworn to before me this

10th day of March A.D. 20 14

DATE 03/10/14

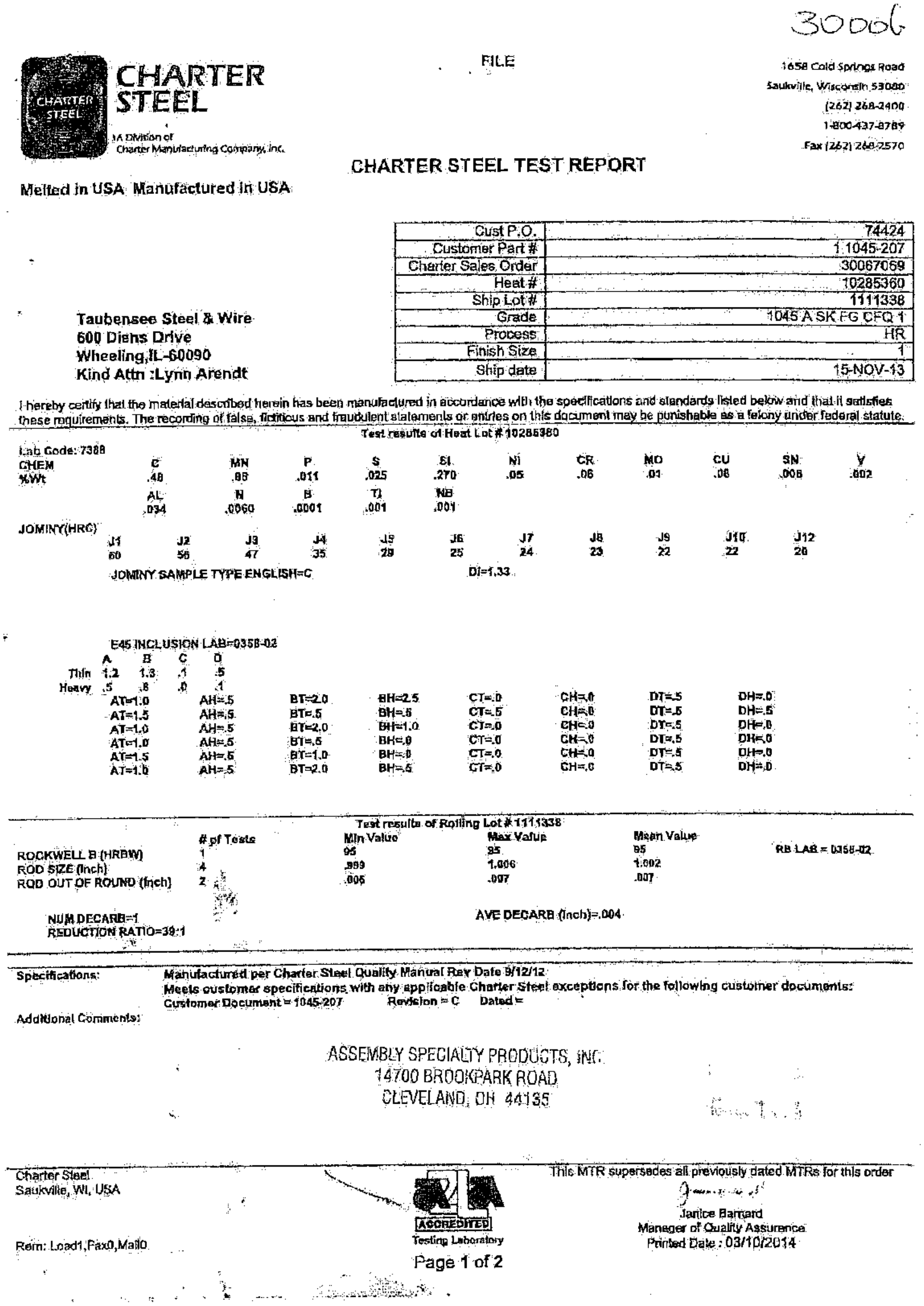
Lisa M Carlson
Notary Public

(SEAL)

OFFICIAL SEAL
LISA M CARLSON
MY COMMISSION EXPIRES 08/12/16

ASSEMBLY SPECIALTY PRODUCTS, INC.
14700 BROOKPARK ROAD
CLEVELAND, OH 44135

DELIVERY COPY



30006

FILE

CHARTER STEEL
A Division of
Charter Manufacturing Company, Inc.

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
Fax (262) 268-2570

CHARTER STEEL TEST REPORT

Melted in USA Manufactured in USA

Taubensee Steel & Wire
600 Diens Drive
Wheeling,IL-60090
Kind Attn :Lynn Arendt

Cust P.O.	74424
Customer Part #	1 1045-207
Charter Sales Order	30067069
Heat #	10285360
Ship Lot #	1111338
Grade	1045 A SK FG CFQ 1
Process	HR
Finish Size	1
Ship date	15-NOV-13

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and that it satisfies these requirements. The recording of false, fictitious and fraudulent statements or entries on this document may be punishable as a felony under federal statute.

Test results of Heat Lot # 10285360

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.48	.86	.011	.025	.270	.05	.06	.01	.08	.006	.002

	AL	N	B	TI	NB
	.034	.0060	.0001	.001	.001

JOMINY(HRC)

J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J12
60	56	47	35	29	25	24	23	22	22	20

JOMINY SAMPLE TYPE ENGLISH=C DI=1.33

E45 INCLUSION LAB=0358-02

	A	B	C	D
Thin	1.2	1.3	.1	.5
Heavy	.5	.8	.0	.1

AT=1.0	AH=.5	BT=2.0	BH=2.5	CT=.0	CH=.0	DT=.5	DH=.0
AT=1.5	AH=.5	BT=.5	BH=.5	CT=.5	CH=.0	DT=.5	DH=.5
AT=1.0	AH=.5	BT=2.0	BH=1.0	CT=.0	CH=.0	DT=.5	DH=.0
AT=1.0	AH=.5	BT=.5	BH=.0	CT=.0	CH=.0	DT=.5	DH=.0
AT=1.5	AH=.5	BT=1.0	BH=.0	CT=.0	CH=.0	DT=.5	DH=.0
AT=1.0	AH=.5	BT=2.0	BH=.5	CT=.0	CH=.0	DT=.5	DH=.0

Test results of Rolling Lot # 1111338

	# of Tests	Min Value	Max Value	Mean Value	
ROCKWELL B (HRBW)	1	95	95	95	RB LAB = 0358-02
ROD SIZE (Inch)	4	.999	1.006	1.002	
ROD OUT OF ROUND (Inch)	2	.006	.007	.007	

NUM DECARB=1 AVE DECARB (Inch)=.004
REDUCTION RATIO=39:1

Specifications: Manufactured per Charter Steel Quality Manual Rev Date 9/12/12
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = 1045-207 Revision = C Dated =

Additional Comments:

ASSEMBLY SPECIALTY PRODUCTS, INC.
14700 BROOKPARK ROAD
CLEVELAND, OH 44135

Charter Steel
Saukville, WI, USA

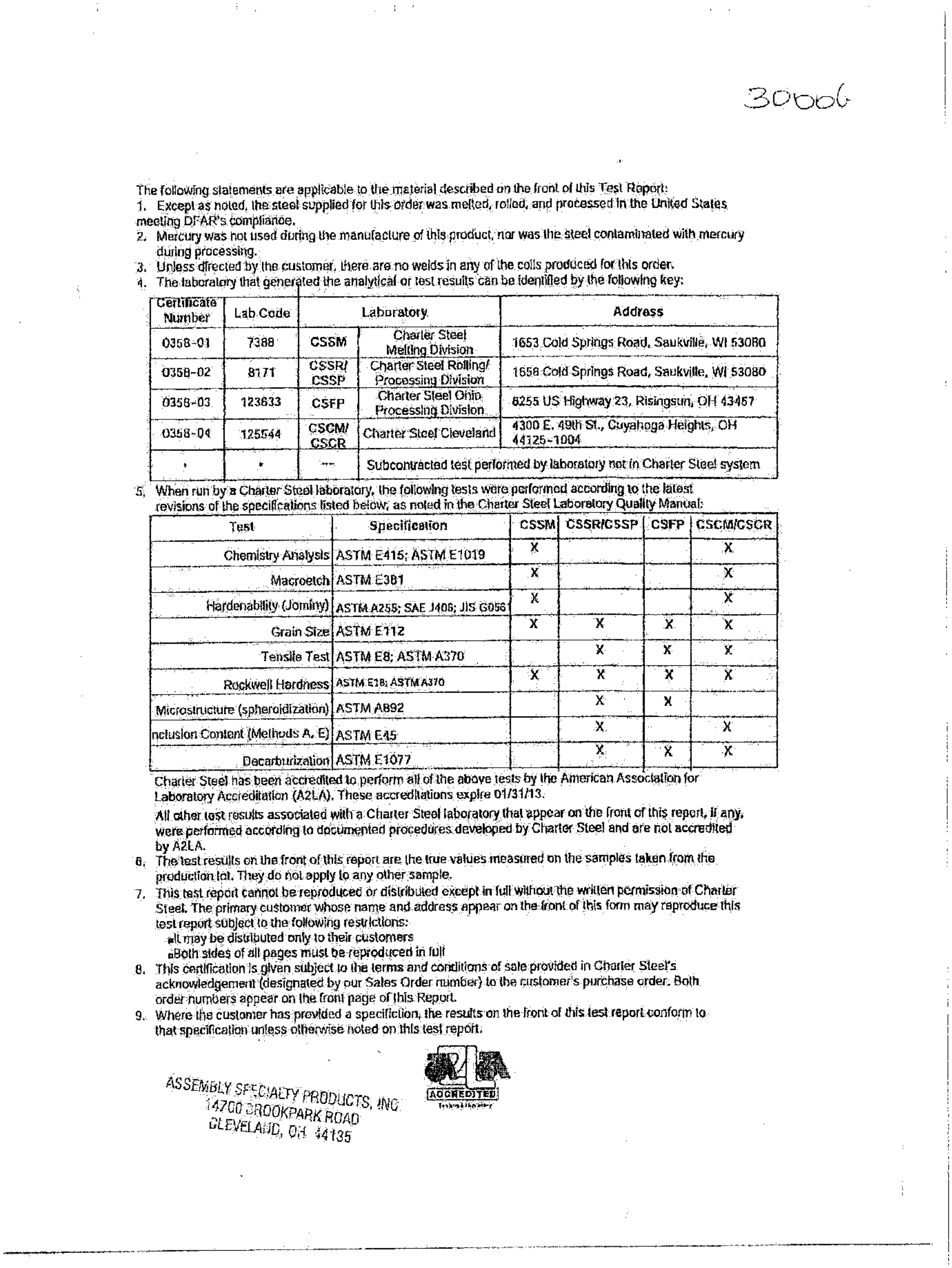
Rem: Load1,Fax0,Mail0

ACCREDITED
Testing Laboratory

Page 1 of 2

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance
Printed Date : 03/10/2014



30006

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFAR's compliance.
2. Mercury was not used during the manufacture of this product, nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	CSSM	Charter Steel Melting Division	1653 Cold Springs Road, Saukville, WI 53080
0358-02	8171	CSSR/ CSSP	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	CSFP	Charter Steel Ohio Processing Division	6255 US Highway 23, Risingsun, OH 43457
0358-04	125544	CSCM/ CSCR	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
•	•	---	Subcontracted test performed by laboratory not in Charter Steel system	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Specification	CSSM	CSSR/CSSP	CSFP	CSCM/CSCR
Chemistry Analysis	ASTM E415; ASTM E1019	X			X
Macroetch	ASTM E381	X			X
Hardenability (Jominy)	ASTM A255; SAE J406; JIS G0561	X			X
Grain Size	ASTM E112	X	X	X	X
Tensile Test	ASTM E8; ASTM A370		X	X	X
Rockwell Hardness	ASTM E18; ASTM A370	X	X	X	X
Microstructure (spheroidization)	ASTM A892		X	X	
nclusion Content (Methods A, E)	ASTM E45		X		X
Decarburization	ASTM E1077		X	X	X

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/13.

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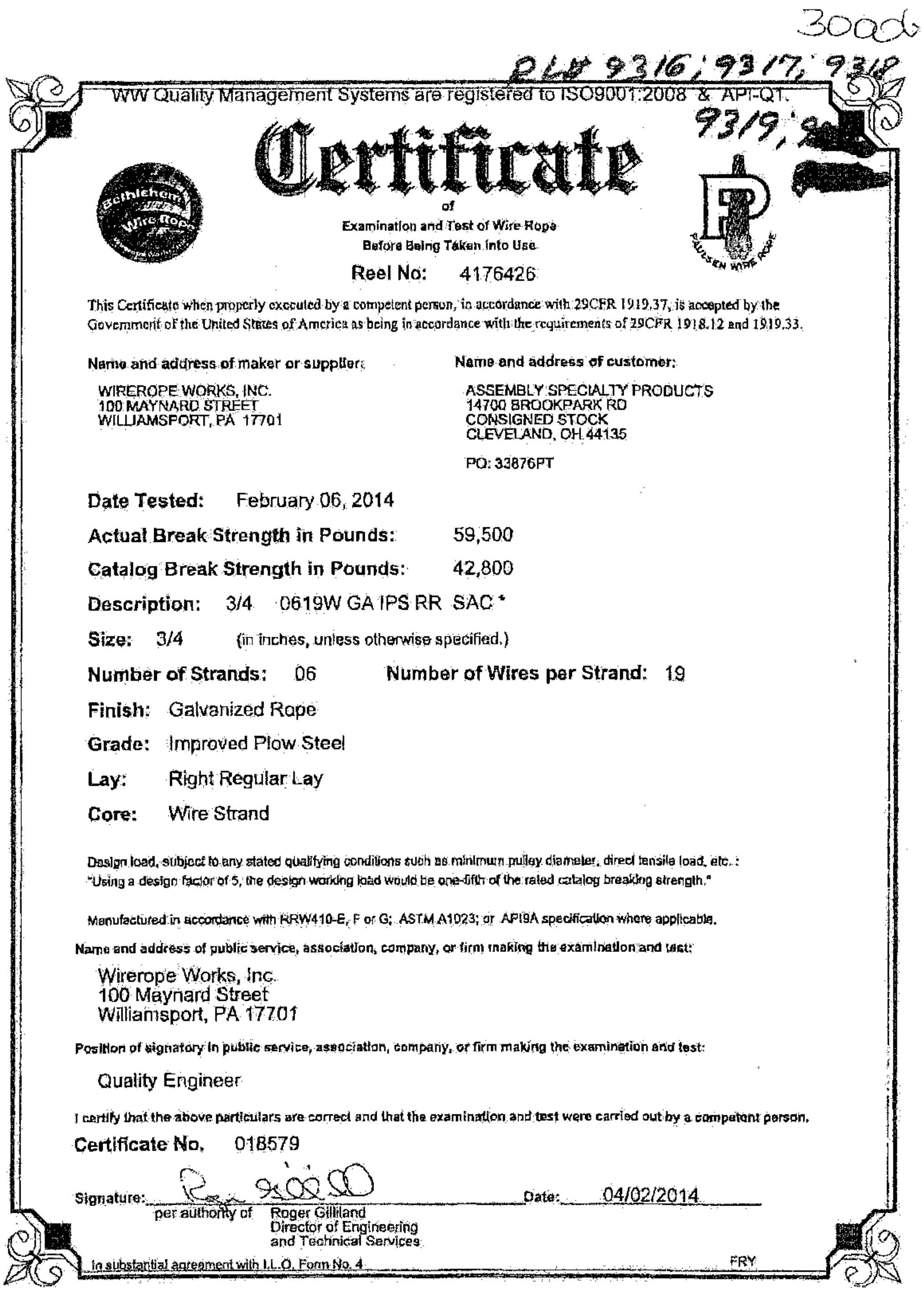
   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgement (designated by our Sales Order number) to the customer's purchase order. Both order numbers appear on the front page of this Report.
9. Where the customer has provided a specifiction, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

ASSEMBLY SPECIALTY PRODUCTS, INC
14700 BROOKPARK ROAD
CLEVELAND, OH 44135



3006

PL# 9316, 9317, 9318, 9319, 9

WW Quality Management Systems are registered to ISO9001:2008 & API-Q1.

Certificate

of

Examination and Test of Wire Rope
Before Being Taken Into Use

Reel No: 4176426

This Certificate when properly executed by a competent person, in accordance with 29CFR 1919.37, is accepted by the Government of the United States of America as being in accordance with the requirements of 29CFR 1918.12 and 1919.33.

Name and address of maker or supplier:

WIREROPE WORKS, INC.
100 MAYNARD STREET
WILLIAMSPORT, PA 17701

Name and address of customer:

ASSEMBLY SPECIALTY PRODUCTS
14700 BROOKPARK RD
CONSIGNED STOCK
CLEVELAND, OH 44135

PO: 33876PT

Date Tested: February 06, 2014

Actual Break Strength in Pounds: 59,500

Catalog Break Strength in Pounds: 42,800

Description: 3/4 0619W GA IPS RR SAC *

Size: 3/4 (in inches, unless otherwise specified.)

Number of Strands: 06 **Number of Wires per Strand:** 19

Finish: Galvanized Rope

Grade: Improved Plow Steel

Lay: Right Regular Lay

Core: Wire Strand

Design load, subject to any stated qualifying conditions such as minimum pulley diameter, direct tensile load, etc.:
"Using a design factor of 5, the design working load would be one-fifth of the rated catalog breaking strength."

Manufactured in accordance with RRW410-E, F or G; ASTM A1023; or API9A specification where applicable.

Name and address of public service, association, company, or firm making the examination and test:

Wirerope Works, Inc.
100 Maynard Street
Williamsport, PA 17701

Position of signatory in public service, association, company, or firm making the examination and test:

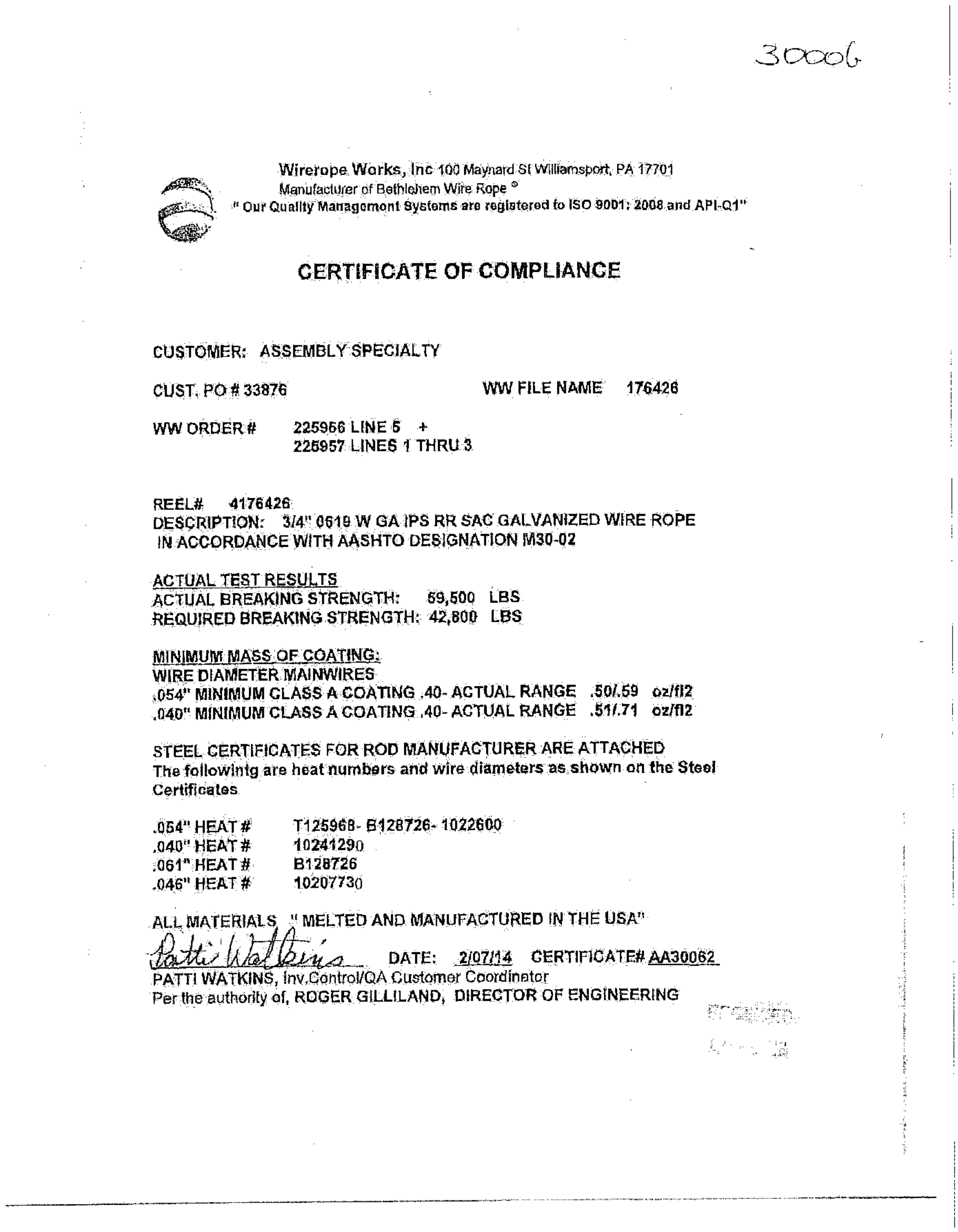
Quality Engineer

I certify that the above particulars are correct and that the examination and test were carried out by a competent person.

Certificate No. 018579

Signature: ______________ Date: 04/02/2014
per authority of Roger Gilliland
Director of Engineering
and Technical Services

In substantial agreement with I.L.O. Form No. 4 FRY



30006

Wirerope Works, Inc 100 Maynard St Williamsport, PA 17701
Manufacturer of Bethlehem Wire Rope ®
" Our Quality Management Systems are registered to ISO 9001: 2008 and API-Q1"

CERTIFICATE OF COMPLIANCE

CUSTOMER: ASSEMBLY SPECIALTY

CUST. PO # 33876 WW FILE NAME 176426

WW ORDER # 225956 LINE 5 +
225957 LINES 1 THRU 3

REEL# 4176426
DESCRIPTION: 3/4" 0619 W GA IPS RR SAC GALVANIZED WIRE ROPE
IN ACCORDANCE WITH AASHTO DESIGNATION M30-02

ACTUAL TEST RESULTS

ACTUAL BREAKING STRENGTH:	59,500	LBS
REQUIRED BREAKING STRENGTH:	42,800	LBS

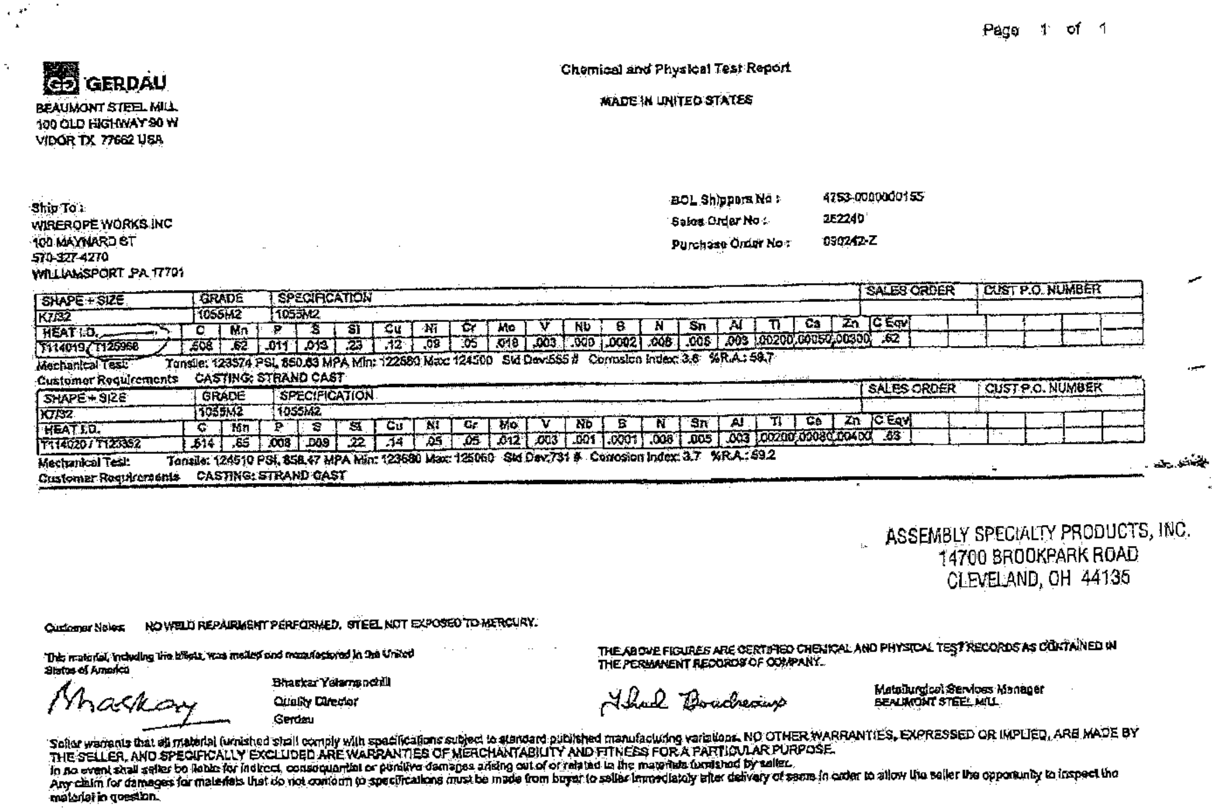
MINIMUM MASS OF COATING:
WIRE DIAMETER MAINWIRES
.054" MINIMUM CLASS A COATING .40- ACTUAL RANGE .50/.59 oz/ft2
.040" MINIMUM CLASS A COATING .40- ACTUAL RANGE .51/.71 oz/ft2

STEEL CERTIFICATES FOR ROD MANUFACTURER ARE ATTACHED
The followintg are heat numbers and wire diameters as shown on the Steel Certificates

.054" HEAT #	T125968- B128726- 1022600
.040" HEAT #	10241290
.061" HEAT #	B128726
.046" HEAT #	10207730

ALL MATERIALS " MELTED AND MANUFACTURED IN THE USA"

Patti Watkins DATE: 2/07/14 CERTIFICATE# AA30062
PATTI WATKINS, Inv.Control/QA Customer Coordinator
Per the authority of, ROGER GILLILAND, DIRECTOR OF ENGINEERING



Page 1 of 1

GERDAU
BEAUMONT STEEL MILL
100 OLD HIGHWAY 90 W
VIDOR TX 77662 USA

Chemical and Physical Test Report

MADE IN UNITED STATES

Ship To :
WIREROPE WORKS INC
100 MAYNARD ST
570-327-4270
WILLIAMSPORT ,PA 17701

BOL Shippers No : 4753-0000000155
Sales Order No : 2E2240
Purchase Order No : 090242-Z

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
K7/32	1055M2	1055M2		

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Ca	Zn	C Eqv
T114019/T125968	.608	.62	.011	.013	.23	.12	.09	.05	.018	.003	.000	.0002	.008	.005	.003	.00200	.00050	.00300	.62

Mechanical Test: Tensile: 123374 PSI, 850.63 MPA Min: 122680 Max: 124500 Std Dev:555 # Corrosion Index: 3.6 %R.A.: 59.7
Customer Requirements CASTING: STRAND CAST

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
K7/32	1055M2	1055M2		

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Ca	Zn	C Eqv
T114020 / T123352	.614	.65	.008	.009	.22	.14	.05	.05	.012	.003	.001	.0001	.006	.005	.003	.00200	.00080	.00400	.63

Mechanical Test: Tensile: 124510 PSI, 858.47 MPA Min: 123680 Max: 125060 Std Dev:731 # Corrosion Index: 3.7 %R.A.: 59.2
Customer Requirements CASTING: STRAND CAST

ASSEMBLY SPECIALTY PRODUCTS, INC.
14700 BROOKPARK ROAD
CLEVELAND, OH 44135

Customer Notes: NO WELD REPAIRMENT PERFORMED. STEEL NOT EXPOSED TO MERCURY.

This material, including the billets, was melted and manufactured in the United States of America

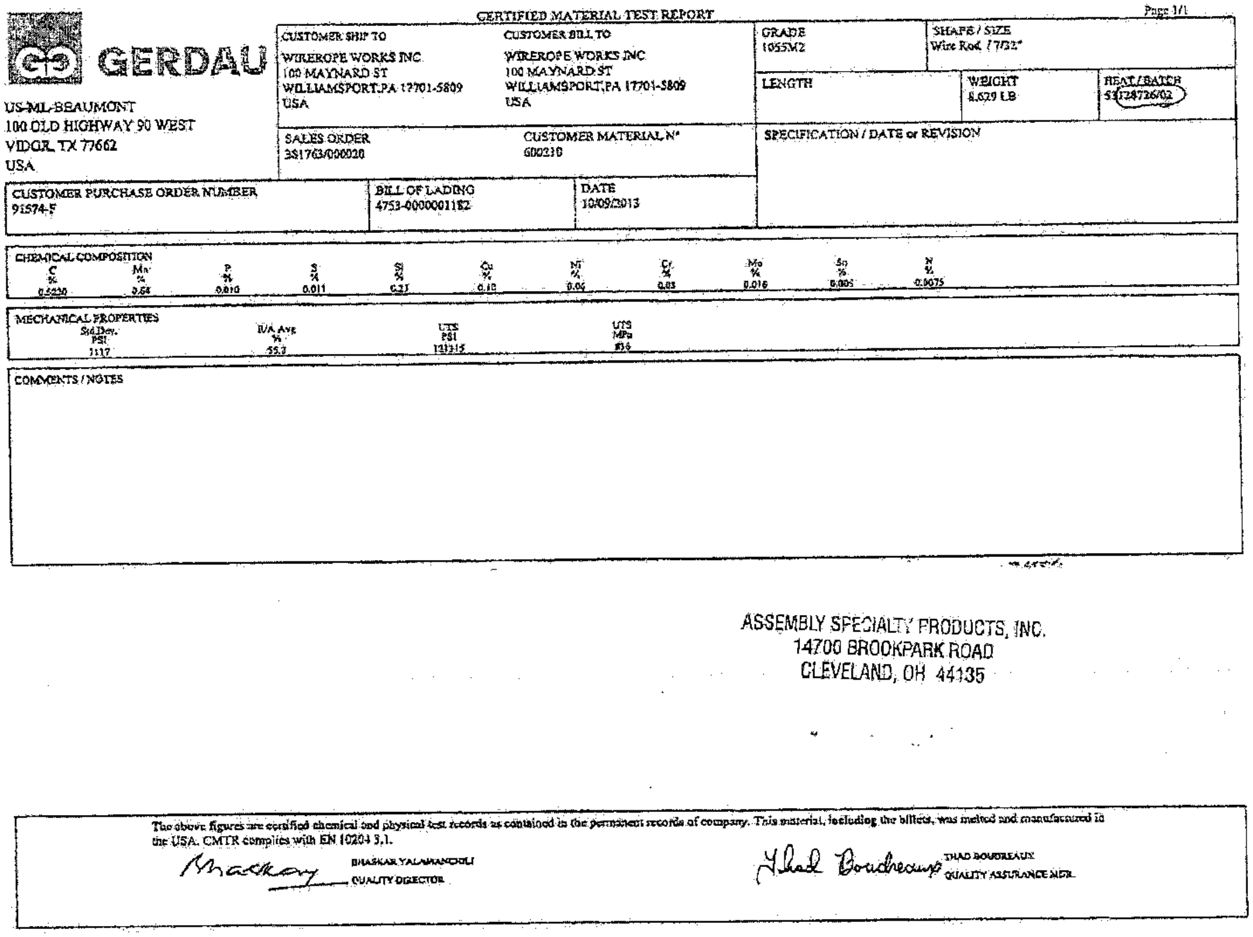
Bhaskar Yalamanchili
Quality Director
Gerdau

THE ABOVE FIGURES ARE CERTIFIED CHEMICAL AND PHYSICAL TEST RECORDS AS CONTAINED IN THE PERMANENT RECORDS OF COMPANY.

Metallurgical Services Manager
BEAUMONT STEEL MILL

Seller warrants that all material furnished shall comply with specifications subject to standard published manufacturing variations. NO OTHER WARRANTIES, EXPRESSED OR IMPLIED, ARE MADE BY THE SELLER, AND SPECIFICALLY EXCLUDED ARE WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.
In no event shall seller be liable for indirect, consequential or punitive damages arising out of or related to the materials furnished by seller.
Any claim for damages for materials that do not conform to specifications must be made from buyer to seller immediately after delivery of same in order to allow the seller the opportunity to inspect the material in question.

30006



GERDAU

US-ML-BEAUMONT
100 OLD HIGHWAY 90 WEST
VIDOR, TX 77662
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO WIREROPE WORKS INC 100 MAYNARD ST WILLIAMSPORT,PA 17701-5809 USA	CUSTOMER BILL TO WIREROPE WORKS INC 100 MAYNARD ST WILLIAMSPORT,PA 17701-5809 USA	GRADE 1055M2	SHAPE / SIZE Wire Rod / 7/32"	
		LENGTH	WEIGHT 8,629 LB	HEAT / BATCH 53128726/02
SALES ORDER 381763/000020	CUSTOMER MATERIAL Nº 600210	SPECIFICATION / DATE or REVISION		

CUSTOMER PURCHASE ORDER NUMBER 91574-F	BILL OF LADING 4753-0000001182	DATE 10/09/2013

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	N %
0.5230	0.64	0.010	0.011	0.21	0.10	0.06	0.03	0.016	0.005	0.0075

MECHANICAL PROPERTIES

Std.Dev. PSI	R/A Ave %	UTS PSI	UTS MPa
1117	55.3	121315	836

COMMENTS / NOTES

ASSEMBLY SPECIALTY PRODUCTS, INC.
14700 BROOKPARK ROAD
CLEVELAND, OH 44135

The above figures are certified chemical and physical test records as contained in the permanent records of company. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

Thad Boudreaux THAD BOUDREAUX
QUALITY ASSURANCE MGR.

300d

3006

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

EMAIL

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

Wirerope Works, Inc.
100 Maynard St.
Roger Gilliland
Williamsport,PA-17701
Kind Attn :Roger Gilliland

Cust P.O.	089981-2
Customer Part #	600210
Charter Sales Order	70036212
Heat #	10226000
Ship Lot #	1082924
Grade	1055 R SK CG HRQ 7/32
Process	HR
Finish Size	7/32

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 10226000

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.51	.84	.009	.009	.220	.04	.06	.02	.10	.008	.002

AL	N	B	TI	NB
.003	.0070	.0001	.001	.001

CHEM. DEVIATION EXT.=GREEN =

Test Results of Rolling Lot# 1082924

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE	2	118.4	122.6	120.5	TENSILE LAB = 0358-02
REDUCTION OF AREA	2	59	59	59	RA LAB = 0358-02
ROD SIZE	8	.217	.222	.220	
ROD OUT OF ROUND	3	.004	.005	.005	

REDUCTION RATIO = 803:1

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = 8000 Revision = 8 Dated = 12-AUG-04

Additional Comments: Melted and Manufactured in the United States of America

ASSEMBLY SPECIALTY PRODUCTS, INC.
14700 BROOKPARK ROAD
CLEVELAND, OH 44135

Charter Steel
Saukville, WI, USA

Rem: Load1,Fax0,Mail0

ACCREDITED

Page 1 of 1

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Janice Barnard
Manager of Quality Assurance
11/12/2012

30006

Heat #
1072600

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFAR's compliance.
2. Mercury was not used during the manufacture of this product, nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key.

Certificate Number	Lab Code	Laboratory		Address
0358-01	7386	CSSM	Charter Steel Melting Division	1653 Cold Springs Road, Saukville, WI 53080
0358-02	8171	CSSR/ CSSP	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	CSFP	Charter Steel Ohio Processing Division	6255 US Highway 23, Risingsun, OH 43457
0358-04	125544	CSCM/ CSCR	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
•	•	--	Subcontracted test performed by laboratory not in Charter Steel system	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Specification	CSSM	CSSR/CSSP	CSFP	CSCM/CSCR
Chemistry Analysis	ASTM E415; ASTM E1019	X			X
Macroetch	ASTM E381	X			X
Hardenability (Jominy)	ASTM A255; SAE J406; JIS G0561	X			X
Grain Size	ASTM E112	X	X	X	X
Tensile Test	ASTM E8; ASTM A370		X	X	X
Rockwell Hardness	ASTM E18; ASTM A370	X	X	X	X
Microstructure (spheroidization)	ASTM A892		X	X	
Inclusion Content (Methods A, E)	ASTM E45		X		X
Decarburization	ASTM E1077		X	X	X

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/13.

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ASSEMBLY SPECIALTY PRODUCTS, INC.
14700 BROOKPARK ROAD
CLEVELAND, OH 44135

ACCREDITED

30006

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

EMAIL

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

Wirerope Works, Inc.
100 Maynard St.
Roger Gilliland
Williamsport,PA-17701
Kind Attn :Roger Gilliland

Cust.P.O.	090624-4
Customer Part #	600276
Charter Sales Order	70038972
Heat #	10241290
Ship Lot #	1089946
Grade	1069 M SK CG HRQ 7/32
Process	HR
Finish Size	7/32

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 10241290

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.70	.65	.007	.007	.200	.04	.05	.01	.07	.005	.002

AL	N	B	TI	NB
.003	.0060	.0001	.002	.000

CHEM. DEVIATION EXT.- GREEN =

Test Results of Rolling Lot# 1089946

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE	4	144.3	158.4	151.4	TENSILE LAB = 0358-02
REDUCTION OF AREA	4	51	58	54	RA LAB = 0358-02
ROD SIZE	12	.213	.224	.219	
ROD OUT OF ROUND	3	.005	.006	.006	

REDUCTION RATIO = 803:1

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,06-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = 6000 Revision = 8 Dated = 12-AUG-04

Additional Comments: Melted and Manufactured in the United States of America

ASSEMBLY SPECIALTY PRODUCTS, INC.
14700 BROOKPARK ROAD
CLEVELAND, OH 44135

Charter Steel
Saukville, Wi, USA

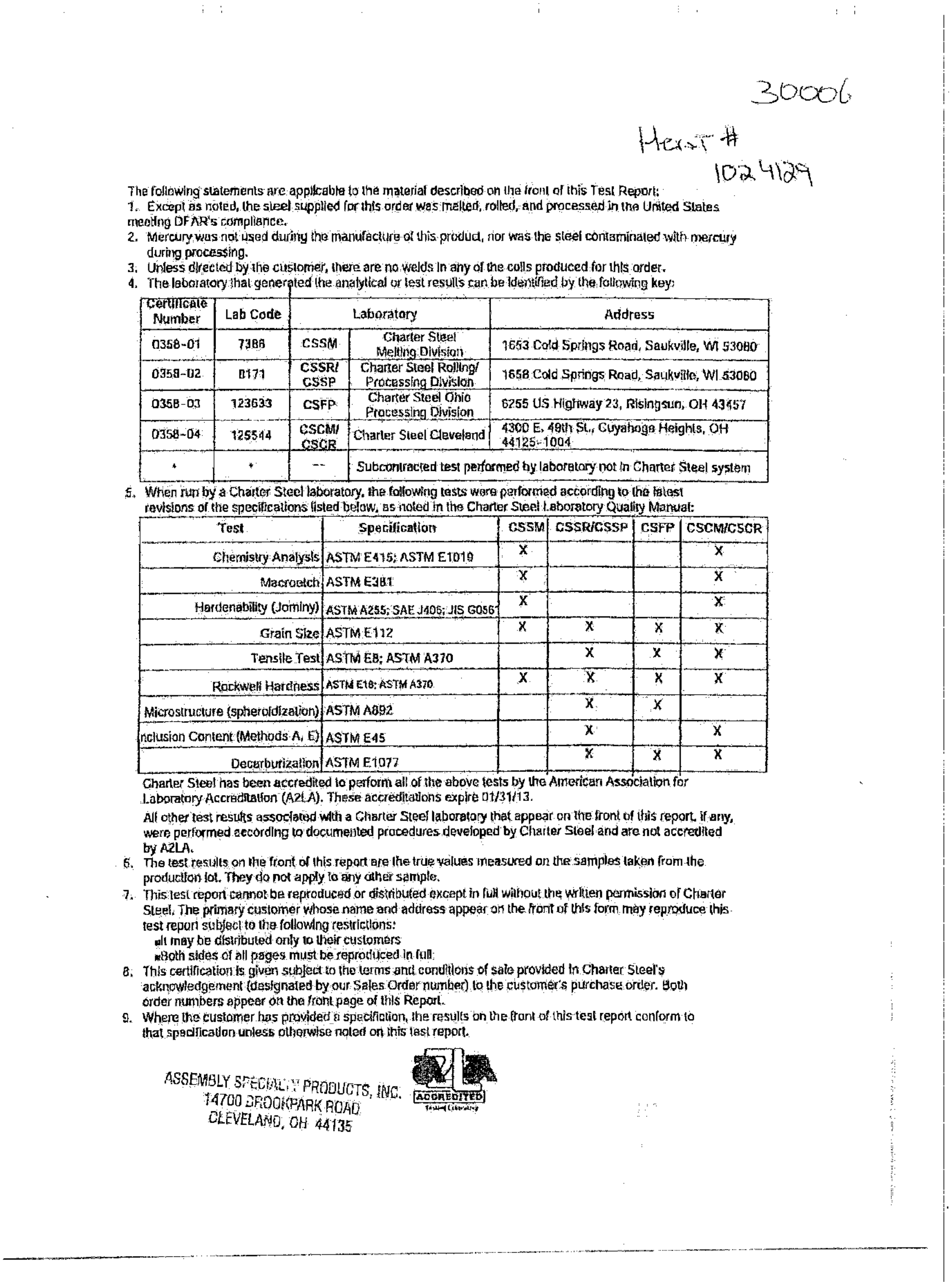
Rem: Load1,Fax0,Mail0

ACCREDITED

Page 1 of 1

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance
02/15/2013



30006

Heat #
1024129

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Chemistry Analysis	ASTM E415; ASTM E1019	X			X
Macroetch	ASTM E381	X			X
Hardenability (Jominy)	ASTM A255; SAE J406; JIS G0561	X			X
Grain Size	ASTM E112	X	X	X	X
Tensile Test	ASTM E8; ASTM A370		X	X	X
Rockwell Hardness	ASTM E18; ASTM A370	X	X	X	X
Microstructure (spheroidization)	ASTM A892		X	X	
nclusion Content (Methods A, E)	ASTM E45		X		X
Decarburization	ASTM E1077		X	X	X

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ASSEMBLY SPECIALTY PRODUCTS, INC.
14700 BROOKPARK ROAD
CLEVELAND, OH 44135

30006

CHARTER STEEL
A Division of
Charter Manufacturing Company, Inc.

EMAIL

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

Wirerope Works, Inc.
100 Maynard St.
Roger Gilliland
Williamsport,PA-17701
Kind Attn :Roger Gilliland

Cust P.O.	089135-4
Customer Part #	600276
Charter Sales Order	70033069
Heat #	10207730
Ship Lot #	1074348
Grade	1069 M SK CG HRQ 7/32
Process	HR
Finish Size	7/32

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 10207730

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.70	.65	.008	.008	.23	.03	.05	.01	.06	.004	.002

AL	N	TI	NB
.003	.0060	.001	.000

CHEM. DEVIATION EXT.-GREEN =

Test Results of Rolling Lot# 1074348

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE	4	140.7	158.9	151.4	TENSILE LAB = 0358-02
REDUCTION OF AREA	4	40	53	51	RA LAB = 0358-02
ROD SIZE	11	.219	.224	.220	
ROD OUT OF ROUND	2	.001	.003	.002	
REDUCTION RATIO = 003:1					

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = 6000 Revision = 8 Dated = 12-AUG-04

Additional Comments: Melted and Manufactured in the United States of America

ASSEMBLY SPECIALTY PRODUCTS, INC
14700 BROOKPARK ROAD
CLEVELAND, OH 44135

Charter Steel
Saukville, WI, USA

Rem: Load1,Fax0,Mail0

ACCREDITED

Page 1 of 1

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance
07/25/2012

3006

Heat # 1020773

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFAR's compliance.
2. Mercury was not used during the manufacture of this product, nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	CSSM	Charter Steel Melting Division	1653 Cold Springs Road, Saukville, WI 53080
0358-02	8171	CSSR/ CSSP	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	CSFP	Charter Steel Ohio Processing Division	6255 US Highway 23, Risingsun, OH 43467
0358-04	125544	CSCM/ CSCR	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
*	*	--	Subcontracted test performed by laboratory not in Charter Steel system	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Specification	CSSM	CSSR/CSSP	CSFP	CSCM/CSCR
Chemistry Analysis	ASTM E415; ASTM E1019	X			X
Macroetch	ASTM E381	X			X
Hardenability (Jominy)	ASTM A255; SAE J406; JIS G0561	X			X
Grain Size	ASTM E112	X	X	X	X
Tensile Test	ASTM E8; ASTM A370		X	X	X
Rockwell Hardness	ASTM E18; ASTM A370	X	X	X	X
Microstructure (spheroidization)	ASTM A892		X	X	
Inclusion Content (Methods A, E)	ASTM E45		X		X
Decarburization	ASTM E1077		X	X	X

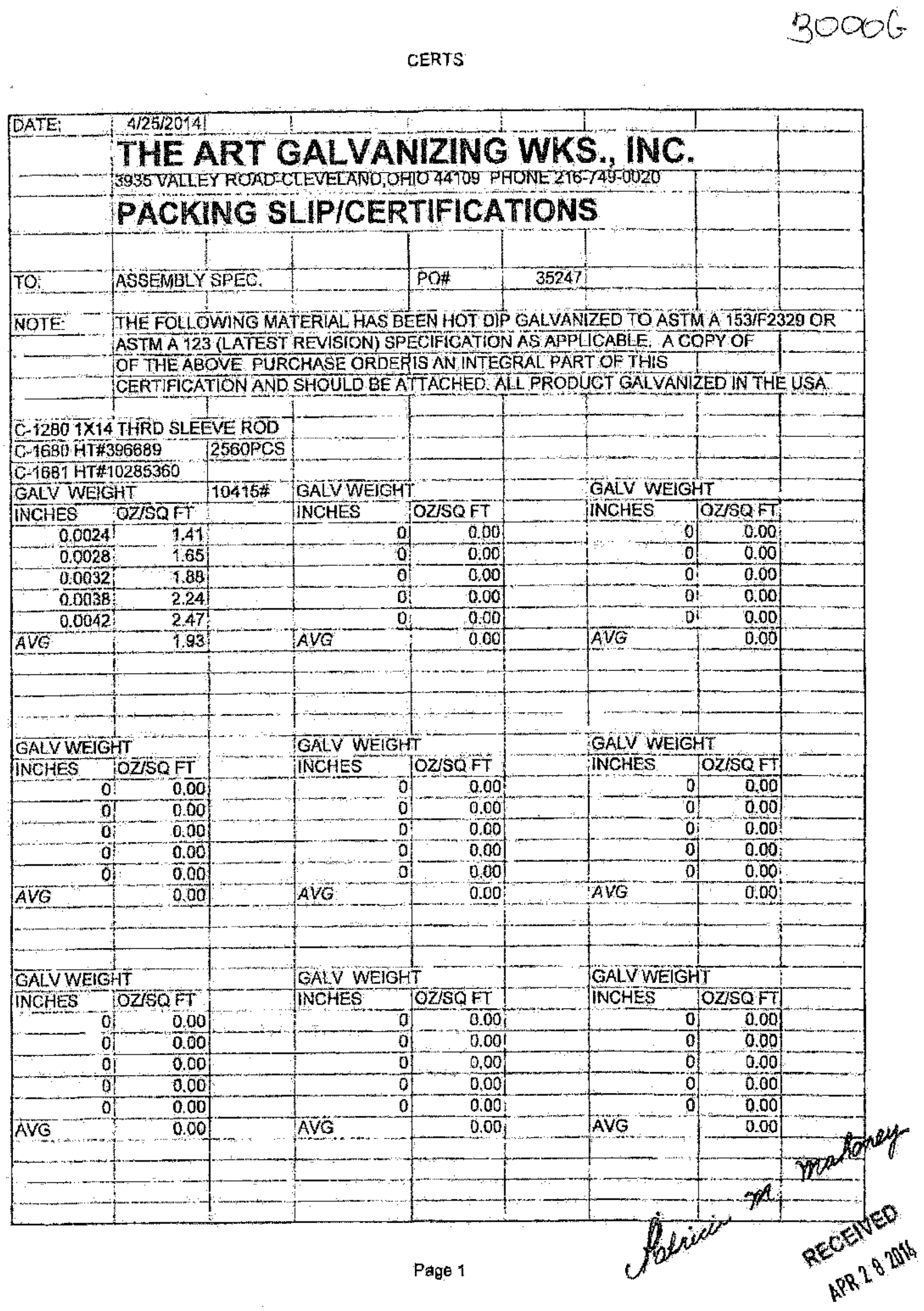
Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/13.

All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

6. The test results on the front of this report are the true values measured on the samples taken from the production lot. They do not apply to any other sample.
7. This test report cannot be reproduced or distributed except in full without the written permission of Charter Steel. The primary customer whose name and address appear on the front of this form may reproduce this test report subject to the following restrictions:
   - It may be distributed only to their customers
   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgement (designated by our Sales Order number) to the customer's purchase order. Both order numbers appear on the front page of this Report.
9. Where the customer has provided a specifiction, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

ASSEMBLY SPECIALTY PRODUCTS, INC
14700 BROOKPARK ROAD
CLEVELAND, OH 44135

ACCREDITED



3000G

CERTS

DATE:	4/25/2014

THE ART GALVANIZING WKS., INC.

3935 VALLEY ROAD-CLEVELAND,OHIO 44109 PHONE 216-749-0020

PACKING SLIP/CERTIFICATIONS

TO: ASSEMBLY SPEC. PO# 35247

NOTE: THE FOLLOWING MATERIAL HAS BEEN HOT DIP GALVANIZED TO ASTM A 153/F2329 OR ASTM A 123 (LATEST REVISION) SPECIFICATION AS APPLICABLE. A COPY OF OF THE ABOVE PURCHASE ORDER IS AN INTEGRAL PART OF THIS CERTIFICATION AND SHOULD BE ATTACHED. ALL PRODUCT GALVANIZED IN THE USA.

C-1280 1X14 THRD SLEEVE ROD
C-1680 HT#396689 2560PCS
C-1681 HT#10285360

GALV WEIGHT		10415#	GALV WEIGHT		GALV WEIGHT	
INCHES	OZ/SQ FT		INCHES	OZ/SQ FT	INCHES	OZ/SQ FT
0.0024	1.41		0	0.00	0	0.00
0.0028	1.65		0	0.00	0	0.00
0.0032	1.88		0	0.00	0	0.00
0.0038	2.24		0	0.00	0	0.00
0.0042	2.47		0	0.00	0	0.00
AVG	1.93		*AVG*	0.00	*AVG*	0.00

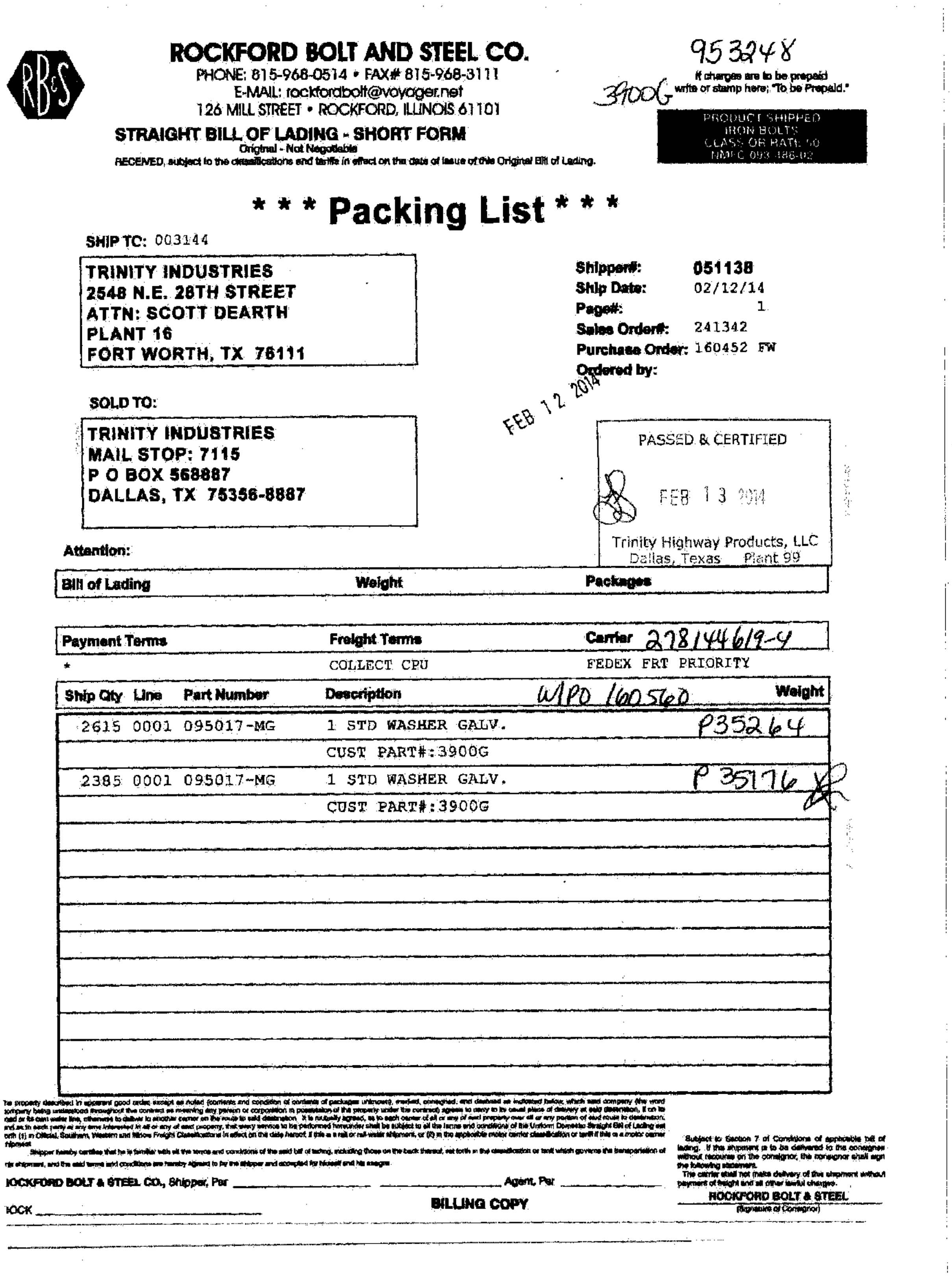
GALV WEIGHT		GALV WEIGHT		GALV WEIGHT	
INCHES	OZ/SQ FT	INCHES	OZ/SQ FT	INCHES	OZ/SQ FT
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
AVG	0.00	*AVG*	0.00	*AVG*	0.00

GALV WEIGHT		GALV WEIGHT		GALV WEIGHT	
INCHES	OZ/SQ FT	INCHES	OZ/SQ FT	INCHES	OZ/SQ FT
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
0	0.00	0	0.00	0	0.00
AVG	0.00	AVG	0.00	AVG	0.00

Patricia M. Maloney

RECEIVED
APR 2 8 2014

Page 1



ROCKFORD BOLT AND STEEL CO.
PHONE: 815-968-0514 • FAX# 815-968-3111
E-MAIL: rockfordbolt@voyager.net
126 MILL STREET • ROCKFORD, ILLINOIS 61101

953248

3900G

If charges are to be prepaid write or stamp here; "To be Prepaid."

PRODUCT SHIPPED
IRON BOLTS
CLASS OR RATE 50
NMFC 093 486-02

STRAIGHT BILL OF LADING - SHORT FORM
Original - Not Negotiable
RECEIVED, subject to the classifications and tariffs in effect on the date of issue of this Original Bill of Lading.

* * * Packing List * * *

SHIP TO: 003144

TRINITY INDUSTRIES
2548 N.E. 28TH STREET
ATTN: SCOTT DEARTH
PLANT 16
FORT WORTH, TX 76111

Shipper#:	051138
Ship Date:	02/12/14
Page#:	1
Sales Order#:	241342
Purchase Order:	160452 FW
Ordered by:	

FEB 12 2014

SOLD TO:

TRINITY INDUSTRIES
MAIL STOP: 7115
P O BOX 568887
DALLAS, TX 75356-8887

PASSED & CERTIFIED
FEB 13 2014
Trinity Highway Products, LLC
Dallas, Texas Plant 99

Attention:

Bill of Lading	**Weight**	**Packages**

Payment Terms	**Freight Terms**	**Carrier** 278144619-4
*	COLLECT CPU	FEDEX FRT PRIORITY

Ship Qty	**Line**	**Part Number**	**Description** W/PO 160560	**Weight**
2615	0001	095017-MG	1 STD WASHER GALV.	P35264
			CUST PART#:3900G	
2385	0001	095017-MG	1 STD WASHER GALV.	P35176
			CUST PART#:3900G	

he property described in apparent good order, except as noted (contents and condition of contents of packages unknown), marked, consigned, and destined as indicated below, which said company (the word company being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its road or its own water line, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the terms and conditions of the Uniform Domestic Straight Bill of Lading set forth (1) in Official, Southern, Western and Illinois Freight Classifications in effect on the date hereof, if this is a rail or rail-water shipment, or (2) in the applicable motor carrier classification or tariff if this is a motor carrier shipment.

Shipper hereby certifies that he is familiar with all the terms and conditions of the said bill of lading, including those on the back thereof, set forth in the classification or tariff which governs the transportation of this shipment, and the said terms and conditions are hereby agreed to by the shipper and accepted for himself and his assigns.

Subject to Section 7 of Conditions of applicable bill of lading. If this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement.
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.

ROCKFORD BOLT & STEEL
(Signature of Consignor)

ROCKFORD BOLT & STEEL CO., Shipper, Per ______________ ______________ Agent, Per ______________

DOCK ______________

BILLING COPY

3900G

CERTIFICATE OF COMPLIANCE

ROCKFORD BOLT & STEEL CO.
126 MILL STREET
ROCKFORD, IL 61101

CUSTOMER NAME: TRINITY INDUSTRIES

CUSTOMER PO: 160452

SHIPPER #: 051138

INVOICE #:

DATE SHIPPED: 02/12/14

ROCKFORD LOT#: P35176 R55419
WROUGHT WASHER LOT: 278640

SPECIFICATION: ASTM F844 STANDARD SPECIFICATIONS FOR UNHARDENED WASHERS FOR GENERAL USE

COATING: ASTM B695, CLASS 55, TYPE 1 MECHANICAL GALVANIZATION
PLATECO, INC: ID 388043

CHEMICAL COMPOSITION

SUPPLIER	HEAT#	C	Mn	P	S
NUCOR	238705	.005	.56	.008	.002

QUANTITY AND DESCRIPTION:

2,385 PCS 1" STANDARD WASHER
P/N 3900G

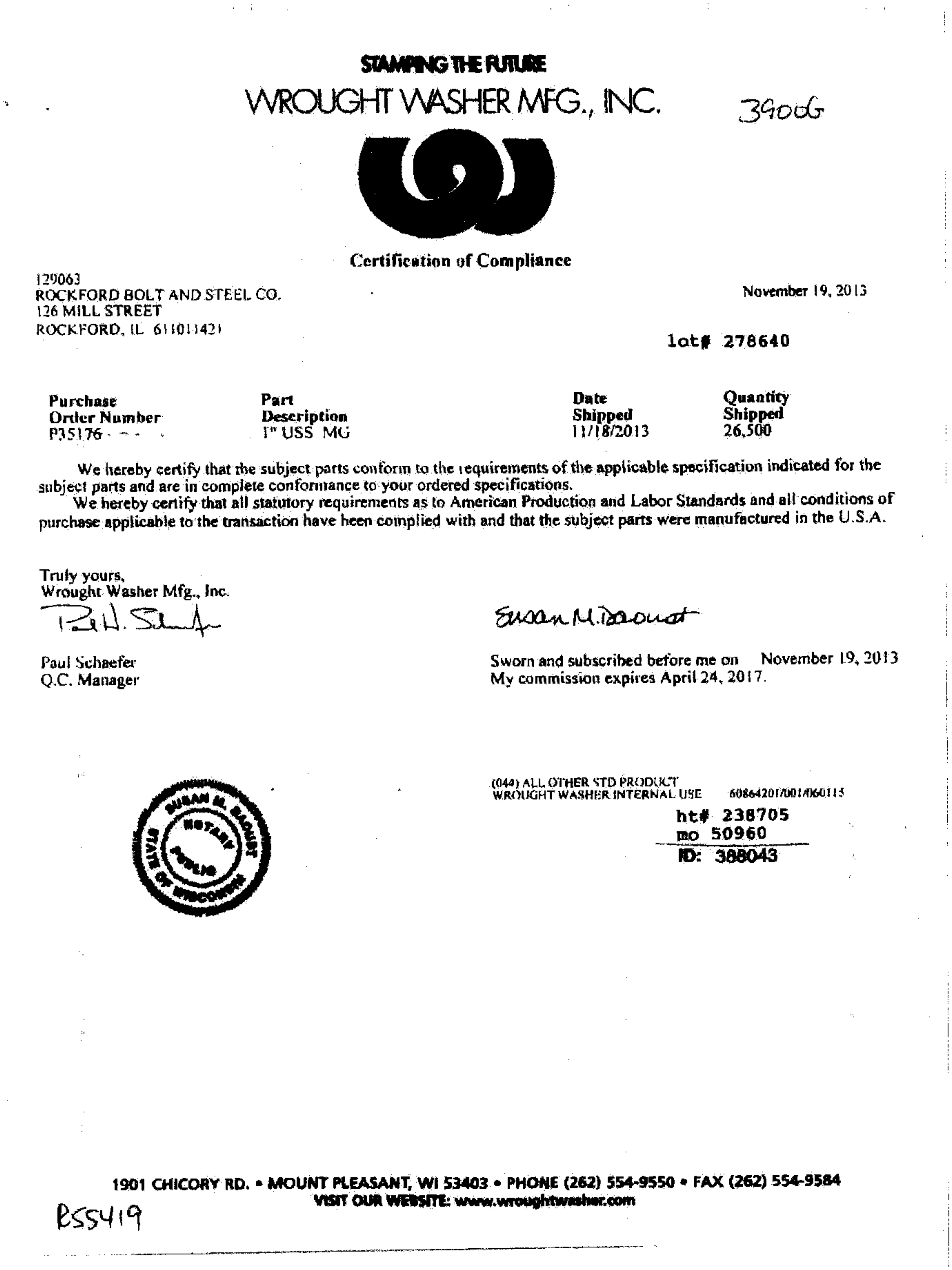
WE HEREBY CERTIFY THE ABOVE PARTS HAVE BEEN MANUFACTURED IN THE U.S.A WITH DOMESTIC STEEL. WE FURTHER CERTIFY THAT THIS DATA IS A TRUE PRERESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENTS PER ABOVE SPECIFICATION.

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS
12 DAY OF February ,20 14
Diana Rasmussen

Linda Melomas
APPROVED SIGNATORY

2/12/14
DATE

OFFICIAL SEAL
DIANA RASMUSSEN
MY COMMISSION EXPIRES 10/15/14



STAMPING THE FUTURE

WROUGHT WASHER MFG., INC.

3900G

Certification of Compliance

129063
ROCKFORD BOLT AND STEEL CO.
126 MILL STREET
ROCKFORD, IL 611011421

November 19, 2013

lot# 278640

Purchase Order Number	Part Description	Date Shipped	Quantity Shipped
P35176	1" USS MG	11/18/2013	26,500

We hereby certify that the subject parts conform to the requirements of the applicable specification indicated for the subject parts and are in complete conformance to your ordered specifications.

We hereby certify that all statutory requirements as to American Production and Labor Standards and all conditions of purchase applicable to the transaction have been complied with and that the subject parts were manufactured in the U.S.A.

Truly yours,
Wrought Washer Mfg., Inc.

Paul Schaefer
Q.C. Manager

Susan M. Baoust

Sworn and subscribed before me on November 19, 2013
My commission expires April 24, 2017.

SUSAN M. BAOUST

(044) ALL OTHER STD PRODUCT
WROUGHT WASHER INTERNAL USE 608642011001060115

ht# 238705
mo 50960
ID: 388043

1901 CHICORY RD. • MOUNT PLEASANT, WI 53403 • PHONE (262) 554-9550 • FAX (262) 554-9584
VISIT OUR WEBSITE: www.wroughtwasher.com

BS5419

NUCOR
SHEET MILL GROUP
Nucor Steel-Crawfordsville
4537 South Nucor Road
Crawfordsville, IN 47933-0907

95000 D025530
Print Date: 10/04/2013
Page: 2 of 2

Order Number: 245251 - 0001
Order Dimensions: 0.1600 X 52.4200
HOT ROLLED BAND

Customer Name: WROUGHT WASHER MFG INC
Customer Address: 2100 S BAY ST
MILWAUKEE WI 53207
Customer PO Number: H2808

Coil Number	Heat	Slab
1828948.000	238705	01

Chemical Analysis

Heat	C	Mn	P	S	Si	Cu	Sn	Ni	Cr	Mo	Al	N	V	Nb	Ti	B	Sb
238705	0.005	0.560	0.008	0.002	1.072	0.132	0.005	0.044	0.058	0.015	0.338	0.004	0.002	<0.001	0.003	<0.001	0.084

39006

MELTED AND ROLLED IN THE USA

THIS IS NOT A CERTIFIED TEST REPORT

PLATECO INC.

Certification

.3900G

Order No.: 538748
Date: 11/13/2013
Entry Date: 11/08/2013
Page: 1 of 1

To:
WROUGHT WASHER MANUFACTURIN(
2100 SOUTH BAY STREET

MILWAUKEE WI 53207

Purchase Order No.: 278640-01
Packing List No.: 060115
ID: 388043
Material: STEEL

1

We are pleased to provide you with the following Certification

Quantity	Part Number / Part Name / Part Description	Pounds
26,500	1 USS o.d. 2.500 + i.d. 1.062(96179) Mech Galv .002 No Chromate / ASTM B-695 Class 50	4,840.00

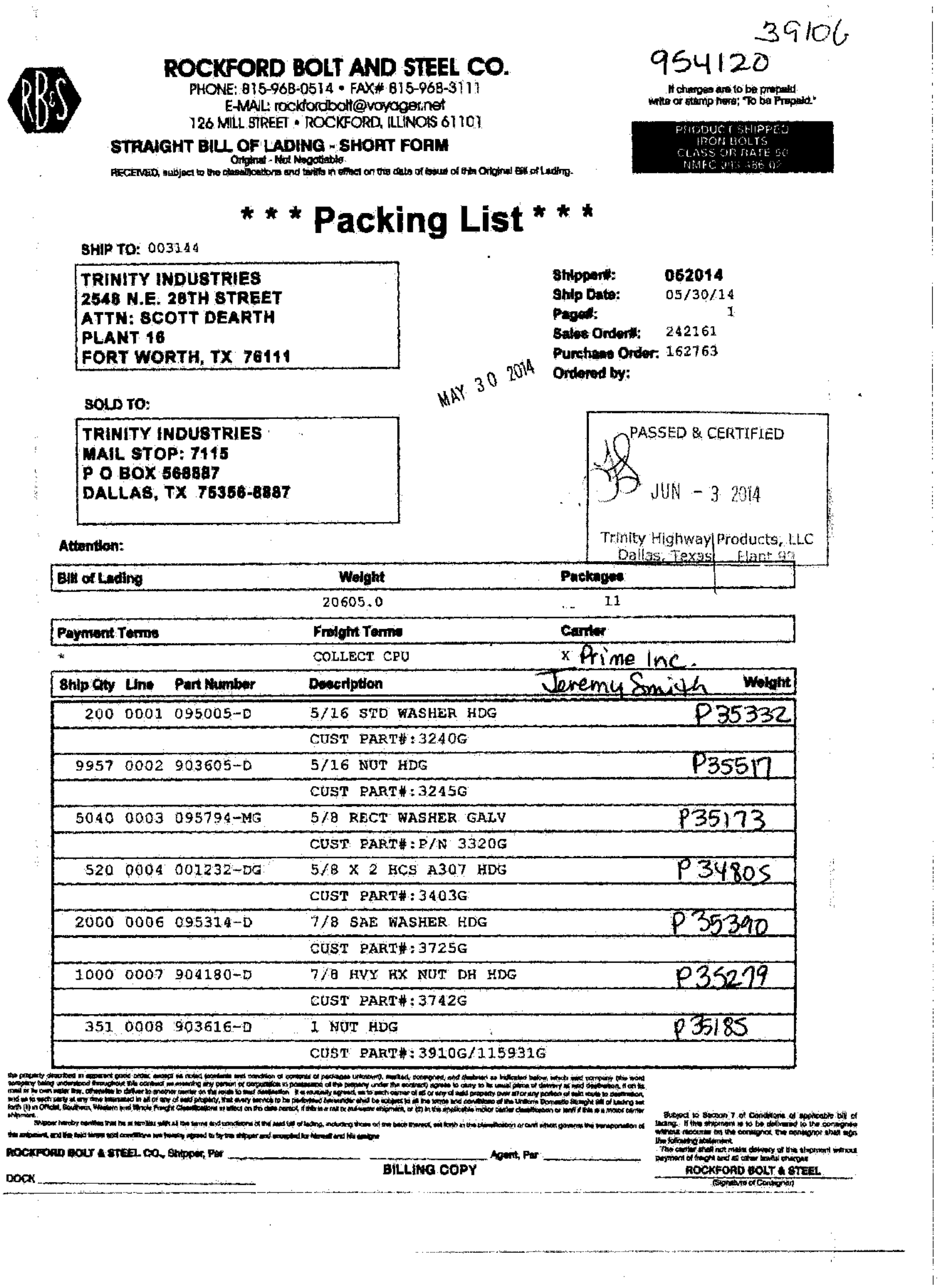
Insp. Type	Scale	Minimum	Maximum	Number	Other
Customer Requirements:					
THICK	INCHES	.002			
VISUAL	NO CHROM				
Other					

Plating performed in the USA

Results:

HIGH .00290
LOW .00201
AVE. .00244

Notes



39106
954120

ROCKFORD BOLT AND STEEL CO.
PHONE: 815-968-0514 • FAX# 815-968-3111
E-MAIL: rockfordbolt@voyager.net
126 MILL STREET • ROCKFORD, ILLINOIS 61101

STRAIGHT BILL OF LADING - SHORT FORM
Original - Not Negotiable
RECEIVED, subject to the classifications and tariffs in effect on the date of issue of this Original Bill of Lading.

If charges are to be prepaid write or stamp here; "To be Prepaid."

PRODUCT SHIPPED
IRON BOLTS
CLASS OR RATE 50
NMFC 013 486 02

* * * Packing List * * *

SHIP TO: 003144

TRINITY INDUSTRIES
2548 N.E. 28TH STREET
ATTN: SCOTT DEARTH
PLANT 16
FORT WORTH, TX 76111

Shipper#: **052014**
Ship Date: 05/30/14
Page#: 1
Sales Order#: 242161
Purchase Order: 162763
Ordered by:

MAY 30 2014

SOLD TO:

TRINITY INDUSTRIES
MAIL STOP: 7115
P O BOX 568887
DALLAS, TX 75356-8887

PASSED & CERTIFIED
JUN - 3 2014
Trinity Highway Products, LLC
Dallas, Texas Plant 99

Attention:

Bill of Lading	**Weight**	**Packages**
	20605.0	11

Payment Terms	**Freight Terms**	**Carrier**
*	COLLECT CPU	x Prime Inc.

Ship Qty	**Line**	**Part Number**	**Description**	Jeremy Smith **Weight**
200	0001	095005-D	5/16 STD WASHER HDG	P35332
			CUST PART#:3240G	
9957	0002	903605-D	5/16 NUT HDG	P35517
			CUST PART#:3245G	
5040	0003	095794-MG	5/8 RECT WASHER GALV	P35173
			CUST PART#:P/N 3320G	
520	0004	001232-DG	5/8 X 2 HCS A307 HDG	P34805
			CUST PART#:3403G	
2000	0006	095314-D	7/8 SAE WASHER HDG	P35390
			CUST PART#:3725G	
1000	0007	904180-D	7/8 HVY HX NUT DH HDG	P35279
			CUST PART#:3742G	
351	0008	903616-D	1 NUT HDG	P35185
			CUST PART#:3910G/115931G	

Subject to Section 7 of Conditions of applicable bill of lading. If this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.

ROCKFORD BOLT & STEEL CO., Shipper, Per ____________________ ____________________ Agent, Per ____________

DOCK ____________________

BILLING COPY

ROCKFORD BOLT & STEEL
(Signature of Consignor)

39106

ROCKFORD BOLT AND STEEL CO.
PHONE: 815-968-0514 • FAX# 815-968-3111
E-MAIL: rockfordbolt@voyager.net
126 MILL STREET • ROCKFORD, ILLINOIS 61101

STRAIGHT BILL OF LADING - SHORT FORM
Original - Not Negotiable
RECEIVED, subject to the classifications and tariffs in effect on the date of issue of the Original Bill of Lading.

If charges are to be prepaid write or stamp here; "To be Prepaid."

PRODUCT SHIPPED
IRON BOLTS
CLASS OR RATE 50
NMFC 093-1a6-02

* * * Packing List * * *

SHIP TO: 003144

TRINITY INDUSTRIES
2548 N.E. 28TH STREET
ATTN: SCOTT DEARTH
PLANT 16
FORT WORTH, TX 76111

MAY 30 2014

Shipper#: 052014
Ship Date: 05/30/14
Page#: 2
Sales Order#: 242161
Purchase Order: 162763
Ordered by:

SOLD TO:

TRINITY INDUSTRIES
MAIL STOP: 7115
P O BOX 568887
DALLAS, TX 75356-8887

Attention:

Bill of Lading	Weight	Packages
	20605.0	11

Payment Terms	Freight Terms	Carrier Prime Inc
*	COLLECT CPU	X Jeremy Smith

Ship Qty	Line	Part Number	Description	Weight
2649	0008	903616-D	1 NUT HDG	P35362
			CUST PART#:3910G/115931G	
8000	0009	095306-D	3/8 SAE WASHER GR8 MG	P35268
			CUST PART#:4254G	
3000	0010	005426-D	3/8 X 1-1/2 HCS GR5 MG	P35278
			CUST PART#:4261G	
2000	0011	005625-D	7/16 X 1-1/2 HCS GR5 MG	P35374
			CUST PART#:4390G	
250	0012	0001-406455	5/8 X 10 HHMB A307 HDG	25867-B
			CUST PART#:4500G	
1100	0013	001232-DG	5/8 X 2 HCS A307 HDG	P35381
			CUST PART#:3403G	
100	0018	0006-408109	7/8 X 18 HHMB A307 HDG	26021
			CUST PART#:3880G	

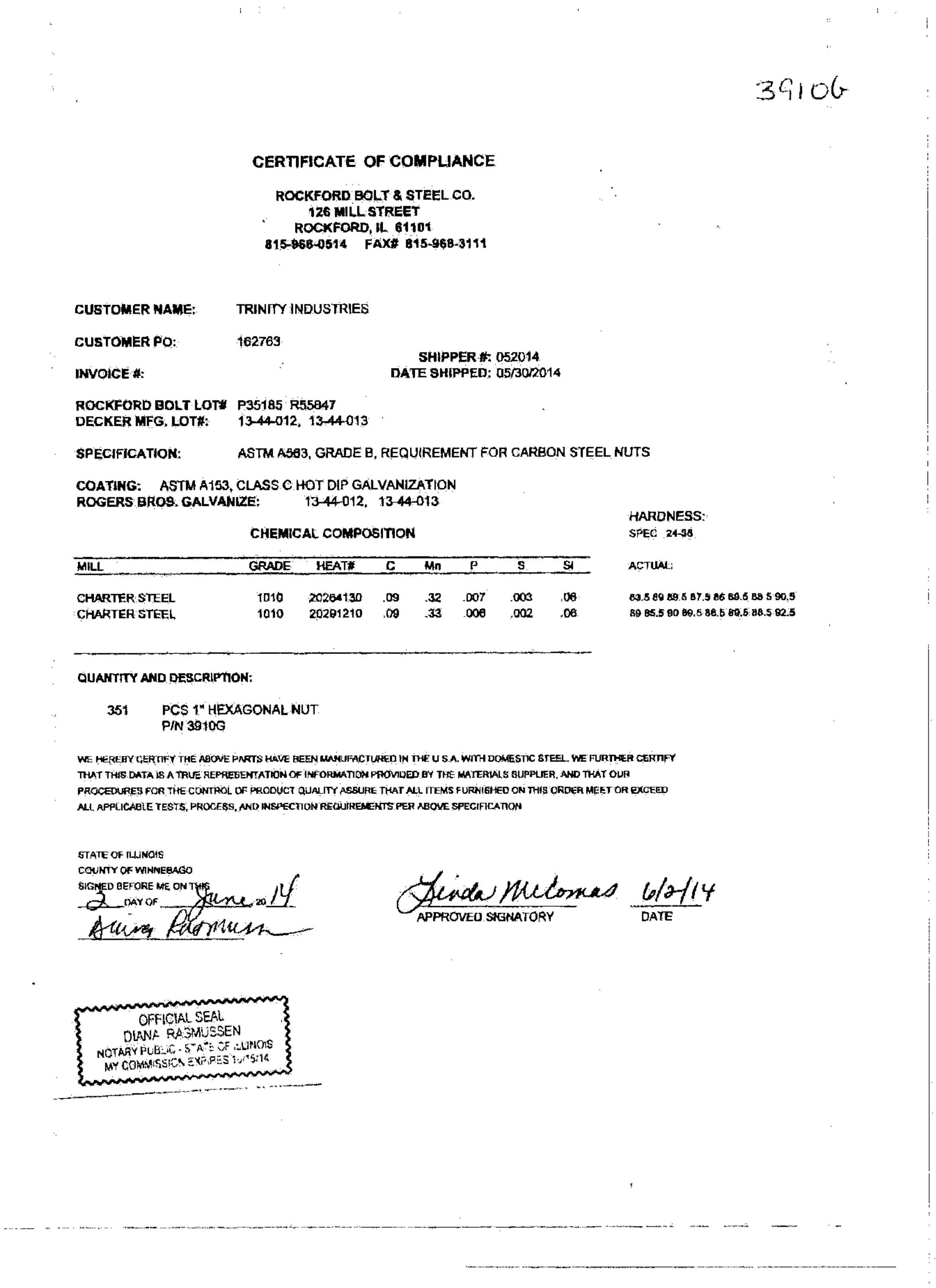
ROCKFORD BOLT & STEEL CO., Shipper, Per ______________________ ______________________ Agent, Per ______________________

DOCK ______________________

BILLING COPY

Subject to Section 7 of Conditions of applicable bill of lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.

ROCKFORD BOLT & STEEL
(Signature of Consignor)



3910G

CERTIFICATE OF COMPLIANCE

ROCKFORD BOLT & STEEL CO.
126 MILL STREET
ROCKFORD, IL 61101
815-968-0514 FAX# 815-968-3111

CUSTOMER NAME: TRINITY INDUSTRIES

CUSTOMER PO: 162763

SHIPPER #: 052014

INVOICE #:

DATE SHIPPED: 05/30/2014

ROCKFORD BOLT LOT# P35185 R55847
DECKER MFG. LOT#: 13-44-012, 13-44-013

SPECIFICATION: ASTM A563, GRADE B, REQUIREMENT FOR CARBON STEEL NUTS

COATING: ASTM A153, CLASS C HOT DIP GALVANIZATION
ROGERS BROS. GALVANIZE: 13-44-012, 13-44-013

HARDNESS:
SPEC 24-36

CHEMICAL COMPOSITION

MILL	GRADE	HEAT#	C	Mn	P	S	SI	ACTUAL:
CHARTER STEEL	1010	20264130	.09	.32	.007	.003	.06	83.5 89 89.5 87.5 86 89.5 88.5 90.5
CHARTER STEEL	1010	20291210	.09	.33	.006	.002	.06	89 85.5 90 89.5 88.5 89.5 88.5 92.5

QUANTITY AND DESCRIPTION:

351 PCS 1" HEXAGONAL NUT
P/N 3910G

WE HEREBY CERTIFY THE ABOVE PARTS HAVE BEEN MANUFACTURED IN THE U S.A. WITH DOMESTIC STEEL. WE FURTHER CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENTS PER ABOVE SPECIFICATION

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS
2 DAY OF June 2014
Diana Rasmussen

Linda McComas 6/2/14
APPROVED SIGNATORY DATE

DIANA RASMUSSEN
MY COMMISSION EXPIRES 1[illegible]/15/14

39106

DECKER

MANUFACTURING CORPORATION

MANUFACTURERS OF INDUSTRIAL FASTENERS & PIPE PLUGS
703 North Clark Street Albion, Michigan 49224

Phone 517-629-3955
Fax 517-629-3535
Sales Fax 517-629-8424
www.deckernut.com

Printed 1/22/2014 11:29:24 AM
January 22, 2014

ROCKFORD BOLT & STEEL CO
126 MILL STREET
ROCKFORD, IL 61101

PRODUCT MATERIAL CERTIFICATION

CUSTOMER PART NUMBER 903616-D
CUSTOMER P.O. NUMBER : P35185
INVOICE 73094

LOT NUMBER: 13-44-012
DATE: May 08, 2013
HEAT NUMBER: 20264130
MATERIAL: STEEL - C1010
DESCRIPTION: 1-8 FIN HX DC .024 OS
QUANTITY: 13,500
MATERIAL SUPPLIER: CHARTER STEEL

We certify the product above was manufactured at DECKER MANUFACTURING CORPORATION from the specified raw material and that said product is certified to be manufactured, randomly sampled, tested and/or inspected and conforms to applicable specifications. We additionally certify that said raw material was domestically manufactured in the United States of America and that said raw material was manufactured free of mercury contamination.

The items were processed under the Decker Quality Manual. The current revision is dated January 12, 2005
No welding was performed.

This document accurately represents values and statements provided by our suppliers accredited testing facility. The original metallurgical test report shall be retained on file by DECKER MANUFACTURING CORPORATION for a period of not less than (10) years.

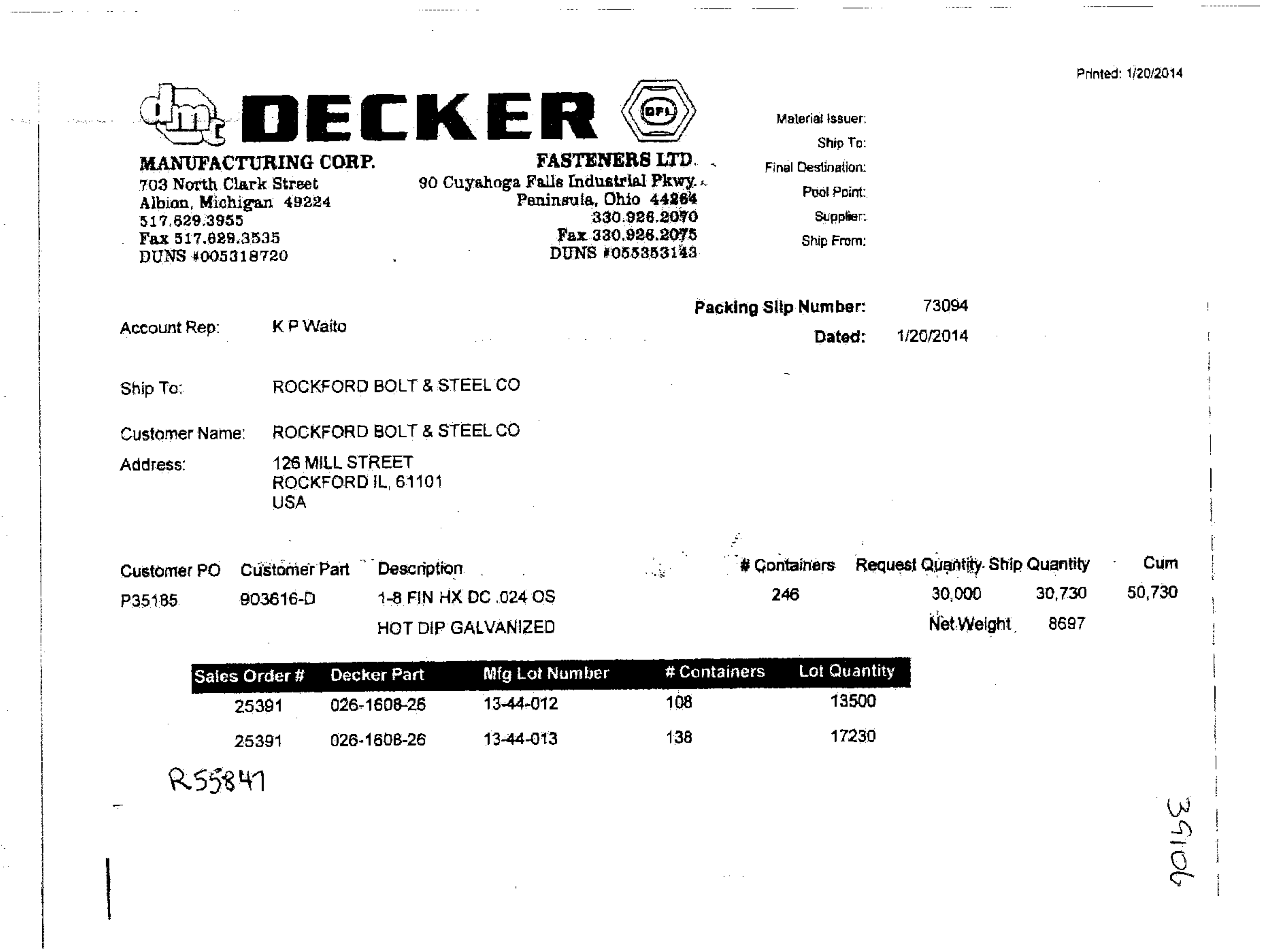
CHEMICAL ANALYSIS BY MATERIAL SUPPLIER:

CARBON : 0.090
MANGANESE 0.320
PHOSPHOROUS : 0.007
SULFUR : 0.003

DECKER MANUFACTURING CORPORATION

Russel L. Wilson
Quality Assurance Manager

The above results pertain only to the items tested. This report shall not be reproduced except in full without the approval of this testing facility.



Printed: 1/20/2014

DECKER

MANUFACTURING CORP.
703 North Clark Street
Albion, Michigan 49224
517.629.3955
Fax 517.629.3535
DUNS #005318720

FASTENERS LTD.
90 Cuyahoga Falls Industrial Pkwy.
Peninsula, Ohio 44264
330.926.2070
Fax 330.926.2075
DUNS #055353143

Material Issuer:
Ship To:
Final Destination:
Pool Point:
Supplier:
Ship From:

Packing Slip Number: 73094
Dated: 1/20/2014

Account Rep: K P Waito

Ship To: ROCKFORD BOLT & STEEL CO

Customer Name: ROCKFORD BOLT & STEEL CO

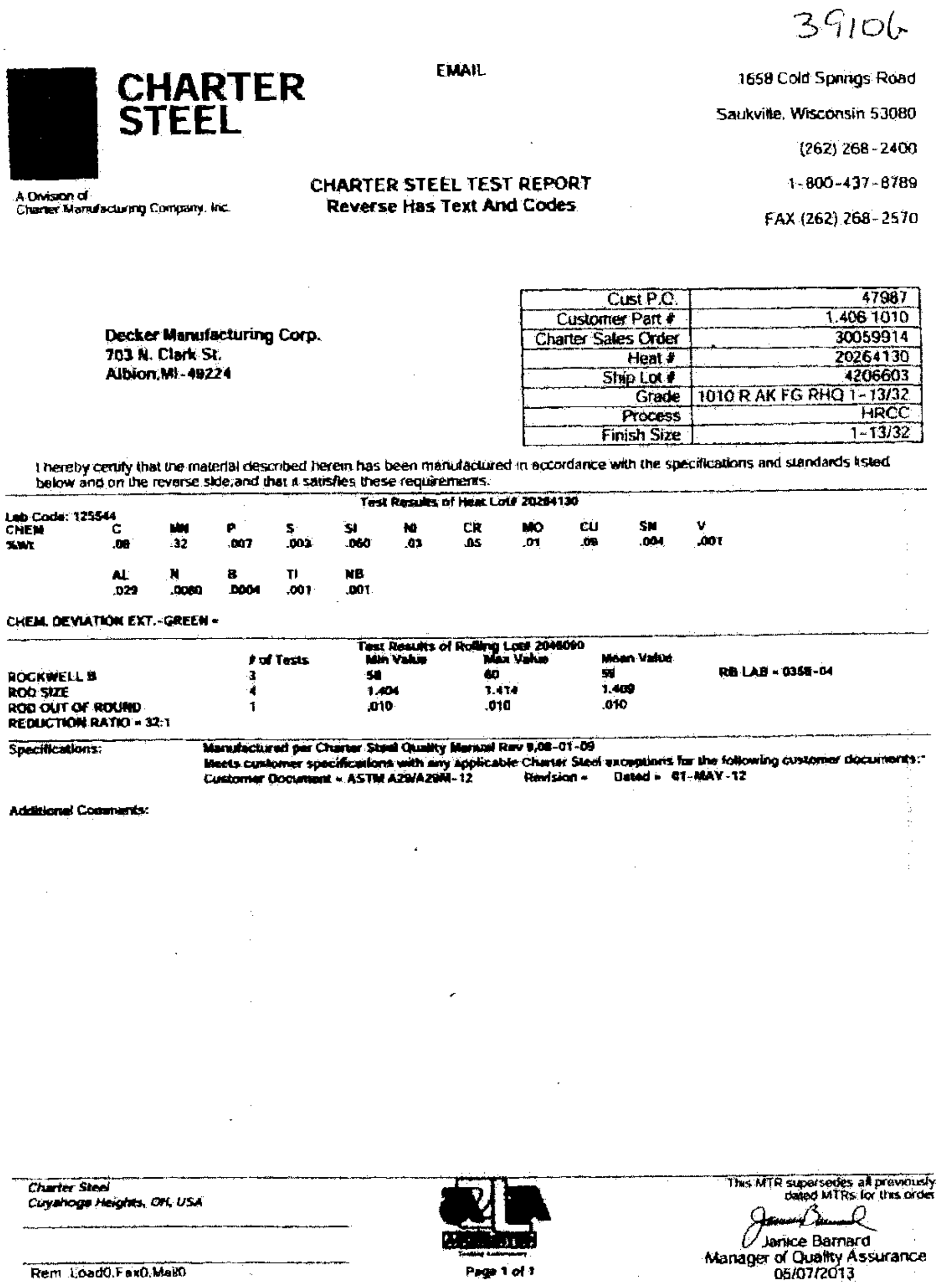
Address:
126 MILL STREET
ROCKFORD IL, 61101
USA

Customer PO	Customer Part	Description	# Containers	Request Quantity	Ship Quantity	Cum
P35185	903616-D	1-8 FIN HX DC .024 OS	246	30,000	30,730	50,730
		HOT DIP GALVANIZED		Net Weight	8697	

Sales Order #	Decker Part	Mfg Lot Number	# Containers	Lot Quantity
25391	026-1608-26	13-44-012	108	13500
25391	026-1608-26	13-44-013	138	17230

R55841

39106



39106

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

EMAIL

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

Decker Manufacturing Corp.
703 N. Clark St.
Albion,MI-49224

Cust P.O.	47987
Customer Part #	1.406 1010
Charter Sales Order	30059914
Heat #	20264130
Ship Lot #	4206603
Grade	1010 R AK FG RHQ 1-13/32
Process	HRCC
Finish Size	1-13/32

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 20264130

Lab Code: 125544

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.08	.32	.007	.003	.060	.03	.05	.01	.09	.004	.001
	AL	N	B	TI	NB						
	.029	.0080	.0004	.001	.001						

CHEM. DEVIATION EXT.-GREEN =

Test Results of Rolling Lot# 2046090

	# of Tests	Min Value	Max Value	Mean Value	
ROCKWELL B	3	58	60	59	RB LAB = 0358-04
ROD SIZE	4	1.404	1.414	1.409	
ROD OUT OF ROUND	1	.010	.010	.010	
REDUCTION RATIO = 32:1					

Specifications:
Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29/A29M-12 Revision = Dated = 01-MAY-12

Additional Comments:

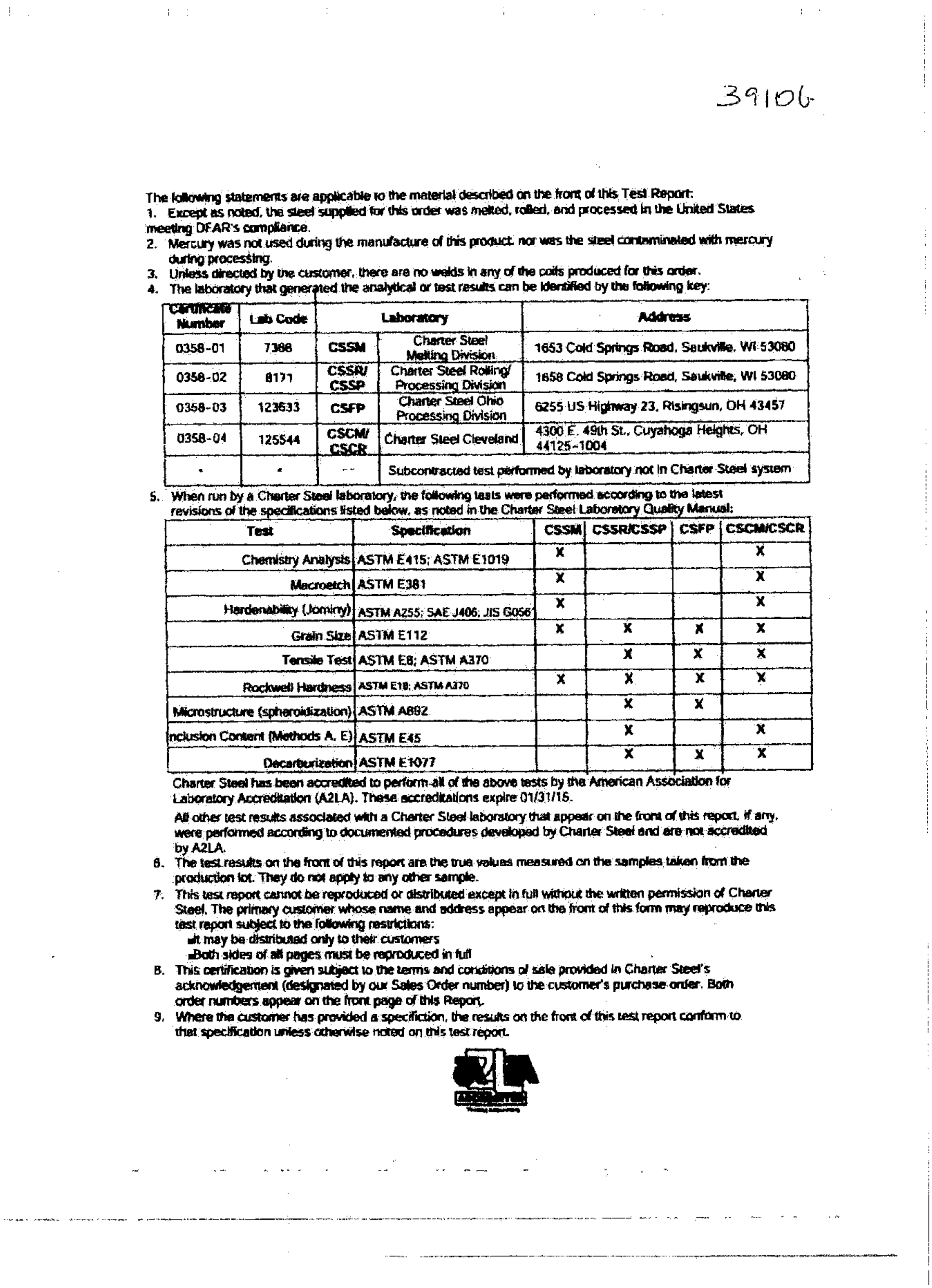
Charter Steel
Cuyahoga Heights, OH, USA

Rem Load0.Fax0.Mail0

Page 1 of 1

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance
05/07/2013



39106

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFAR's compliance.
2. Mercury was not used during the manufacture of this product nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	CSSM	Charter Steel Melting Division	1653 Cold Springs Road, Saukville, WI 53080
0358-02	8171	CSSR/ CSSP	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	CSFP	Charter Steel Ohio Processing Division	6255 US Highway 23, Risingsun, OH 43457
0358-04	125544	CSCM/ CSCR	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
•	•	--	Subcontracted test performed by laboratory not in Charter Steel system	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

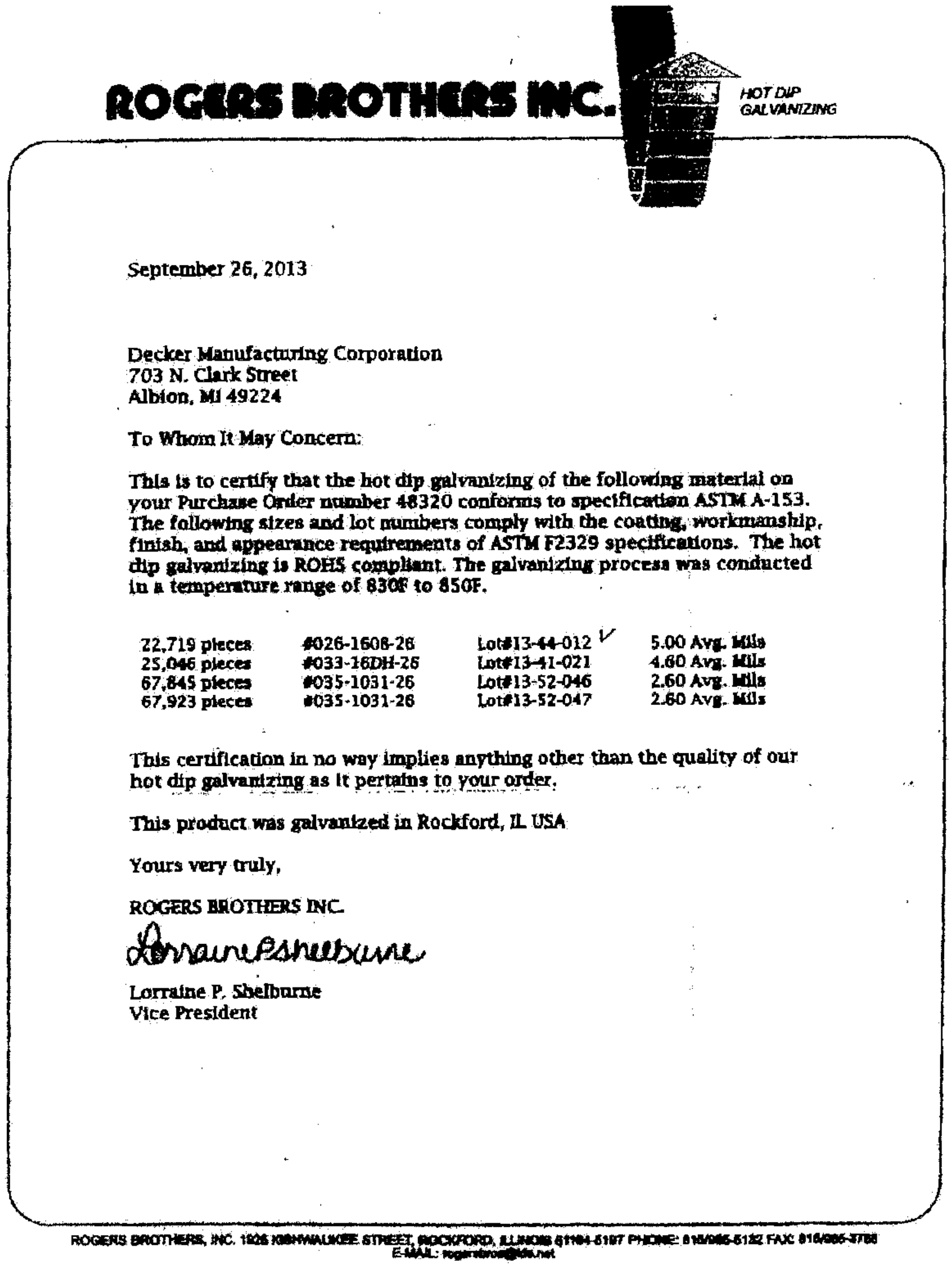
Test	Specification	CSSM	CSSR/CSSP	CSFP	CSCM/CSCR
Chemistry Analysis	ASTM E415; ASTM E1019	X			X
Macroetch	ASTM E381	X			X
Hardenability (Jominy)	ASTM A255; SAE J406; JIS G0561	X			X
Grain Size	ASTM E112	X	X	X	X
Tensile Test	ASTM E8; ASTM A370		X	X	X
Rockwell Hardness	ASTM E18; ASTM A370	X	X	X	X
Microstructure (spheroidization)	ASTM A892		X	X	
Inclusion Content (Methods A, E)	ASTM E45		X		X
Decarburization	ASTM E1077		X	X	X

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/15.

All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

6. The test results on the front of this report are the true values measured on the samples taken from the production lot. They do not apply to any other sample.
7. This test report cannot be reproduced or distributed except in full without the written permission of Charter Steel. The primary customer whose name and address appear on the front of this form may reproduce this test report subject to the following restrictions:
   - It may be distributed only to their customers
   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgement (designated by our Sales Order number) to the customer's purchase order. Both order numbers appear on the front page of this Report.
9. Where the customer has provided a specifiction, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

39106



ROGERS BROTHERS INC.
HOT DIP GALVANIZING

September 26, 2013

Decker Manufacturing Corporation
703 N. Clark Street
Albion, MI 49224

To Whom It May Concern:

This is to certify that the hot dip galvanizing of the following material on your Purchase Order number 48320 conforms to specification ASTM A-153. The following sizes and lot numbers comply with the coating, workmanship, finish, and appearance requirements of ASTM F2329 specifications. The hot dip galvanizing is ROHS compliant. The galvanizing process was conducted in a temperature range of 830F to 850F.

22,719 pieces	#026-1608-26	Lot#13-44-012 ✓	5.00 Avg. Mils
25,046 pieces	#033-16DH-26	Lot#13-41-021	4.60 Avg. Mils
67,845 pieces	#035-1031-26	Lot#13-52-046	2.60 Avg. Mils
67,923 pieces	#035-1031-26	Lot#13-52-047	2.60 Avg. Mils

This certification in no way implies anything other than the quality of our hot dip galvanizing as it pertains to your order.

This product was galvanized in Rockford, IL USA

Yours very truly,

ROGERS BROTHERS INC.

Lorraine P Shelburne

Lorraine P. Shelburne
Vice President

ROGERS BROTHERS, INC. 1926 KISHWAUKEE STREET, ROCKFORD, ILLINOIS 61104-5197 PHONE: 815/965-5132 FAX: 815/965-3788
E-MAIL: rogersbros@[illegible]

39106

DECKER
MANUFACTURING CORPORATION
MANUFACTURERS OF INDUSTRIAL FASTENERS & PIPE PLUGS
703 North Clark Street Albion, Michigan 49224

Phone 517-629-3955
Fax 517-629-3535
Sales Fax 517-629-8424
www.deckernut.com

Printed: 1/22/2014 11:30:00 AM
January 22, 2014

ROCKFORD BOLT & STEEL CO
126 MILL STREET
ROCKFORD, IL 61101

PRODUCT MATERIAL CERTIFICATION

CUSTOMER PART NUMBER : 903616-D
CUSTOMER P.O. NUMBER : P35185
INVOICE: 73094

LOT NUMBER: 13-44-013
DATE: Nov 24, 2013
HEAT NUMBER: 20201210
MATERIAL: STEEL - C1010
DESCRIPTION: 1-8 FIN HX DC .024 OS
QUANTITY: 17,230
MATERIAL SUPPLIER: CHARTER STEEL

We certify the product above was manufactured at DECKER MANUFACTURING CORPORATION from the specified raw material and that said product is certified to be manufactured, randomly sampled, tested and/or inspected and conforms to applicable specifications. We additionally certify that said raw material was domestically manufactured in the United States of America and that said raw material was manufactured free of mercury contamination.

The items were processed under the Decker Quality Manual. The current revision is dated January 12, 2005
No welding was performed.

This document accurately represents values and statements provided by our suppliers accredited testing facility. The original metallurgical test report shall be retained on file by DECKER MANUFACTURING CORPORATION for a period of not less than (10) years.

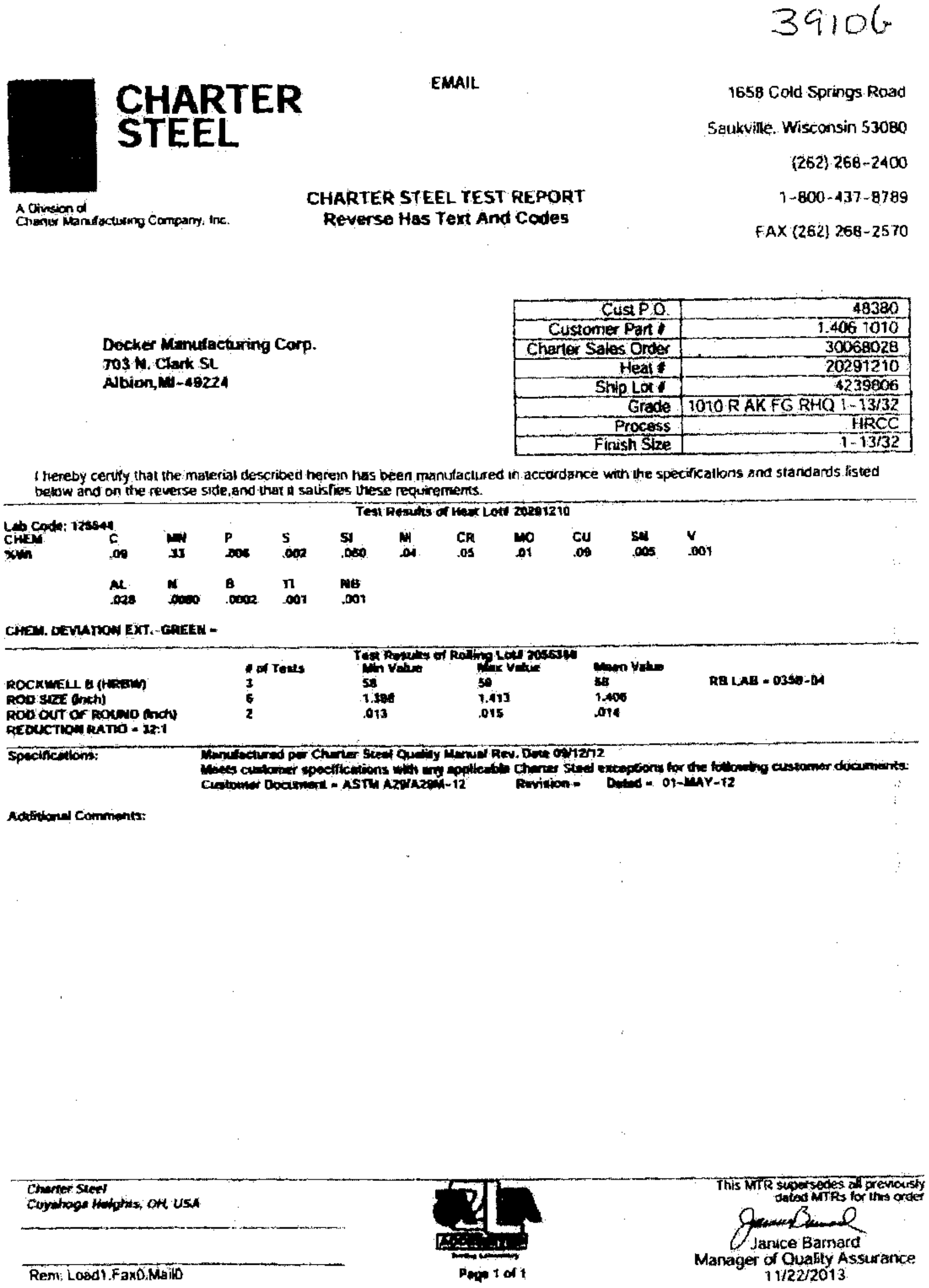
CHEMICAL ANALYSIS BY MATERIAL SUPPLIER

CARBON : 0.090
MANGANESE : 0.330
PHOSPHOROUS : 0.006
SULFUR : 0.002

DECKER MANUFACTURING CORPORATION

Russel L. Wilson
Quality Assurance Manager

The above results pertain only to the items tested. This report shall not be reproduced except in full without the approval of this testing facility



39106

CHARTER STEEL

A Division of Charter Manufacturing Company, Inc.

EMAIL

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

Decker Manufacturing Corp.
703 N. Clark St.
Albion,MI-49224

Cust P.O.	48380
Customer Part #	1.406 1010
Charter Sales Order	30068028
Heat #	20291210
Ship Lot #	4239806
Grade	1010 R AK FG RHQ 1-13/32
Process	HRCC
Finish Size	1-13/32

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 20291210

Lab Code: 125644

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.09	.33	.006	.002	.060	.04	.05	.01	.09	.005	.001

AL	N	B	TI	NB
.028	.0080	.0002	.001	.001

CHEM. DEVIATION EXT. - GREEN =

Test Results of Rolling Lot# 2056380

	# of Tests	Min Value	Max Value	Mean Value	
ROCKWELL B (HRBW)	3	58	59	58	RB LAB = 0358-04
ROD SIZE (Inch)	6	1.398	1.413	1.406	
ROD OUT OF ROUND (Inch)	2	.013	.015	.014	
REDUCTION RATIO = 32:1					

Specifications: **Manufactured per Charter Steel Quality Manual Rev. Date 09/12/12**
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29/A29M-12 Revision = Dated = 01-MAY-12

Additional Comments:

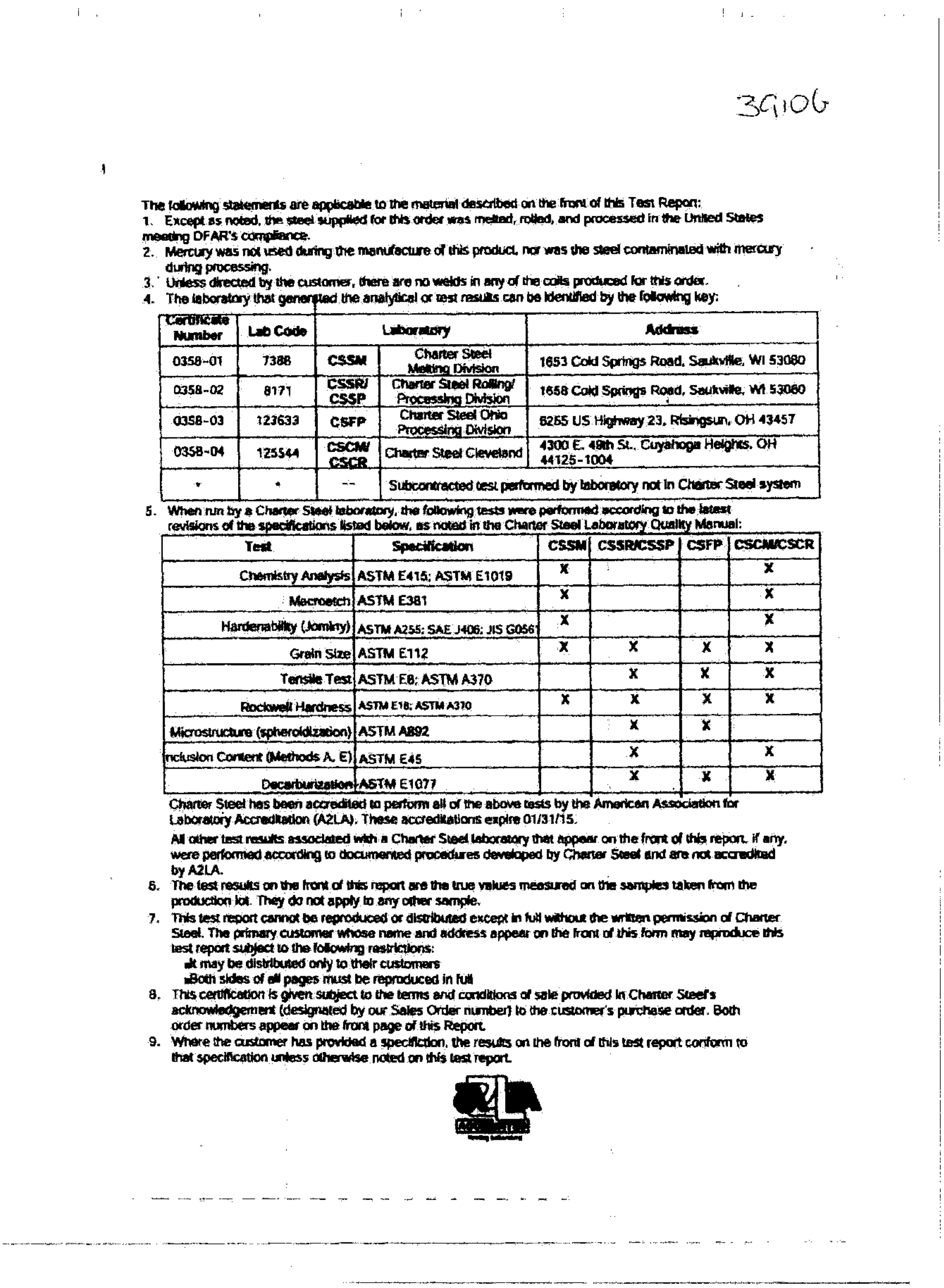
Charter Steel
Cuyahoga Heights, OH, USA

Rem: Load1,Fax0,Mail0

Page 1 of 1

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Janice Barnard
Manager of Quality Assurance
11/22/2013



39106

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFAR's compliance.
2. Mercury was not used during the manufacture of this product, nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
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0358-02	8171	**CSSR/ CSSP**	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	**CSFP**	Charter Steel Ohio Processing Division	6265 US Highway 23, Risingsun, OH 43457
0358-04	125544	**CSCM/ CSCR**	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
*	*	--	Subcontracted test performed by laboratory not in Charter Steel system	

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Macroetch	ASTM E381	X			X
Hardenability (Jominy)	ASTM A255; SAE J406; JIS G0561	X			X
Grain Size	ASTM E112	X	X	X	X
Tensile Test	ASTM E8; ASTM A370		X	X	X
Rockwell Hardness	ASTM E18; ASTM A370	X	X	X	X
Microstructure (spheroidization)	ASTM A892		X	X	
Inclusion Content (Methods A, E)	ASTM E45		X		X
Decarburization	ASTM E1077		X	X	X

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/15.

All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

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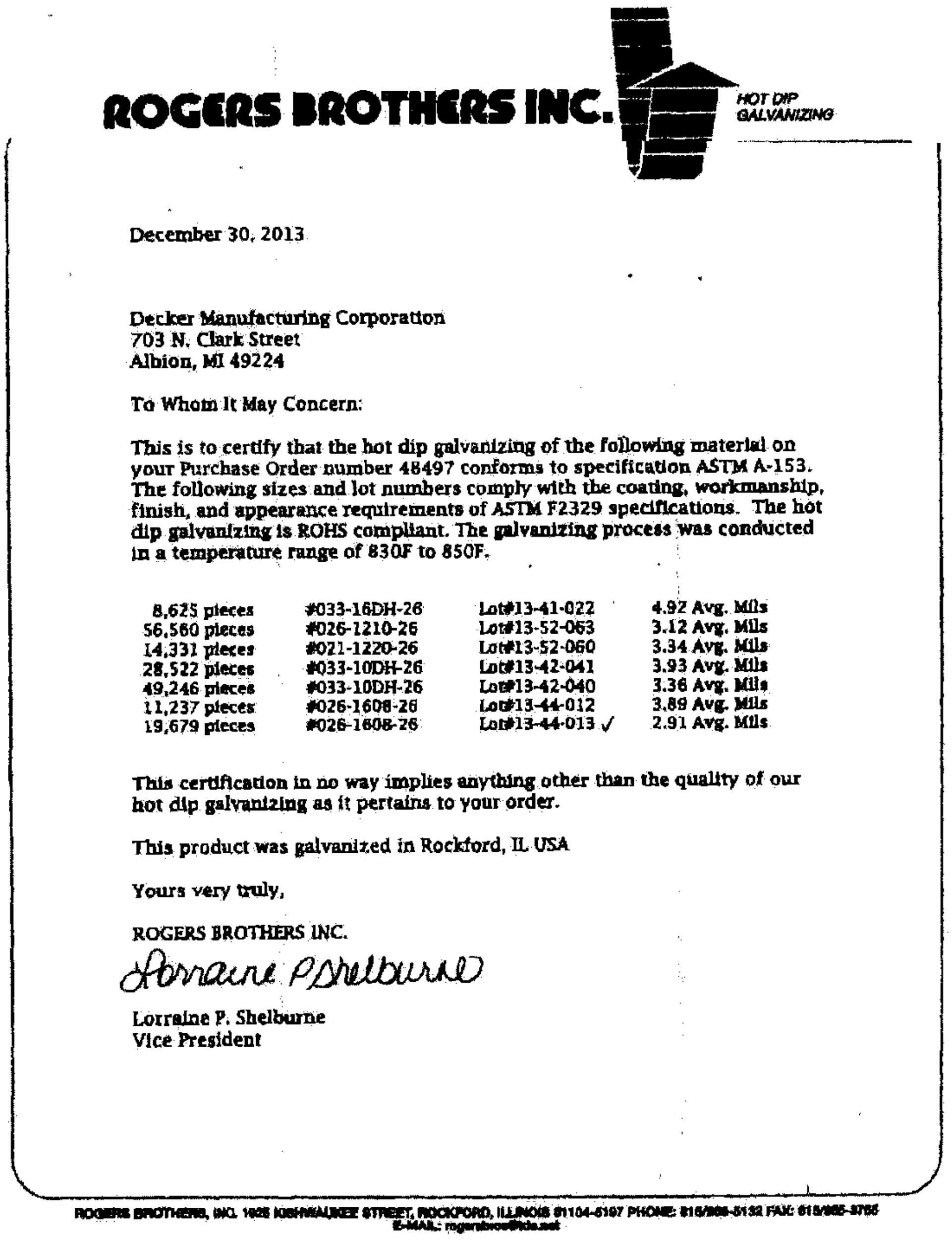
39106



ROGERS BROTHERS INC.
HOT DIP GALVANIZING

December 30, 2013

Decker Manufacturing Corporation
703 N. Clark Street
Albion, MI 49224

To Whom It May Concern:

This is to certify that the hot dip galvanizing of the following material on your Purchase Order number 48497 conforms to specification ASTM A-153. The following sizes and lot numbers comply with the coating, workmanship, finish, and appearance requirements of ASTM F2329 specifications. The hot dip galvanizing is ROHS compliant. The galvanizing process was conducted in a temperature range of 830F to 850F.

8,625 pieces	#033-16DH-26	Lot#13-41-022	4.92 Avg. Mils
56,560 pieces	#026-1210-26	Lot#13-52-063	3.12 Avg. Mils
14,331 pieces	#021-1220-26	Lot#13-52-060	3.34 Avg. Mils
28,522 pieces	#033-10DH-26	Lot#13-42-041	3.93 Avg. Mils
49,246 pieces	#033-10DH-26	Lot#13-42-040	3.36 Avg. Mils
11,237 pieces	#026-1608-26	Lot#13-44-012	3.89 Avg. Mils
19,679 pieces	#026-1608-26	Lot#13-44-013 ✓	2.91 Avg. Mils

This certification in no way implies anything other than the quality of our hot dip galvanizing as it pertains to your order.

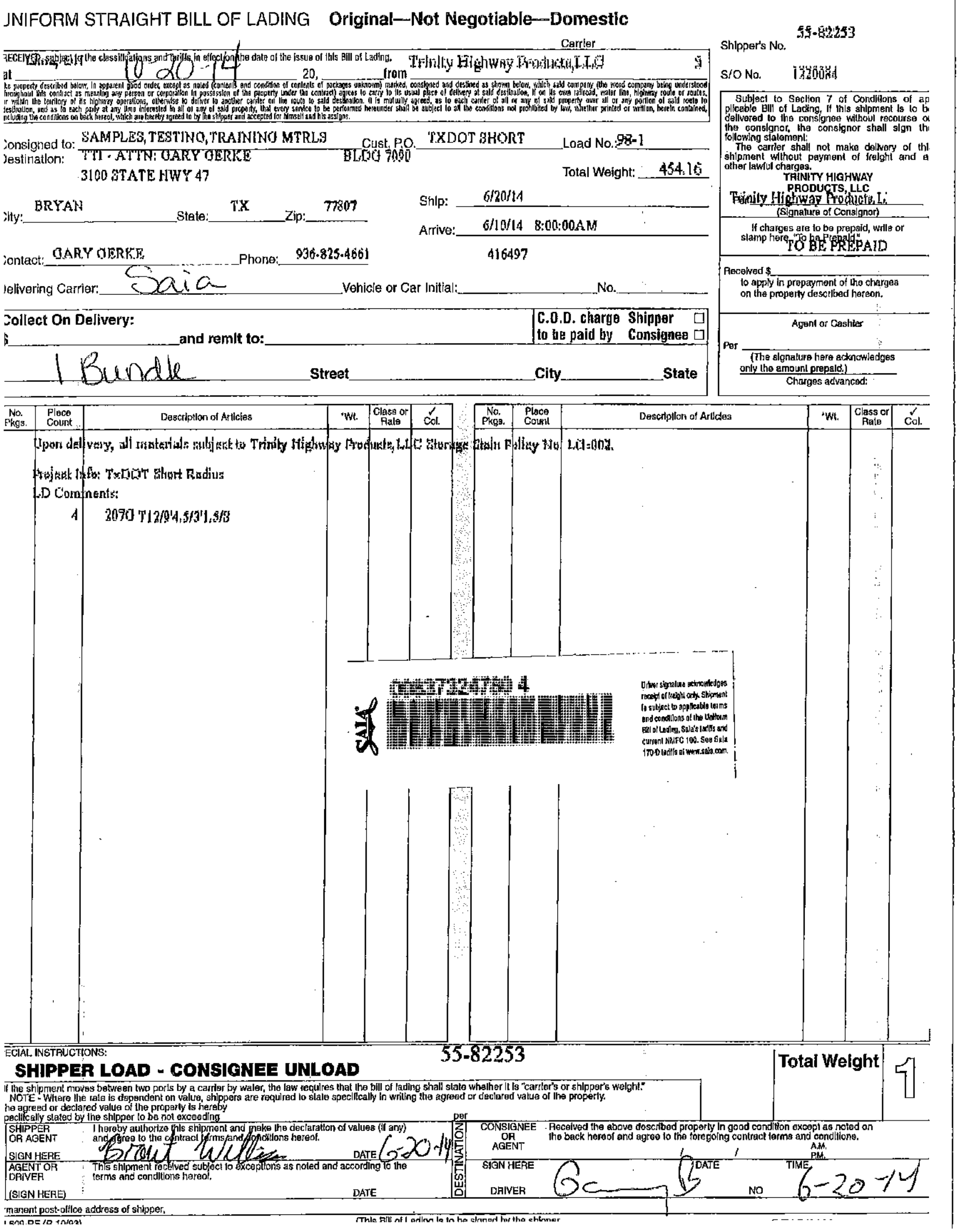
This product was galvanized in Rockford, IL USA

Yours very truly,

ROGERS BROTHERS INC.

Lorraine P Shelburne

Lorraine P. Shelburne
Vice President



JNIFORM STRAIGHT BILL OF LADING **Original—Not Negotiable—Domestic**

Shipper's No. 55-82253

S/O No. 1320084

Carrier

ECEIVED, subject to the classifications and tariffs in effect on the date of the issue of this Bill of Lading, [illegible]

at 6-20-14 20, from Trinity Highway Products,LLC $

ke property described below, in apparent good order, except as noted (contents and condition of contents of packages unknown) marked, consigned and destined as shown below, which said company (the word company being understood hroughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its own railroad, water line, highway route or routes, r within the territory of its highway operations, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to lestination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the conditions not prohibited by law, whether printed or written, herein contained, ncluding the conditions on back hereof, which are hereby agreed to by the shipper and accepted for himself and his assigns.

:onsigned to: SAMPLES,TESTING,TRAINING MTRLS Cust. P.O. TXDOT SHORT Load No. 98-1
)estination: TTI - ATTN: GARY GERKE BLDG 7090
3100 STATE HWY 47 Total Weight: 454.16
City: BRYAN State: TX Zip: 77807 Ship: 6/20/14
Arrive: 6/10/14 8:00:00AM
:ontact: GARY GERKE Phone: 936-825-4661 416497
)elivering Carrier: Saia Vehicle or Car Initial: No.

Subject to Section 7 of Conditions of ap plicable Bill of Lading, if this shipment is to b delivered to the consignee without recourse o the consignor, the consignor shall sign th following statement:

The carrier shall not make delivery of thi shipment without payment of freight and a other lawful charges.

TRINITY HIGHWAY
PRODUCTS, LLC
Trinity Highway Products,L
(Signature of Consignor)

If charges are to be prepaid, write or stamp here, "To be Prepaid." TO BE PREPAID

Received $ ____
to apply in prepayment of the charges on the property described hereon.

Agent or Cashier

Per ____
(The signature here acknowledges only the amount prepaid.)
Charges advanced:

:ollect On Delivery:
$ ____ and remit to: ____
C.O.D. charge to be paid by Shipper ☐ Consignee ☐
1 Bundle Street ____ City ____ State

No. Pkgs.	Place Count	Description of Articles	*Wt.	Class or Rate	✓ Col.	No. Pkgs.	Place Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
	Upon delivery, all materials subject to Trinity Highway Products,LLC Storage Stain Policy No LCI-002.										
	Project Info: TxDOT Short Radius										
	LD Comments:										
	4	2070 T12/9'4.5/3'1.5/8									

SAIA [illegible] 4

Driver signature acknowledges receipt of freight only. Shipment is subject to applicable terms and conditions of the Uniform Bill of Lading, Saia's tariffs and current NMFC 100. See Saia 170-D tariffs at www.saia.com.

ECIAL INSTRUCTIONS: 55-82253
SHIPPER LOAD - CONSIGNEE UNLOAD

Total Weight 1

If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is "carrier's or shipper's weight."
NOTE - Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property.
he agreed or declared value of the property is hereby pecifically stated by the shipper to be not exceeding ____ per

SHIPPER OR AGENT SIGN HERE: I hereby authorize this shipment and make the declaration of values (if any) and agree to the contract terms and conditions hereof. Brent Willis DATE 6-20-14

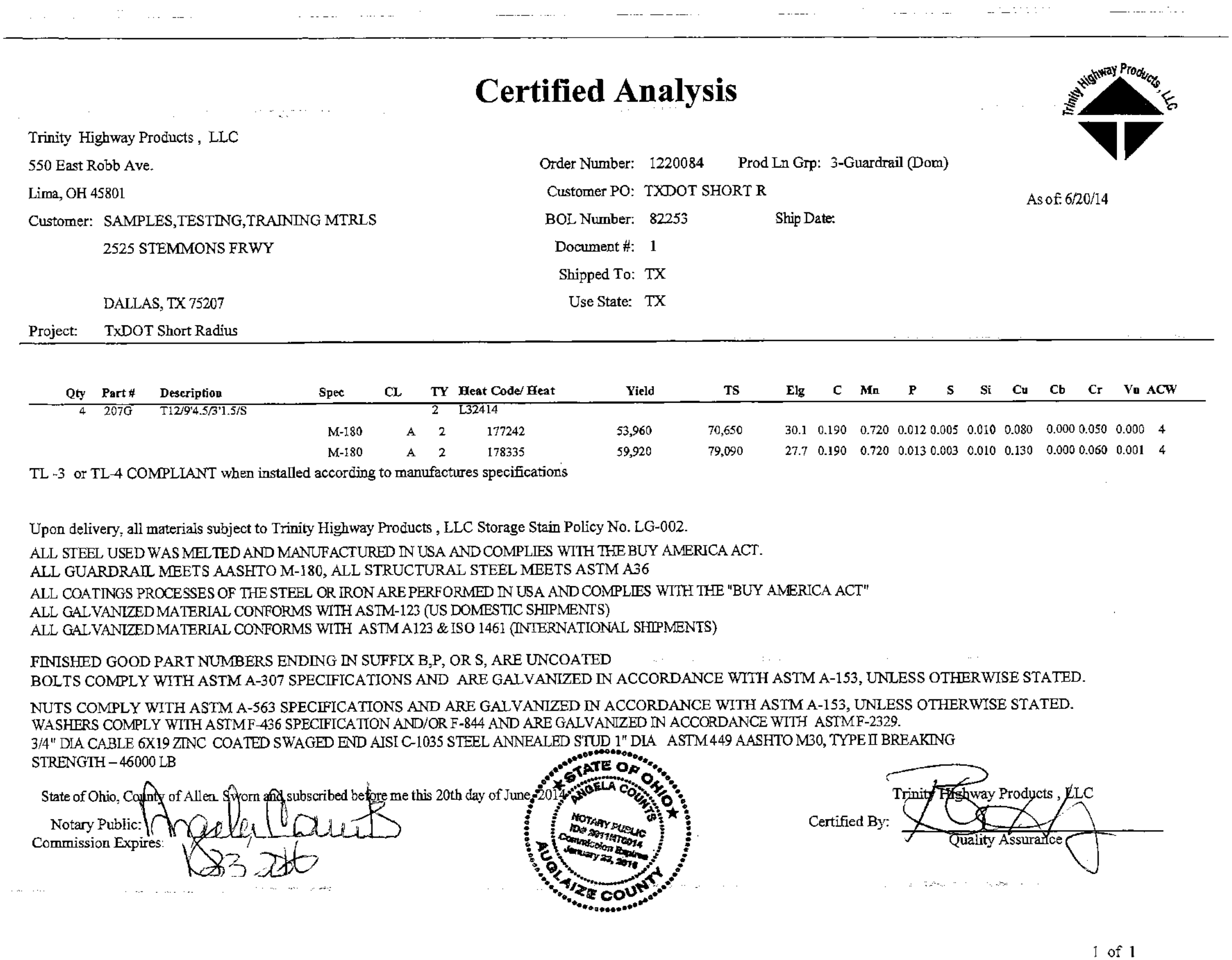
AGENT OR DRIVER (SIGN HERE): This shipment received subject to exceptions as noted and according to the terms and conditions hereof. DATE

DESTINATION

CONSIGNEE OR AGENT: Received the above described property in good condition except as noted on the back hereof and agree to the foregoing contract terms and conditions.
SIGN HERE DATE TIME A.M. P.M. 6-20-14
DRIVER NO

manent post-office address of shipper,

(This Bill of Lading is to be signed by the shipper



Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207
Project: TxDOT Short Radius

Order Number: 1220084 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: TXDOT SHORT R
BOL Number: 82253 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 6/20/14

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
4	207G	T12/9'4.5/3'1.5/S			2	L32414													
			M-180	A	2	177242	53,960	70,650	30.1	0.190	0.720	0.012	0.005	0.010	0.080	0.000	0.050	0.000	4
			M-180	A	2	178335	59,920	79,090	27.7	0.190	0.720	0.013	0.003	0.010	0.130	0.000	0.060	0.001	4

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

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.
ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

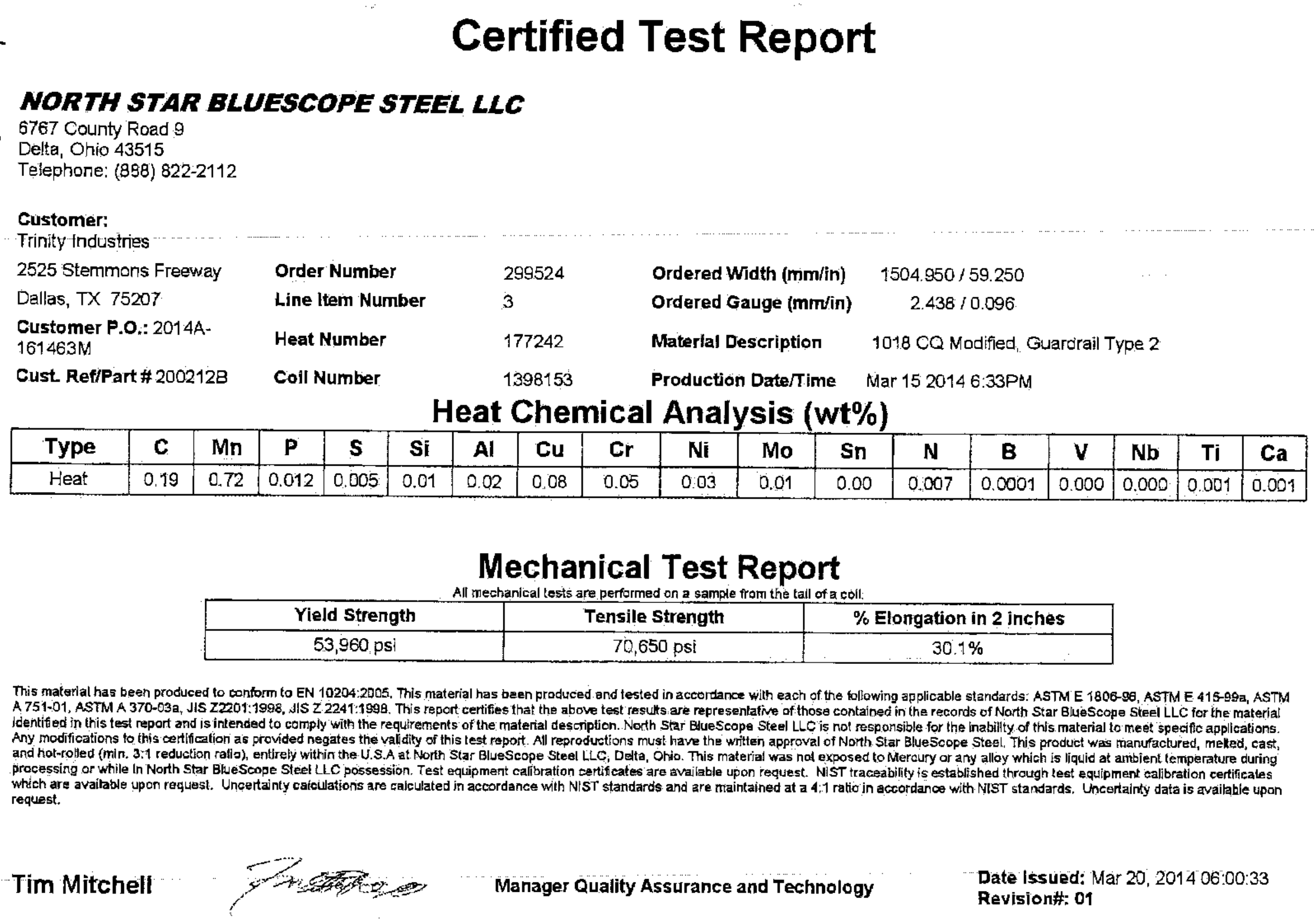
State of Ohio, County of Allen. Sworn and subscribed before me this 20th day of June, 2014.
Notary Public: Angela Counts
Commission Expires: 1-23-2016

Angela Counts
Notary Public

Certified By: Trinity Highway Products , LLC
Quality Assurance

1 of 1

2075



Certified Test Report

NORTH STAR BLUESCOPE STEEL LLC
6767 County Road 9
Delta, Ohio 43515
Telephone: (888) 822-2112

Customer:
Trinity Industries
2525 Stemmons Freeway
Dallas, TX 75207

Customer P.O.: 2014A-161463M	**Order Number**	299524	**Ordered Width (mm/in)**	1504.950 / 59.250
	Line Item Number	3	**Ordered Gauge (mm/in)**	2.438 / 0.096
	Heat Number	177242	**Material Description**	1018 CQ Modified, Guardrail Type 2
Cust. Ref/Part # 200212B	**Coil Number**	1398153	**Production Date/Time**	Mar 15 2014 6:33PM

Heat Chemical Analysis (wt%)

Type	C	Mn	P	S	Si	Al	Cu	Cr	Ni	Mo	Sn	N	B	V	Nb	Ti	Ca
Heat	0.19	0.72	0.012	0.005	0.01	0.02	0.08	0.05	0.03	0.01	0.00	0.007	0.0001	0.000	0.000	0.001	0.001

Mechanical Test Report

All mechanical tests are performed on a sample from the tail of a coil.

Yield Strength	Tensile Strength	% Elongation in 2 inches
53,960 psi	70,650 psi	30.1%

This material has been produced to conform to EN 10204:2005. This material has been produced and tested in accordance with each of the following applicable standards: ASTM E 1806-96, ASTM E 415-99a, ASTM A 751-01, ASTM A 370-03a, JIS Z2201:1998, JIS Z 2241:1998. This report certifies that the above test results are representative of those contained in the records of North Star BlueScope Steel LLC for the material identified in this test report and is intended to comply with the requirements of the material description. North Star BlueScope Steel LLC is not responsible for the inability of this material to meet specific applications. Any modifications to this certification as provided negates the validity of this test report. All reproductions must have the written approval of North Star BlueScope Steel. This product was manufactured, melted, cast, and hot-rolled (min. 3:1 reduction ratio), entirely within the U.S.A at North Star BlueScope Steel LLC, Delta, Ohio. This material was not exposed to Mercury or any alloy which is liquid at ambient temperature during processing or while in North Star BlueScope Steel LLC possession. Test equipment calibration certificates are available upon request. NIST traceability is established through test equipment calibration certificates which are available upon request. Uncertainty calculations are calculated in accordance with NIST standards and are maintained at a 4:1 ratio in accordance with NIST standards. Uncertainty data is available upon request.

Tim Mitchell Manager Quality Assurance and Technology

Date Issued: Mar 20, 2014 06:00:33
Revision#: 01

2076

Certified Test Report

NORTH STAR BLUESCOPE STEEL LLC

6767 County Road 9
Delta, Ohio 43515
Telephone: (888) 822-2112

Customer: Trinity Industries 2525 Stemmons Freeway Dallas, TX 75207				**Ordered Width (mm/in)**	1504.950 / 59.250
		Order Number	299524	**Ordered Gauge (mm/in)**	2.438 / 0.096
Customer P.O.:	2014A-161824N	**Line Item No**	4	**Production Date/Time**	4/18/2014 19:39:32
Cust. Ref/Part #:		**Heat Number**	178335	**Coil Number**	1407248
200212B		**Material Desc:**	1018 CQ Modified, Guardrail Type 2		

Chemical Analysis (wt%)

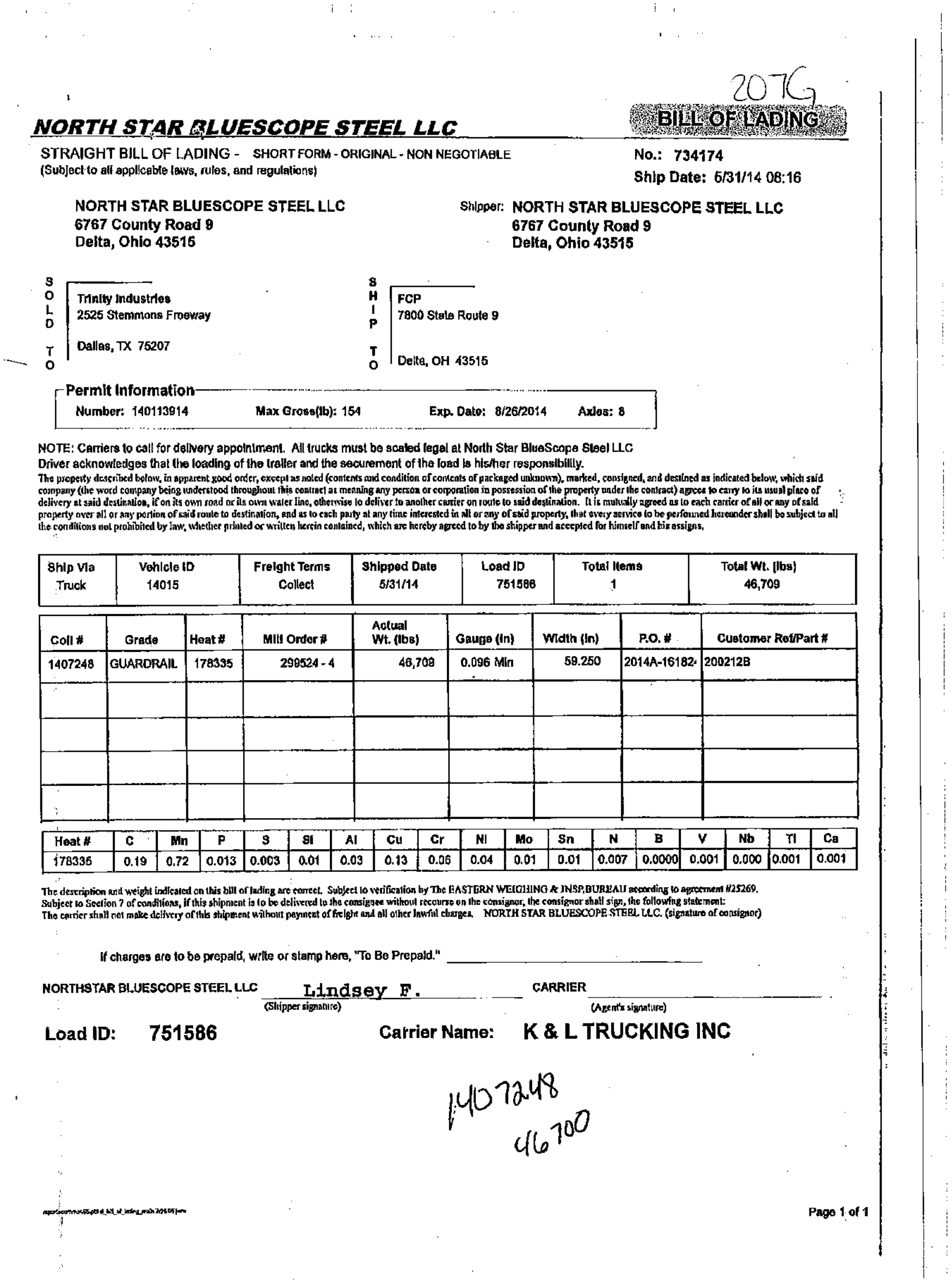
Type	C	Mn	P	S	Si	Al	Cu	Cr	Ni	Mo	Sn	N	B	V	Nb	Ti	Ca	Pb
Heat	0.19	0.72	0.013	0.003	0.01	0.03	0.13	0.06	0.04	0.01	0.01	0.007	0.0000	0.001	0.000	0.001	0.001	0.000

Mechanical Test Report

Yield Strength	Tensile Strength	% Elongation in 2 inches
59,920 psi	79,090 psi	27.7%

This material has been produced to conform to DIN/EN 10204:2005 3.1 and has been manufactured to a fully killed fine grain practice.
This material has been produced and tested in accordance with each of the following applicable standards:
ASTM E 1806-96, ASTM E 415-99a, ASTM A 751-01, ASTM A 370-03a, JIS Z2201:1998, JIS Z 2241:1998.
This report certifies that the above test results are representative of those contained in the records of North Star BlueScope Steel LLC for the material identified in this test report and is intended to comply with the requirements of the material description. North Star BlueScope Steel LLC is not responsible for the inability of this material to meet specific applications.
Any modifications to this certification as provided negates the validity of this test report. All reproductions must have the written approval of North Star BlueScope Steel.
This product was manufactured, melted, cast, and hot-rolled (min. 3:1 reduction ratio), entirely within the U.S.A at North Star BlueScope Steel LLC, Delta, Ohio.
This material was not exposed to Mercury or any alloy which is liquid at ambient temperature during processing or while in North Star BlueScope Steel LLC possession.
Test equipment calibration certificates are available upon request. NIST traceability is established through test equipment calibration certificates which are available upon request.
Uncertainty calculations are calculated in accordance with NIST standards and are maintained at a 4:1 ratio in accordance with NIST standards. Uncertainty data is available upon request.

Tim Mitchell **Manager Quality Assurance and Technology** **Date Issued:** May. 31, 2014 8:16:5
Revision#: 01



2076

NORTH STAR BLUESCOPE STEEL LLC **BILL OF LADING**

STRAIGHT BILL OF LADING - SHORT FORM - ORIGINAL - NON NEGOTIABLE
(Subject to all applicable laws, rules, and regulations)

No.: 734174
Ship Date: 5/31/14 08:16

NORTH STAR BLUESCOPE STEEL LLC
6767 County Road 9
Delta, Ohio 43515

Shipper: NORTH STAR BLUESCOPE STEEL LLC
6767 County Road 9
Delta, Ohio 43515

SOLD TO
Trinity Industries
2525 Stemmons Freeway
Dallas, TX 75207

SHIP TO
FCP
7800 State Route 9
Delta, OH 43515

Permit Information

Number: 140113914 Max Gross(lb): 154 Exp. Date: 8/26/2014 Axles: 8

NOTE: Carriers to call for delivery appointment. All trucks must be scaled legal at North Star BlueScope Steel LLC
Driver acknowledges that the loading of the trailer and the securement of the load is his/her responsibility.

The property described below, in apparent good order, except as noted (contents and condition of contents of packaged unknown), marked, consigned, and destined as indicated below, which said company (the word company being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its own road or its own water line, otherwise to deliver to another carrier on route to said destination. It is mutually agreed as to each carrier of all or any of said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the conditions not prohibited by law, whether printed or written herein contained, which are hereby agreed to by the shipper and accepted for himself and his assigns.

Ship Via	Vehicle ID	Freight Terms	Shipped Date	Load ID	Total Items	Total Wt. (lbs)
Truck	14015	Collect	5/31/14	751586	1	46,709

Coil #	Grade	Heat #	Mill Order #	Actual Wt. (lbs)	Gauge (in)	Width (in)	P.O. #	Customer Ref/Part #
1407248	GUARDRAIL	178335	299524 - 4	46,709	0.096 Min	59.250	2014A-16182	200212B

Heat #	C	Mn	P	S	Si	Al	Cu	Cr	Ni	Mo	Sn	N	B	V	Nb	Ti	Ca
178335	0.19	0.72	0.013	0.003	0.01	0.03	0.13	0.06	0.04	0.01	0.01	0.007	0.0000	0.001	0.000	0.001	0.001

The description and weight indicated on this bill of lading are correct. Subject to verification by The EASTERN WEIGHING & INSP.BUREAU according to agreement #25269.
Subject to Section 7 of conditions, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign, the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges. NORTH STAR BLUESCOPE STEEL LLC. (signature of consignor)

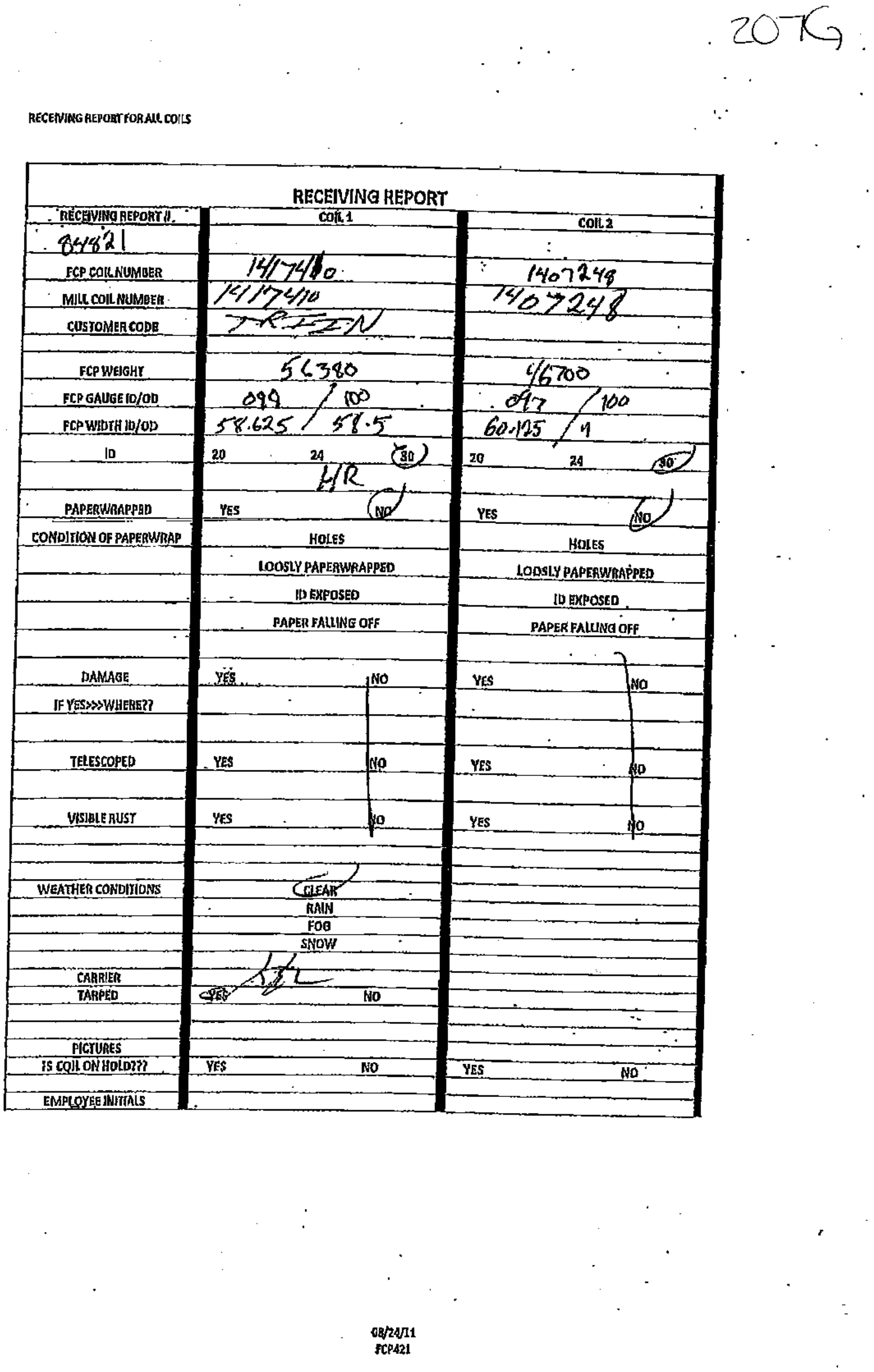
If charges are to be prepaid, write or stamp here, "To Be Prepaid." ____________________

NORTHSTAR BLUESCOPE STEEL LLC Lindsey F. (Shipper signature) CARRIER ____________________ (Agent's signature)

Load ID: 751586 **Carrier Name: K & L TRUCKING INC**

1407248
46700

Page 1 of 1



20Kg

RECEIVING REPORT FOR ALL COILS

RECEIVING REPORT

RECEIVING REPORT #.	COIL 1	COIL 2
84821		
FCP COIL NUMBER	1417410	1407248
MILL COIL NUMBER	1417410	1407248
CUSTOMER CODE	TRIIN	
FCP WEIGHT	56380	46700
FCP GAUGE ID/OD	099 / 100	097 / 100
FCP WIDTH ID/OD	58.625 / 58.5	60.125 / 4
ID	20 24 [✓ 30]	20 24 [✓ 30]
	HR	
PAPERWRAPPED	YES [✓ NO]	YES [✓ NO]
CONDITION OF PAPERWRAP	HOLES	HOLES
	LOOSLY PAPERWRAPPED	LOOSLY PAPERWRAPPED
	ID EXPOSED	ID EXPOSED
	PAPER FALLING OFF	PAPER FALLING OFF
DAMAGE	YES [✓ NO]	YES [✓ NO]
IF YES>>>WHERE??		
TELESCOPED	YES [✓ NO]	YES [✓ NO]
VISIBLE RUST	YES [✓ NO]	YES [✓ NO]
WEATHER CONDITIONS	[✓ CLEAR] RAIN FOG SNOW	
CARRIER TARPED	[✓ YES] NO	
PICTURES		
IS COIL ON HOLD???	YES NO	YES NO
EMPLOYEE INITIALS		

08/24/11
FCP421

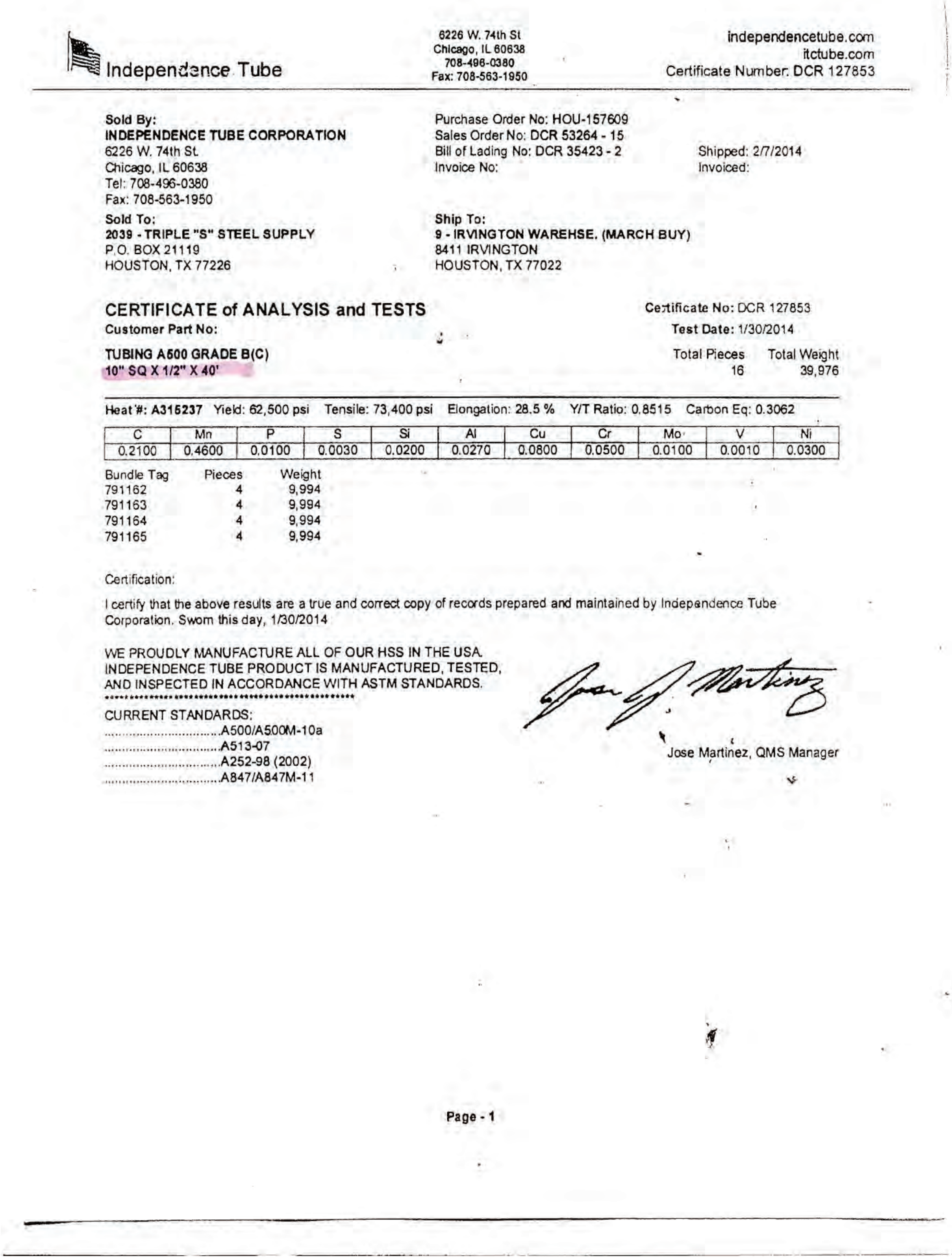
207G

84821

```
                    *FULTON COUNTY PROCESSING, LTD

6/02/14  10:32         Inventory Receiving Register                 1

TAG NUMBER      WEIGHT SHP WT GRADE GAUGE     WIDTH    LENGTH    ITMS     VALUE

1407248-00   01  46700  46709 HR    .096       59.25                1
  Heat Num.  178335           Location   CF-14
 Owner#      TRIIN      +Frt Bill#  734174
                                             I.D.       .0970       O.D.       .10
 Descript n 60.125 60.125
  Rec Rpt# 84821 DateRecd  6/02/14  Mill Coil# 1407248  +Vendor Nm  NORST
-------------------------------------------------------------------------------------------------
1417410-00   01  56380  56458 HR    .096       57.50                1
  Heat Num.  179549           Location   CF-14
 Owner#      TRIIN      +Frt Bill#  734175
                                             I.D.       .0990       O.D.       .10
 Descript n 58.625 58.500
  Rec Rpt# 84821 DateRecd  6/02/14  Mill Coil# 1417410  +Vendor Nm  NORST
-------------------------------------------------------------------------------------------------
    2           103080 103167                                   2       .00


    2           103080 103167                                   2       .00
```

PASSED & CERTIFIED
JUN - 3 2014
Trinity Highway Products, LLC
Dallas, Texas Plant 99

CP



Independence Tube

6226 W. 74th St
Chicago, IL 60638
708-496-0380
Fax: 708-563-1950

independencetube.com
itctube.com
Certificate Number: DCR 127853

Sold By:
INDEPENDENCE TUBE CORPORATION
6226 W. 74th St.
Chicago, IL 60638
Tel: 708-496-0380
Fax: 708-563-1950

Purchase Order No: HOU-157609
Sales Order No: DCR 53264 - 15
Bill of Lading No: DCR 35423 - 2
Invoice No:

Shipped: 2/7/2014
Invoiced:

Sold To:
2039 - TRIPLE "S" STEEL SUPPLY
P.O. BOX 21119
HOUSTON, TX 77226

Ship To:
9 - IRVINGTON WAREHSE. (MARCH BUY)
8411 IRVINGTON
HOUSTON, TX 77022

CERTIFICATE of ANALYSIS and TESTS

Customer Part No:

Certificate No: DCR 127853
Test Date: 1/30/2014

TUBING A500 GRADE B(C)
10" SQ X 1/2" X 40'

Total Pieces	Total Weight
16	39,976

Heat #: A315237 Yield: 62,500 psi Tensile: 73,400 psi Elongation: 28.5 % Y/T Ratio: 0.8515 Carbon Eq: 0.3062

C	Mn	P	S	Si	Al	Cu	Cr	Mo	V	Ni
0.2100	0.4600	0.0100	0.0030	0.0200	0.0270	0.0800	0.0500	0.0100	0.0010	0.0300

Bundle Tag	Pieces	Weight
791162	4	9,994
791163	4	9,994
791164	4	9,994
791165	4	9,994

Certification:

I certify that the above results are a true and correct copy of records prepared and maintained by Independence Tube Corporation. Sworn this day, 1/30/2014

WE PROUDLY MANUFACTURE ALL OF OUR HSS IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED, AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.
****

CURRENT STANDARDS:
...............................A500/A500M-10a
...............................A513-07
...............................A252-98 (2002)
...............................A847/A847M-11

Jose J. Martinez

Jose Martinez, QMS Manager

Page - 1

APPENDIX E. INFORMATION FOR CRASH TEST NO. 467114-3

E1. TEST VEHICLE MEASUREMENTS AND INFORMATION

Table E1. Vehicle Properties for Test No. 467114-3.

Date: 2014-07-14 Test No.: 467114-3 VIN No.: 1D7HA182085549506

Year: 2008 Make: Dodge Model: Ram 1500 Quad Cab

Tire Size: P265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 201042

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

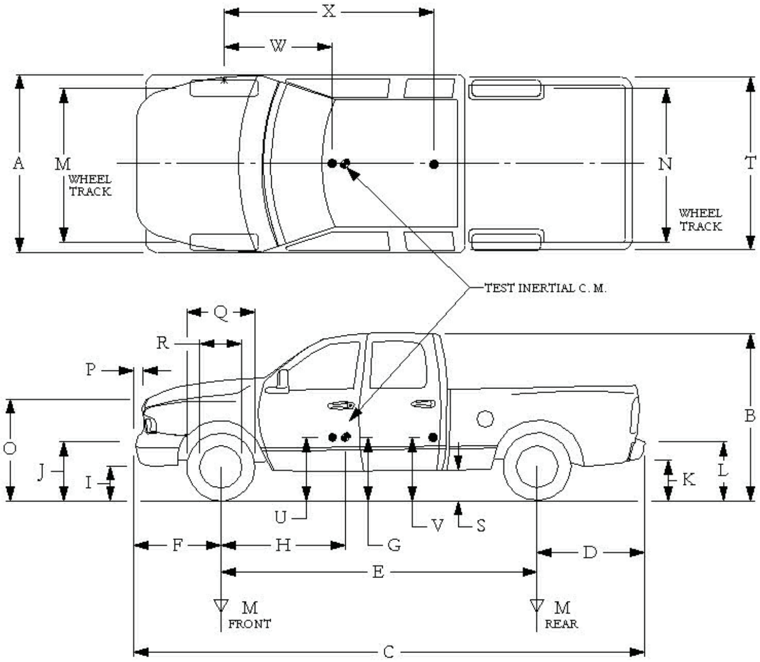
NOTES: None

Engine Type: V-8
Engine CID: 5.7 liter

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

Optional Equipment:
None

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



Geometry: inches

A	78.25	F	36.00	K	20.50	P	2.88	U	28.50
B	74.00	G	28.38	L	29.00	Q	30.50	V	30.50
C	223.75	H	61.62	M	68.50	R	16.00	W	61.60
D	47.25	I	15.25	N	68.00	S	15.00	X	76.80
E	140.50	J	26.75	O	46.00	T	77.50		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	18.00
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	11.00	Bottom Frame Height - Rear	24.75

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2887	2830	2830
Back	3900	M_{rear}	2046	2211	2211
Total	6700	M_{Total}	4933	5041	5041

Mass Distribution:
lb LF: 1449 RF: 1381 LR: 1059 RR: 1152

Table E2. Vehicle Parametric Measurements for Vertical CG for Test No. 467114-3.

Date: 2014-07-17 Test No.: 467114-3 VIN: 1D7HA182085549506

Year: 2008 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 201042

Engine: 5.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 176 lb (440 lb max)

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

Measured Vehicle Weights: (lb)

LF: 1449 RF: 1381 Front Axle: 2830

LR: 1059 RR: 1152 Rear Axle: 2211

Left: 2508 Right: 2533 Total: 5041

5000 ±110 lb allow ed

Wheel Base: 140.5 inches Track: F: 68.5 inches R: 68 inches

148 ±12 inches allow ed

Track = (F+R)/2 = 67 ±1.5 inches allow ed

Center of Gravity, SAE J874 Suspension Method

X: 61.62 in Rear of Front Axle (63 ±4 inches allow ed)

Y: 0.17 in Left - Right + of Vehicle Centerline

Z: 28.375 in Above Ground (minumum 28.0 inches allow ed)

Hood Height: 46.00 inches Front Bumper Height: 26.75 inches

43 ±4 inches allowed

Front Overhang: 36.00 inches Rear Bumper Height: 29.00 inches

39 ±3 inches allowed

Overall Length: 223.75 inches

237 ±13 inches allowed

Table E3. Exterior Crush Measurements for Test No. 467114-3.

Date: 2014-07-14 Test No.: 467114-3 VIN No.: 1D7HA182085549506

Year: 2008 Make: Dodge Model: Ram 1500 Quad Cab

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		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	30	7.75	48	4	4	7.5	4	2.75	1.5	-6
	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).

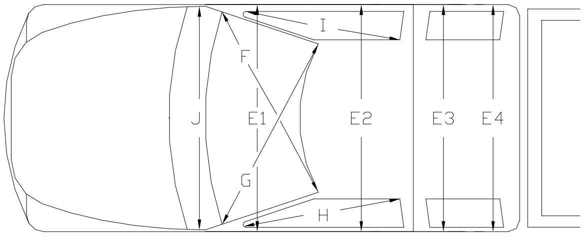
***Measure and document on the vehicle diagram the location of the maximum crush.

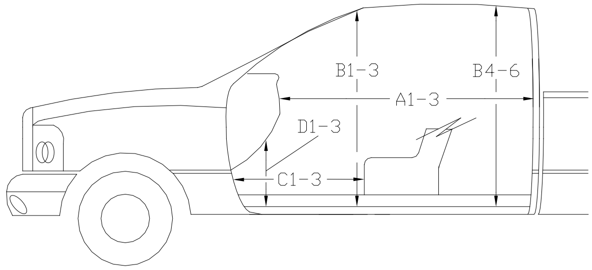
Note: Use as many lines/columns as necessary to describe each damage profile.

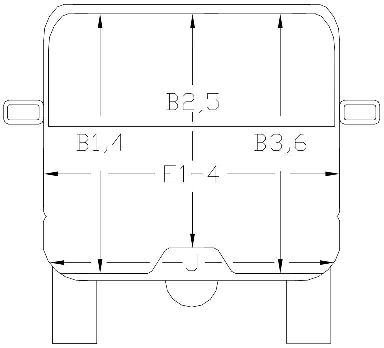
Table E4. Occupant Compartment Measurements for Test No. 467114-3.

Date: 2014-07-14 Test No.: 467114-3 VIN No.: 1D7HA182085549506

Year: 2008 Make: Dodge Model: Ram 1500 Quad Cab







OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	**After** (inches)
A1	65.00	65.00
A2	65.00	65.00
A3	65.00	65.00
B1	45.25	45.25
B2	39.25	39.25
B3	45.25	45.25
B4	39.25	39.25
B5	41.50	41.50
B6	39.25	39.25
C1	29.00	29.00
C2	-----	-----
C3	26.50	26.50
D1	12.75	12.75
D2	-----	-----
D3	11.50	11.50
E1	62.75	62.75
E2	64.50	64.50
E3	64.25	64.25
E4	64.25	64.25
F	60.00	60.00
G	60.00	60.00
H	39.00	39.00
I	39.00	39.00
J*	62.25	62.25

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

E2. SEQUENTIAL PHOTOGRAPHS

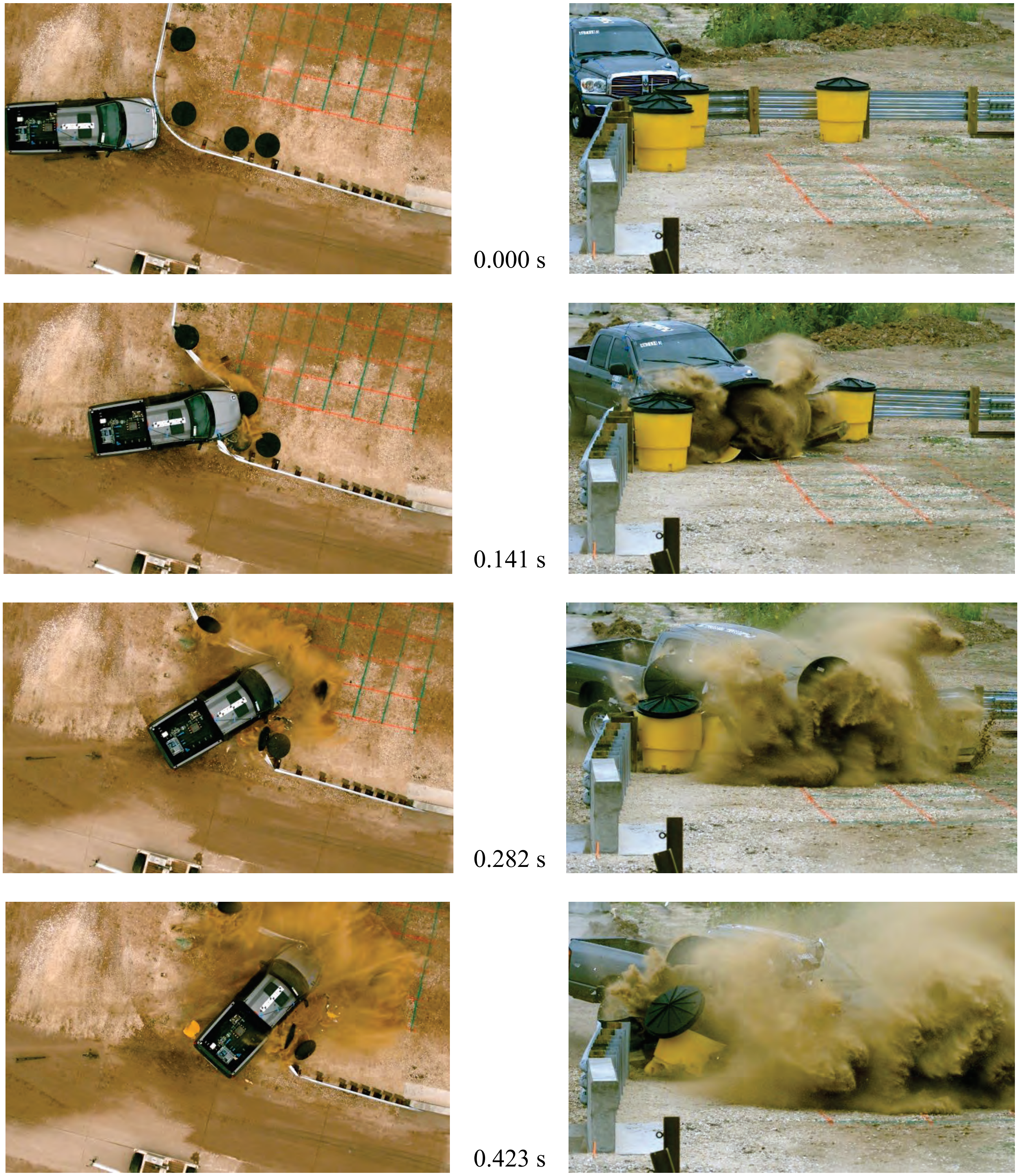
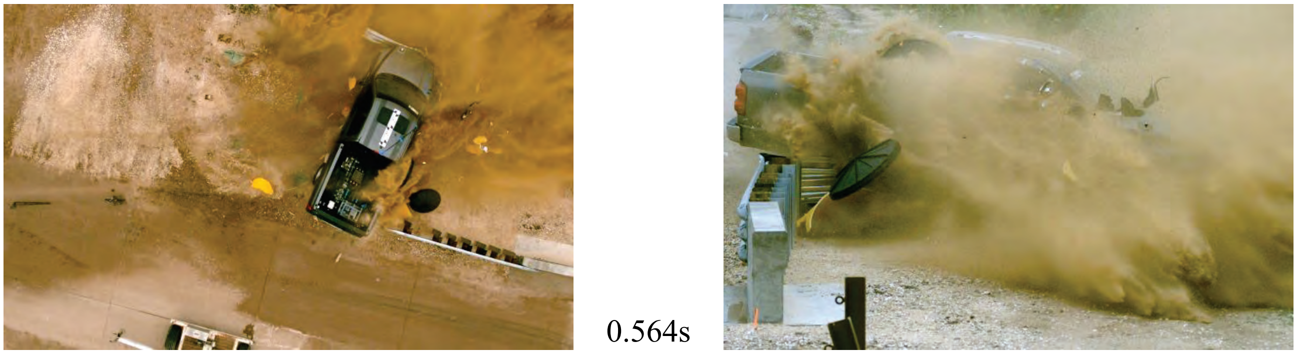


Figure E1. Sequential Photographs for Test No. 467114-3 (Overhead and Frontal Views).



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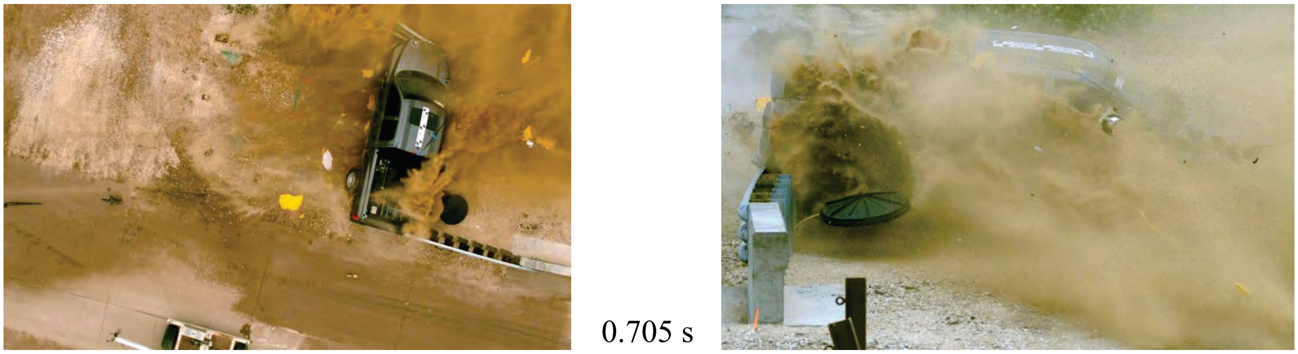

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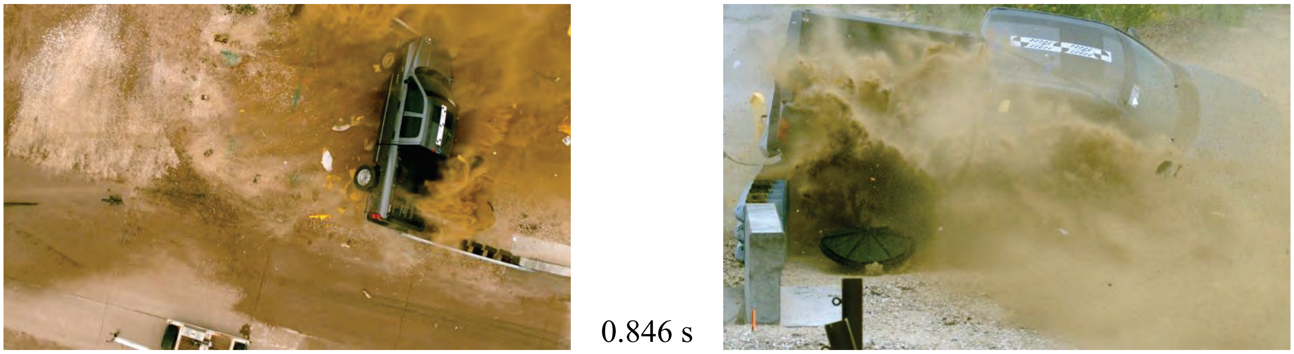

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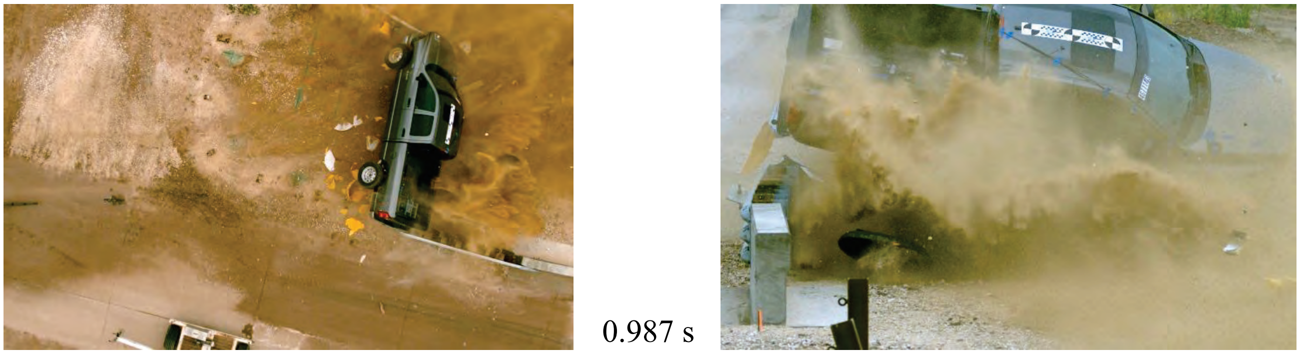

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Figure E1. Sequential Photographs for Test No. 467114-3
(Overhead and Frontal Views) (Continued).

E3. VEHICLE ANGULAR DISPLACEMENTS

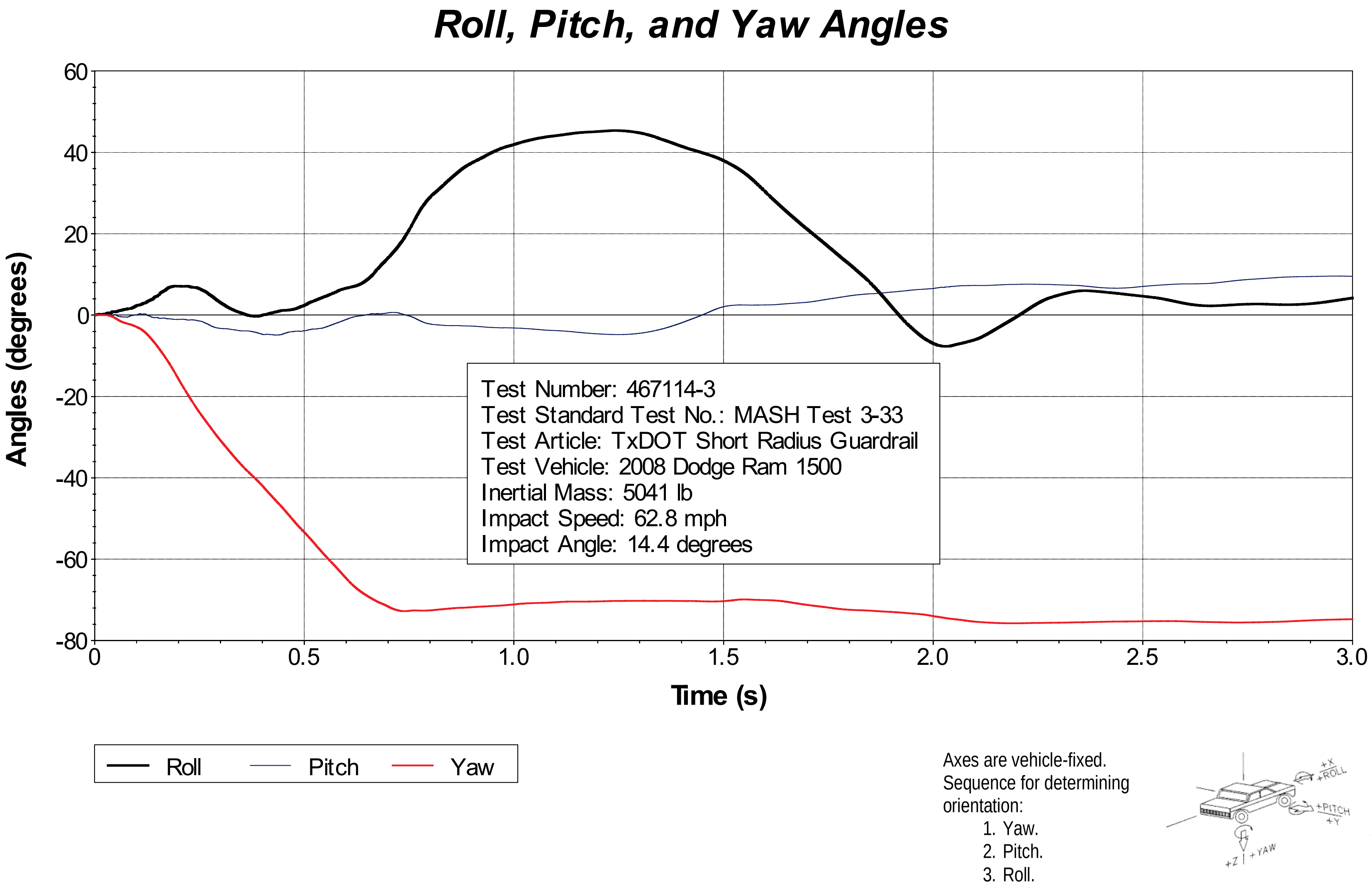


Figure E2. Vehicle Angular Displacements for Test No. 467114-3.

E4. VEHICLE ACCELERATIONS

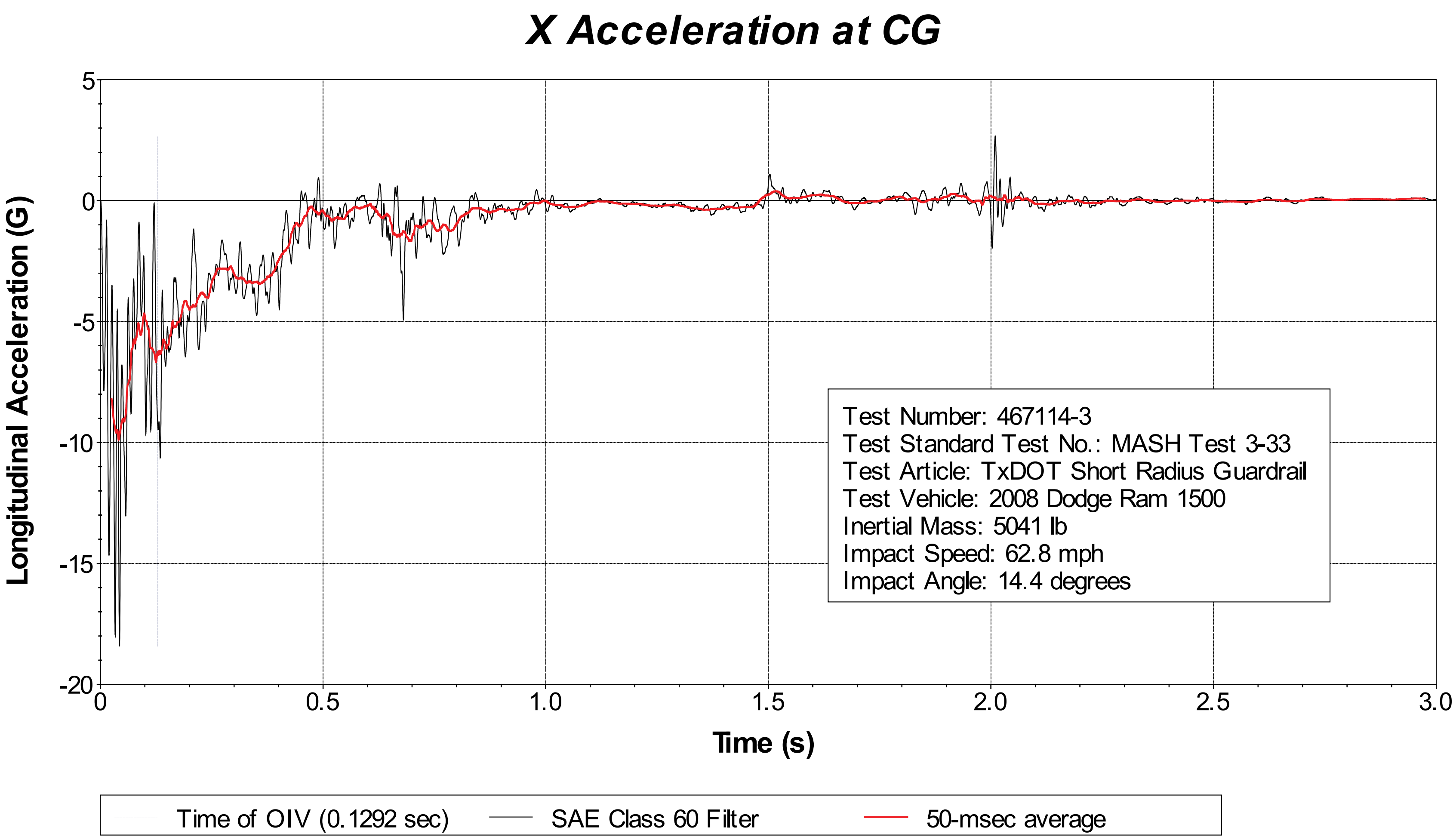


Figure E3. Vehicle Longitudinal Accelerometer Trace for Test No. 467114-3 (Accelerometer Located at Center of Gravity).

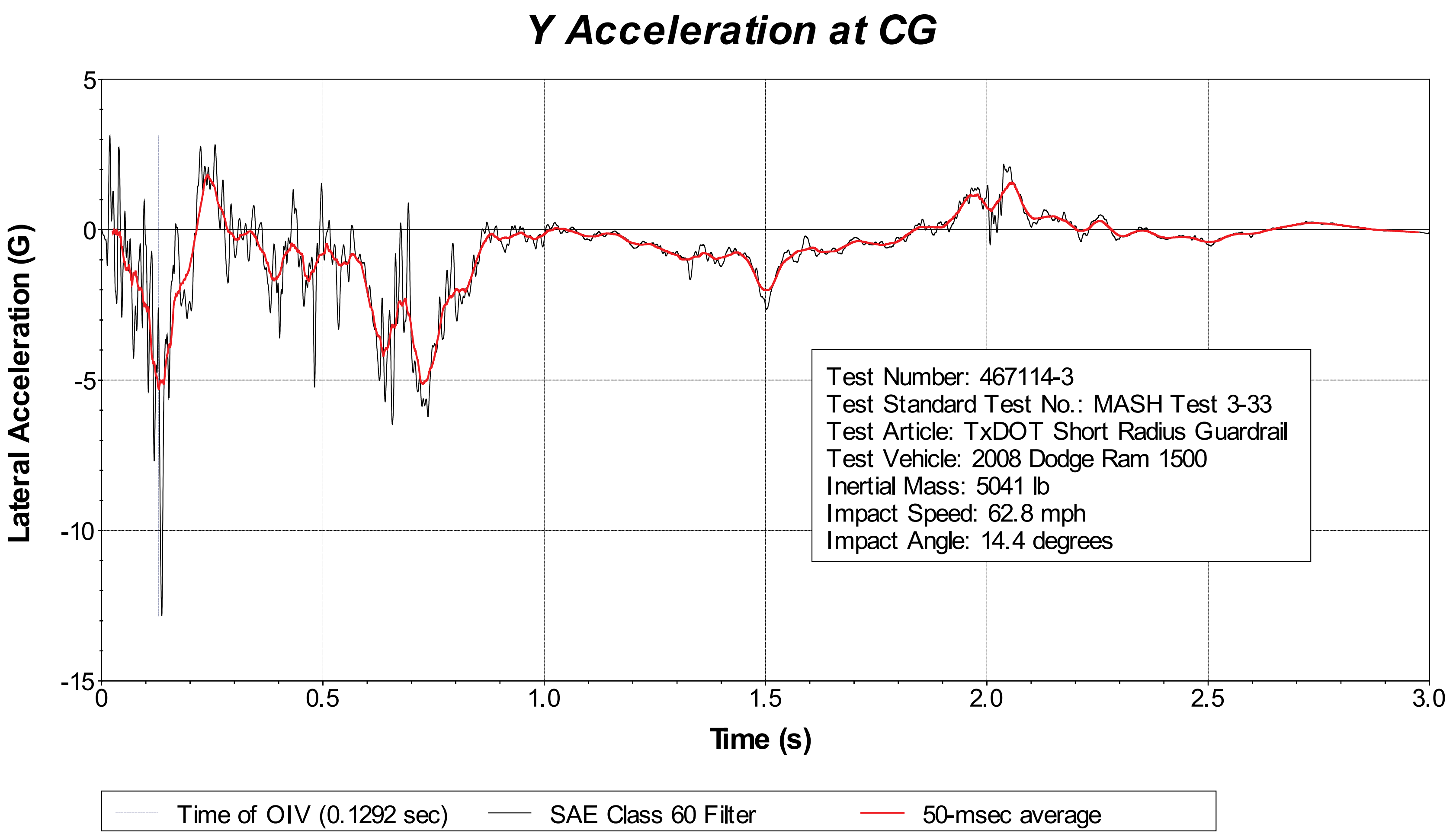


Figure E4. Vehicle Lateral Accelerometer Trace for Test No. 467114-3 (Accelerometer Located at Center of Gravity).

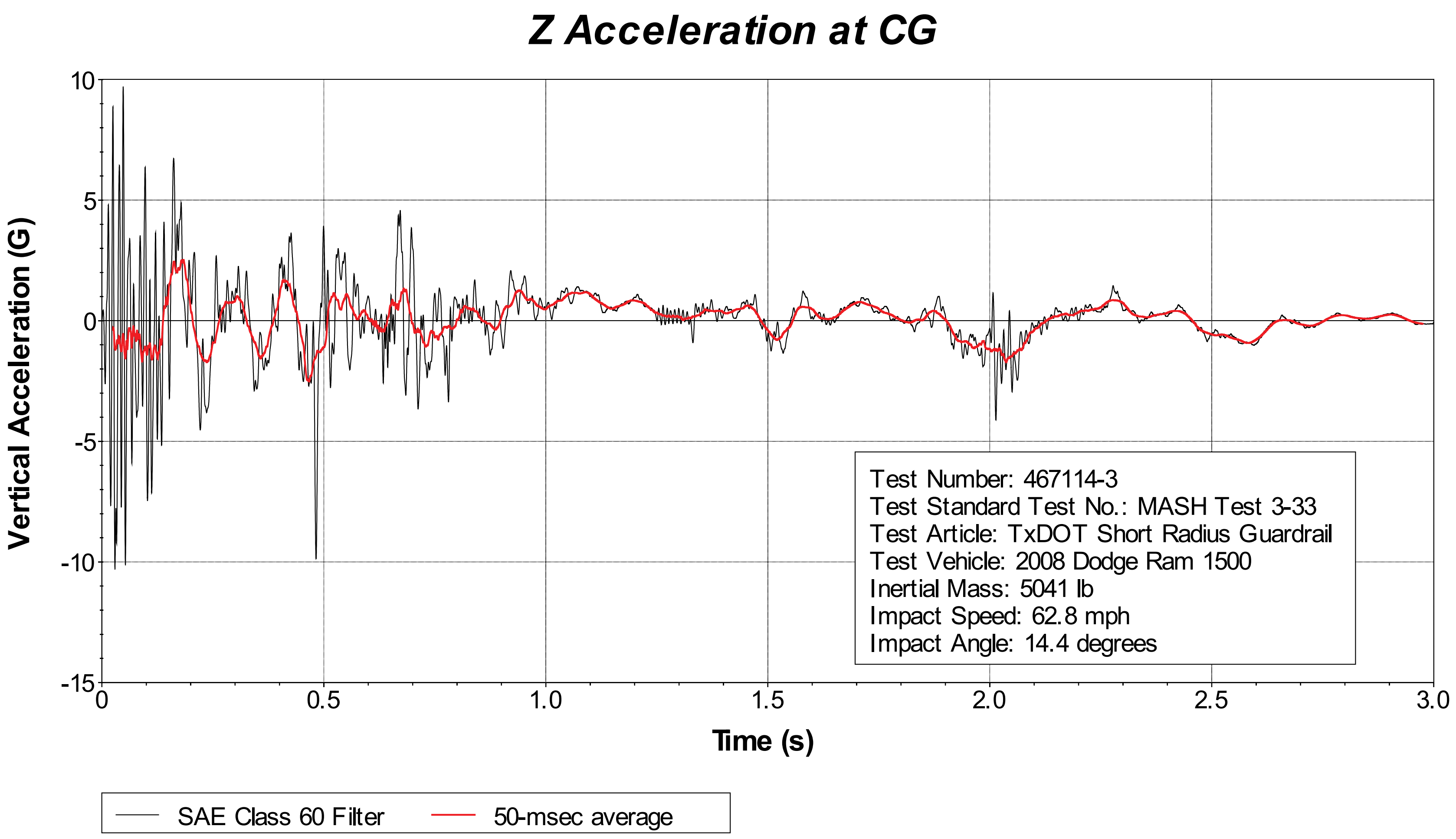


Figure E5. Vehicle Vertical Accelerometer Trace for Test No.467114-3 (Accelerometer Located at Center of Gravity).

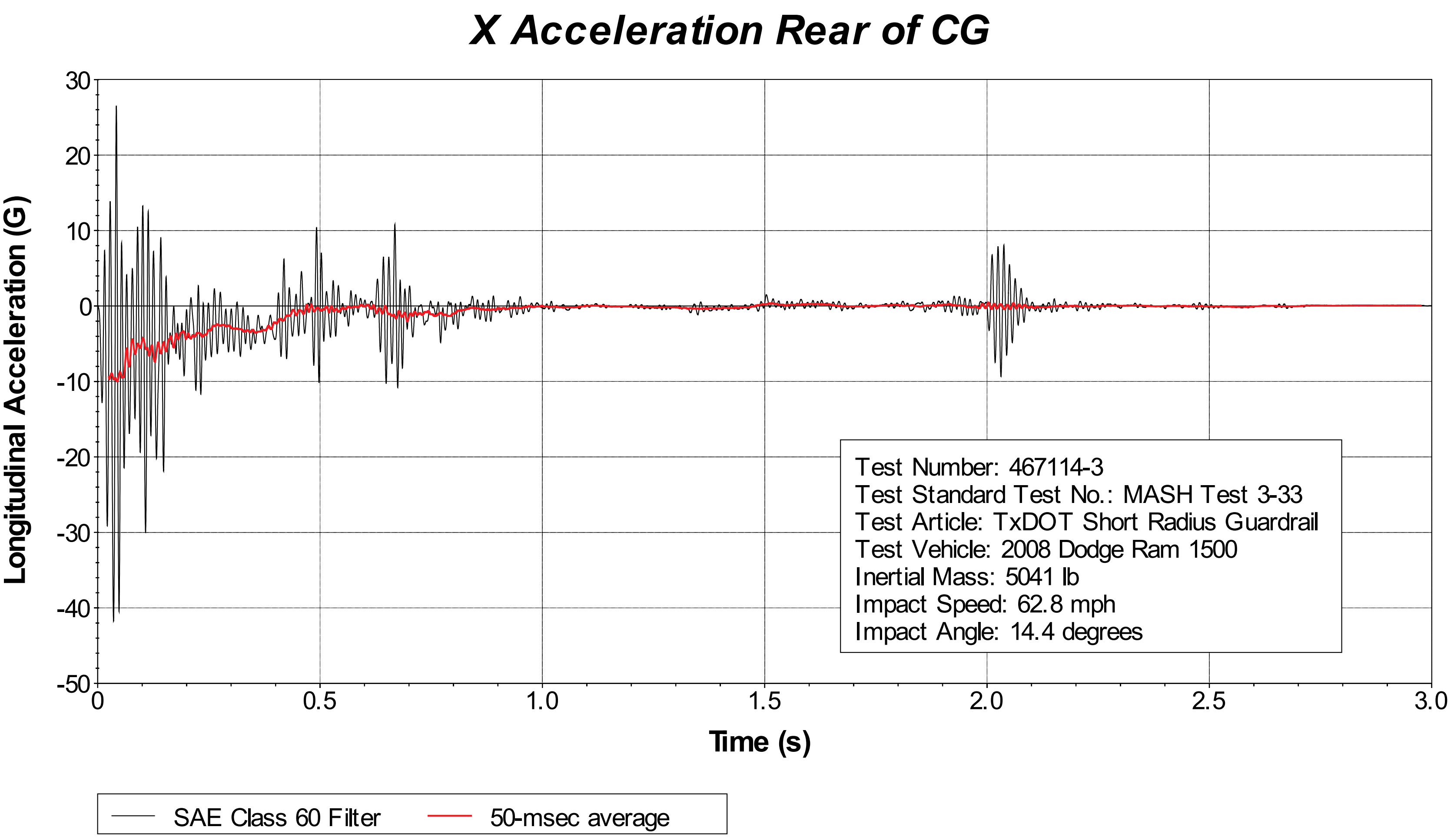


Figure E6. Vehicle Longitudinal Accelerometer Trace for Test No. 467114-3 (Accelerometer Located Rear of Center of Gravity).

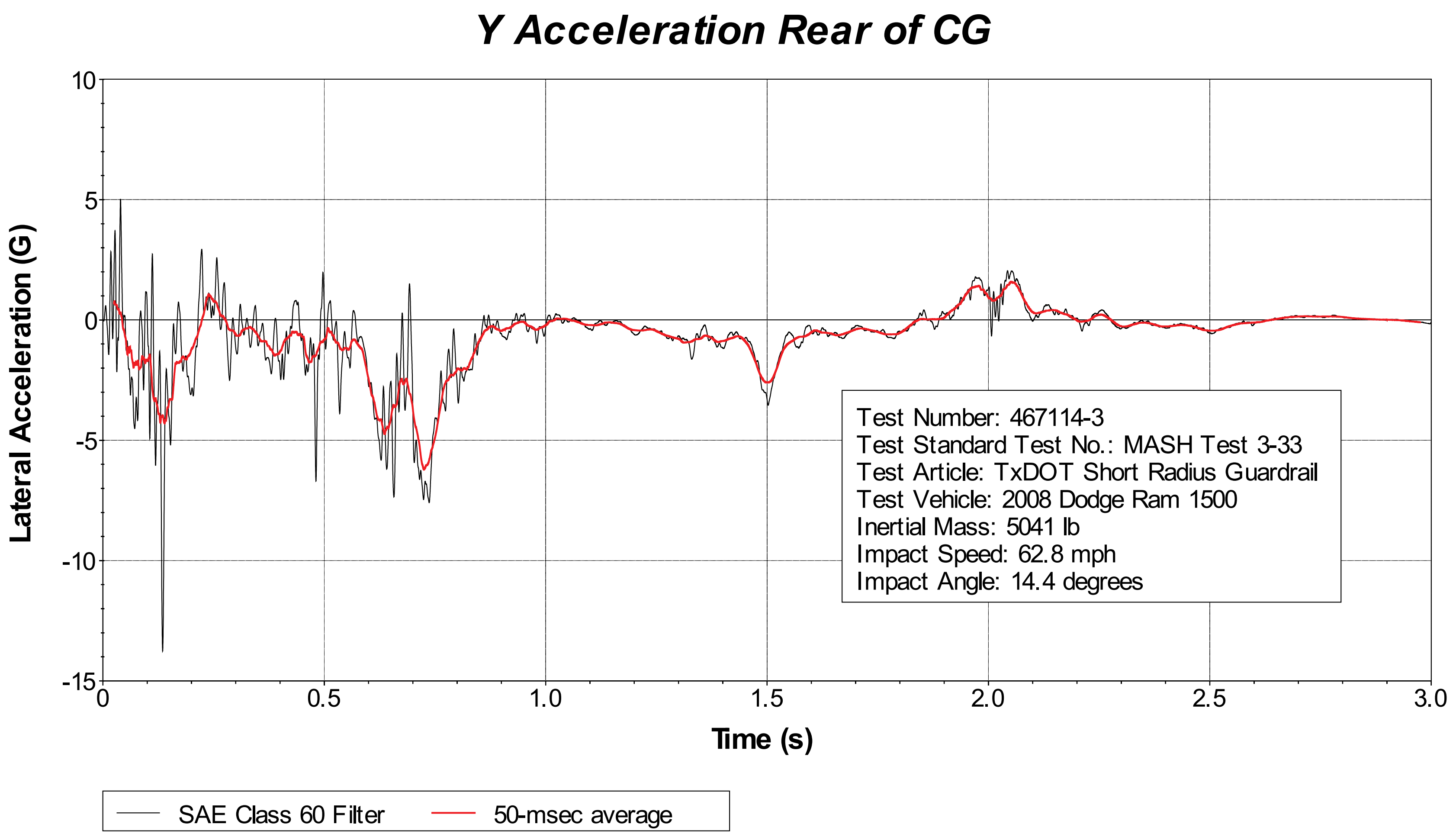
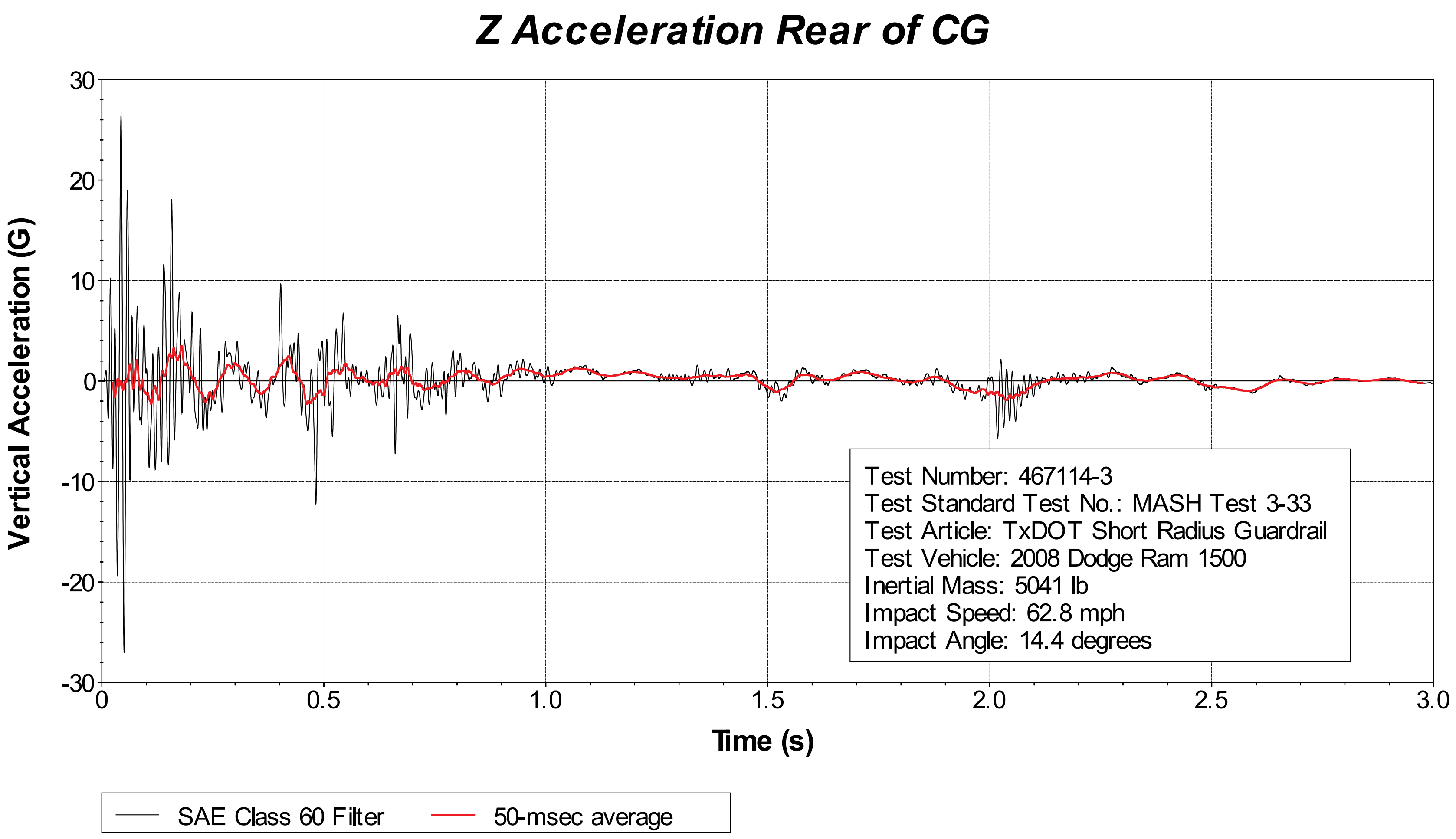


Figure E7. Vehicle Lateral Accelerometer Trace for Test No. 467114-3
(Accelerometer Located Rear of Center of Gravity).



Test Number: 467114-3
Test Standard Test No.: MASH Test 3-33
Test Article: TxDOT Short Radius Guardrail
Test Vehicle: 2008 Dodge Ram 1500
Inertial Mass: 5041 lb
Impact Speed: 62.8 mph
Impact Angle: 14.4 degrees

Figure E8. Vehicle Vertical Accelerometer Trace for Test No. 467114-3 (Accelerometer Located Rear of Center of Gravity).

APPENDIX F. INFORMATION FOR CRASH TEST NO. 467114-4

F1. TEST VEHICLE MEASUREMENTS AND INFORMATION

Table F1. Vehicle Properties for Test No. 467114-4.

Date: 2014-07-23 Test No.: 467114-4 VIN No.: KNADE223296443375

Year: 2009 Make: Kia Model: Rio

Tire Inflation Pressure: 32 psi Odometer: 105712 Tire Size: P185/65R14

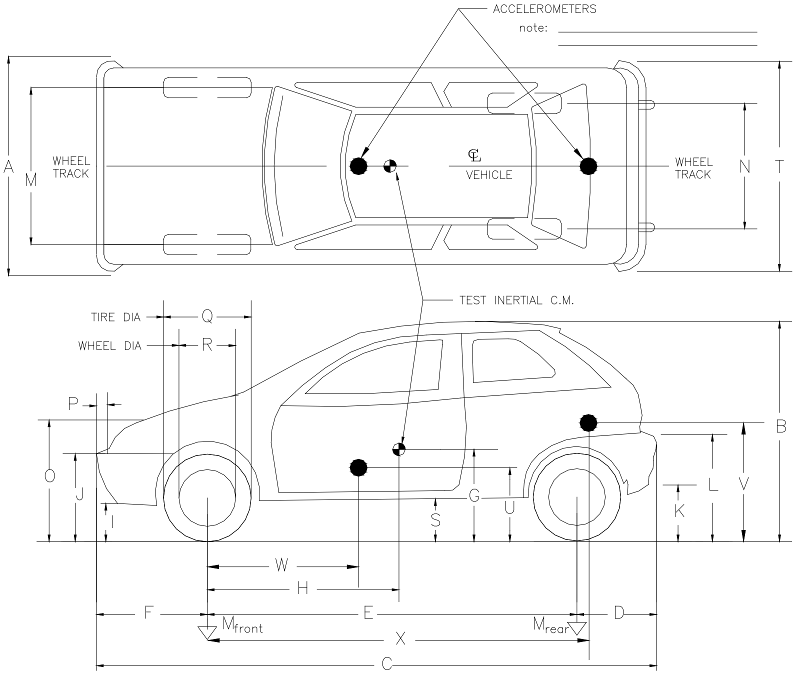
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None

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

Dummy Data:
Type: 50th percentile male
Mass: 165 lb
Seat Position: Rt front passenger



Geometry: inches

A	66.38	F	33.00	K	12.50	P	4.17	U	14.50
B	58.00	G	-----	L	25.00	Q	22.19	V	21.50
C	165.75	H	35.56	M	57.75	R	15.38	W	44.00
D	34.00	I	8.50	N	57.12	S	7.75	X	108.50
E	98.75	J	21.50	O	31.50	T	66.12		

Wheel Center Ht Front 11.00 Wheel Center Ht Rear 11.00

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1918	M_{front}	1584	1551	1642
Back	1874	M_{rear}	863	873	947
Total	3638	M_{Total}	2447	2424	2589

Mass Distribution:
lb LF: 792 RF: 759 LR: 440 RR: 433

Table F2. Exterior Crush Measurements for Test No. 467114-4.

Date: 2014-07-23 Test No.: 467114-4 VIN No.: KNADE223296443375

Year: 2009 Make: Kia Model: Rio

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	48	10	48	9.25	10	8.5	7.25	7.25	7.5	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).

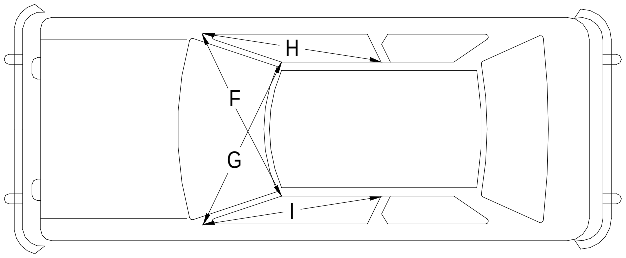
***Measure and document on the vehicle diagram the location of the maximum crush.

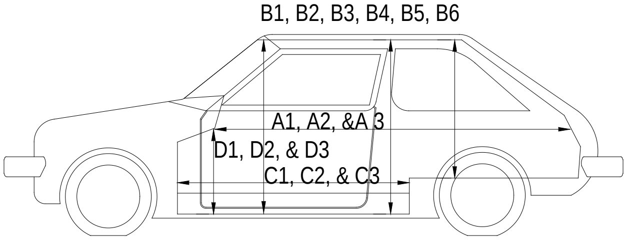
Note: Use as many lines/columns as necessary to describe each damage profile.

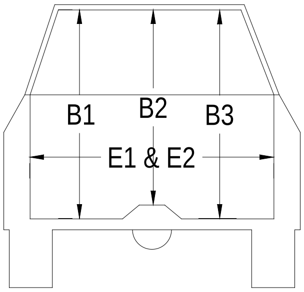
Table F3. Occupant Compartment Measurements for Test No. 467114-4.

Date: 2014-07-23 Test No.: 467114-4 VIN No.: KNADE223296443375

Year: 2009 Make: Kia Model: Rio





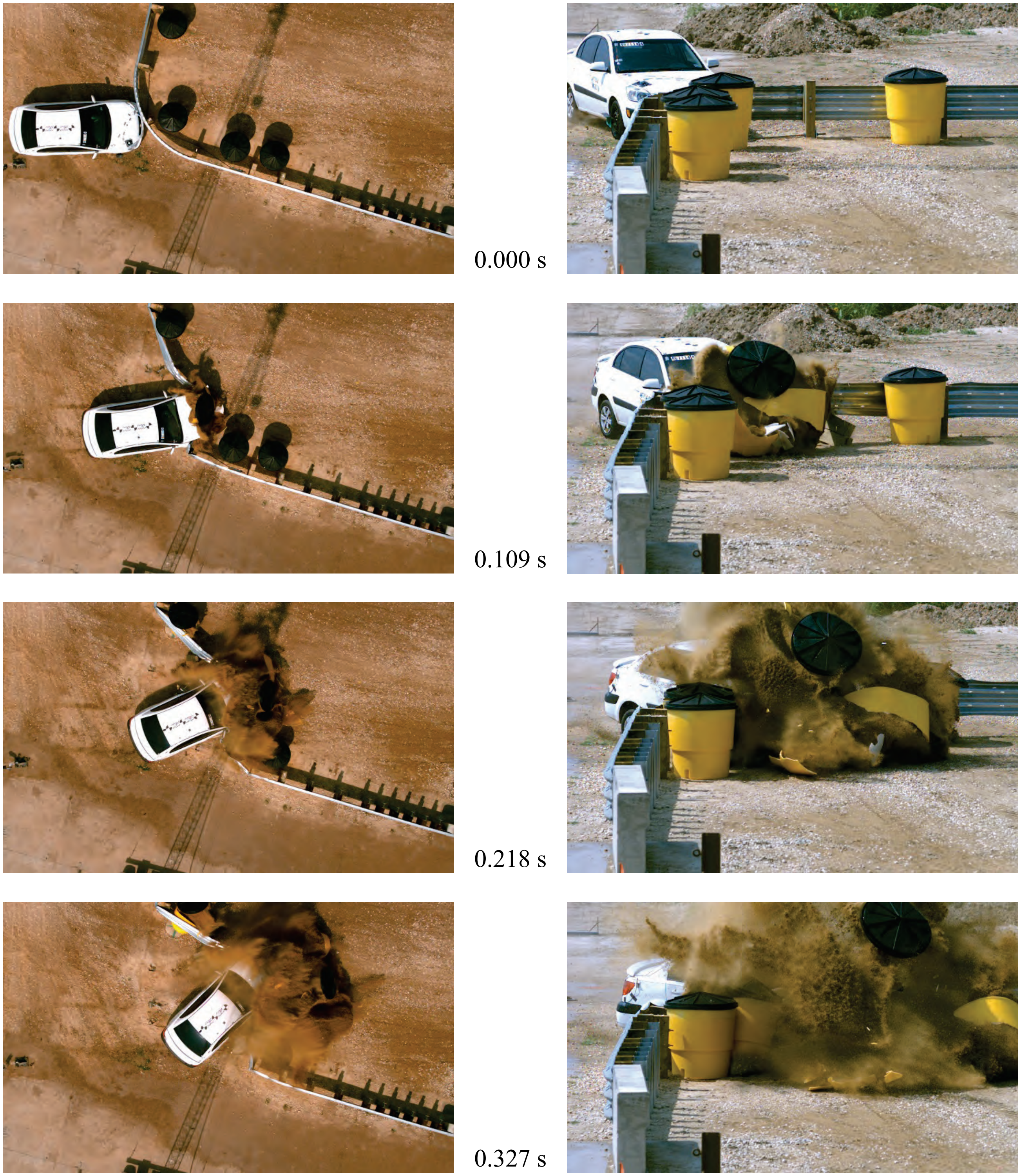


*Lateral area across the cab from
driver’s side kickpanel to passenger’s side kickpanel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	67.50	67.50
A2	67.50	67.50
A3	67.50	67.50
B1	40.50	40.50
B2	35.75	35.75
B3	40.50	40.50
B4	36.25	36.25
B5	35.75	35.75
B6	36.25	36.25
C1	27.00	27.00
C2	-----	-----
C3	27.00	27.00
D1	9.75	9.75
D2	-----	-----
D3	9.75	9.75
E1	51.50	51.00
E2	51.50	51.00
F	50.50	50.50
G	50.50	50.50
H	37.50	37.50
I	37.50	37.50
J*	51.00	51.00

F2. SEQUENTIAL PHOTOGRAPHS



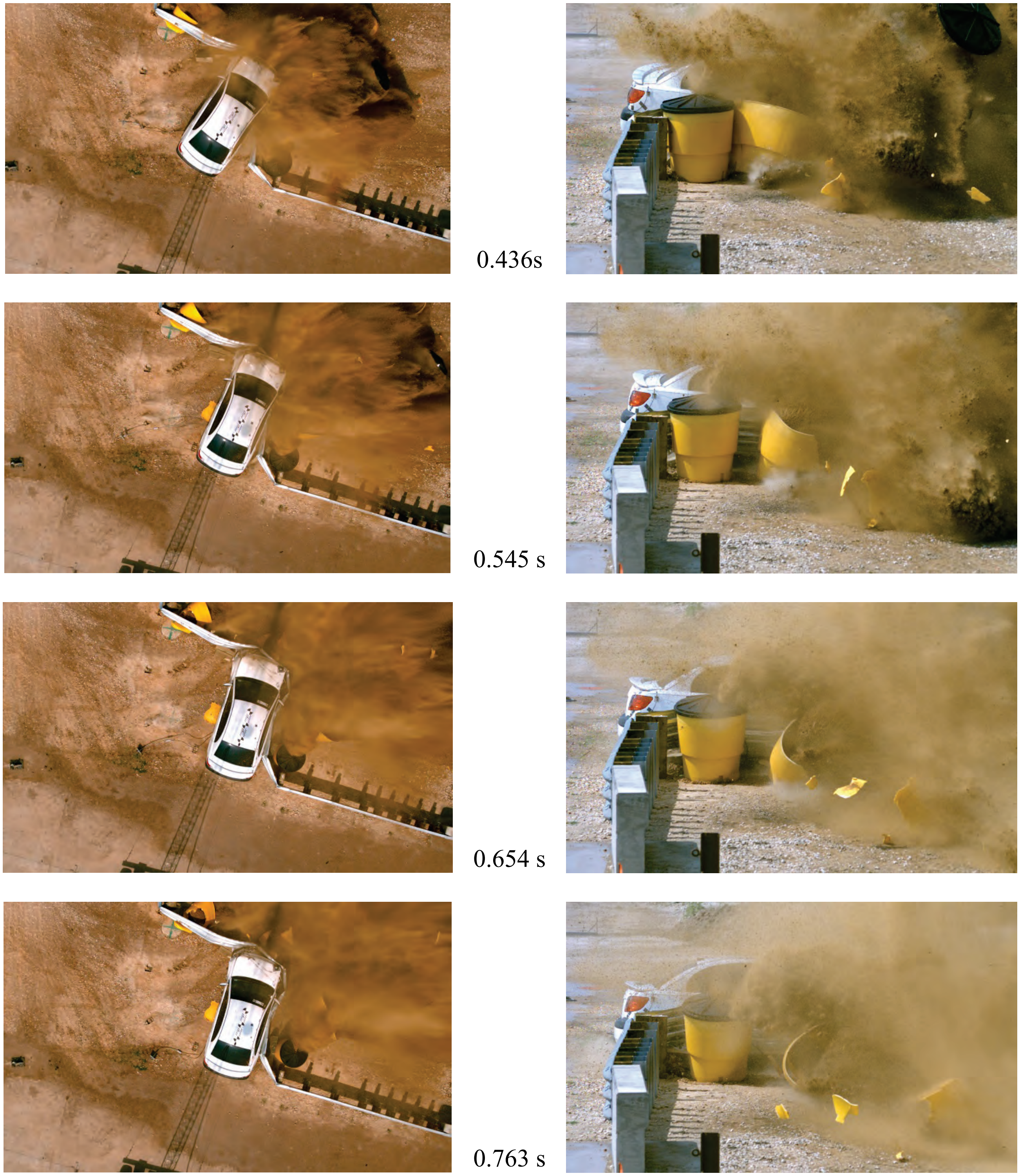
0.000 s

0.109 s

0.218 s

0.327 s

Figure F1. Sequential Photographs for Test No. 467114-4 (Overhead and Frontal Views).



0.436s

0.545 s

0.654 s

0.763 s

Figure F1. Sequential Photographs for Test No. 467114-4
(Overhead and Frontal Views) (Continued).

0.000 s

0.109 s

0.218 s

0.327 s

0.436 s

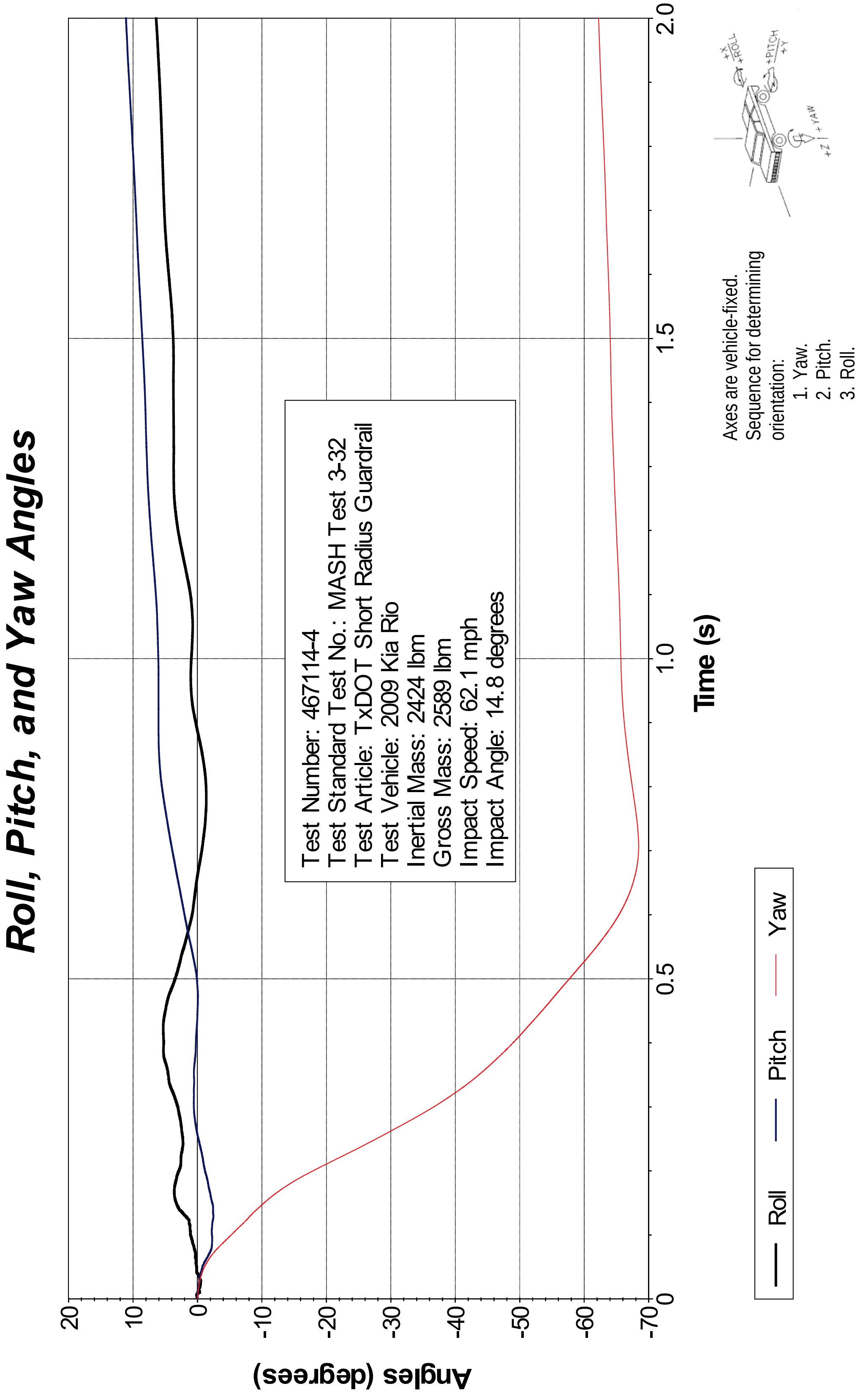
0.545 s

0.654 s

0.763 s

Figure F2. Sequential Photographs for Test No. 467114-4 (Rear View).

F3. VEHICLE ANGULAR DISPLACEMENTS



Test Number: 467114-4
Test Standard Test No.: MASH Test 3-32
Test Article: TxDOT Short Radius Guardrail
Test Vehicle: 2009 Kia Rio
Inertial Mass: 2424 lbm
Gross Mass: 2589 lbm
Impact Speed: 62.1 mph
Impact Angle: 14.8 degrees

Axes are vehicle-fixed.
Sequence for determining orientation:
1. Yaw.
2. Pitch.
3. Roll.

Figure F3. Vehicle Angular Displacements for Test No. 467114-4.

F4. VEHICLE ACCELERATIONS

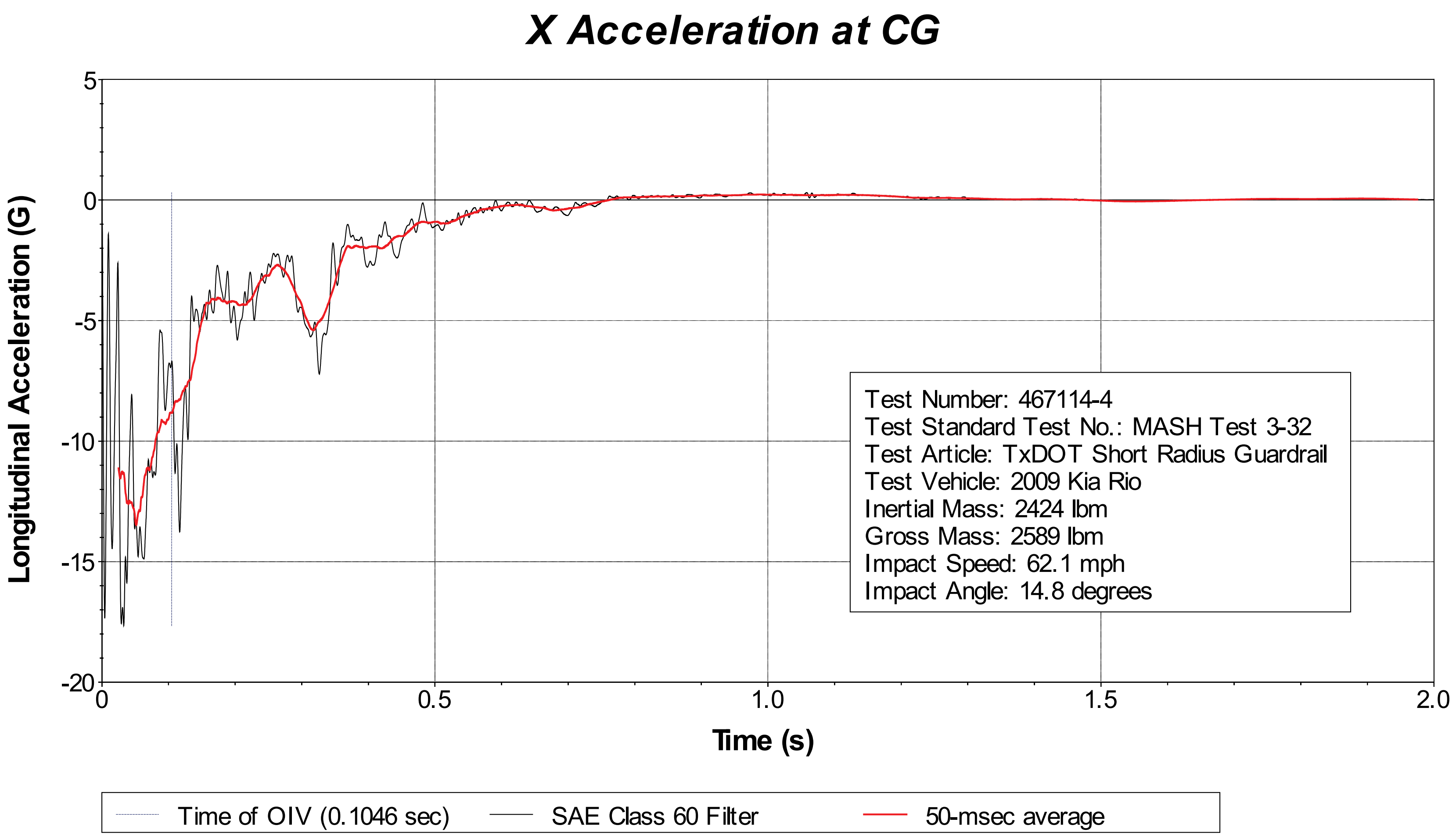


Figure F4. Vehicle Longitudinal Accelerometer Trace for Test No. 467114-4 (Accelerometer Located at Center of Gravity).

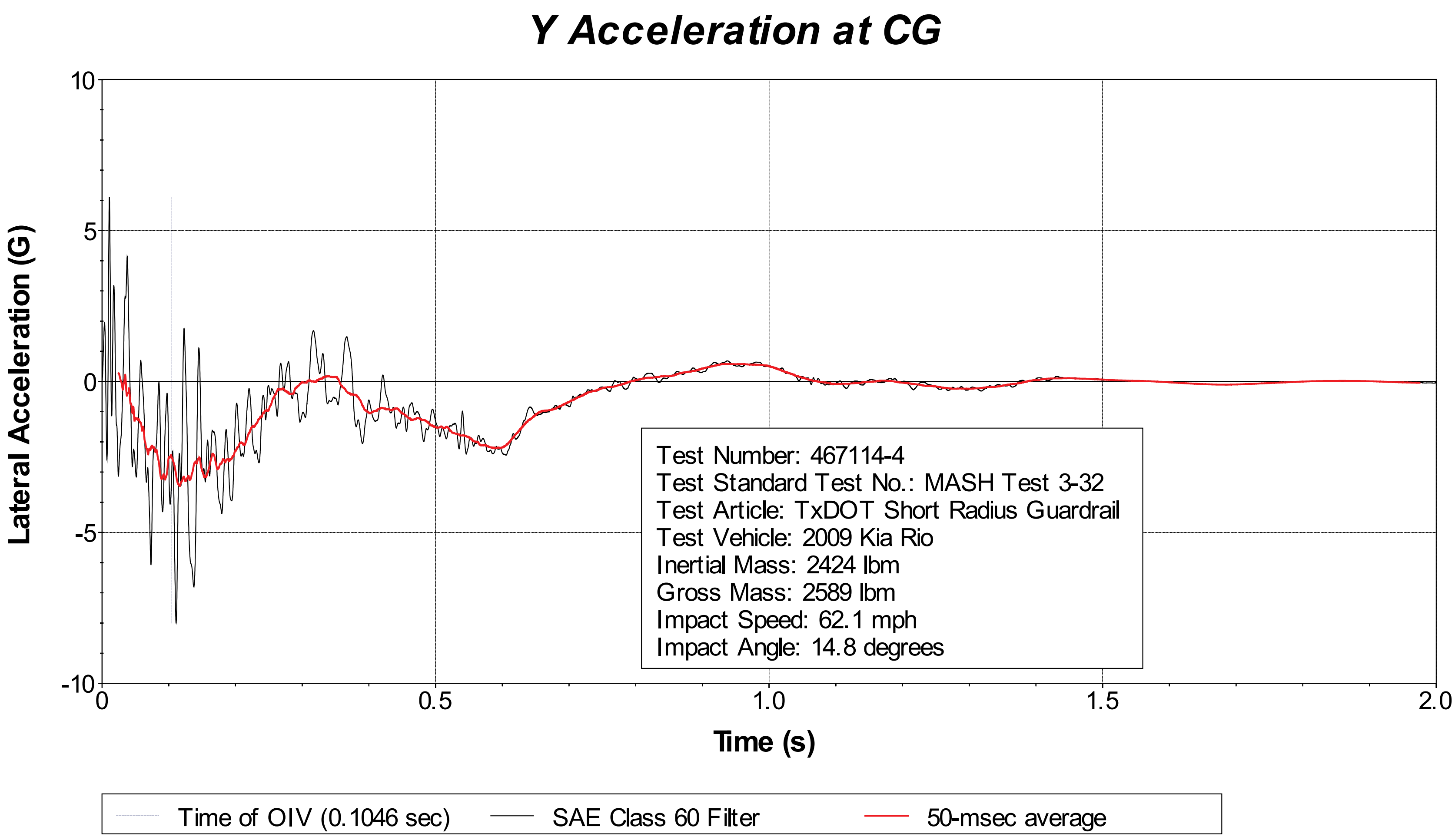


Figure F5. Vehicle Lateral Accelerometer Trace for Test No. 467114-4 (Accelerometer Located at Center of Gravity).

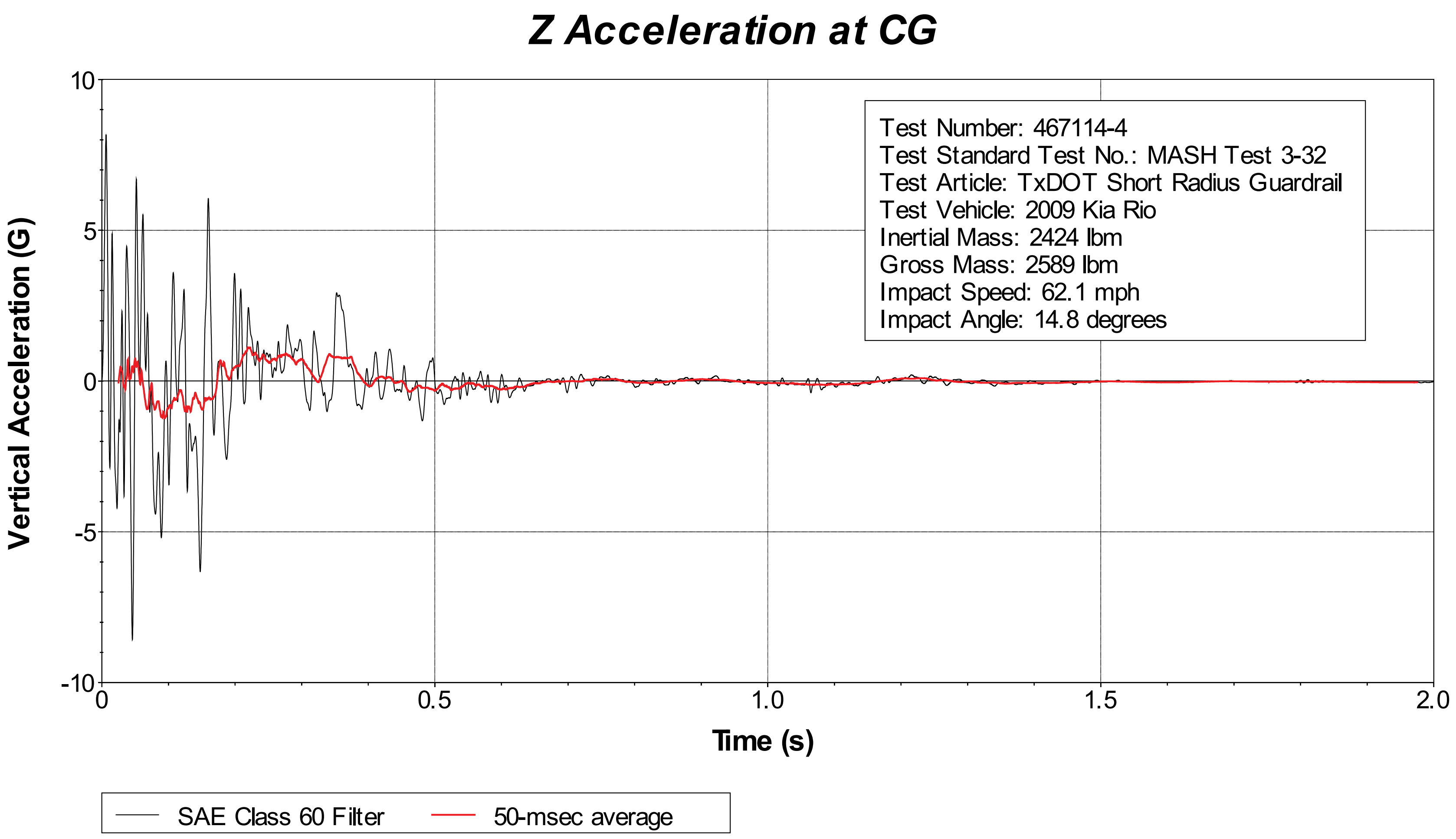


Figure F6. Vehicle Vertical Accelerometer Trace for Test No. 467114-4 (Accelerometer Located at Center of Gravity).

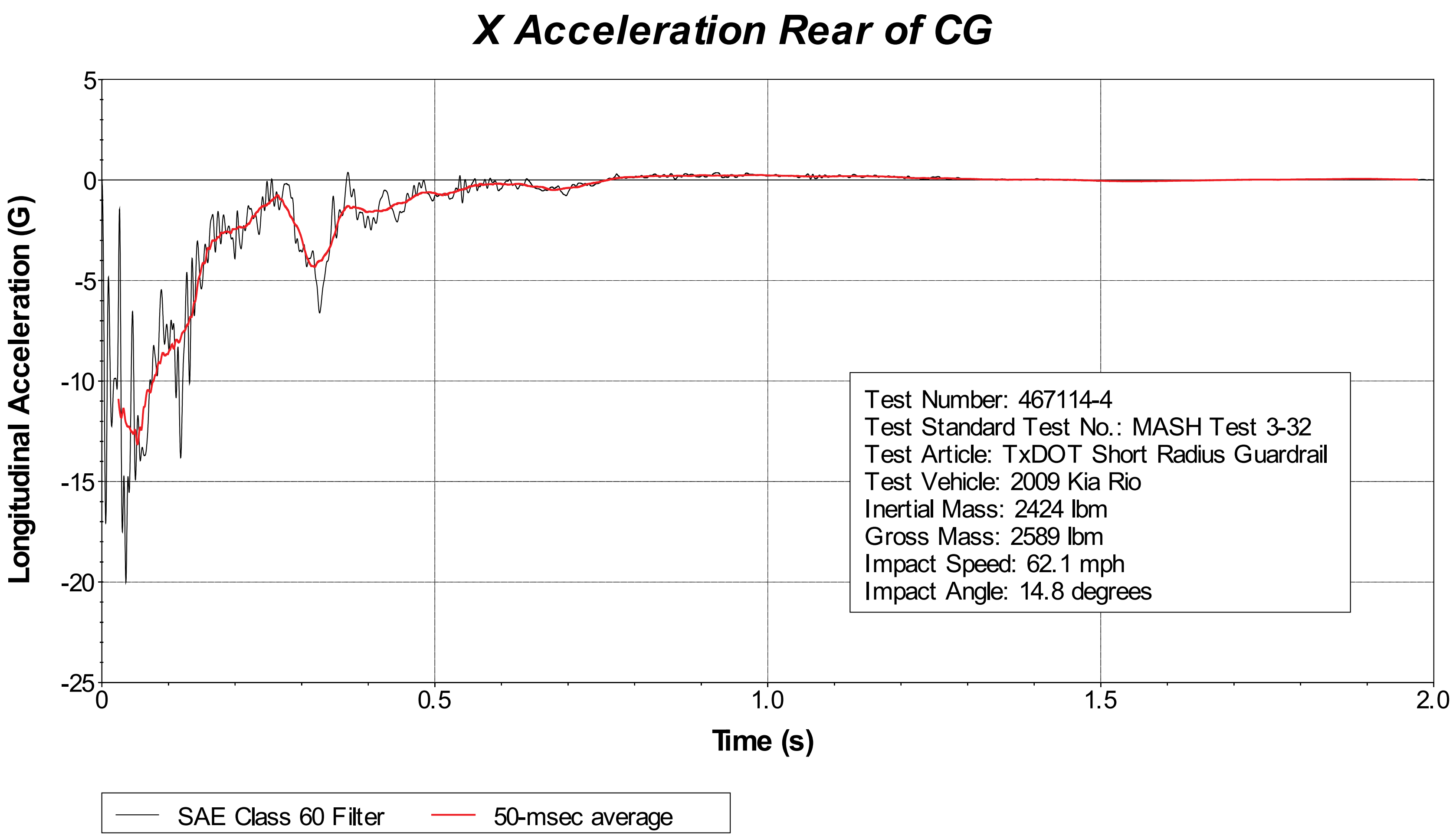


Figure F7. Vehicle Longitudinal Accelerometer Trace for Test No. 467114-4 (Accelerometer Located Rear of Center of Gravity).

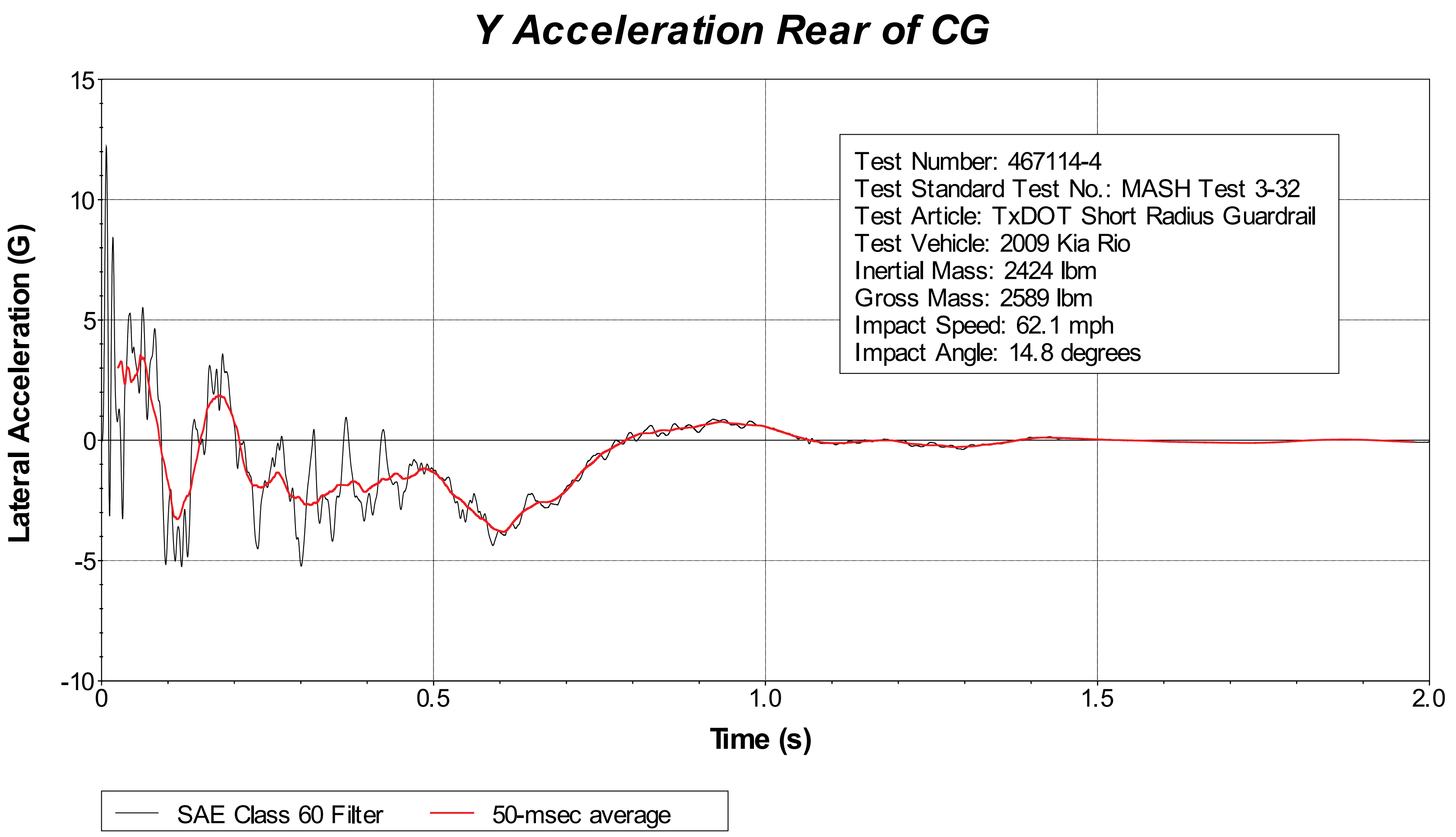


Figure F8. Vehicle Lateral Accelerometer Trace for Test No. 467114-4 (Accelerometer Located Rear of Center of Gravity).

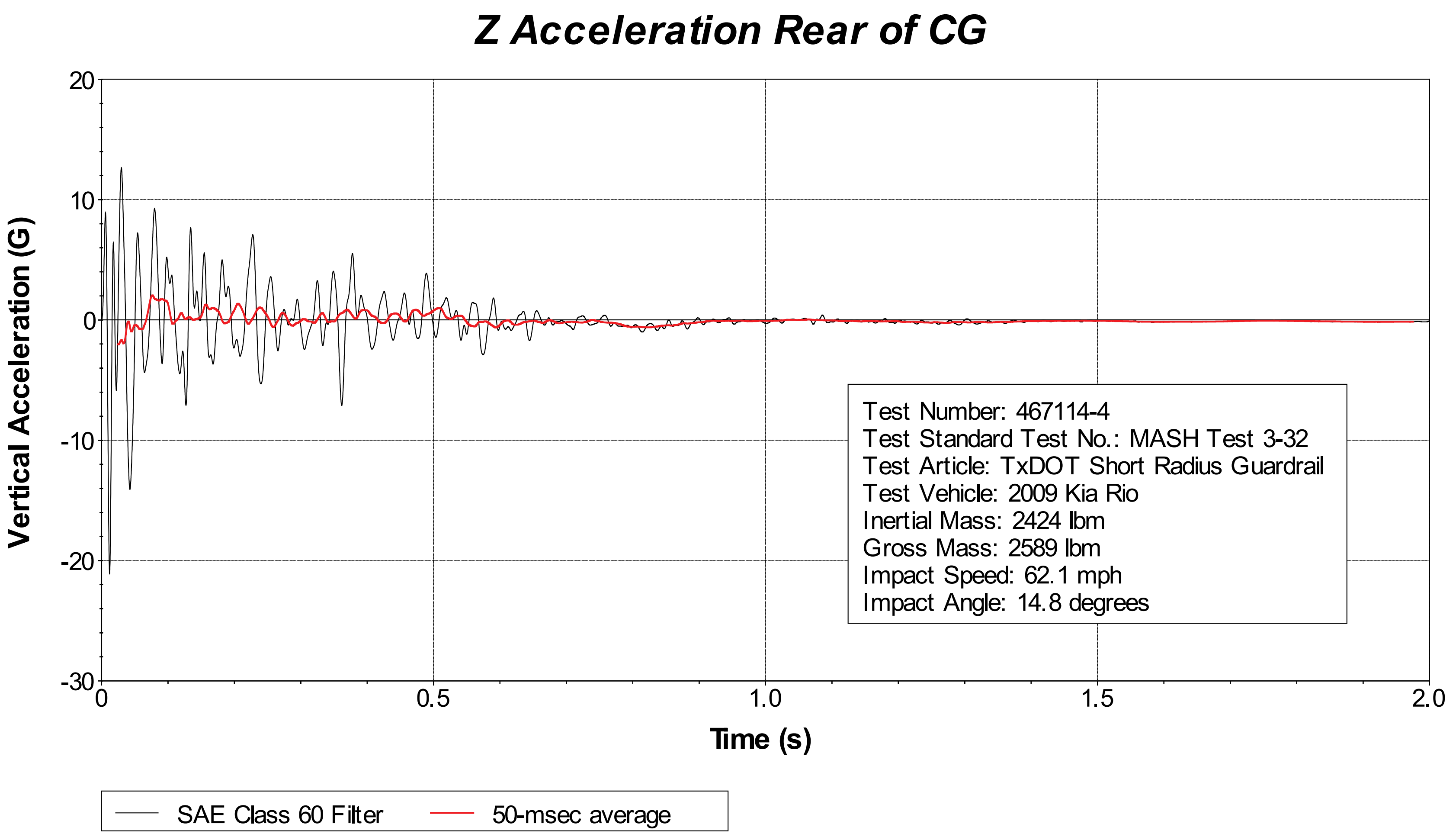


Figure F9. Vehicle Vertical Accelerometer Trace for Test No. 467114-4 (Accelerometer Located Rear of Center of Gravity).

APPENDIX G. INFORMATION FOR CRASH TEST NO. 467114-5

G1. TEST VEHICLE MEASUREMENTS AND INFORMATION

Table G1. Vehicle Properties for Test No. 467114-5.

Date: 2014-07-29 Test No.: 467114-5 VIN No.: 1D7HA18N78S232225

Year: 2008 Make: Dodge Model: Ram 1500 Quad Cab

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

Tread Type: Highway Odometer: 157860

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

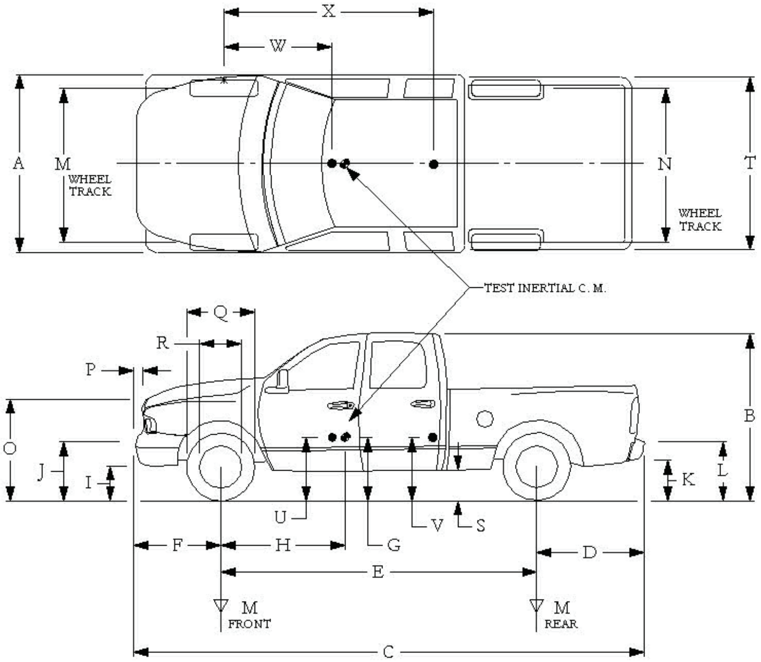
NOTES: None

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: No dummy
Mass: NA
Seat Position: NA



Geometry: inches

A	78.25	F	36.00	K	20.50	P	2.88	U	28.50
B	75.00	G	28.94	L	29.00	Q	30.50	V	30.50
C	223.75	H	62.63	M	68.50	R	16.00	W	62.60
D	47.25	I	16.00	N	68.00	S	15.25	X	77.00
E	140.50	J	27.00	O	46.50	T	77.50		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	18.75
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	11.00	Bottom Frame Height - Rear	26.00

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2834	2784	2784
Back	3900	M_{rear}	1999	2239	2239
Total	6700	M_{Total}	4833	5023	5023

Mass Distribution:
lb LF: 1428 RF: 1356 LR: 1139 RR: 1100

Table G2. Vehicle Parametric Measurements for Vertical CG for Test No. 467114-5.

Date: 2014-07-29 Test No.: 467114-5 VIN: 1D7HA18N78S232225

Year: 2008 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 157860

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 304 lb (440 lb max)

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

Measured Vehicle Weights: (lb)						
LF:	1428	RF:	1356	Front Axle:	2784	
LR:	1139	RR:	1100	Rear Axle:	2239	
Left:	2567	Right:	2456	Total:	5023	
					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:	62.63 in	Rear of Front Axle	(63 ±4 inches allowed)			
Y:	-0.76 in	Left - Right +	of Vehicle Centerline			
Z:	28.9375 in	Above Ground	(minumum 28.0 inches allowed)			

Hood Height: 46.50 inches

43 ±4 inches allowed

Front Bumper Height: 27.00 inches

Front Overhang: 36.00 inches

39 ±3 inches allowed

Rear Bumper Height: 29.00 inches

Overall Length: 223.75 inches

237 ±13 inches allowed

Table G3. Exterior Crush Measurements for Test No. 467114-5.

Date: 2014-07-29 Test No.: 467114-5 VIN No.: 1D7HA18N78S232225

Year: 2008 Make: Dodge Model: Ram 1500 Quad Cab

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	20.0	7.0	30	7	2	1	0.5	0.5	0	-15
2	Side plane at bumper ht	20.0	9.0	56	3.5	-----	-----	-----	7	9	+72
	Measurements recorded										
	in inches										

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

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

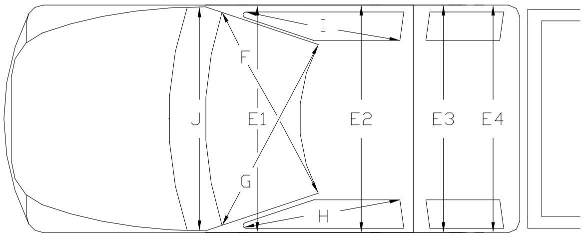
***Measure and document on the vehicle diagram the location of the maximum crush.

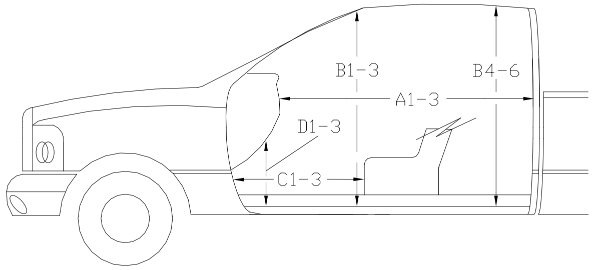
Note: Use as many lines/columns as necessary to describe each damage profile.

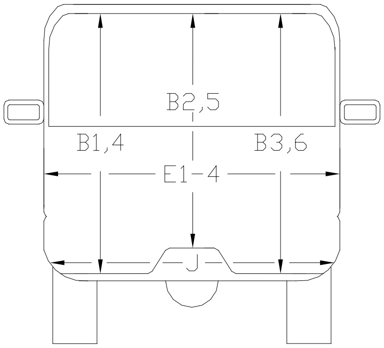
Table G4. Occupant Compartment Measurements for Test No. 467114-5.

Date: 2014-07-29 Test No.: 467114-5 VIN No.: 1D7HA18N78S232225

Year: 2008 Make: Dodge Model: Ram 1500 Quad Cab





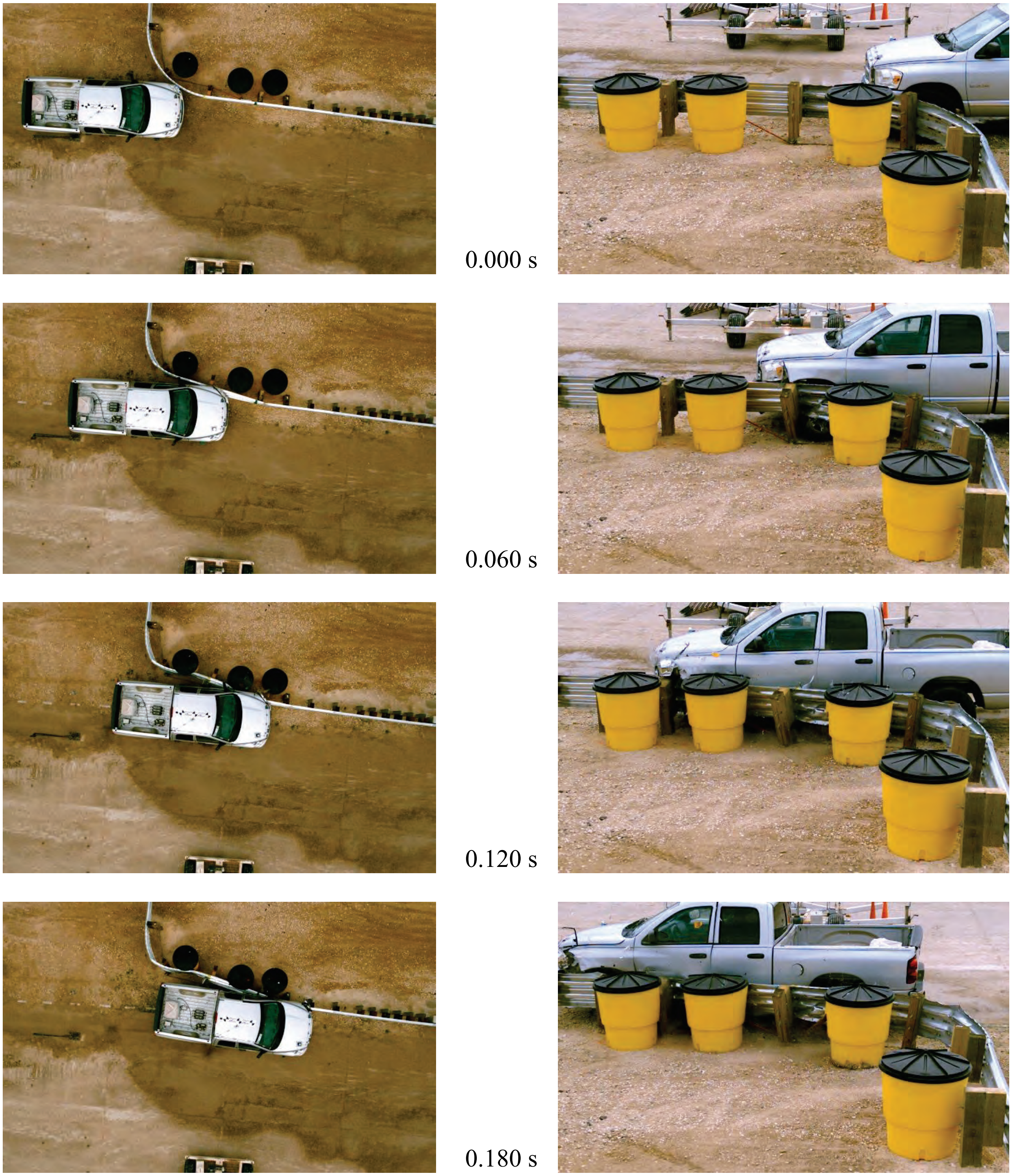


OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	65.00	65.00
A2	64.75	64.75
A3	65.25	65.25
B1	45.00	45.00
B2	39.00	39.00
B3	45.00	45.00
B4	42.25	42.25
B5	45.00	45.00
B6	42.25	42.25
C1	29.00	29.00
C2	-----	-----
C3	26.75	26.75
D1	12.75	12.75
D2	-----	-----
D3	11.50	11.50
E1	62.75	62.50
E2	64.75	65.00
E3	64.00	64.25
E4	64.50	64.50
F	60.00	60.00
G	60.00	60.00
H	39.00	39.00
I	39.00	39.00
J*	62.25	61.75

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

G2. SEQUENTIAL PHOTOGRAPHS



0.000 s

0.060 s

0.120 s

0.180 s

Figure G1. Sequential Photographs for Test No. 467114-5 (Overhead and Rear Views).

0.240s

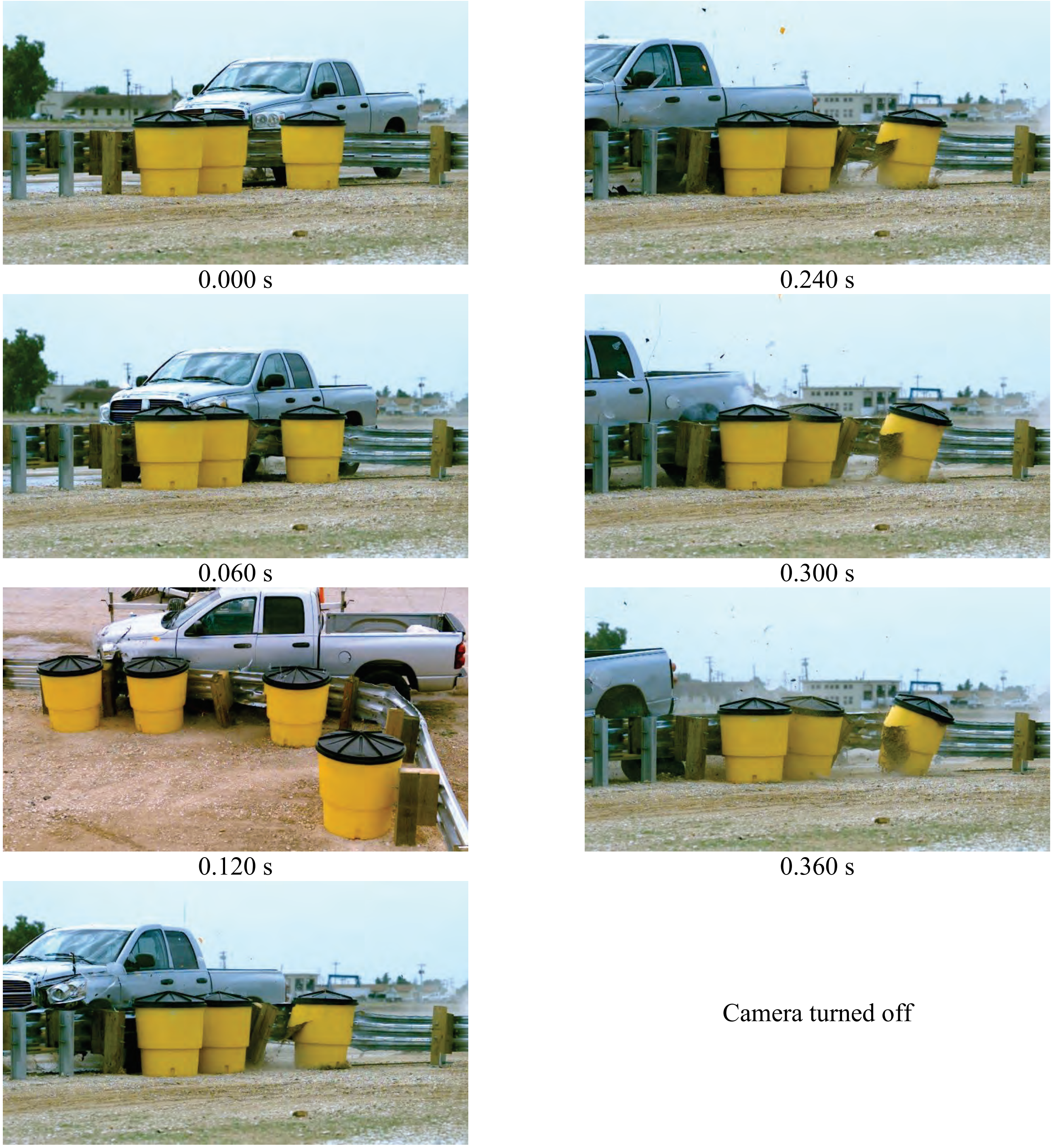
0.300 s

0.360 s

0.420 s

Camera turned off

Figure G1. Sequential Photographs for Test No. 467114-5 (Overhead and Rear Views) (Continued).



0.000 s

0.060 s

0.120 s

0.180 s

0.240 s

0.300 s

0.360 s

Camera turned off

0.763 s

Figure G2. Sequential Photographs for Test No. 467114-5 (Rear View).

G3. VEHICLE ANGULAR DISPLACEMENTS

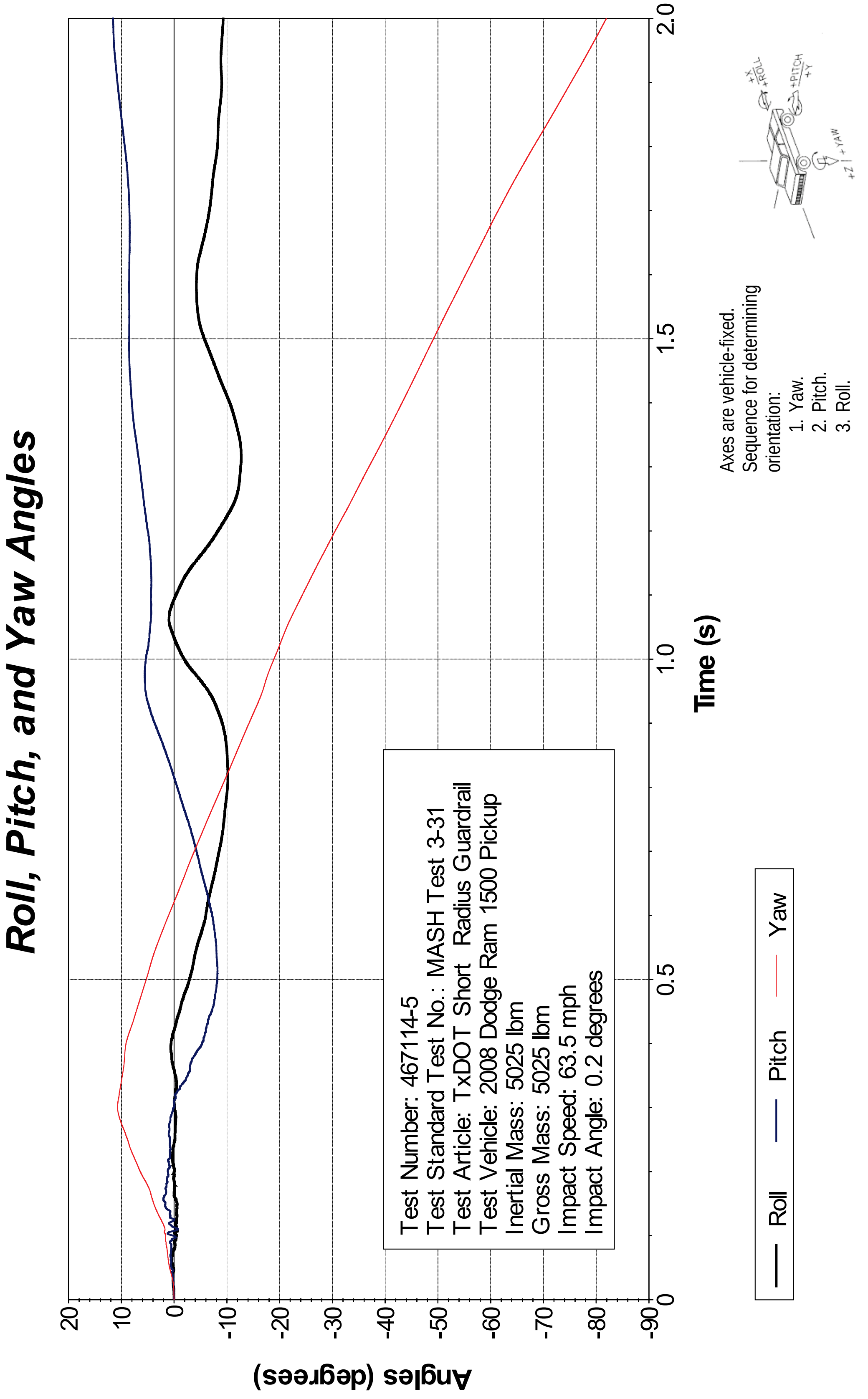


Figure G3. Vehicle Angular Displacements for Test No. 467114-5.

G4. VEHICLE ACCELERATIONS

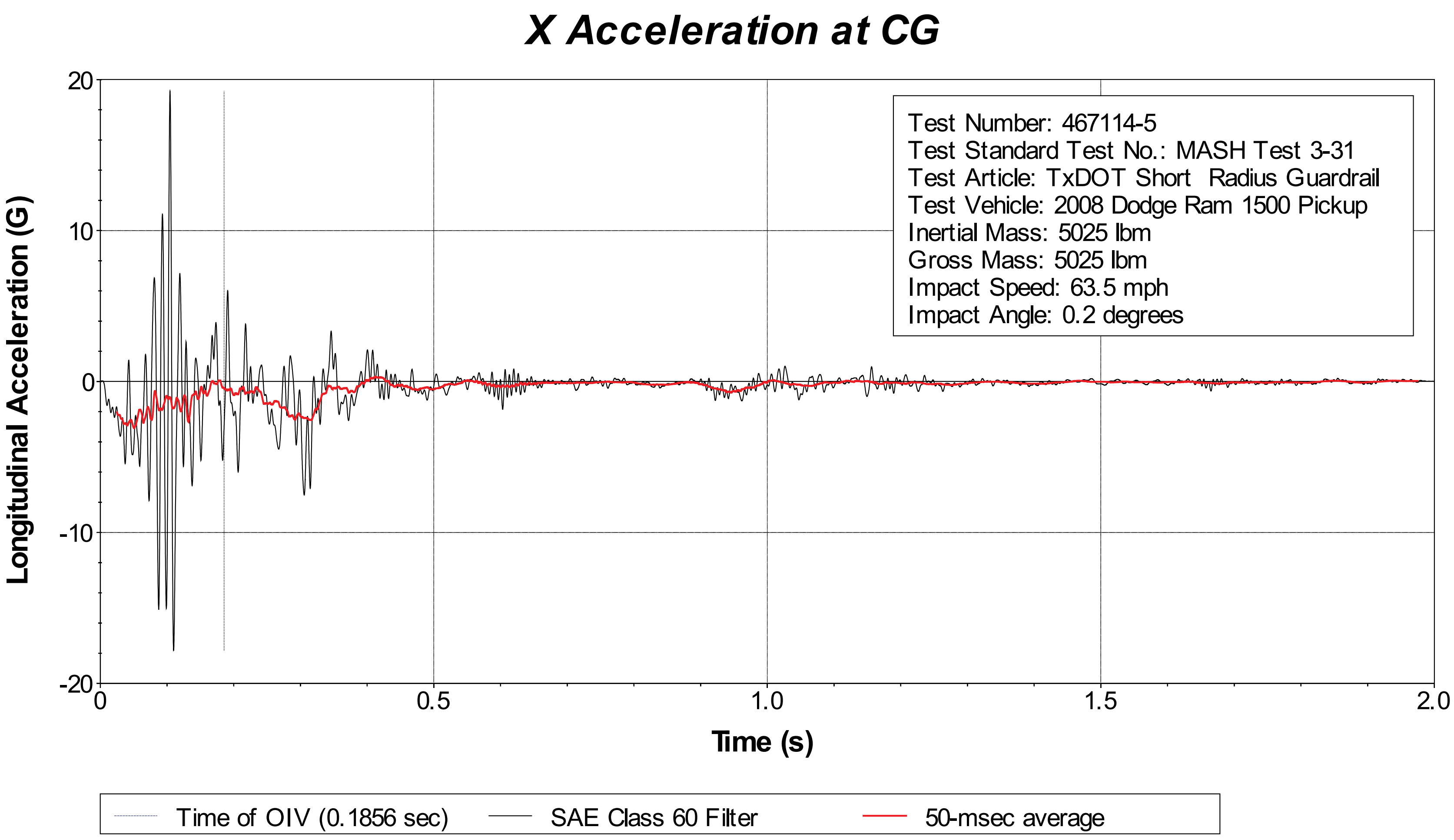


Figure G4. Vehicle Longitudinal Accelerometer Trace for Test No. 467114-5 (Accelerometer Located at Center of Gravity).

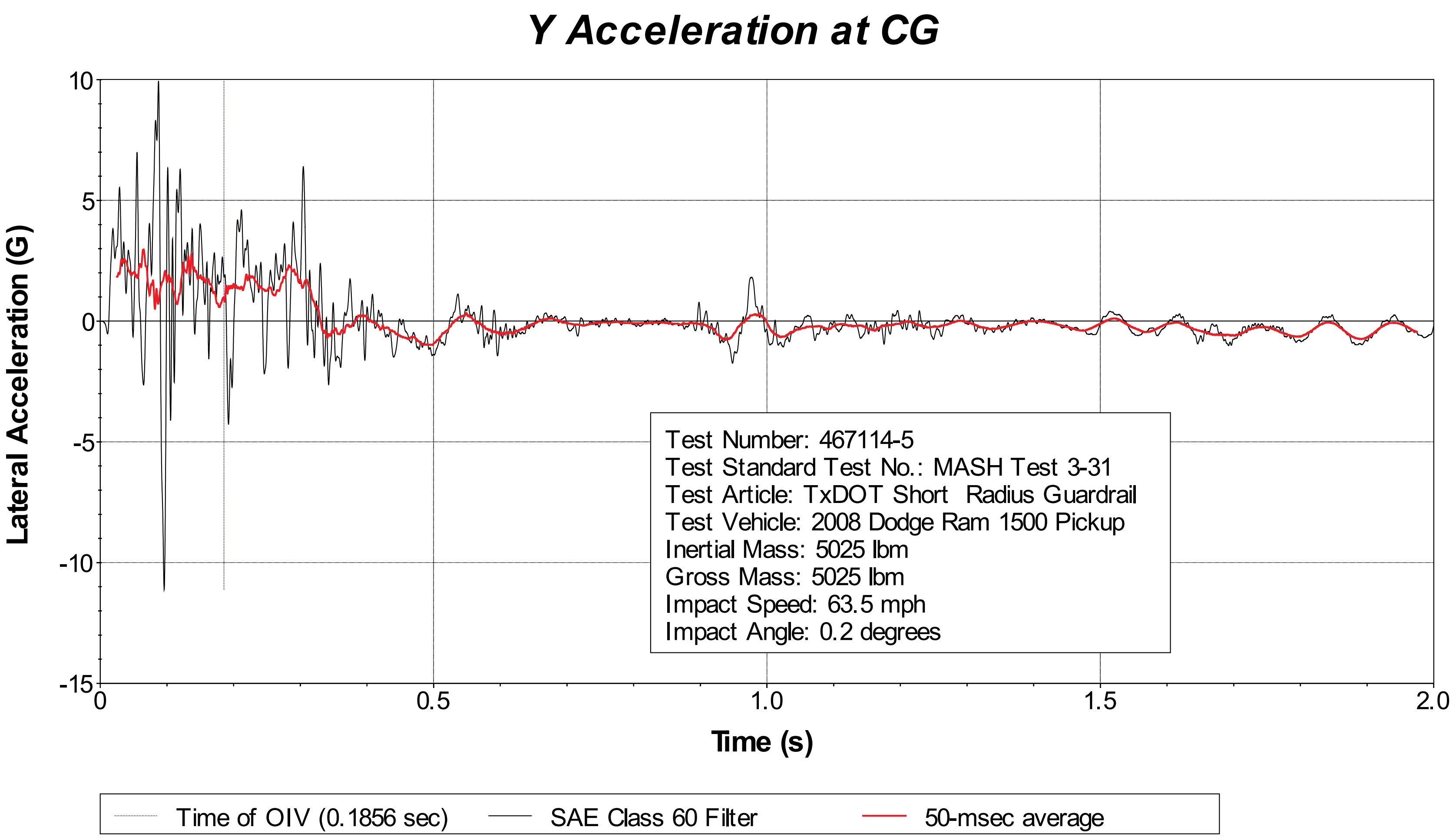


Figure G5. Vehicle Lateral Accelerometer Trace for Test No. 467114-5 (Accelerometer Located at Center of Gravity).

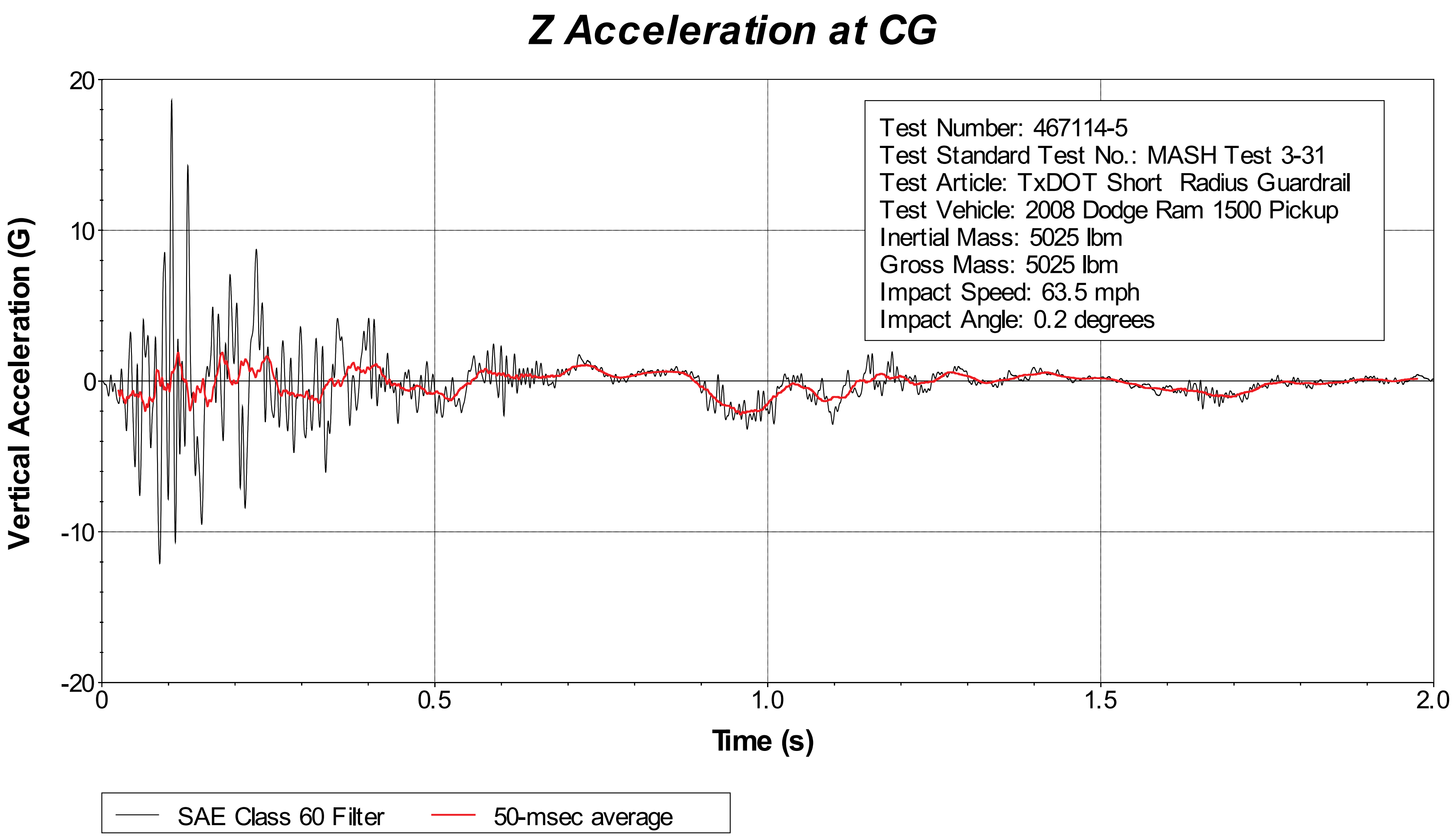


Figure G6. Vehicle Vertical Accelerometer Trace for Test No. 467114-5 (Accelerometer Located at Center of Gravity).

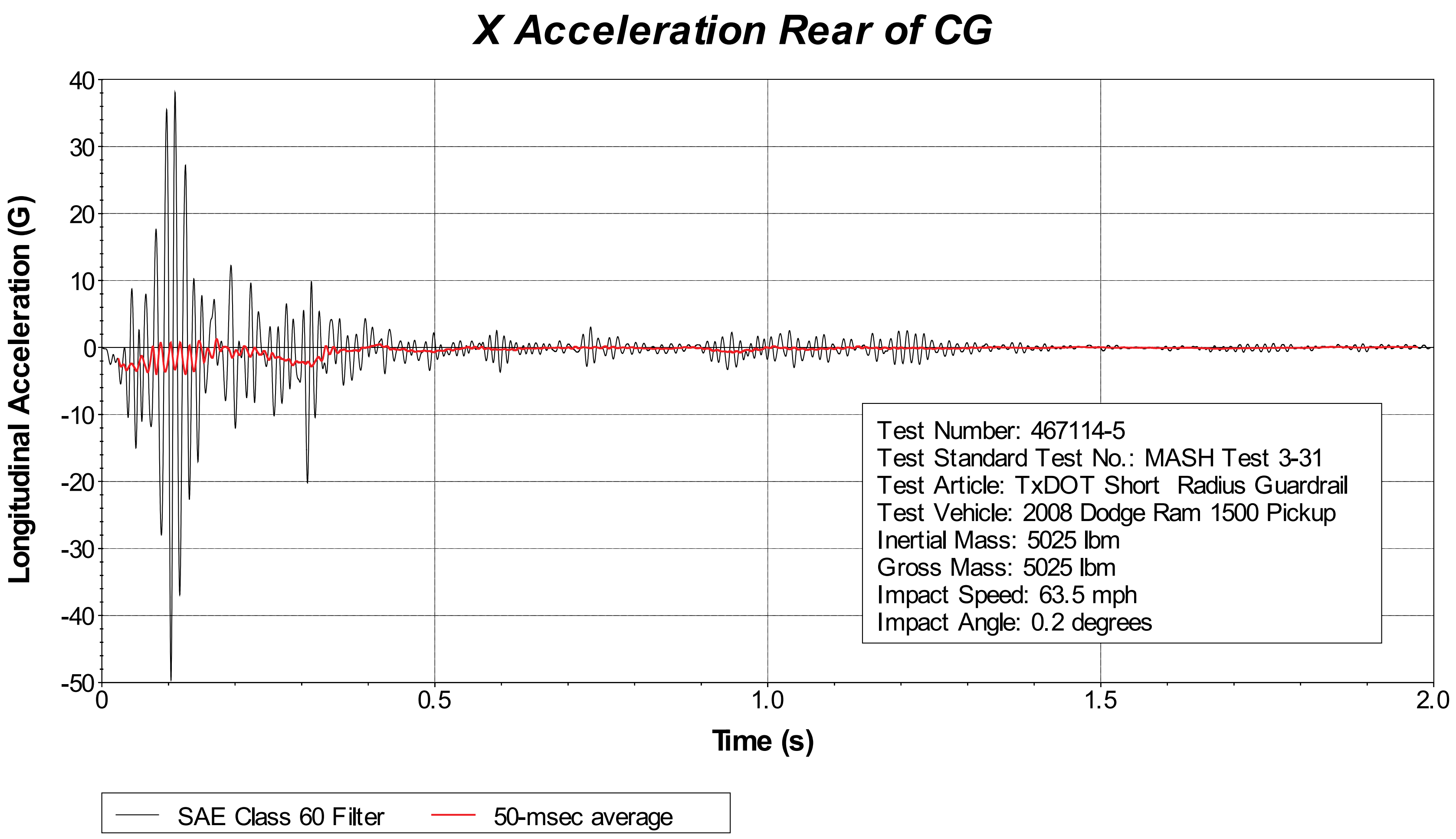


Figure G7. Vehicle Longitudinal Accelerometer Trace for Test No. 467114-5 (Accelerometer Located Rear of Center of Gravity).

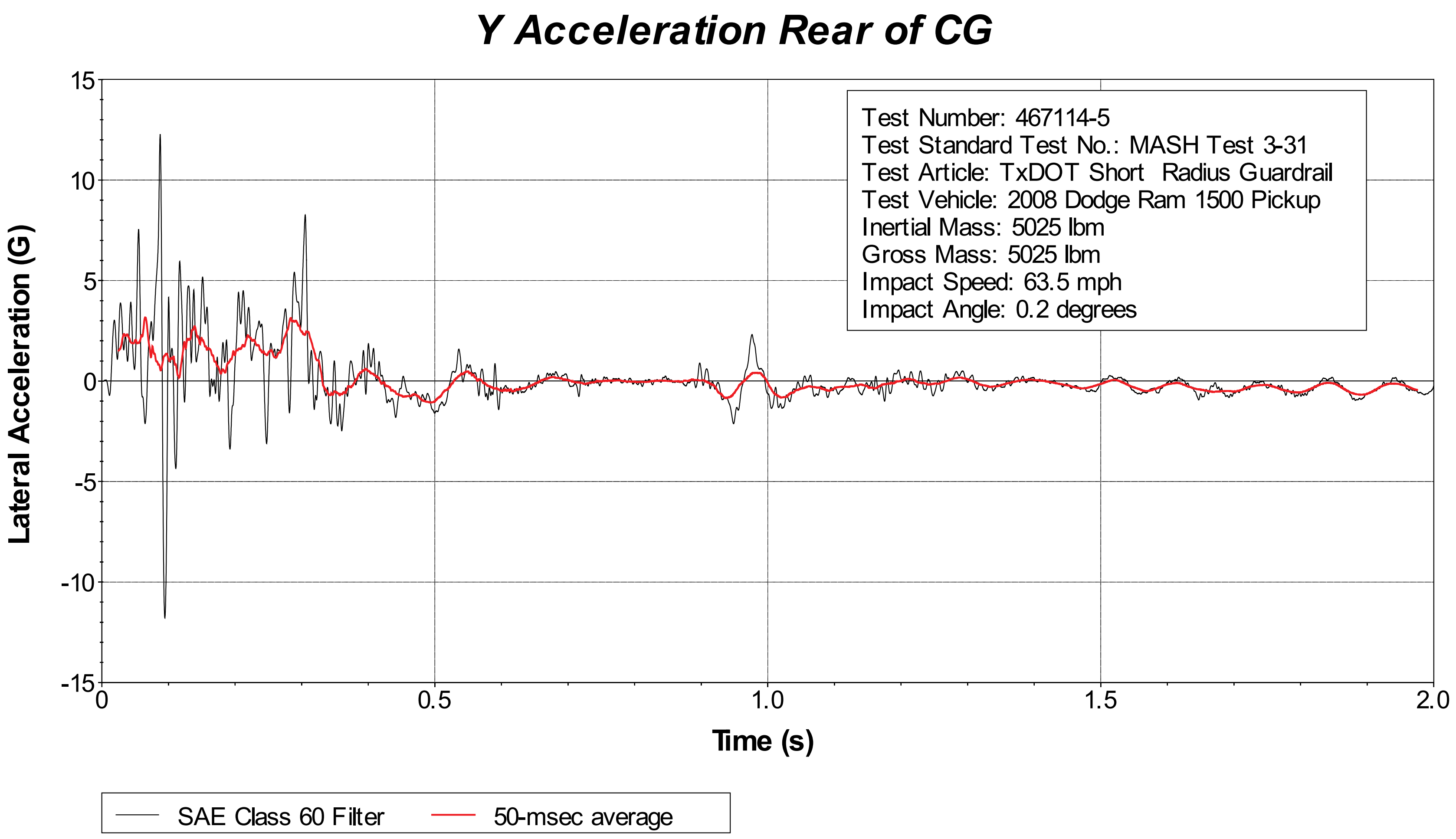


Figure G8. Vehicle Lateral Accelerometer Trace for Test No. 467114-5 (Accelerometer Located Rear of Center of Gravity).

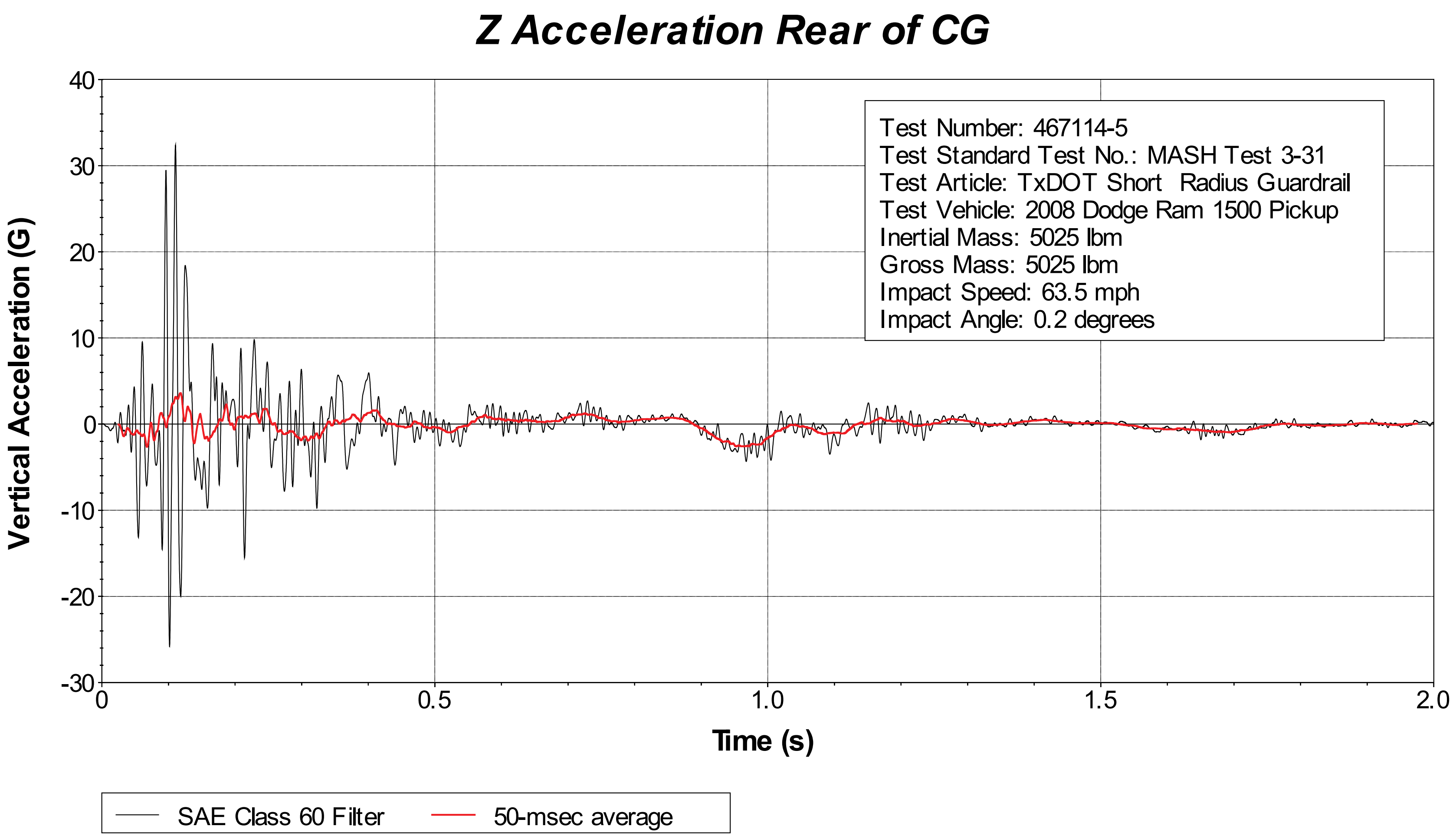


Figure G9. Vehicle Vertical Accelerometer Trace for Test No. 467114-5
(Accelerometer Located Rear of Center of Gravity).

APPENDIX H. INFORMATION FOR CRASH TEST NO. 467114-6

H1. TEST VEHICLE MEASUREMENTS AND INFORMATION

Table H1. Vehicle Properties for Test No. 467114-6.

Date: 2014-08-06 Test No.: 467114-6 VIN No.: 1D7HA18288S468451

Year: 2008 Make: Dodge Model: Ram 1500 Quad Cab

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

Tread Type: Highway Odometer: 154771

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

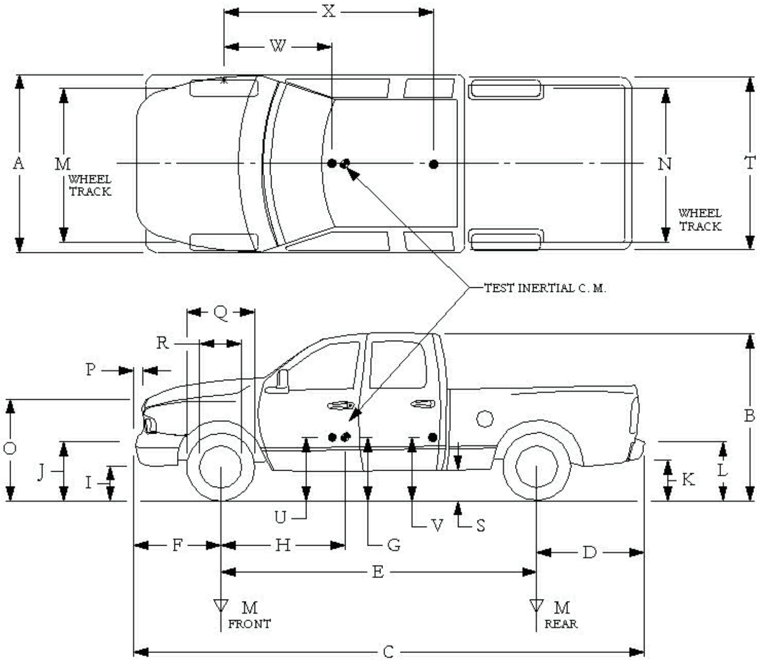
NOTES: None

Engine Type: V-8
Engine CID: 5.7 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	78.25	F	36.00	K	21.25	P	2.88	U	28.50
B	75.00	G	28.88	L	29.75	Q	30.50	V	30.50
C	223.75	H	61.34	M	68.50	R	16.00	W	61.30
D	47.25	I	15.50	N	68.00	S	16.00	X	76.25
E	140.50	J	27.00	O	45.50	T	77.50		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	18.00
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	11.00	Bottom Frame Height - Rear	25.50

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2882	2826	2826
Back	3900	M_{rear}	2053	2190	2190
Total	6700	M_{Total}	4935	5016	5016

Mass Distribution:
lb LF: 1428 RF: 1398 LR: 1103 RR: 1087

Table H2. Vehicle Parametric Measurements for Vertical CG for Test No. 467114-6.

Date: 2014-08-06 Test No.: 467114-6 VIN: 1D7HA18288S468451

Year: 2008 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 154771

Engine: 5.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 175 lb (440 lb max)

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

Measured Vehicle Weights: (lb)						
LF:	1428	RF:	1398	Front Axle:	2826	
LR:	1103	RR:	1087	Rear Axle:	2190	
Left:	2531	Right:	2485	Total:	5016	
					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:	61.34 inches	Rear of Front Axle	(63 ±4 inches allowed)			
Y:	-0.31 inches	Left - Right +	of Vehicle Centerline			
Z:	28.875 inches	Above Ground	(minumum 28.0 inches allowed)			

Hood Height: 45.50 inches
43 ±4 inches allowed

Front Bumper Height: 27.00 inches

Front Overhang: 36.00 inches
39 ±3 inches allowed

Rear Bumper Height: 29.75 inches

Overall Length: 223.75 inches
237 ±13 inches allowed

Table H3. Exterior Crush Measurements for Test No. 467114-6.

Date: 2014-08-06 Test No.: 467114-6 VIN No.: 1D7HA18288S468451

Year: 2008 Make: Dodge Model: Ram 1500 Quad Cab

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	-----	24	-----	-----	-----	-----	-----	-----	-----	-----
2	Side plane at bumper ht	-----	17	-----	-----	-----	-----	-----	-----	-----	-----
	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).

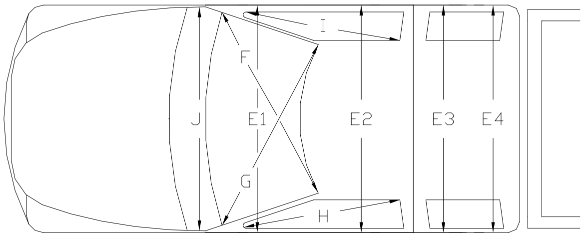
***Measure and document on the vehicle diagram the location of the maximum crush.

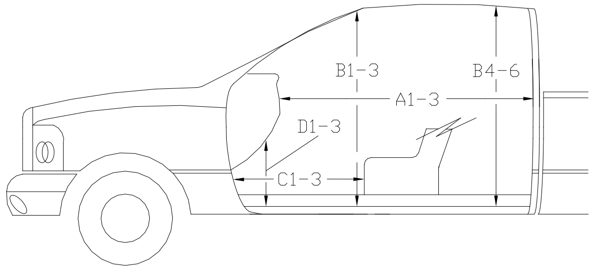
Note: Use as many lines/columns as necessary to describe each damage profile.

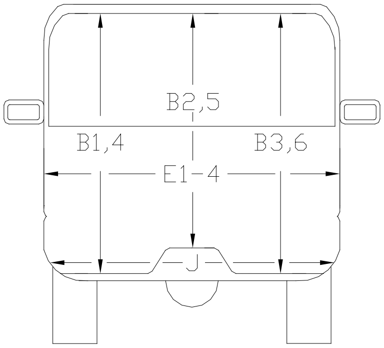
Table H4. Occupant Compartment Measurements for Test No. 467114-6.

Date: 2014-08-06 Test No.: 467114-6 VIN No.: 1D7HA18288S468451

Year: 2008 Make: Dodge Model: Ram 1500 Quad Cab





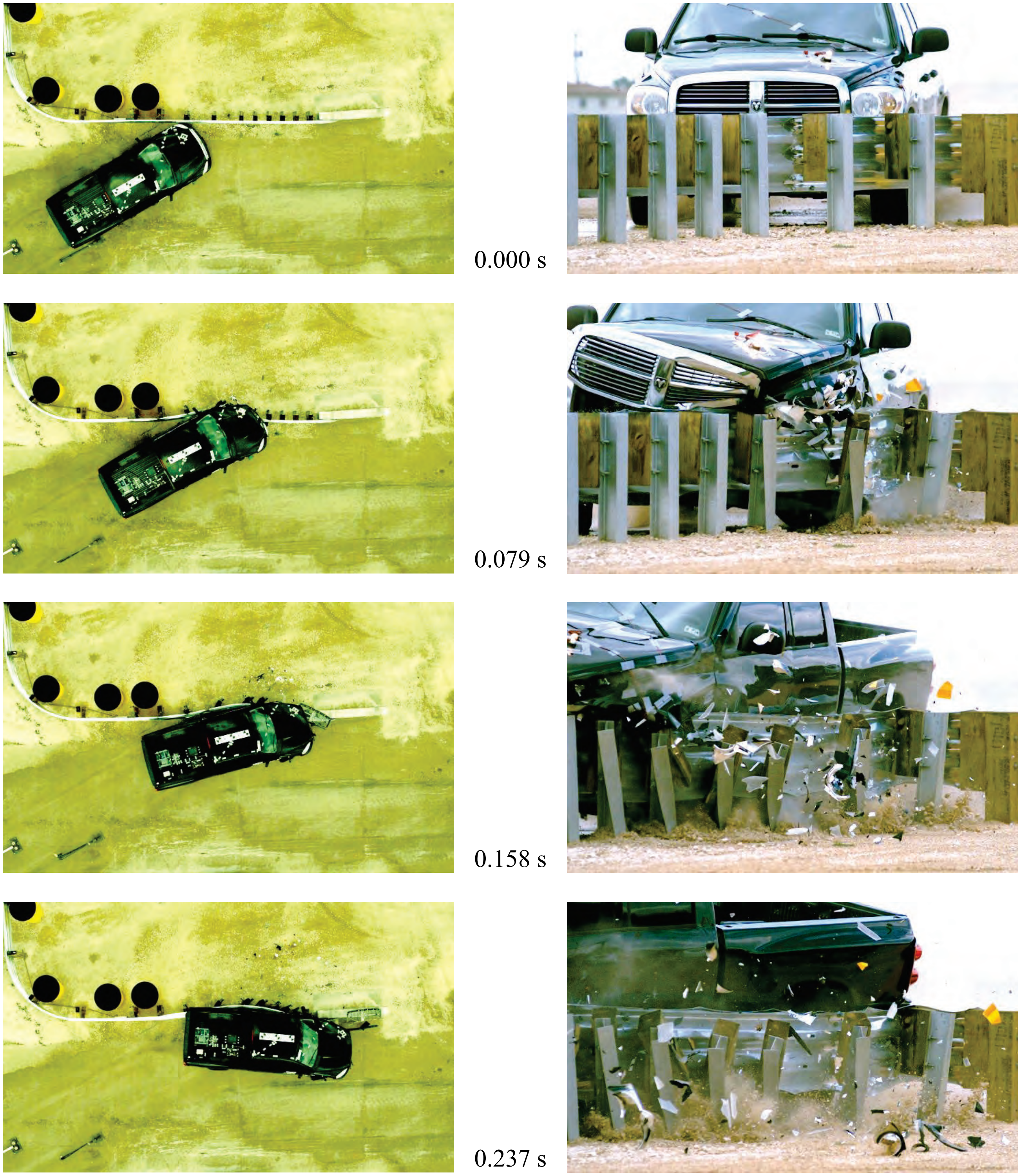


*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	65.00	64.25
A2	65.00	64.50
A3	65.25	63.50
B1	45.50	49.00
B2	39.00	42.00
B3	45.50	38.00
B4	42.00	32.50
B5	44.75	45.50
B6	42.00	42.50
C1	28.75	-----
C2	-----	-----
C3	26.50	-----
D1	12.75	12.00
D2	-----	-----
D3	11.75	11.50
E1	62.75	61.50
E2	64.50	65.50
E3	64.00	NA
E4	64.25	NA
F	60.00	NA
G	60.00	NA
H	39.00	NA
I	39.00	NA
J*	62.25	59.00

H2. SEQUENTIAL PHOTOGRAPHS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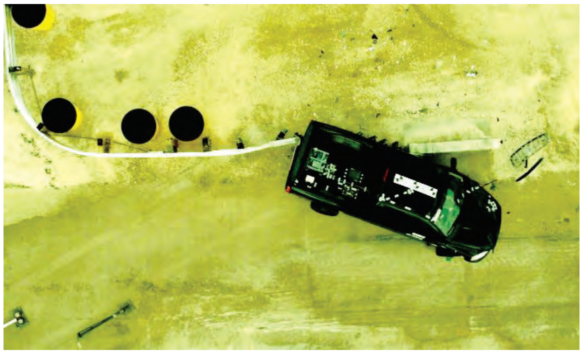
0.079 s

0.158 s

0.237 s

Figure H1. Sequential Photographs for Test No. 467114-6 (Overhead and Rear Views).



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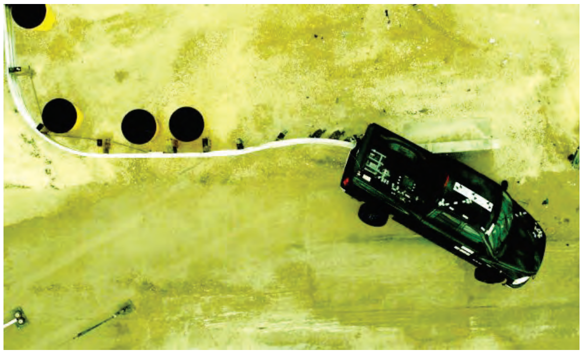

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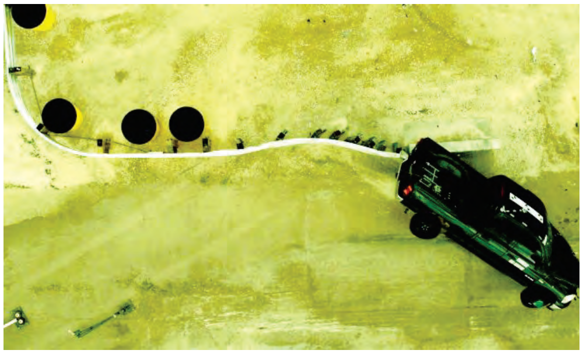

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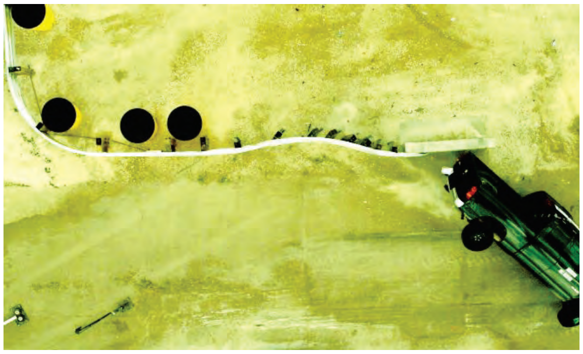
Out of View



0.553 s

Out of View

Figure H1. Sequential Photographs for Test No. 467114-6
(Overhead and Rear Views) (Continued).

H3. VEHICLE ANGULAR DISPLACEMENTS

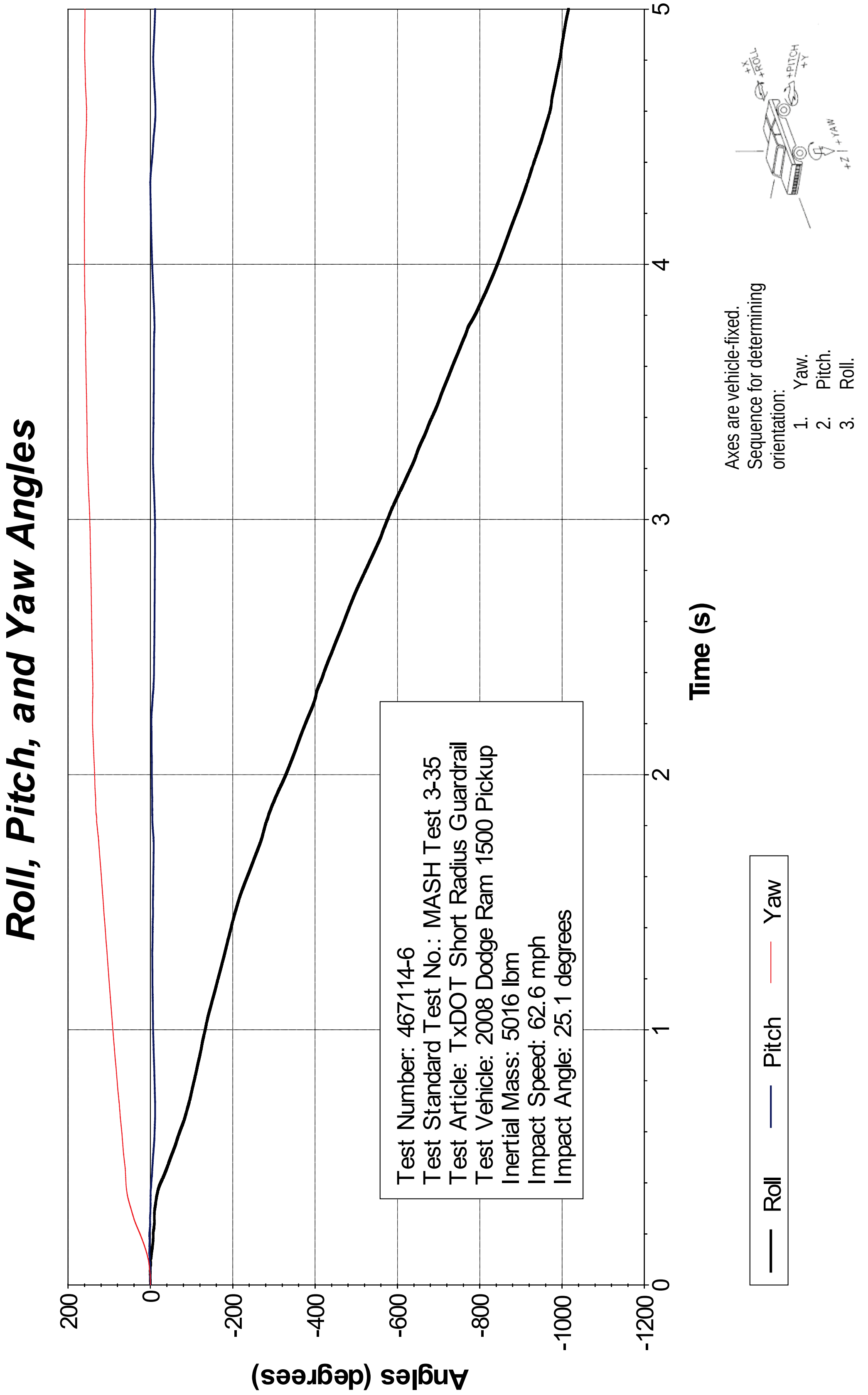


Figure H2. Vehicle Angular Displacements for Test No. 467114-6.

H4. VEHICLE ACCELERATIONS

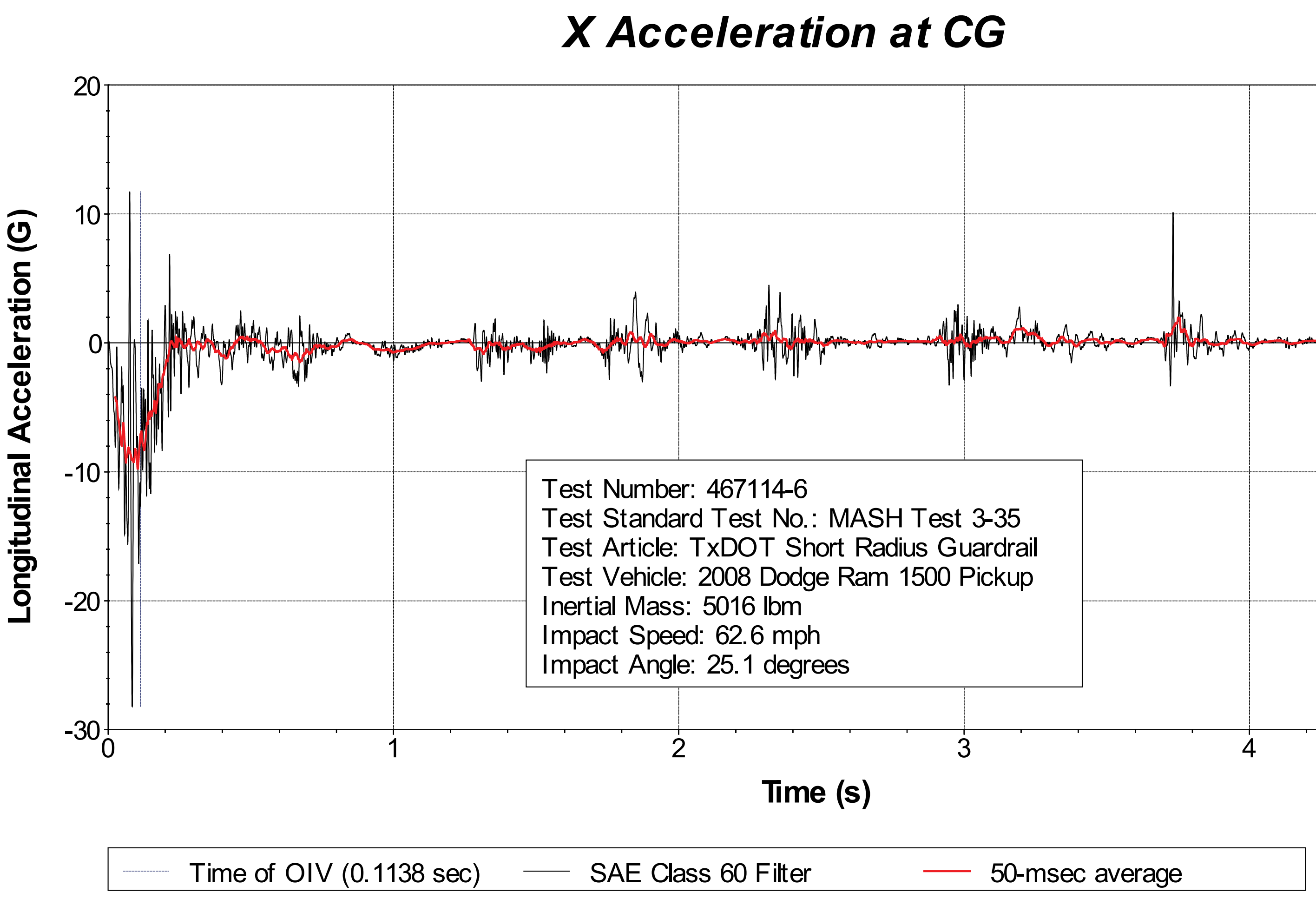


Figure H3. Vehicle Longitudinal Accelerometer Trace for Test No. 467114-6 (Accelerometer Located at Center of Gravity).

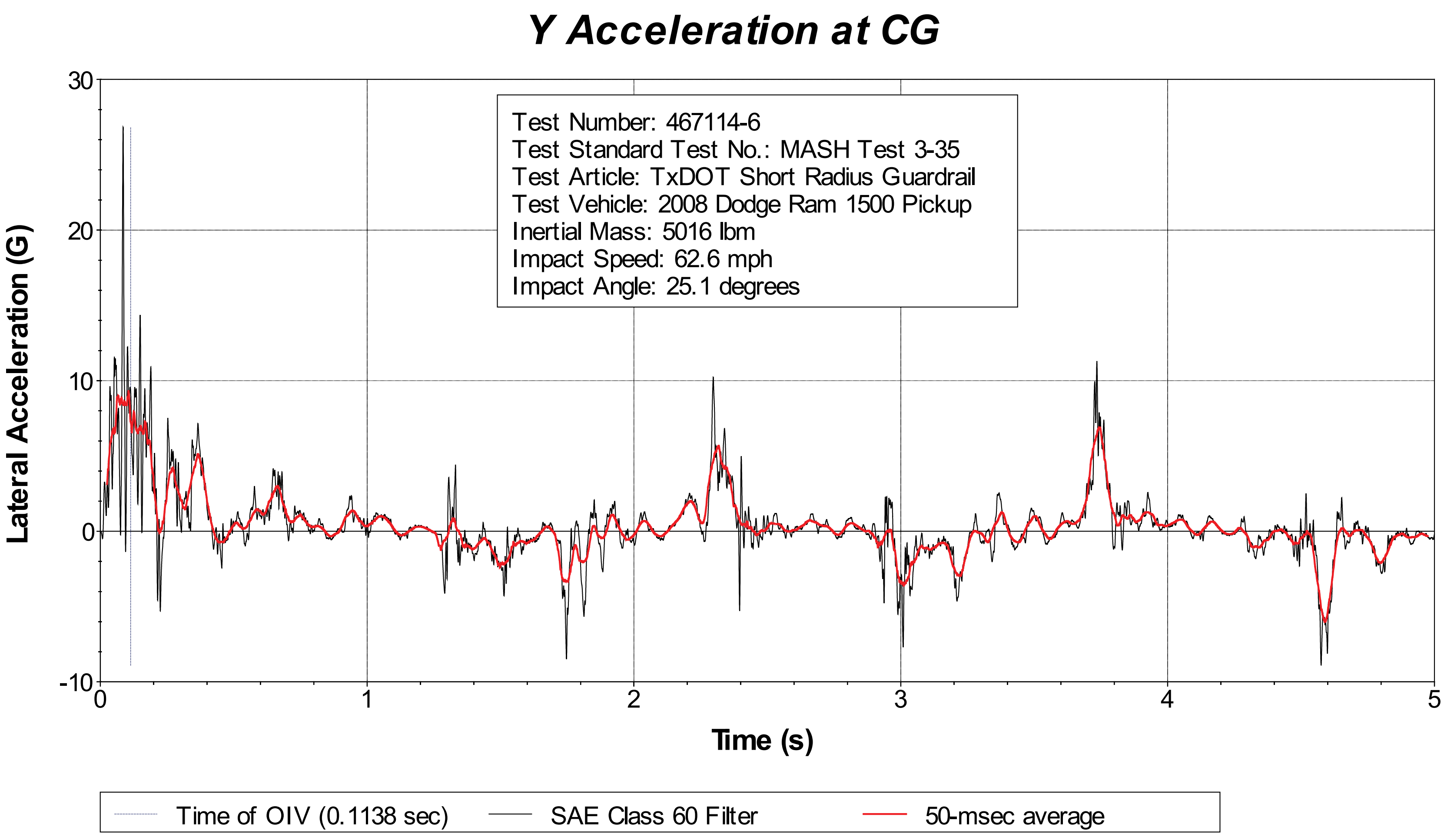


Figure H4. Vehicle Lateral Accelerometer Trace for Test No. 467114-6 (Accelerometer Located at Center of Gravity).

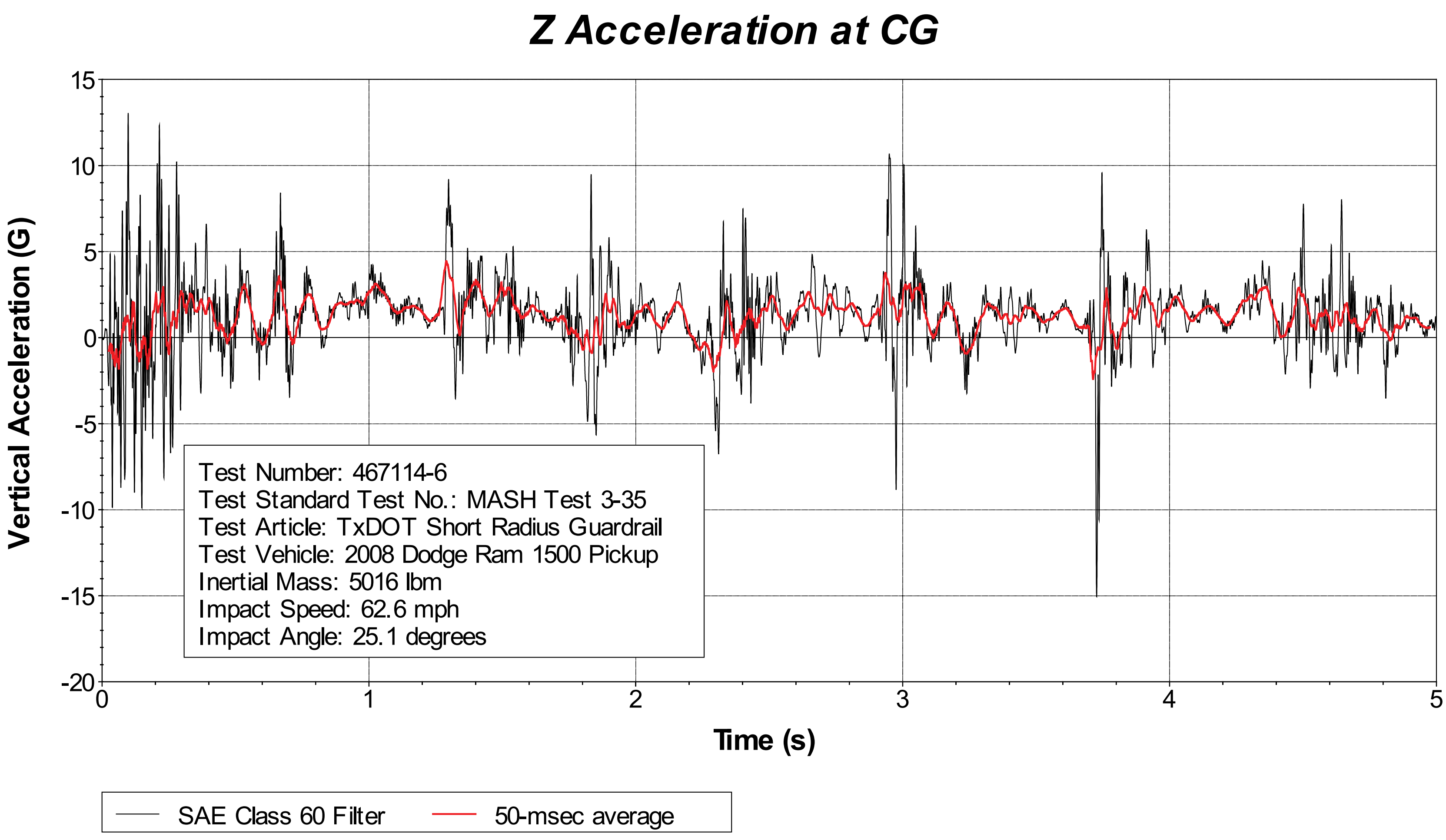


Figure H5. Vehicle Vertical Accelerometer Trace for Test No. 467114-6 (Accelerometer Located at Center of Gravity).

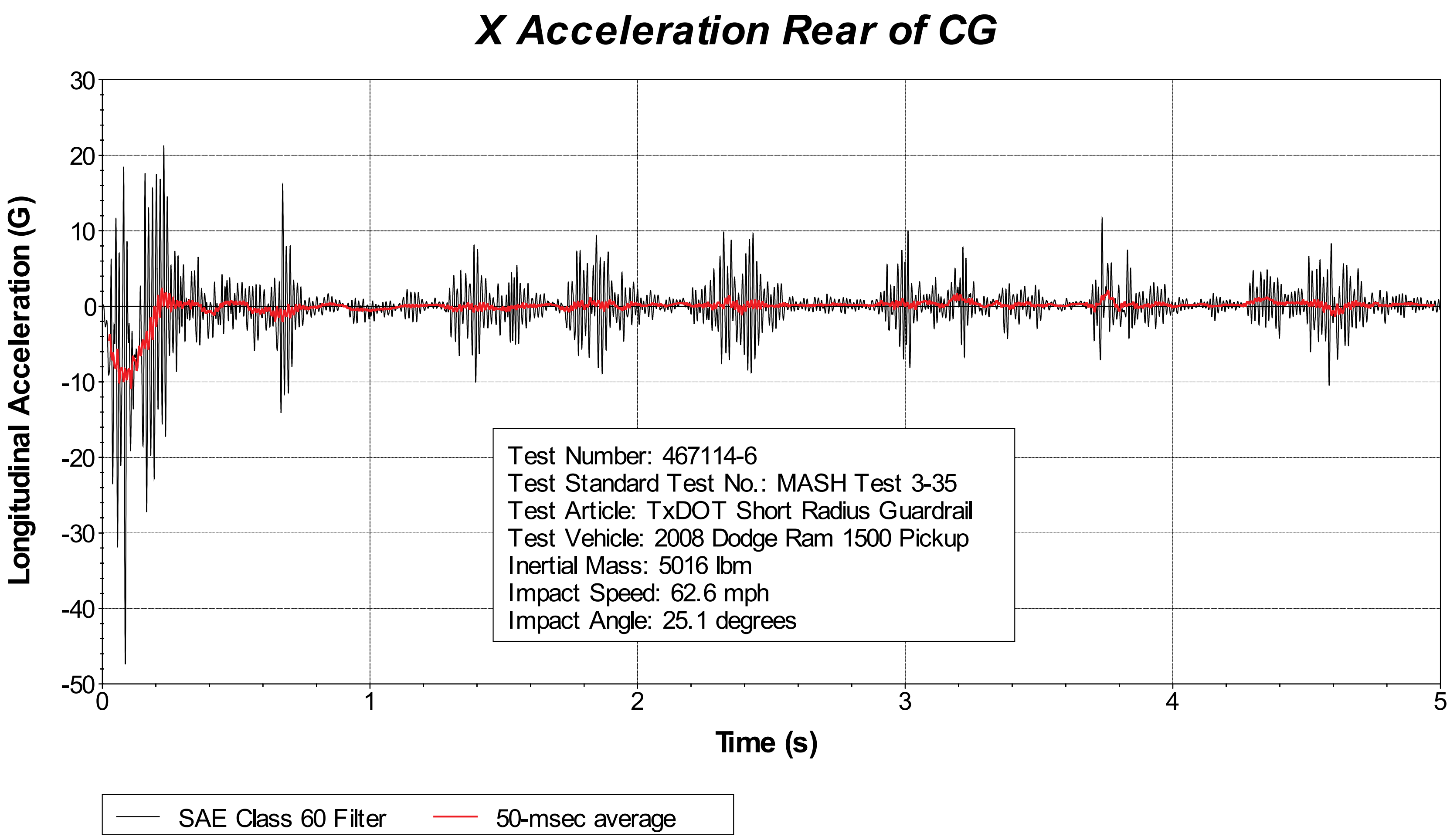


Figure H6. Vehicle Longitudinal Accelerometer Trace for Test No. 467114-6 (Accelerometer Located Rear of Center of Gravity).

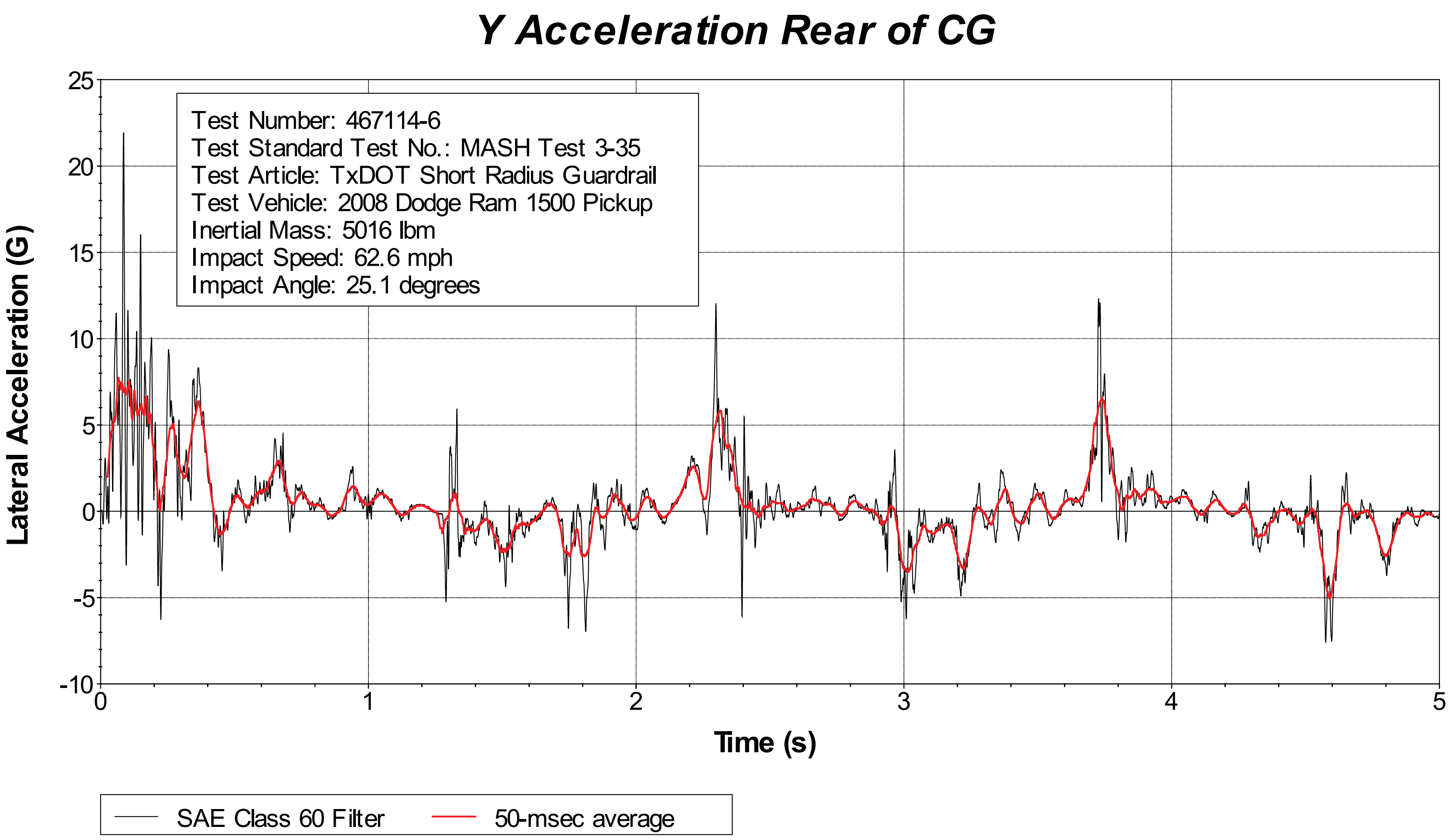


Figure H7. Vehicle Lateral Accelerometer Trace for Test No. 467114-6 (Accelerometer Located Rear of Center of Gravity).

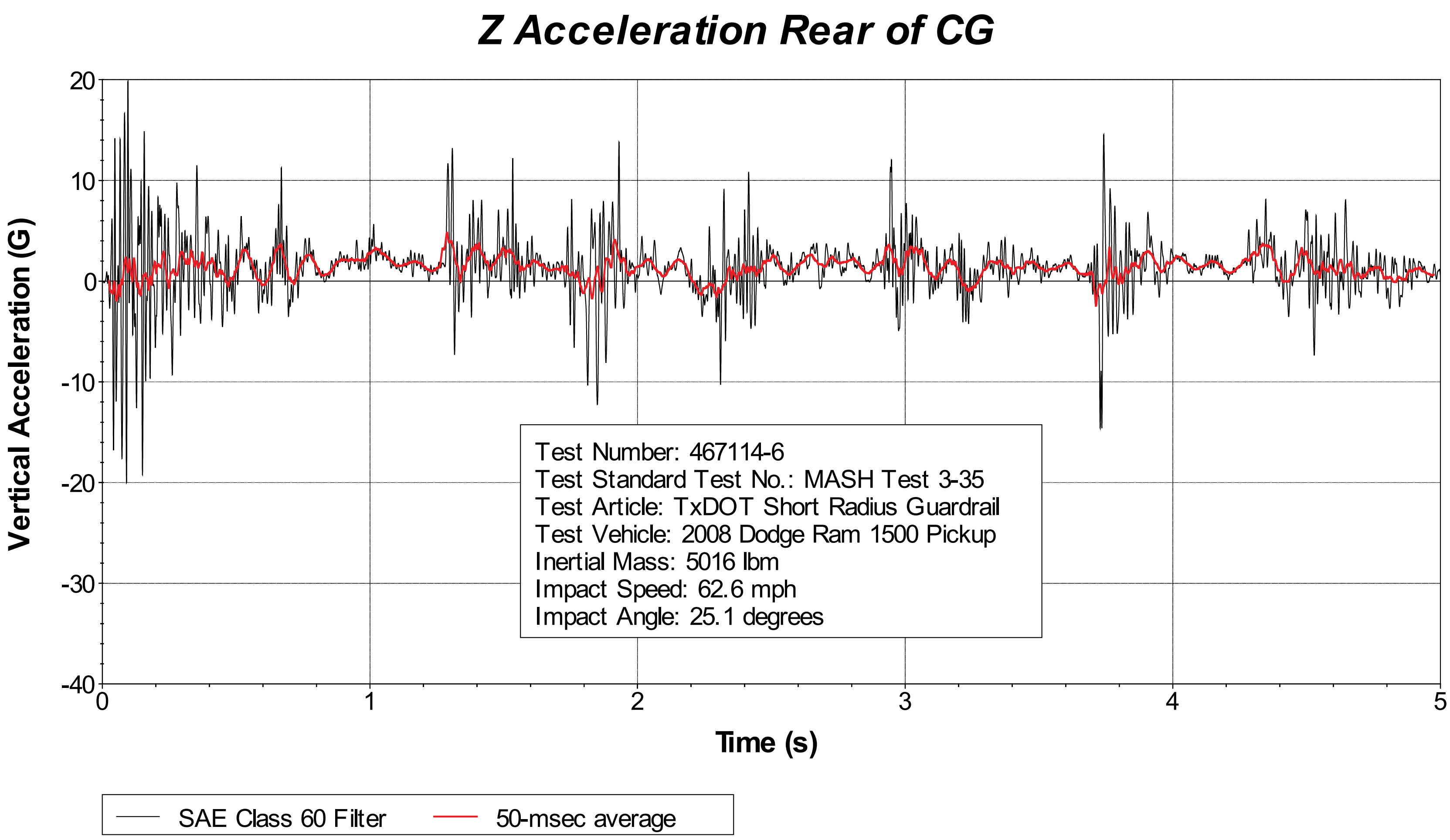


Figure H8. Vehicle Vertical Accelerometer Trace for Test No. 467114-6 (Accelerometer Located Rear of Center of Gravity).

APPENDIX I. INFORMATION FOR CRASH TEST NO. 467114-7

I1. TEST VEHICLE MEASUREMENTS AND INFORMATION

Table I1. Vehicle Properties for Test No. 467114-7.

Date: 2014-08-22 Test No.: 467114-7 VIN No.: 1D7HA18N68S575523

Year: 2008 Make: Dodge Model: Ram 1500 Quad Cab

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

Tread Type: Highway Odometer: 160282

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

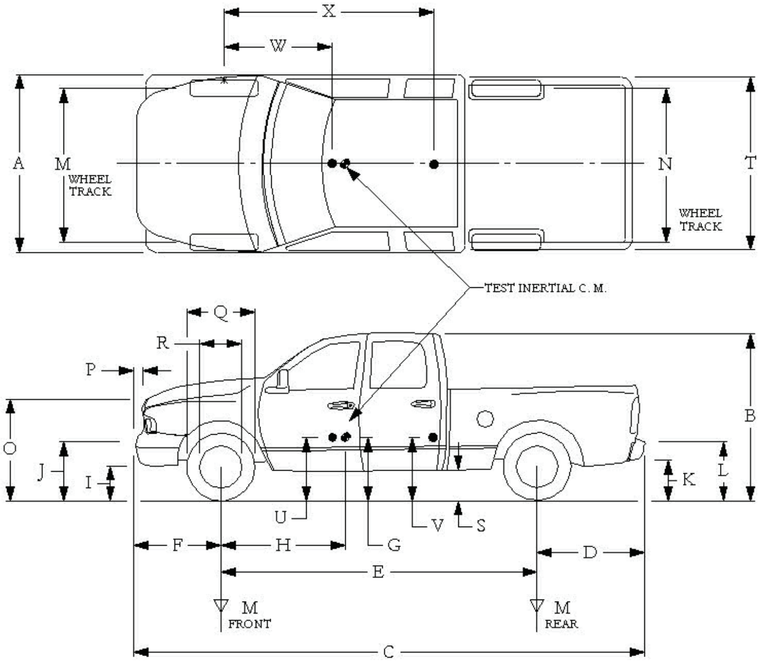
NOTES: None

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: No dummy used
Mass: NA
Seat Position: NA



Geometry: inches

A	78.25	F	36.00	K	21.25	P	2.88	U	28.50
B	45.00	G	28.00	L	29.75	Q	30.50	V	30.50
C	223.75	H	61.82	M	68.50	R	16.00	W	61.80
D	47.25	I	15.50	N	68.00	S	15.50	X	76.50
E	140.50	J	27.00	O	45.50	T	77.50		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	18.00
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	11.00	Bottom Frame Height - Rear	25.50

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2799	2808	2808
Back	3900	M_{rear}	1913	2206	2206
Total	6700	M_{Total}	4712	5014	5014

Mass Distribution:
lb LF: 1450 RF: 1358 LR: 1100 RR: 1106

Table I2. Vehicle Parametric Measurements for Vertical CG for Test No. 467114-7.

Date: 2014-08-22 Test No.: 467114-7 VIN: 1D7HA18N68S575523

Year: 2008 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 160282

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 247 lb (440 lb max)

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

Measured Vehicle Weights: (lb)								
LF:	1450		RF:	1358		Front Axle:	2808	
LR:	1100		RR:	1106		Rear Axle:	2206	
Left:	2550		Right:	2464		Total:	5014	
							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:	61.82	in	Rear of Front Axle	(63 ±4 inches allowed)				
Y:	-0.59	in	Left -	Right +	of Vehicle Centerline			
Z:	28	in	Above Ground	(minumum 28.0 inches allowed)				

Hood Height: 45.50 inches
43 ±4 inches allowed

Front Bumper Height: 27.00 inches

Front Overhang: 36.00 inches
39 ±3 inches allowed

Rear Bumper Height: 29.75 inches

Overall Length: 223.75 inches
237 ±13 inches allowed

Table I3. Exterior Crush Measurements for Test No. 467114-7.

Date: 2014-08-22 Test No.: 467114-7 VIN No.: 1D7HA18N68S575523

Year: 2008 Make: Dodge Model: Ram 1500 Quad Cab

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	30.0	24.0	29	24	20	11	6	2	1	-6
2	Side plane at bumper ht	30.0	24.0	60	2	5.5	---	---	20	24	+77
	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).

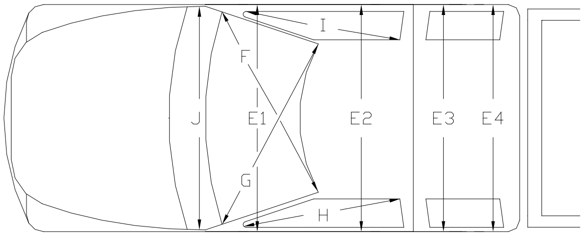
***Measure and document on the vehicle diagram the location of the maximum crush.

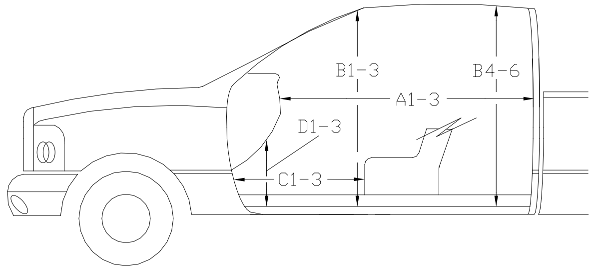
Note: Use as many lines/columns as necessary to describe each damage profile.

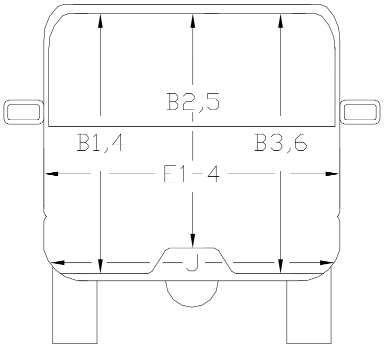
Table I4. Occupant Compartment Measurements for Test No. 467114-7.

Date: 2014-08-22 Test No.: 467114-7 VIN No.: 1D7HA18N68S575523

Year: 2008 Make: Dodge Model: Ram 1500 Quad Cab





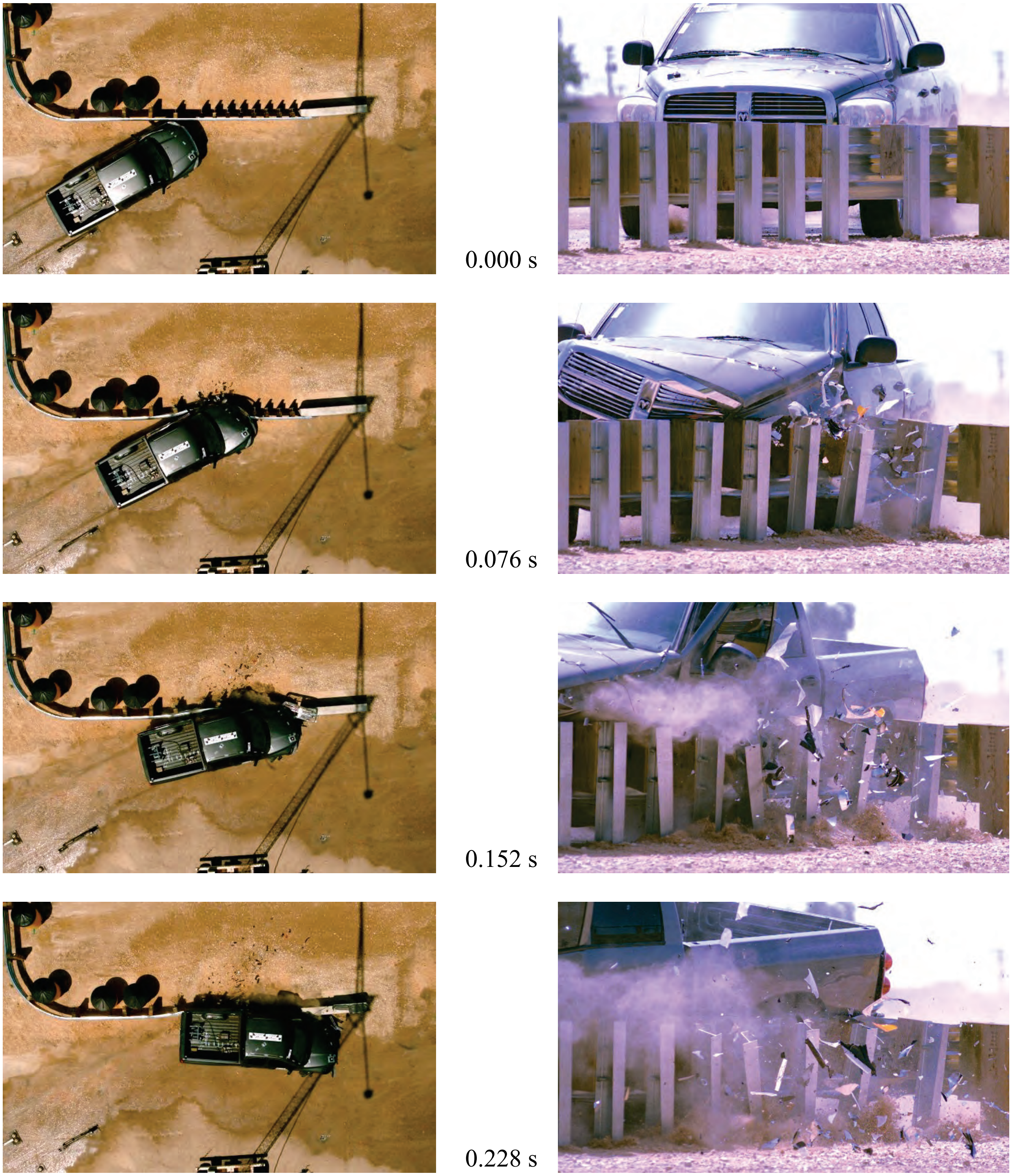


OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	65.00	65.00
A2	65.25	65.25
A3	65.25	65.25
B1	45.25	45.25
B2	39.25	39.25
B3	45.25	45.25
B4	12.12	12.12
B5	45.00	45.00
B6	42.12	42.12
C1	27.50	25.00
C2	-----	-----
C3	26.50	26.50
D1	12.75	12.75
D2	-----	-----
D3	11.50	11.50
E1	62.50	NA
E2	64.50	NA
E3	64.00	63.00
E4	64.25	64.00
F	60.00	60.00
G	60.00	60.00
H	39.00	39.00
I	39.00	39.00
J*	62.25	60.25

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

I2. SEQUENTIAL PHOTOGRAPHS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0.152 s

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Figure I1. Sequential Photographs for Test No. 467114-7 (Overhead and Rear Views).

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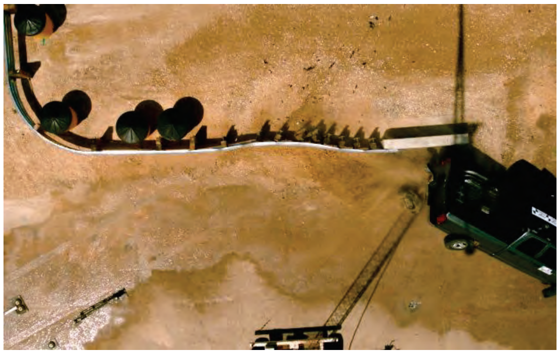
0.380 s

0.456 s

Camera turned off



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Camera turned off

Figure I1. Sequential Photographs for Test No. 467114-7 (Overhead and Rear Views) (Continued).

0.000 s

0.076 s

0.152 s

0.228 s

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0.532 s

Figure I2. Sequential Photographs for Test No. 467114-7 (Rear View).

I3. VEHICLE ANGULAR DISPLACEMENTS

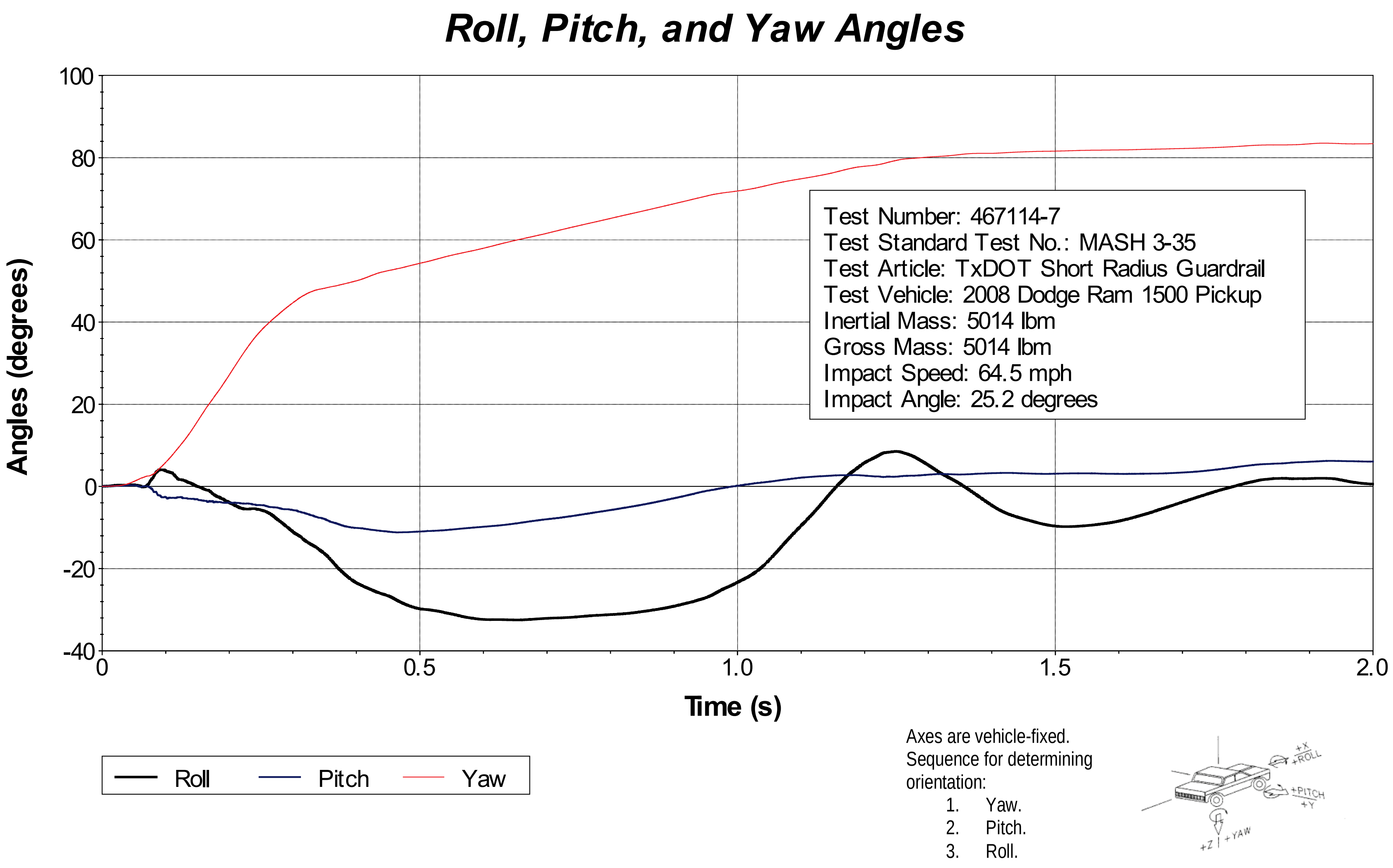

Figure I3. Vehicle Angular Displacements for Test No. 467114-7.

I4. VEHICLE ACCELERATIONS

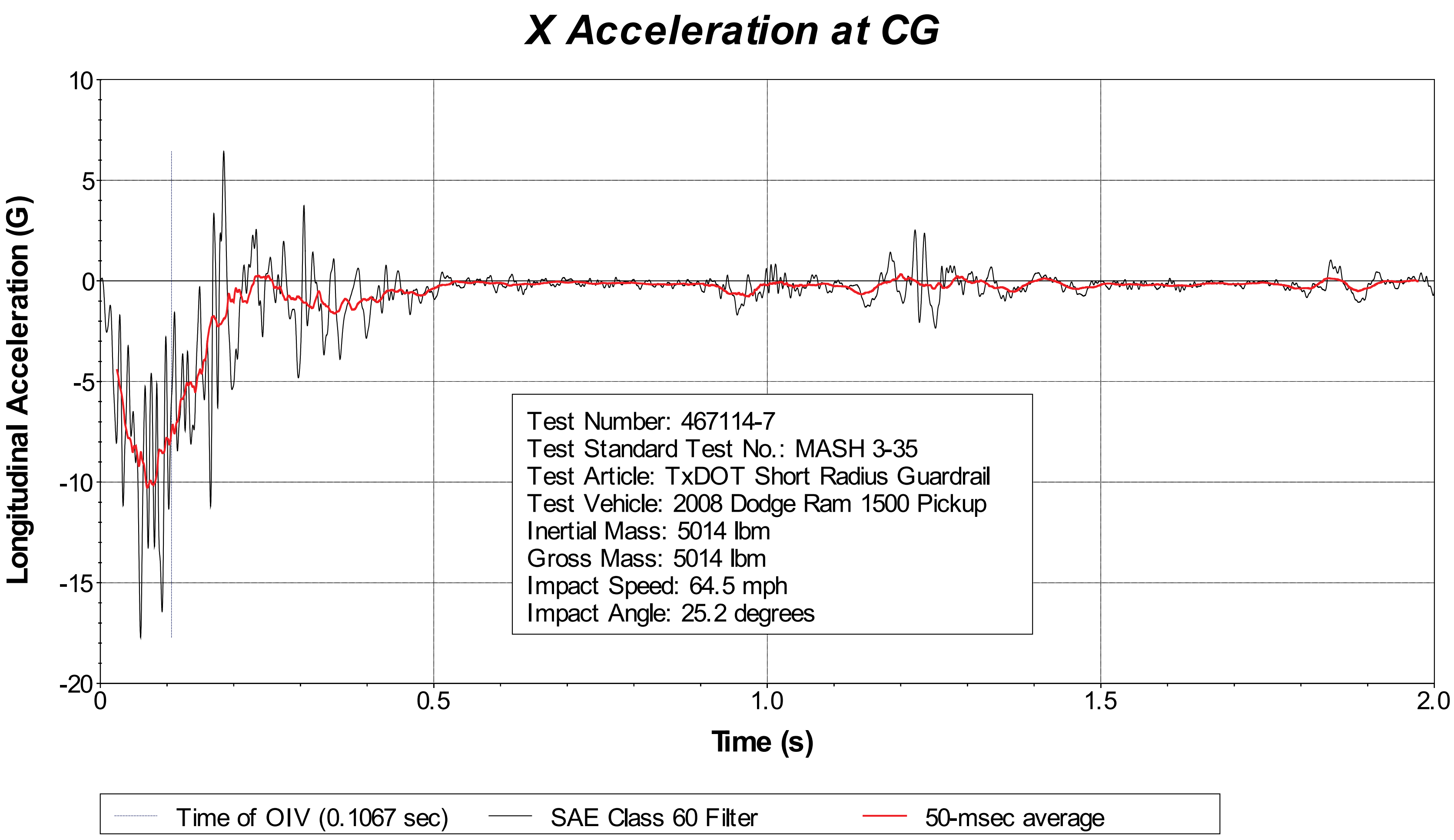

Figure I4. Vehicle Longitudinal Accelerometer Trace for Test No. 467114-7 (Accelerometer Located at Center of Gravity).

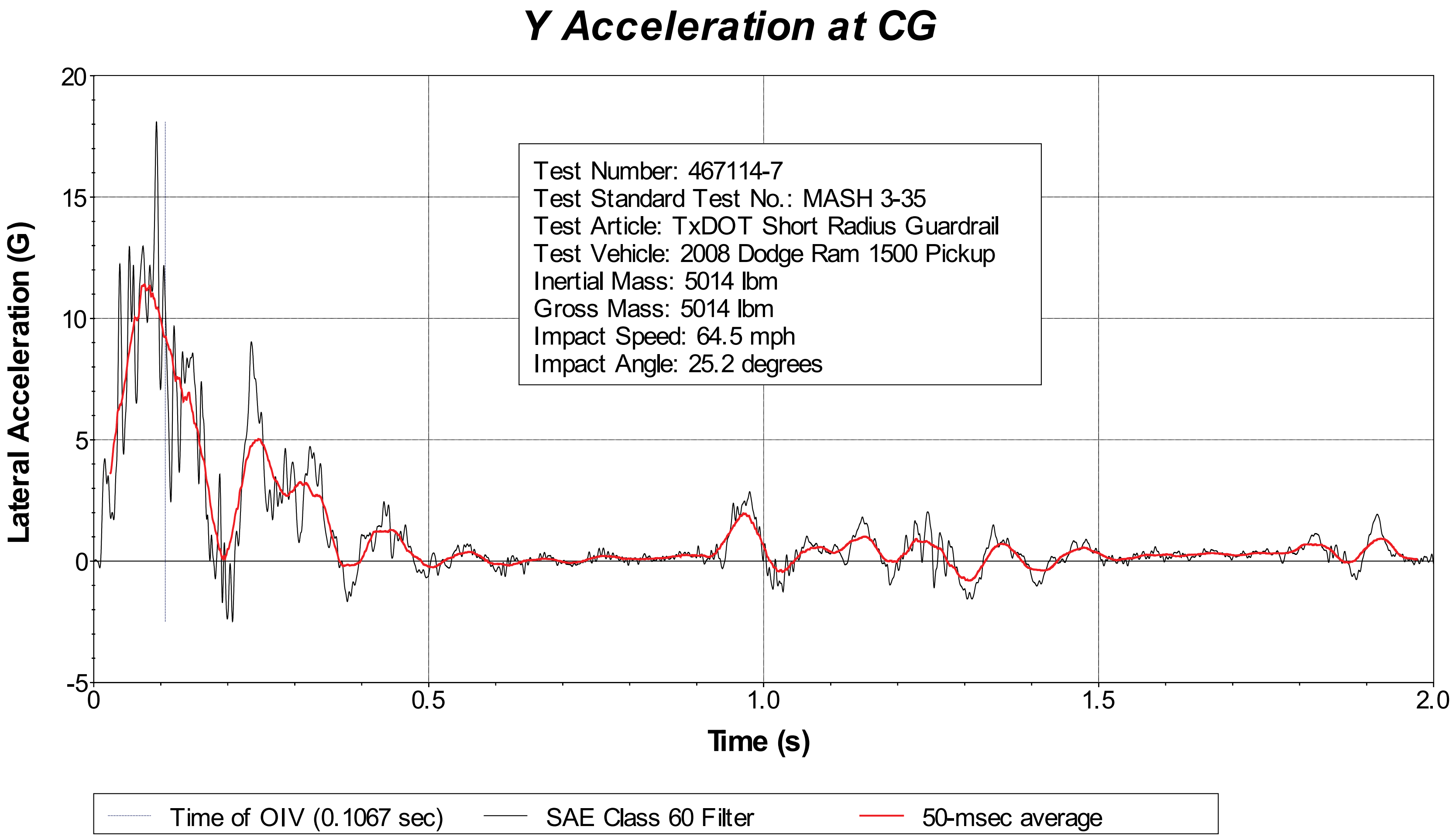

Figure I5. Vehicle Lateral Accelerometer Trace for Test No. 467114-7 (Accelerometer Located at Center of Gravity).

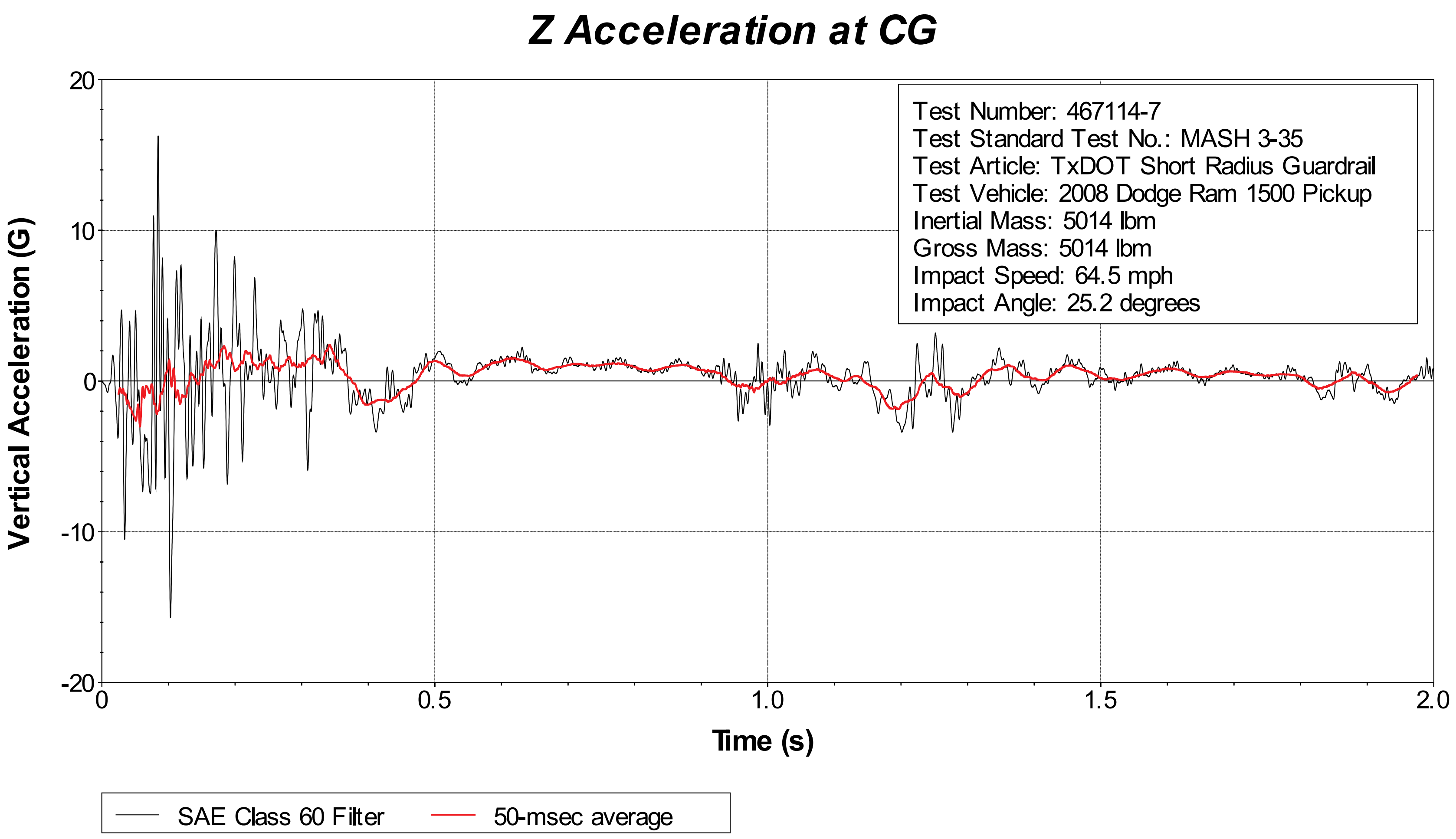

Figure I6. Vehicle Vertical Accelerometer Trace for Test No. 467114-7 (Accelerometer Located at Center of Gravity).

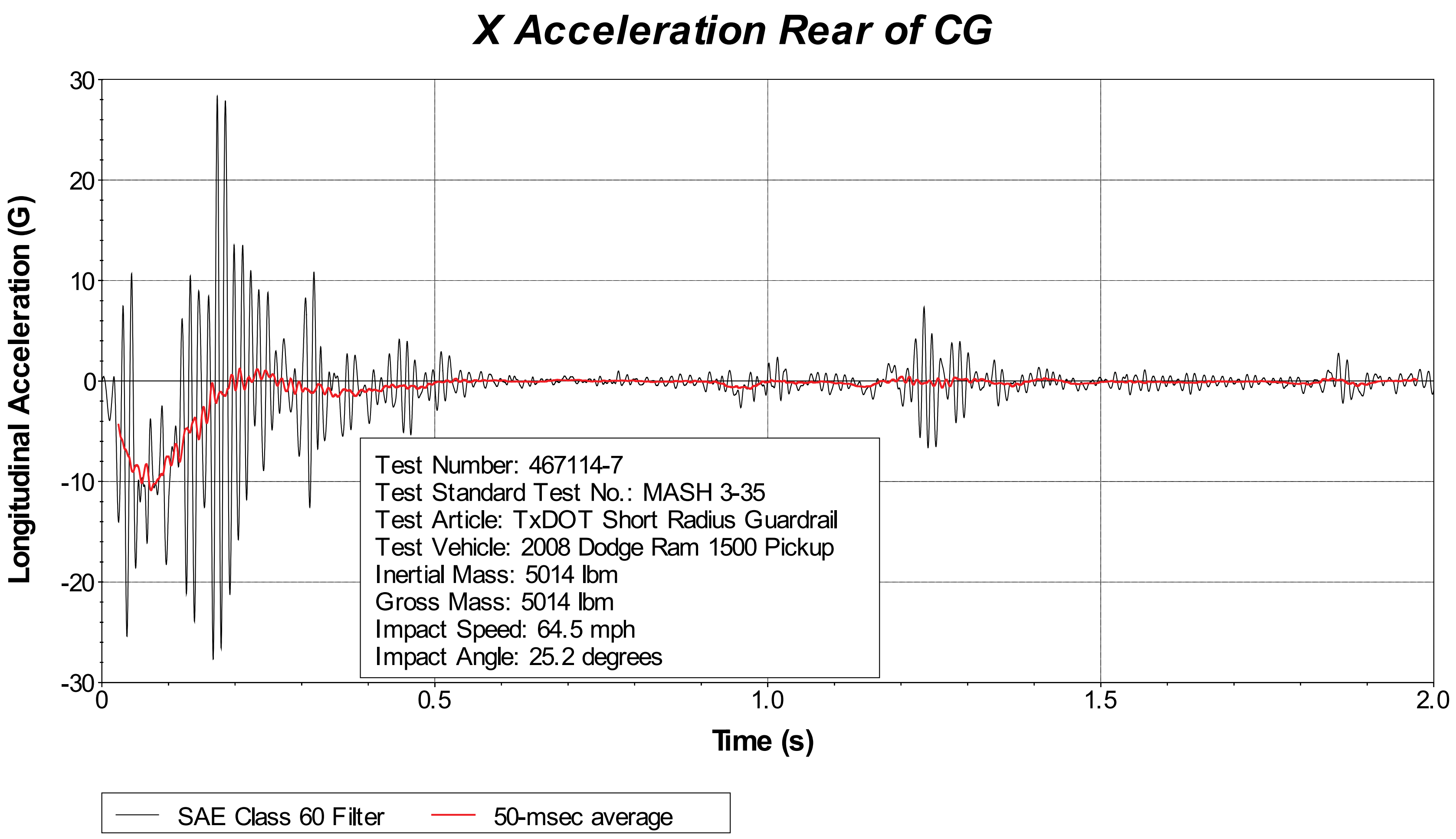

Figure I7. Vehicle Longitudinal Accelerometer Trace for Test No. 467114-7 (Accelerometer Located Rear of Center of Gravity).

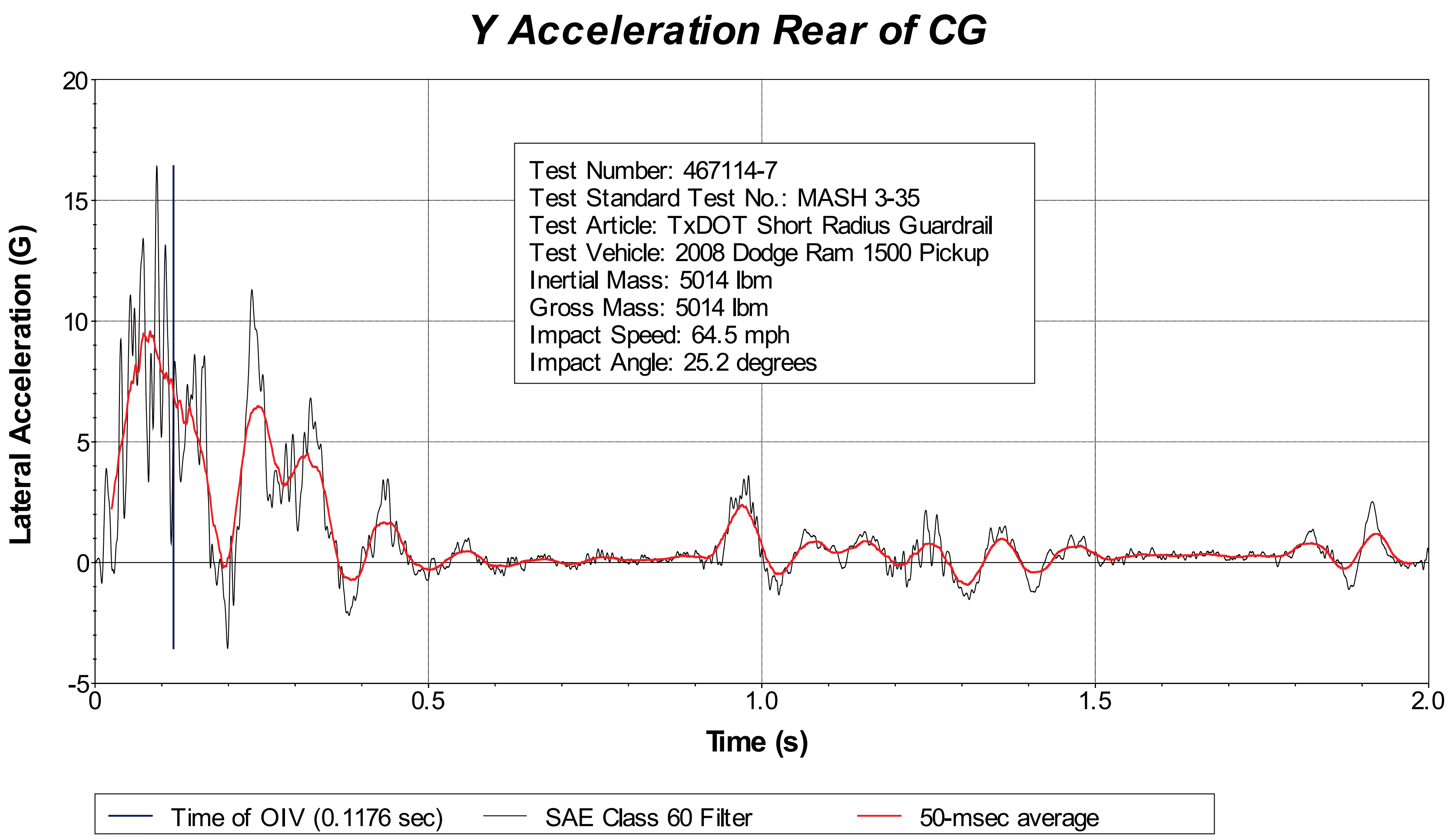

Figure I8. Vehicle Lateral Accelerometer Trace for Test No. 467114-7 (Accelerometer Located Rear of Center of Gravity).

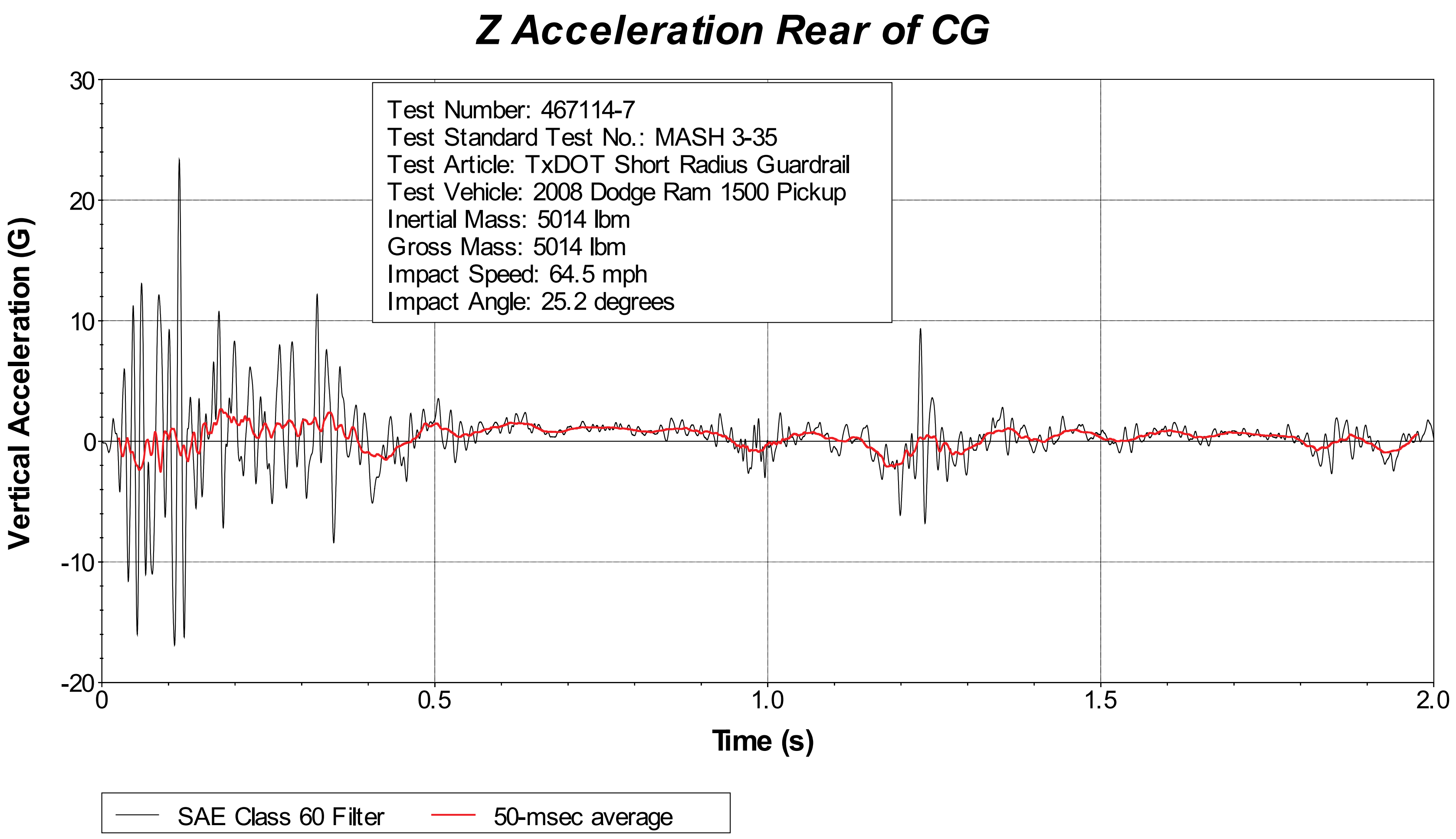

Figure I9. Vehicle Vertical Accelerometer Trace for Test No. 467114-7 (Accelerometer Located Rear of Center of Gravity).