*Research Project Number TPF-5(193) Supplement #116*

# DEVELOPMENT OF A MASH TL-3 APPROACH GUARDRAIL TRANSITION TO A MASH TL-4 STEEL BRIDGE RAIL


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## UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in standard full-scale crash testing and non-standard testing of roadside safety features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration.

## INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Karla Lechtenberg, Research Engineer

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| SI* (MODERN METRIC) CONVERSION FACTORS | | | | |
|---|---|---|---|---|
| **APPROXIMATE CONVERSIONS TO SI UNITS** | | | | |
| **Symbol** | **When You Know** | **Multiply By** | **To Find** | **Symbol** |
| | | **LENGTH** | | |
| in. | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yard | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| | | NOTE: volumes greater than 1,000 L shall be shown in $m^3$ | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short ton (2,000 lb) | 0.907 | megagrams (or “metric ton”) | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| °F | Fahrenheit | 5(F-32)/9<br>or (F-32)/1.8 | Celsius | °C |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela per square meter | $cd/m^2$ |
| | | **FORCE & PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | newtons | N |
| $lbf/in^2$ | poundforce per square inch | 6.89 | kilopascals | kPa |
| **APPROXIMATE CONVERSIONS FROM SI UNITS** | | | | |
| **Symbol** | **When You Know** | **Multiply By** | **To Find** | **Symbol** |
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in. |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yard | $yd^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliter | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.314 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or “metric ton”) | 1.103 | short ton (2,000 lb) | T |
| | | **TEMPERATURE (exact degrees)** | | |
| °C | Celsius | 1.8C+32 | Fahrenheit | °F |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| $cd/m^2$ | candela per square meter | 0.2919 | foot-Lamberts | fl |
| | | **FORCE & PRESSURE or STRESS** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | $lbf/in^2$ |

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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# 1 INTRODUCTION

## 1.1 Background and Problem Statement

Over the past few decades, the Ohio and Illinois Departments of Transportation (Ohio DOT and Illinois DOT) have regularly installed steel-tube bridge railings to safely treat the edges of their bridges. These bridge railings consist of multiple steel-tube rails mounted to the face of I-section steel posts, as shown in Figures 1 and 2 for the states of Ohio and Illinois, respectively. The systems were designed without a curb to allow water to drain off the sides of a bridge, and the posts were mounted to the side of the bridge deck to maximize the traversable width of the bridge.

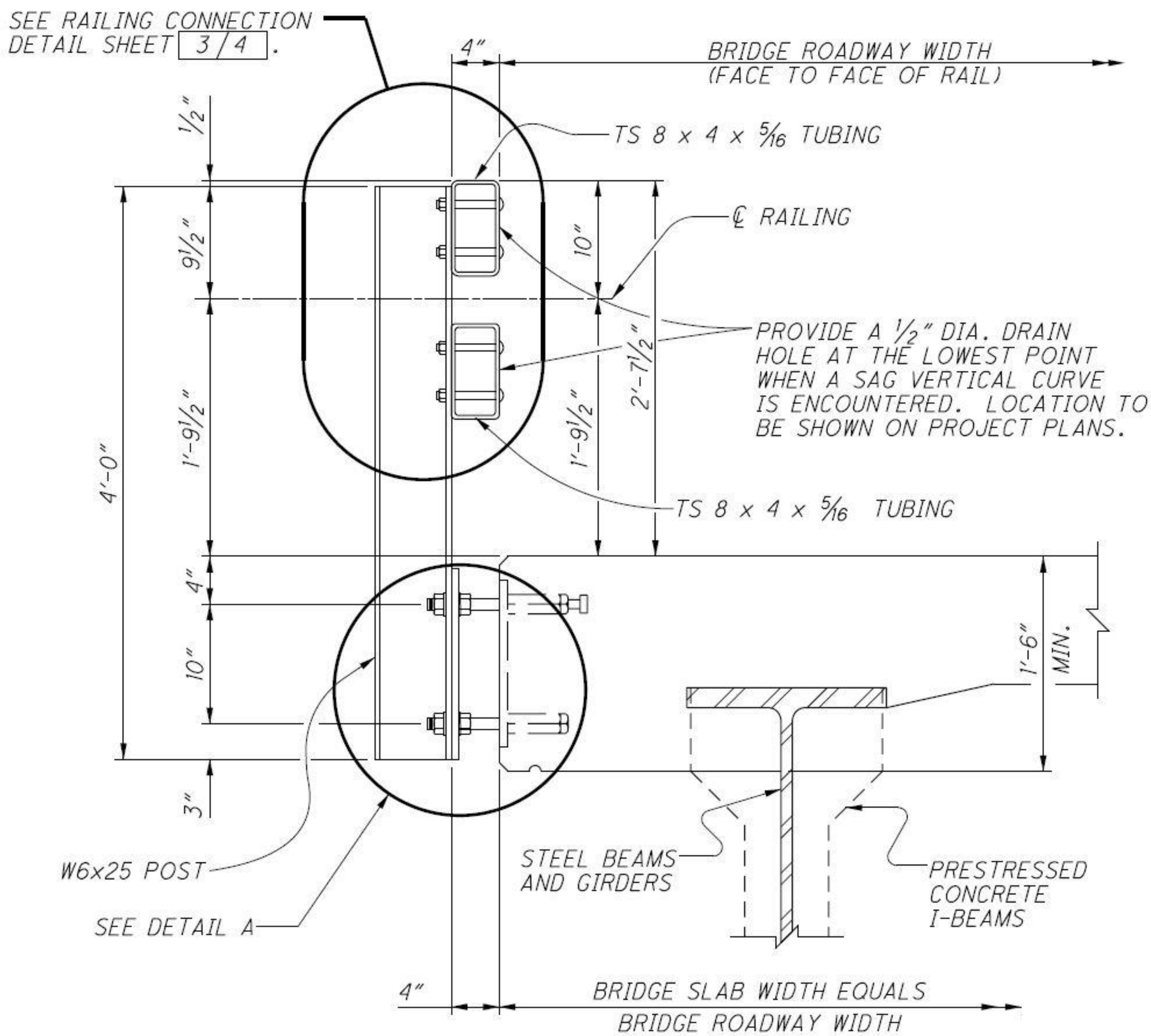



Figure 1. Existing Ohio Side-Mounted Steel-Tube Bridge Railing [1]

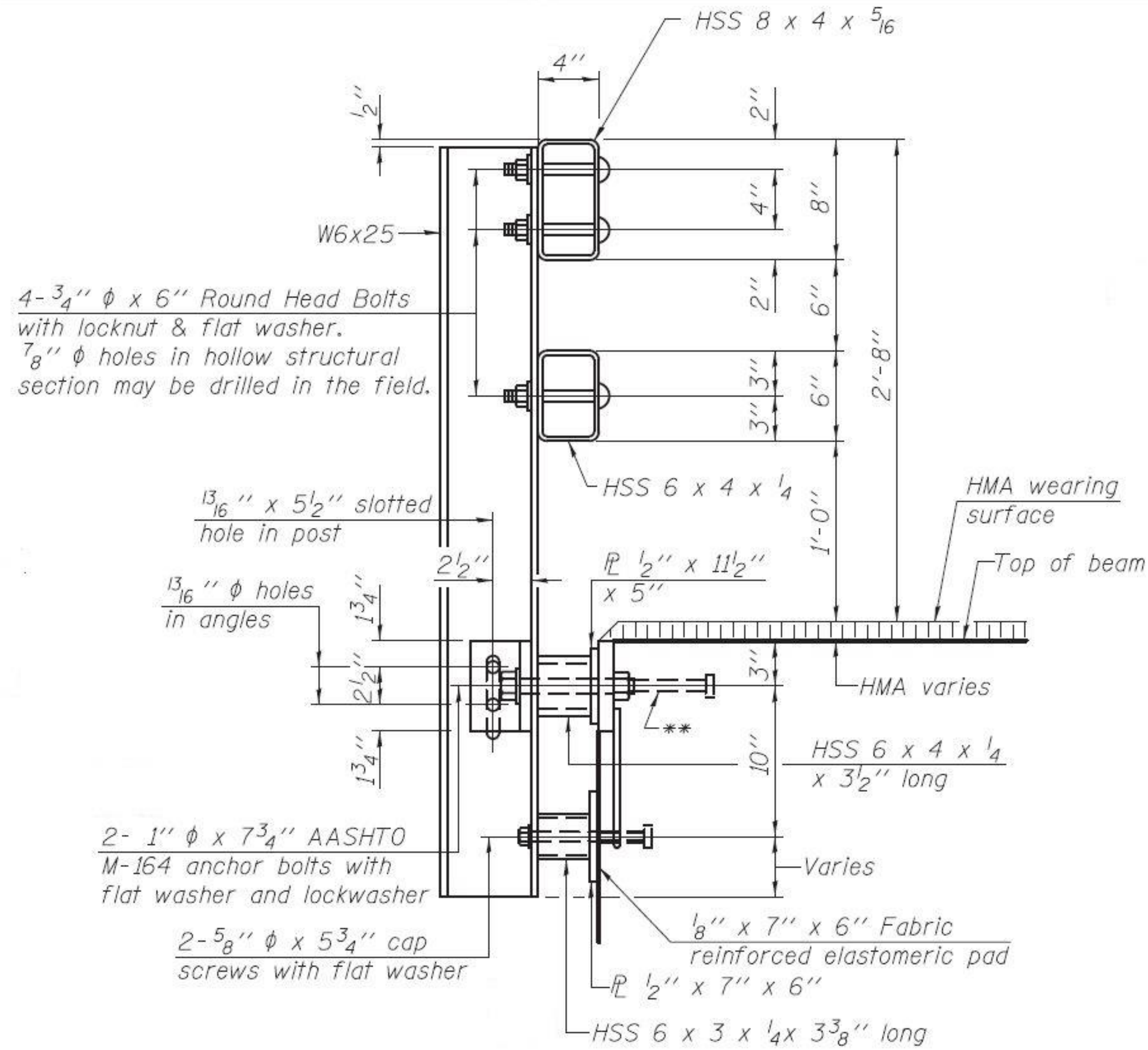



Figure 2. Existing Illinois Side-Mounted Steel-Tube Bridge Railing [2]

The bridge railings shown in Figures 1 and 2 were originally developed to satisfy the Test Level 4 (TL-4) safety criteria found in National Cooperative Highway Research Program (NCHRP) Report No. 350 [3]. However, in 2009, the American Association of State Highway and Transportation Officials (AASHTO) implemented a new standard for the evaluation of roadside hardware, the *Manual for Assessing Safety Hardware* (MASH) [4]. The MASH criteria superseded the criteria found in NCHRP Report 350 and significantly increased the impact severity for the three crash tests prescribed under TL-4 conditions. Specifically, the impact angle for the small car test was increased, the impact speed for the single unit truck test was increased, and the weight of all three vehicles (small car, pickup truck, and the single unit truck) were increased. Note, the 2nd Edition of MASH was published in 2016 [5] with minimal changes to the criteria for evaluating bridge rails. As such, the existing steel-tube bridge rails needed to be modified and evaluated to the new MASH 2016 TL-4 safety performance criteria.

The ends of bridge rails require approach guardrail transitions (AGTs) to safely connect the bridge rail to guardrail systems on the adjacent roadway. Specifically configured to prevent pocketing and vehicle snag on the bridge rail end, AGTs are typically designed to meet TL-3 impact safety standards. With the geometric and strength modifications required of the steel-tube bridge rail to satisfy MASH 2016 TL-4 criteria, development of a new AGT and associated modifications to the ends of the bridge rail were also required to complete the design of the desired MASH 2016 TL-4 bridge rail.

## 1.2 Research Objectives

The objective of this research study was to develop a MASH 2016 TL-4 steel-tube bridge rail with a TL-3 approach guardrail transition. The design and evaluation of the bridge rail was completed in previous phases of this research. Documentation of the development of the bridge rail can be found in reports by Pena and Mauricio [6-9]. The research efforts documented herein cover the development and evaluation of the AGT attached to the ends of the new bridge rail.

The AGT was required to safely connect the new MASH TL-4 steel-tube bridge rail to the Midwest Guardrail System (MGS) located on the adjacent roadway while preventing snagging on the bridge rail during both conventional and reverse-direction (traveling from bridge to roadway) impacts. Additionally, it was desired to maximize the distance between the final AGT post and the first bridge rail post to avoid post installation obstacles, such as bridge abutments and wing walls. Since the bridge rail was developed to remain crashworthy after roadway overlays up to 3 in. thick, the same criteria were desired for the adjacent AGT. Although the bridge rail was MASH TL-4 compliant, the AGT was only required to satisfy MASH TL-3 criteria, which matched the test level of the adjacent MGS.

The research presented in this report pertains only to the development and MASH 2016 evaluation of the new TL-3 AGT to the TL-4 steel-tube bridge rail. Recommendations and implementation guidance for both the bridge rail and the AGT were documented in a separate summary report [10], the fourth and final report in the series related to this research project.

## 1.3 Research Scope

Development of a MASH TL-3 AGT for use with the new TL-4 steel-tube bridge rail began with the review of previous NCHRP Report 350 and MASH AGTs connected to steel-tube bridge rails. A previously developed W-to-thrie beam guardrail stiffness transition was selected for use at the upstream end of the AGT, so design efforts focused on the downstream region of the AGT and the end of the bridge rail. Modifications were made to the steel tube rails to prevent vehicle snag, and new rail components were designed to connect with the thrie-beam AGT. LS-DYNA computer simulations were utilized to conduct preliminary evaluations of the new AGT concepts and to identify critical impact points (CIPs). Two full-scale crash tests were conducted on the new AGT in accordance with MASH test designation nos. 3-20 and 3-21. Finally, the test results were evaluated in accordance with MASH safety performance criteria.

# 2 LITERATURE REVIEW

A literature review was performed on connections between previously crash-tested AGTs and bridge rails that were considered relevant to the development of a TL-3 AGT for use with the new TL-4 steel-tube bridge rail. The review focused on MASH TL-3 AGTs and NCHRP Report 350 TL-3 and TL-4 AGTs. Relevant systems are discussed in the following sections.

Various thrie-beam AGTs that connect to steel bridge rails and incorporate tube-section rail elements exist in current roadside applications. However, not all AGTs have been crash tested. The bridge rails tended to consist of strong, steel posts that were either side-mounted or top-mounted to the bridge deck. The AGTs typically incorporated nested thrie beam guardrail and guardrail posts with a reduced post spacing as compared to typical guardrail installations.

## 2.1 Ohio MGS Bridge Terminal Assembly, Type 1

Ohio DOT's MGS Bridge Terminal Assembly, Type 1 was a 31-in. tall thrie-beam transition connecting to the 31-in. tall Twin Steel Tube Bridge Railing or a concrete parapet [11], as shown in Figure 3. The AGT consisted of nested thrie-beam rail on 12-in. deep wood blockouts mounted on six W6x9 steel posts spaced at 18¾-in. on-center, commonly referred to as quarter-post spacing. No actual crash test data and/or Federal Highway Administration (FHWA) reports were found, but detailed plans of the system were obtained from Ohio DOT. Complete drawing details for the transition and bridge rail are shown in Figures A-1 through A-6 of Appendix A.

The Twin Steel Tube Bridge Railing was a curb- or side-mounted system consisting of wide-flange posts and tubular steel rail elements designed and tested to the former AASHTO crash standards as satisfying Performance Level 2 (PL-2) safety criteria [12], approximately equivalent to NCHRP Report 350 TL-4 safety standards. The bridge rail consisted of W6x25 posts spaced at 6 ft – 3 in. with two HSS8x4x$^{5}/_{16}$ rail elements, as shown in Figure 4.

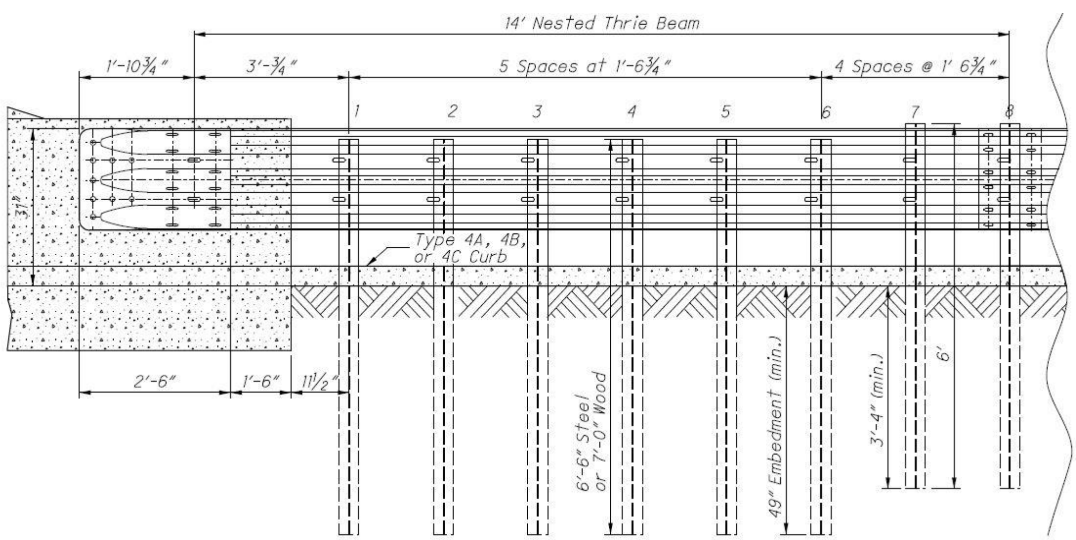



Figure 3. Ohio DOT MGS Bridge Terminal Assembly, Type 1 [11]

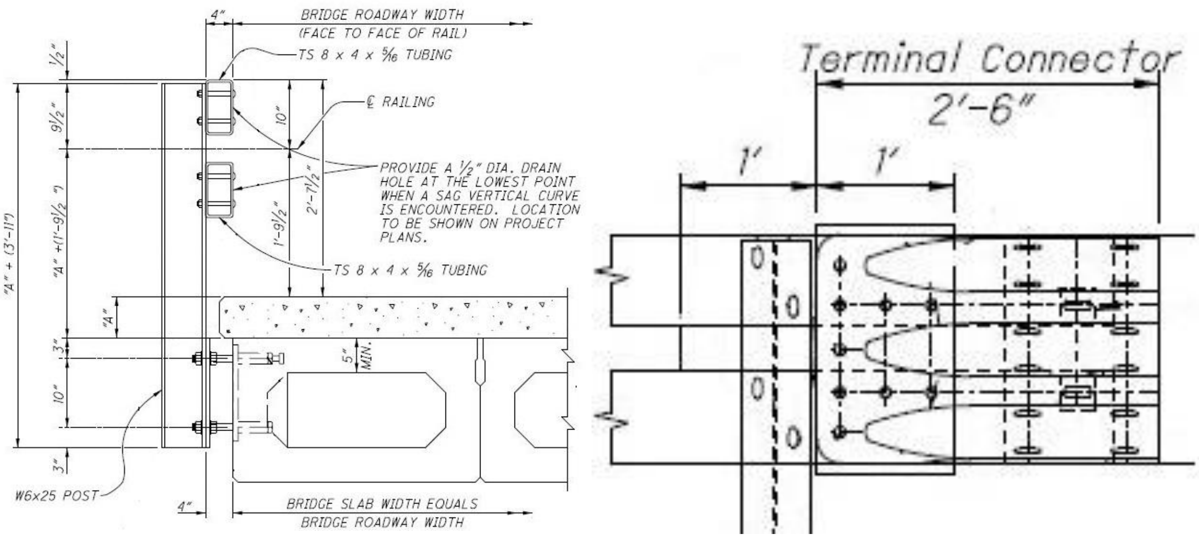



Figure 4. Ohio DOT Twin Steel Bridge Railing with AGT Terminal Connector [1, 11]

The connection of the thrie-beam rail to the steel-tube bridge rail consisted of a ½-in. thick guardrail connection plate mounted to the front face of the tube railings at 1 ft upstream from the first bridge rail post, as shown in Figure 5. The guardrail connection plate was a 12-in. x 22-in. rectangular plate with a ½-in. stiffener on the back side of the plate. A separate ½-in. thick deflector plate was welded to the rectangular plate and stiffener and was situated between the tube railings. This deflector plate tapered 4 in. to the backside of the railings over a 12-in. length at a 3:1 taper ratio to prevent snag at the connection during reverse-direction impacts. However, the transition system was never tested in the reverse direction or in the normal traffic direction.

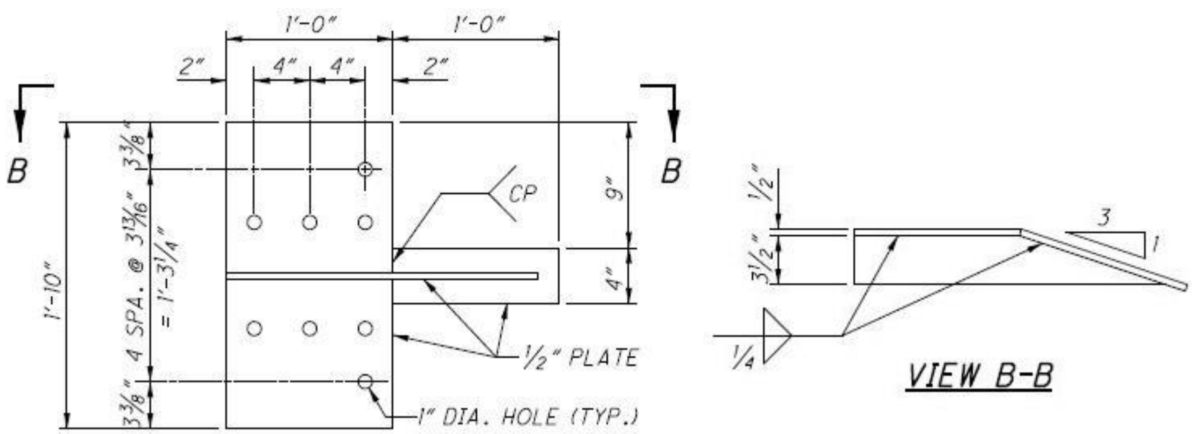



Figure 5. Ohio Guardrail Connection Plate [11]

A thrie-beam terminal connector was connected to nested thrie-beam rails and mounted to the connection plate and the tube railings with eight ⅞-in. diameter by 6-in. long A325 bolts. The nested thrie-beam rails and terminal connector were also connected to the front face of the tube railings using two ⅝-in. diameter by 7-in. long bolts, with plate washers and hex nuts. Bearing plates were placed between the guardrail and the tube railings.

## 2.2 Illinois Traffic Barrier Terminal, Type 6A

The Illinois Traffic Barrier Terminal, Type 6A was a 31-in. tall thrie-beam transition connecting to a 32-in. tall top- or side-mounted, two-tube bridge rail [13], as shown in Figure 6. Similar to the Ohio AGT, the Illinois AGT utilized nested thrie-beam rail, six W6x9 steel posts at quarter-post spacing, and 8-in. deep wood blockouts. No crash test data was found on the Illinois AGT. Complete drawing details for the transition and bridge rail are shown in Figures A-7 through A-10 of Appendix A.

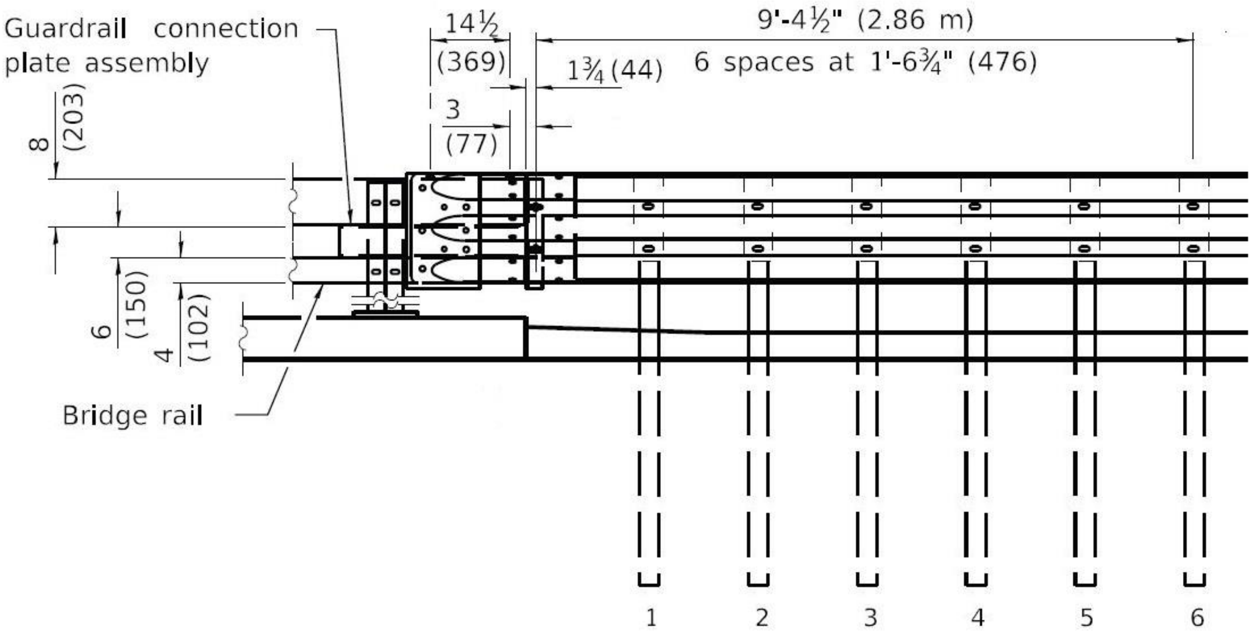


Figure 6. Illinois Traffic Barrier Terminal, Type 6A [13]

The Illinois Type SM Side-Mounted Bridge Rail was a side-mounted railing consisting of wide-flange posts and tubular steel rail elements designed and tested to the former AASHTO PL-2 crash safety standards [14], approximately equivalent to NCHRP Report 350 TL-4 standards. The bridge rail design consisted of W6x25 posts spaced at 6 ft – 3 in. with an HSS8x4x$^{5}/_{16}$ top rail element and an HSS6x4x¼ bottom rail element, as shown in Figure 7.

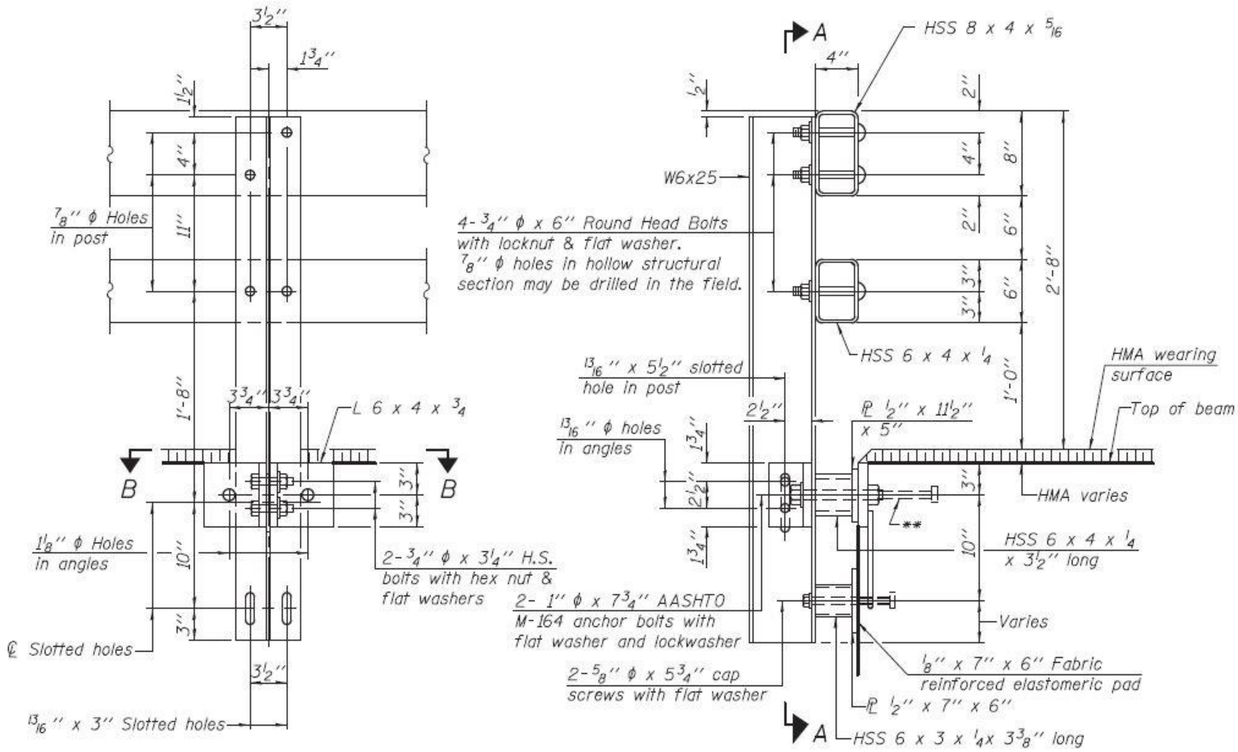



Figure 7. Illinois Type Side-Mounted Bridge Rail [14]

The connection of the thrie-beam rail to the steel-tube bridge rail consisted of a ½-in. guardrail connection plate mounted to the front face of the tube railings at 1 ft upstream from the first bridge rail post, as shown in Figure 8. The guardrail connection plate consisted of a 13⅜-in. x 21-in. rectangular plate, a ⅜-in. stiffener on the back side of the plate, and a 4-in. x 4-in. x ⅜-in. angle. The stiffener and angle were placed below the top railing and above the lower railing, respectively. A separate ½-in. deflector plate was welded to the rectangular plate and stiffener and was situated between the tube railings. This deflector plate tapered 4 in. to the backside of the railings over a 12 in. length at a 3:1 taper to prevent snag at the connection in reverse-direction impacts. However, the transition system was never tested in the reverse direction.

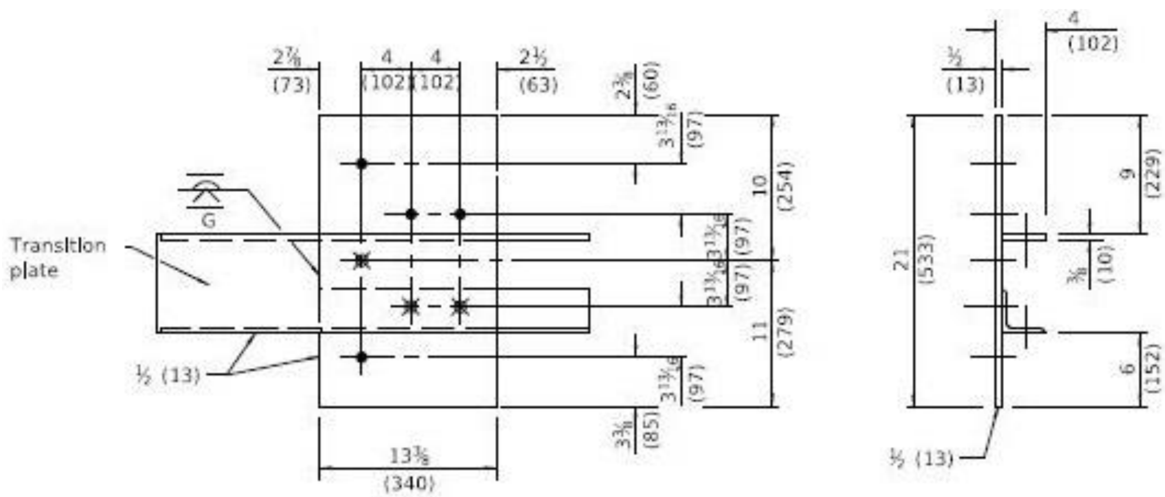



Figure 8. Illinois Guardrail Connection Plate [13]

The thrie-beam terminal connector mounted the guardrail connection plate to the bridge rail with seven ⅞-in. diameter, high-strength bolts. The spliced connection between the nested thrie-beam rails and terminal connector was also connected to the ends of the bridge rail with a 5-in. x 3-in. x ¼-in. steel angle. The angle bolted to rail cap plates welded to the ends at the bridge railings. These $^{3}/_{16}$-in. rail cap plates utilized ⅝-in. reduced base welded studs with ⅝-in. washers and self-locking nuts or nuts and jam nuts for the guardrail connection.

## 2.3 Texas T131RC Bridge Rail Transition

The Texas DOT T131RC Bridge Rail Transition was a 31-in. tall thrie-beam transition connecting to a 36-in. tall top-Texas T131RC bridge rail [15], as shown in Figure 9. The T131RC transition consisted of two nested 12-gauge thrie beam rails supported by six W6x8.5 posts spaced at 37½ in. on-center and was developed to satisfy MASH TL-3 impact safety criteria [15]. Complete drawing details for the transition and bridge rail are shown in Figures A-11 through A-26 of Appendix A.

Figure 9. Texas T131RC Bridge Rail and Transition [15]

The Texas T131RC Bridge Rail consisted of two HSS6x6x¼ structural tubes supported by W6x20 steel posts spaced at 5 ft. The bridge rail was successfully crash tested in accordance with MASH TL-3 test criteria [16]. The system was anchored into an 8-in. wide x 11-in. high, cast-in-place concrete curb that was anchored to a cast-in-place, 8-in. thick, cantilevered concrete deck. The width of the cantilever was 20¾ in.

The nested thrie-beam transition connected to a 10-gauge terminal connector and was anchored to the end of the bridge rail. The terminal connector was attached to the traffic face of the HSS6x6x¼ railings used for the T131RC Bridge Rail using three ⅞-in. diameter, A325 bolts. The terminal connector was anchored to the end of the rail near the W6x15 bridge rail post in the concrete curb. Two HSS sections called fill blocks were located between the tube railings and curb and attached to the bridge rail using two ¾-in. diameter by 20-in. long bolts. These fill blocks were mounted flush to the tube railings to prevent vehicle snag in reverse-direction impacts. The fill blocks were fabricated using HSS6x6x¼ tubes and were tapered to the back side of the bridge rail on the exposed end in the installation. The top rail tapered down 5 in. over a 22-in. length at a 4:1 taper rate, terminating behind the thrie-beam rail of the AGT.

The transition system successfully passed the small car and pickup truck full-scale crash tests required by MASH TL-3. The 1100C small passenger vehicle impacted the transition 5 ft upstream from the first bridge rail post, at an impact speed and angle of 61.5 mph and 25.6 degrees, respectively. The 2270P pickup truck impacted the transition 7.2 ft upstream from the first bridge rail post, at an impact speed and angle of 62.7 mph and 25.1 degrees, respectively. Minimal dynamic and permanent deformations were observed, which would not require repair after most impacts. The transition system was not tested in the reverse direction.

## 2.4 Oregon Two-Tube Side Mount Rail Transition

The Oregon Two-Tube Side Mount Rail Transition was a 31-in. tall thrie-beam transition connecting to a 32½-in. tall Two-Tube Side Mount Rail [17-18], as shown in Figure 10. The Oregon transition system consisted of nested 12-gauge thrie-beam rails supported by six W6x9 steel posts at quarter-post spacing. The bridge rail consisted of an HSS8x4x$^{5}/_{16}$ top rail and an HSS6x4x¼ lower rail supported by W6x25 steel posts spaced at 6 ft – 3 in. on-center. Drawing details for the transition and bridge rail are shown in Figures A-27 and A-28 of Appendix A.

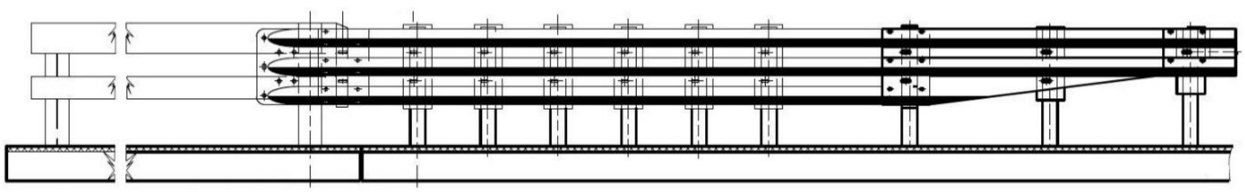


Figure 10. The Oregon Two-Tube Side Mount Rail and Transition [17]

The connection of the thrie-beam rail to the bridge rail consisted of a ½-in. guardrail connection plate mounted to the front face of the tube railings located at the first bridge rail post, as shown in Figure 11. The guardrail connection plate consisted of a 12-in. x 22-in. rectangular plate, a ⅜-in. stiffener on the back side of the plate, and a 4-in. x 3½-in. x ⅜-in. steel angle. The stiffener and angle were placed below the top railing and above the lower railing, respectively. No deflector plate was utilized between the middle tube railings. No crash test data was found on the transition to the Oregon Two-Tube Bridge Rail.

The thrie-beam terminal connector attached the guardrail connection plate to the bridge railings with six ⅞-in. diameter A325 bolts. The spliced connection between the nested thrie-beam rails and terminal connector was also connected to the ends of the bridge railings with a 3-in. x 4-in. x ¼-in. steel angle. The angle bolted to rail cap plates welded to the ends at the bridge railings. These $^{3}/_{16}$-in. rail cap plates utilized ⅝-in. welded studs for the guardrail connection.

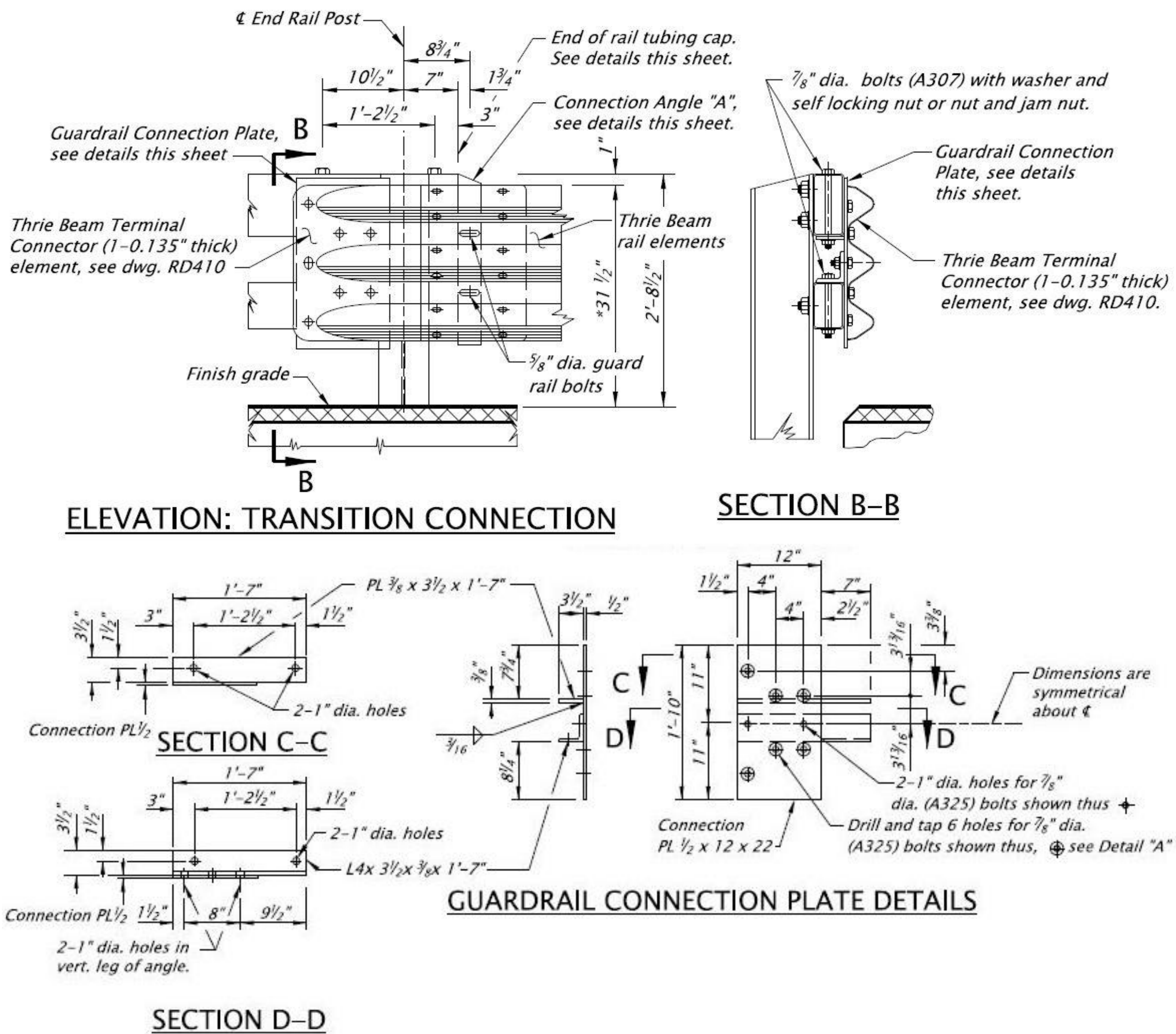



Figure 11. Oregon Transition Connection and Guardrail Connection Plate [17]

## 2.5 Alaska Multi State Thrie-Beam Transition

The Alaska Multi State Thrie-Beam Transition was a 31-in. tall thrie-beam transition connecting to the 34-in. tall Alaska Multi-State Bridge Rail [19-20], as shown in Figure 12. The Alaska transition system consisted of nested 12-gauge thrie-beam rails on six W6x9 steel posts at quarter-post spacing. The bridge rail consisted of an HSS8x4x$^{5}/_{16}$ top rail element and an HSS6x4x¼ lower rail element supported by W8x24 steel posts spaced at 10 ft – 4½ in. on-center. Both the transition and the bridge rail were successfully evaluated to NCHRP Report 350 TL-4 safety performance criteria [19-20]. Drawing details for the transition and bridge rail are shown in Figures A-29 through A-33 of Appendix A.

Figure 12. The Alaska Multi State Thrie-Beam Transition and Bridge Rail [19]

The Alaska transition connection was similar in design to the Illinois and Oregon AGT connections. The Alaska connection of the thrie-beam rail to the bridge rail consisted of a ½-in. guardrail connection plate mounted to the front face of the tube railings located at the first bridge rail post, as shown in Figure 13. The guardrail connection plate consisted of a 13½-in. x 22-in. rectangular plate, a ⅜-in. stiffener on the back side of the plate, and a 4-in. x 4-in. x ⅜-in. steel angle. The stiffener and angle were placed below the top railing and above the lower railing, respectively. No deflector plate was utilized between the middle tube railings.

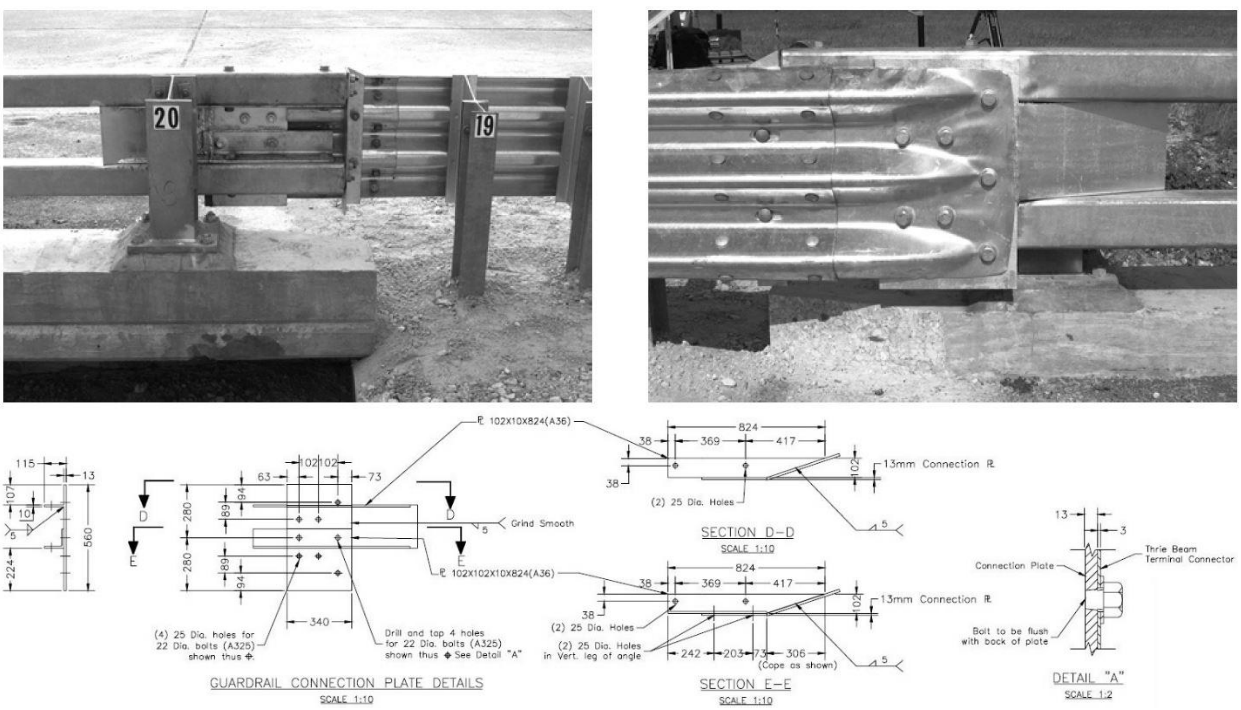



Figure 13. Alaska Guardrail Connection Plate [19]

The thrie-beam terminal connector mounted the guardrail connection plate to the bridge rail with seven ⅞-in. diameter A325 bolts. The spliced connection between the nested thrie-beam rails and terminal connector was also connected to the ends of the bridge railings with a 5-in. x 3-in. x ¼-in. steel angle, as shown in Figure 13. The angle bolted to rail cap plates welded to the ends at the bridge railings. These $^{3}/_{16}$-in. rail cap plates utilized ⅝-in. welded studs for the guardrail connection. A separate ½-in. deflector plate was welded to the rectangular plate and stiffener and was situated between the tube railings. This deflector plate tapered 4 in. to the backside of the railings over a 12-in. length at a 3:1 taper rate, which was designed to prevent snag at the connection in reverse-direction impacts. However, the transition system was never tested in the reverse direction.

The Alaska transition system was successfully crash tested with an 1,810-lb passenger car impacting the system at 62 mph at a 20-degree angle, a 4,410-lb pickup truck impacting the system at 62 mph at a 25-degree angle, and a 18,000-lb single-unit truck impacting the system at 50 mph at a 15-degree angle. The transition sustained minimal damage. However, structural damage was imparted to the bridge deck at the first bridge rail post in the single-unit truck test. The end of the curb at the edge of the bridge deck was cracked and pushed back ⅞ in. This transition system was never tested in the reverse direction. The Alaska Multi State Thrie-Beam Transition satisfied all NCHRP Report 350 TL-4 criteria.

## 2.6 California Type 115 Transition

The California Type 115 Transition was a 31-in. tall thrie-beam transition connecting to the 30-in. tall California Type 115 bridge rail [21], as shown in Figure 14. The Type 115 transition consisted of 10-gauge thrie-beam rails supported by three 6-ft long timber posts with wood blockouts spaced at 37½-in. on-center. The California Type 115 bridge rail featured two HSS4x4x¼ tube rails with W8x31 posts spaced at a minimum and maximum of 6 ft and 8 ft, respectively. The bridge rail met the AASHTO *Guide Specifications for Bridge Rails* PL-1 criteria [21]. The transition system failed to meet the intended PL-2 criteria but performed adequately for a PL-1 rating. Details for the transition and bridge rail are shown in Figures A-34 through A-36 of Appendix A.

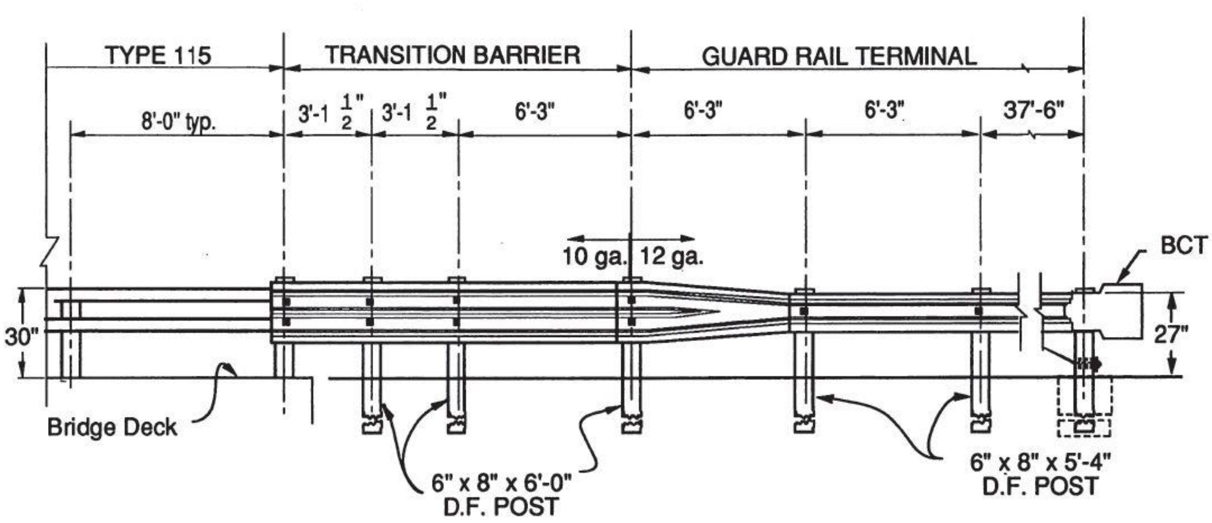



Figure 14. The California Type 115 Bridge Rail and Transition [21]

The thrie-beam transition barrier was attached to the Type 115 bridge rail with a 12-in. x 20-in. x ¼-in. steel plate. A 12-in. long HSS4x4x¼ structural steel tube was welded onto the plate. The flat side of the plate was bolted to the thrie beam. The side of the plate with the steel tube was fitted between the two tube railings on the Type 115 bridge rail and was bolted to the post, as shown in Figure 15.

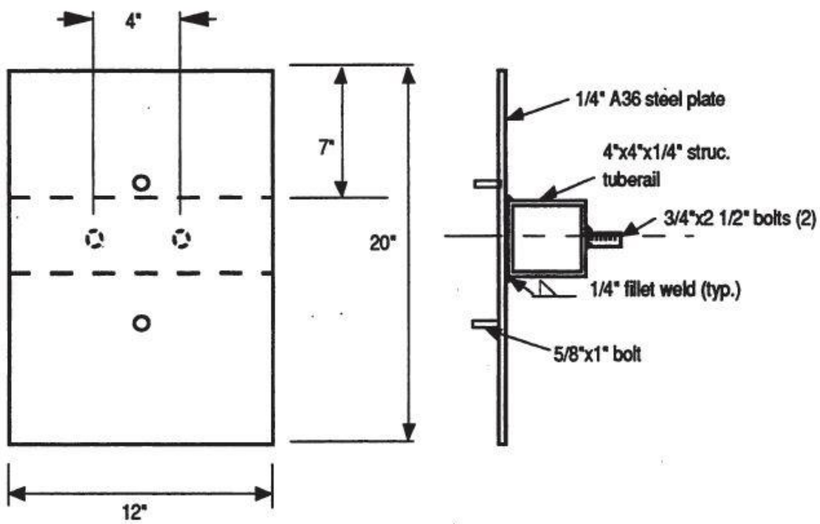



Figure 15. Transition to Type 115 Bridge Rail Connector [21]

There was one impact test on the Type 115 bridge rail transition. A 5,400-lb 1985 Chevy Custom Deluxe pickup truck impacted the transition and bridge rail connection at an AASHTO PL-1 impact speed and angle of 46.5 mph and 19.2 degrees, respectively. The pickup truck was redirected when some pocketing occurred upstream from the first transition post. The pocketing issue, in conjunction with wheel snag during two crash tests on the bridge rail, led to the recommendation that the Type 115 transition and bridge rail only be used as a PL-1 rated system [21]. The transition system was never tested in the reverse direction. Furthermore, after considerations of the transition design, it was concluded that there may be issues with reverse-direction impacts. Therefore, the transition was recommended to not be used where impacts could occur in the reverse direction.

## 2.7 New Hampshire T2 Steel Bridge Rail Transition

The New Hampshire T2 Steel Bridge Rail Transition was a 32-in. tall thrie-beam transition connecting to the 34-in. tall T2 Steel Bridge Rail by a two-tube transition rail [22], as shown in Figure 16. The T2 transition consisted of nested 12-gauge thrie beam rails supported by seven 6-in. x 8-in. x 7-ft long wood posts spaced at 18¾ in. on-center and satisfied NCHRP Report 350 TL-3 testing criteria. Transition and bridge rail drawing details are shown in Figures A-37 and A-38 of Appendix A.

The bridge rail consisted of an HSS8x4x$^{5}/_{16}$ top rail element and an HSS4x4x¼ lower rail element supported by W6x25 steel posts spaced at 8 ft and was successfully crash tested by the New Hampshire Transportation Consortium to meet AASHTO PL-2 testing criteria [22], approximately equivalent to NCHRP Report 350 TL-4 requirements. A 7-in. tall simulated curb was installed throughout the transition and extended in front of the rail tubes by 6 in. and in front of the thrie-beam rail by 1¼ in.

Figure 16. The New Hampshire T2 Steel Bridge Rail and Transition [22]

The connection of the thrie-beam rail to the steel-tube bridge rail consisted of two tube transition rails of the same tubular elements used in the bridge rail by means of a ½-in. guardrail connection plate mounted to the front face of the tube railings, as shown in Figure 17. The guardrail connection plate consisted of a 20-in. x 27-in. x ½-in. rectangular plate with clipped corners on the downstream end of the plate. A separate ½-in. thick deflector plate was bolted to the middle of the connection plate and tapered 3-in. to the backside of the railings over a 6-in. length at a 2:1 taper rate, designed to prevent snag at the connection in reverse-direction impacts. However, the transition system was never tested in the reverse direction.

The guardrail connection plate was bolted to the ends of the two tube transition rails and to the first adjacent AGT post. The thrie-beam terminal connector mounted the guardrail connection plate to the bridge railings with eight ⅞-in. diameter, high-strength bolts. The spliced connection between the nested thrie-beam rails and terminal connector was connected to the first adjacent AGT post using two ⅝-in. diameter standard guardrail bolts.

The transition system was successfully crash tested with a 4,410-lb pickup truck impacting the transition connection 67 in. upstream from the first bridge rail post at an impact speed and angle of 63.6 mph and 24.9 degrees, respectively. Moderate damage was imparted to the rail in the form of deformations to the lower two corrugations.

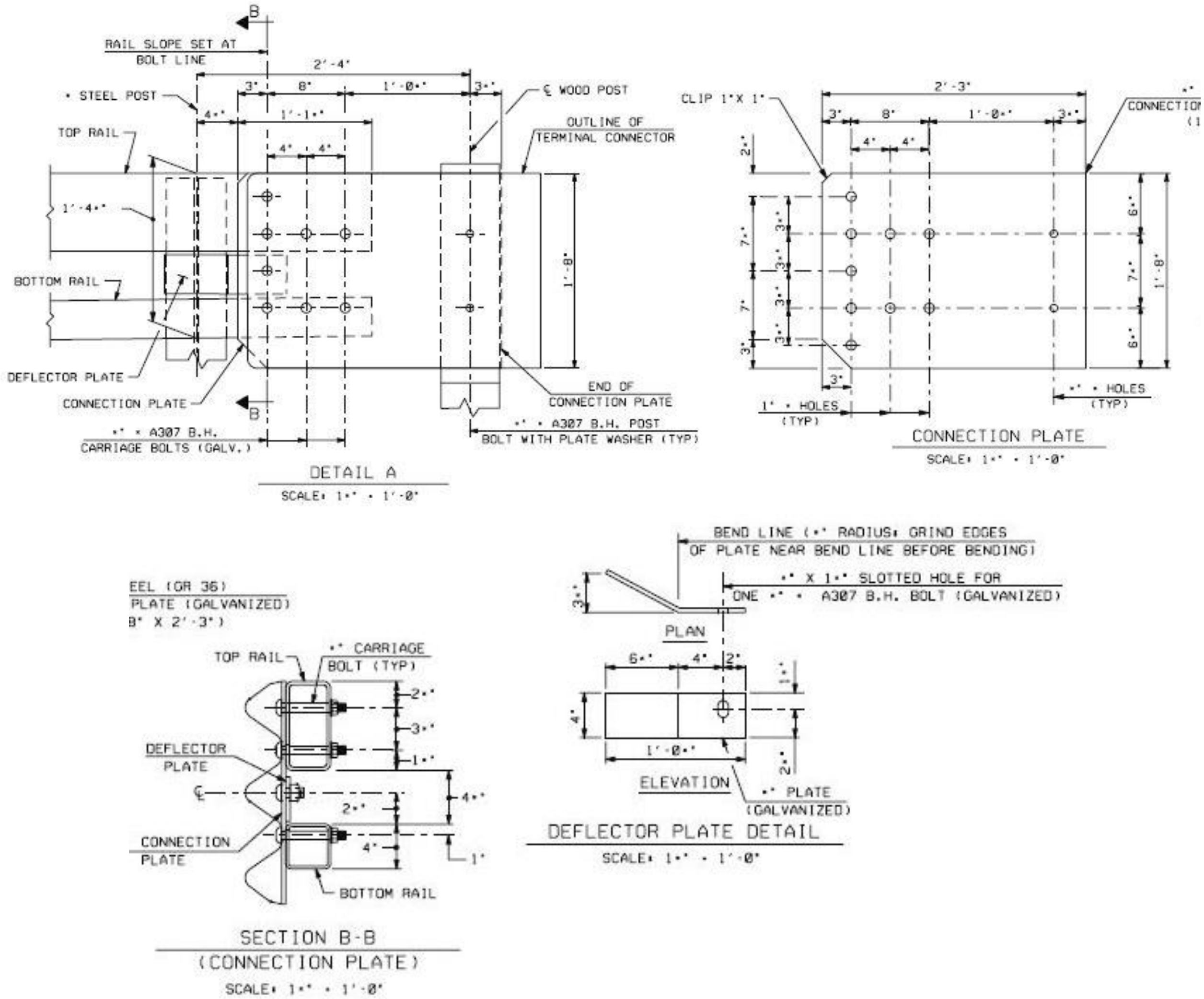



Figure 17. NH T2 Transition Guardrail Connection Plate [22]

## 2.8 Wisconsin Thrie-Beam Transition

The Wisconsin Thrie-Beam Transition was a 31½-in. tall transition connecting to the 42-in. tall Type "M" Tubular Steel Bridge Rail [23], as shown in Figure 18. The transition system consisted of nested 12-gauge thrie-beam rails supported by six 6-in. x 8-in. x 7-ft long wood posts at quarter-post spacing and satisfied NCHRP Report 350 TL-3 testing criteria. The bridge rail consisted of an HSS5x4x¼ top rail element and HSS5x5x¼ middle and lower rail elements supported by W6x25 steel posts spaced at 6 ft – 6 in. and was successfully crash tested to meet NCHRP Report 350 TL-4 testing criteria [23]. Drawing details for the transition and bridge rail are shown in Figures A-39 and A-40 of Appendix A.

Figure 18. Wisconsin Thrie-Beam Transition and Type "M" Steel Tube Bridge Rail [23]

The connection of the thrie-beam rail to the bridge rail consisted of a back-up plate and an anchor plate, as shown in Figure 19. The ½-in. back-up plate consisted of a 22-in. x 20-in. section mounted to the front face of the middle tube railings of the bridge rail with clipped corners on the downstream side of the plate. The back-up plate tapered back 5 in. between the lower railings over a 20-in. length at a 4:1 taper rate and was bolted to the back side of the tube railings. This tapered back section of the back-up plate was designed to prevent vehicle snag in reverse-direction impacts. However, the transition system was never tested in the reverse direction.

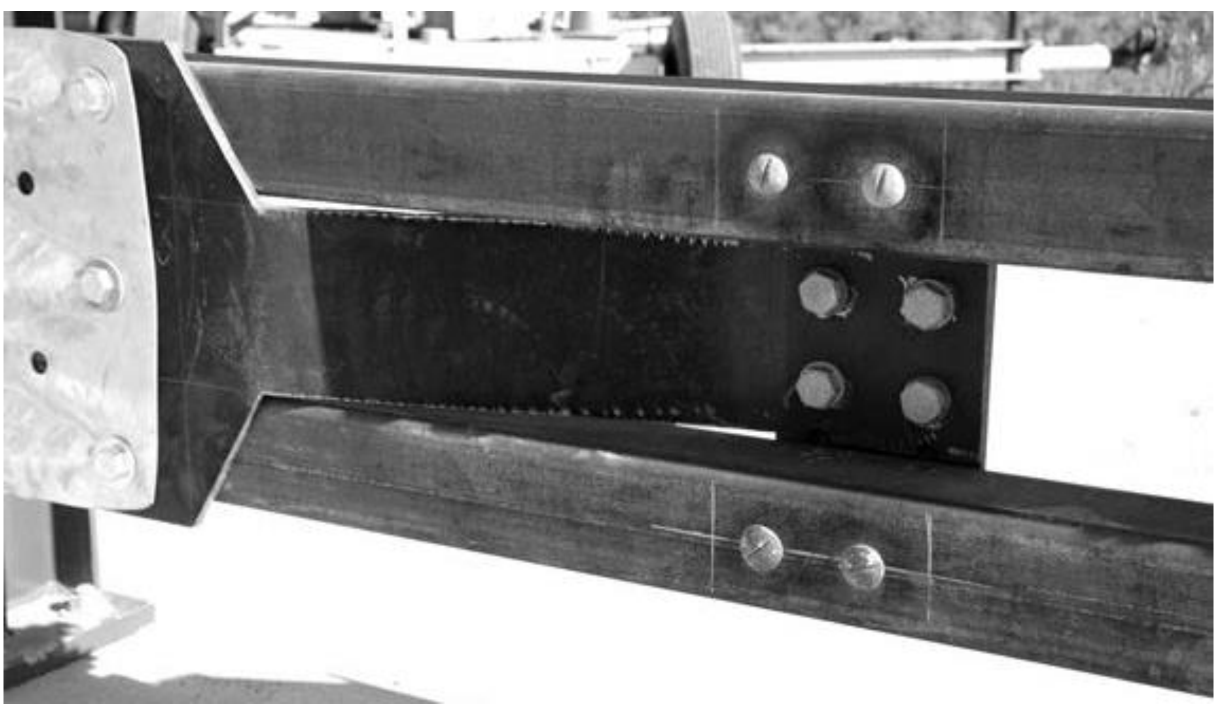


Figure 19. Wisconsin Back-Up Plate [23]

The thrie-beam terminal connector was connected to the back-up plate and the lower tube railings with five ⅞-in. diameter x 7-in. long high-strength bolts and two ⅞-in. diameter x 1½-in. long threaded shop welded studs. At the last bridge rail post, the HSS5x4x¼ top rail element tapered down 12 in. over a 24-in. length at a 2:1 slope and was welded to the top of the middle tube railing. Termination of both the tapered top rail element and the ends of the middle and lower rail elements was situated behind the thrie-beam rail 18 in. downstream from the first guardrail post.

The transition system was successfully crash tested with a 4,410-lb pickup truck impacting the system at a speed and angle of 62.6 mph and 25.2 degrees, respectively. The transition was impacted 82 in. downstream from the first bridge rail post. No snagging or vehicle instability occurred during the impact event. As previously noted, the transition system was never tested in the reverse direction.

### 2.9 TL-4 Bridge Rail and Transition for Transverse Glulam Decks

The TL-4 AGT was a 31-in. thrie-beam system connected to a 36-in. tall TL-4 thrie-beam and steel tube bridge railing [24], as shown in Figure 20. The transition system consisted of 10-gauge thrie-beam supported by five W6x15 posts spaced at 37½ in. on-center and was developed to satisfy NCHRP Report 350 TL-4 criteria. The thrie-beam bridge rail consisted of 10-gauge thrie-beam rail and an HSS8x3x$^{3}/_{16}$ upper tube rail supported by W6x15 posts spaced at 8 ft on-center and was successfully crash tested to meet NCHRP Report 350 TL-4 criteria [24]. The bridge rail was anchored to a 5⅛-in. thick transverse glulam timber deck with a 2-in. wearing surface.

Figure 20. TL-4 Thrie-Beam Bridge Rail and AGT for Timber Decks [24]

Within the bridge rail section, the upper tube rail was attached to the top of the steel spacer blocks. At the connection of the AGT to the bridge rail, the upper tube rail was flared back 8 in. over a 32-in. length at a 1:4 ratio to connect on top of the first transition post. The upper tube was attached to the top of the first transition post and then sloped down 8 in. over a 24-in. length at a

1:3 ratio to attach to the tube rail terminator connection to the second transition post. These lateral and vertical tapers are shown in Figure 21.

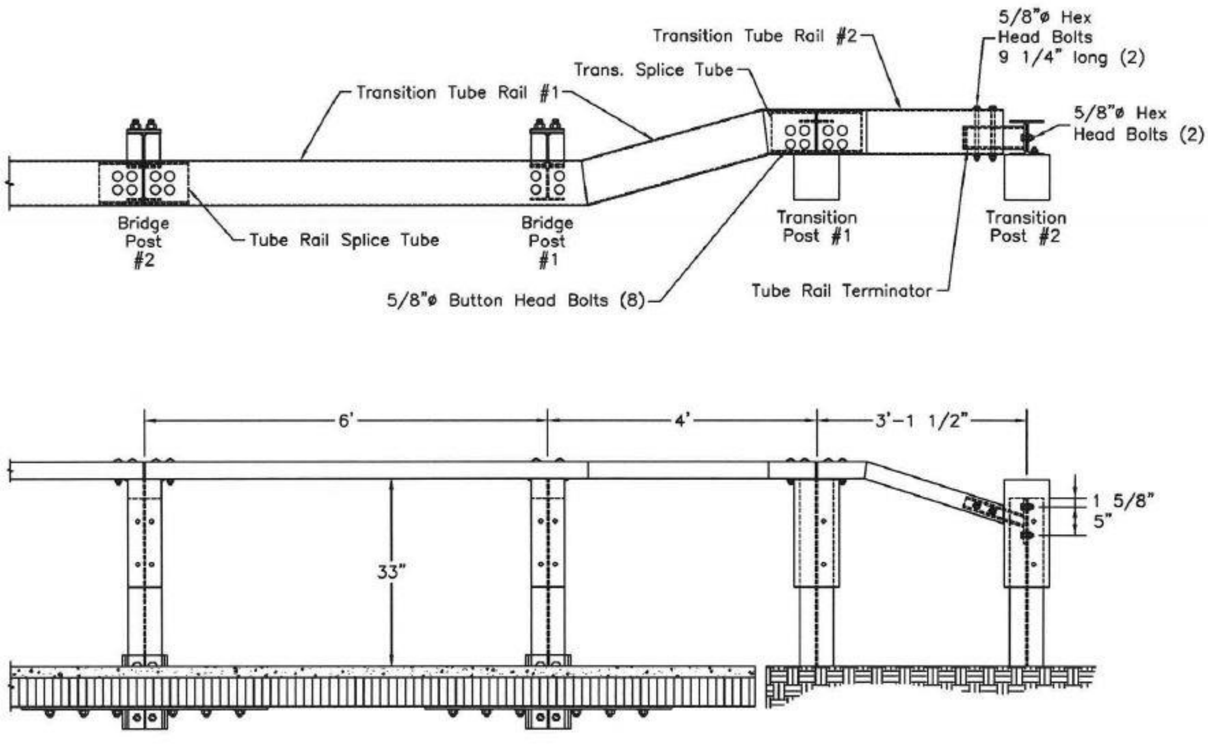



Figure 21. Top Bridge Rail Transition Details [24]

The transition system was successfully crash tested with a pickup truck and a single-unit truck. The 4,396-lb pickup truck impacted the transition 5.7 ft upstream from the first bridge rail post at an impact speed and angle of 58.2 mph and 25.5 degrees, respectively. The 17,650-lb single-unit truck impacted the transition 7.8 ft upstream from the first bridge rail post at an impact speed and angle of 50.8 mph and 15.2 degrees, respectively. In the analysis of the test results from both crash tests, Midwest Roadside Safety Facility (MwRSF) determined that the transition system adequately contained and redirected the vehicles with controlled lateral displacements of the guardrail transition.

# 3 APPROACH GUARDRAIL TRANSITION CONNECTION DESIGN

## 3.1 Design Criteria

The intent of the research project was to develop a transition between MGS and the newly developed Ohio/Illinois steel-tube bridge rail. Although the bridge rail was developed to be MASH TL-4 compliant, the AGT was only required to satisfy MASH TL-3 criteria. Note that MGS installations adjacent to the bridge rail are also MASH TL-3 systems. Thus, the transition from TL-3 to TL-4 would occur downstream from the first bridge post. To satisfy MASH TL-3 criteria, the AGT must provide sufficient lateral strength to redirect passenger vehicles and be configured with a geometry to prevent vehicle snag.

Additionally, the AGT must be crashworthy before and after roadway overlays. The TL-4 steel-tube bridge railing was designed to remain MASH crashworthy after overlays up to 3 in. thick. Thus, it was desired for the AGT to remain crashworthy after roadway overlays without adjusting the bridge rail or the adjacent AGT.

Finally, it was desired to maximize the longitudinal distance between the adjacent transition and bridge rail posts (i.e., between the last transition post and first bridge rail post, or between the first transition post and last bridge rail post). Maximizing this longitudinal distance helps to avoid installation issues adjacent to the bridge end where abutments, bents, or wing walls could prevent post placement. Often, bridge rails in both Illinois and Ohio must incorporate a top-mounted end post to aid in connecting bridge rails to the adjacent approach guardrails, as shown in Figure 22. Eliminating the need for this end post would reduce hardware and simplify installation.

Figure 22. Top-Mounted Bridge Rail End Post

### 3.2 Base AGT Configuration

MASH AGTs typically follow one of two different post-spacing configurations near the bridge end for connecting the thrie-beam rail: (1) a ¼-post spacing configuration, which incorporates W6x9 steel posts at 18¾ in. on-center or (2) a ½-post spacing configuration, which incorporates W6x15 posts at 37½ in. on-center, as shown in Figure 23. The ½-post spacing configuration was viewed as the more desirable AGT layout as it would allow greater distance between the adjacent transition and bridge rail posts.

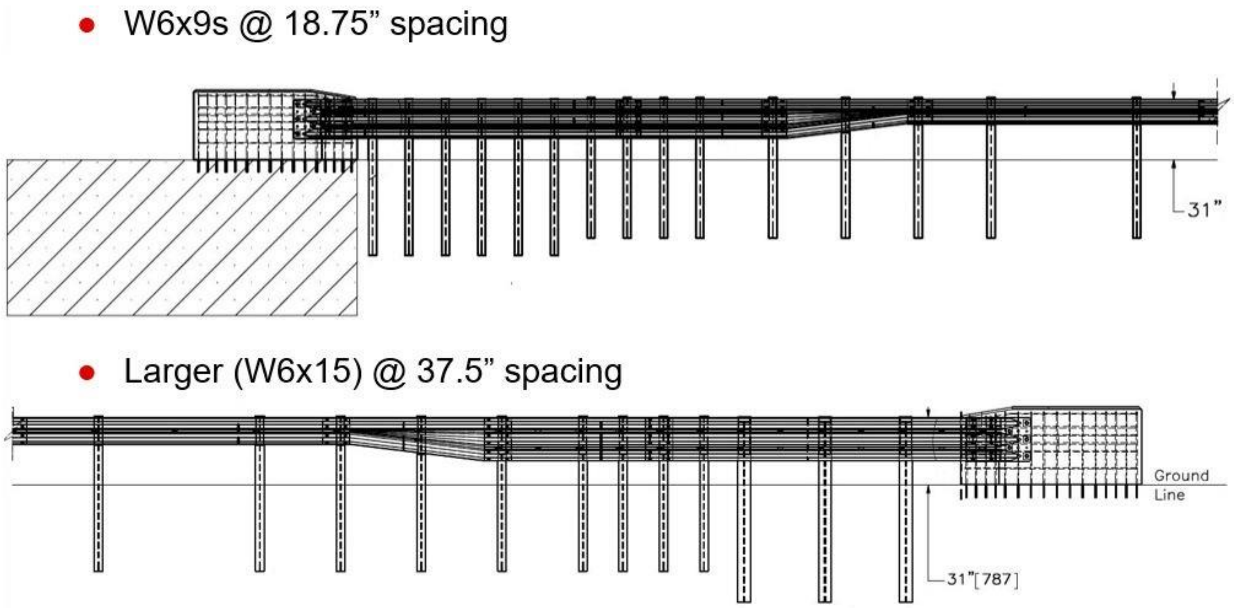



Figure 23. AGT Post Spacing Configuration

Historically, thrie beam AGTs have been designed, evaluated, and installed with 31-in. top mounting heights. Unfortunately, roadway overlays reduce the effective height of the guardrail relative to the new roadway surface unless milling or grinding of the roadway occurs in conjunction with the resurfacing. Although limited research exists on AGTs with lower heights, full-scale crash testing on the upstream end of an AGT, which had stiffened W-beam rail mounted at a 27.75-in. height, resulted in the rollover of a 2000P pickup truck [25]. The reduced guardrail height coupled with the increase in barrier stiffness caused the high center-of-mass vehicle to roll toward the system. Thus, an AGT with an effective height below 31 in. is not recommended without further evaluation.

Since the new AGT was desired to be crashworthy even after placement of a 3-in. thick roadway overlay, the height of the AGT needed to be raised above the standard 31 in. A 34-in. top mounting height was recommended so that the thrie beam rail would be reduced to the standard 31 in. height after a 3-in. overlay, as shown in Figure 24. Note that the same 3-in. increase in top mounting height was incorporated into the design of the new bridge rail, which brought its height to 39 in. from a nominal height of 36 in.

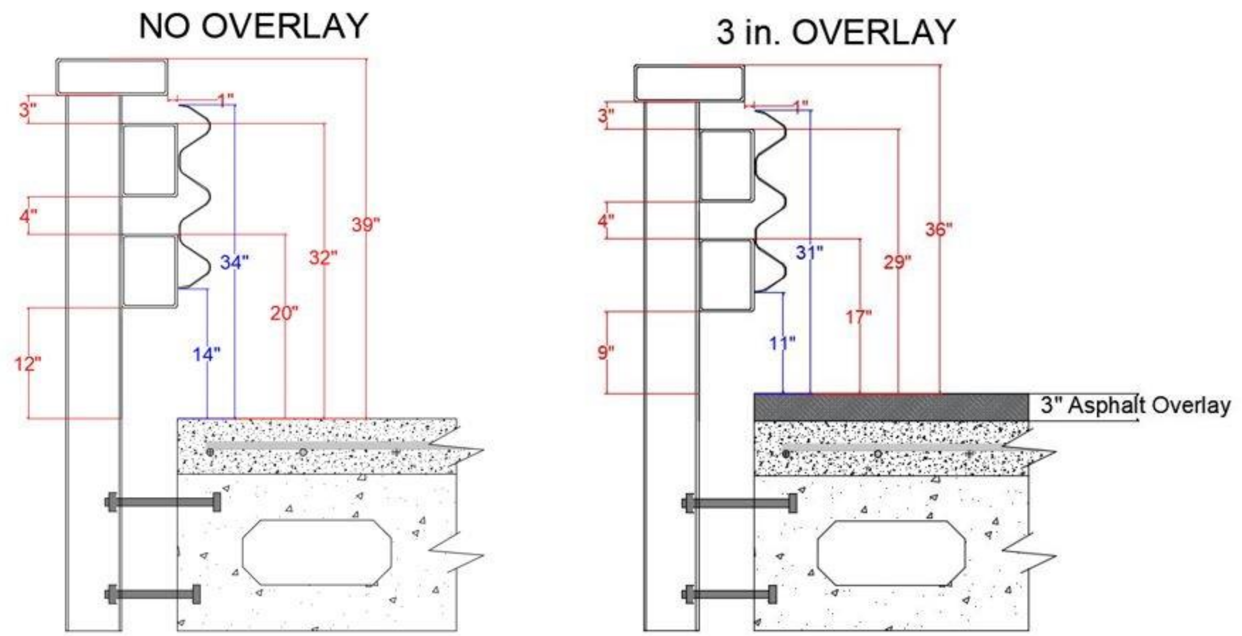



Figure 24. Transition Top Mounting Height

One AGT system was developed with a ½-post spacing configuration, a 34-in. top mounting height, and has satisfied MASH TL-3 evaluation criteria. The Nebraska DOT specifically developed a 34-in. tall AGT, shown in Figure 25, to be crashworthy before and after placement of a 3-in. thick roadway overlay, thus matching the desired criteria for the new AGT [26]. Although the 34-in. AGT was developed for use with a standardized concrete buttress, the connection hardware could be modified to attach to the TL-4 steel-tube bridge railing. Therefore, the Nebraska DOT's 34-in. tall AGT was selected as the base configuration for the new AGT to steel-tube bridge railing.

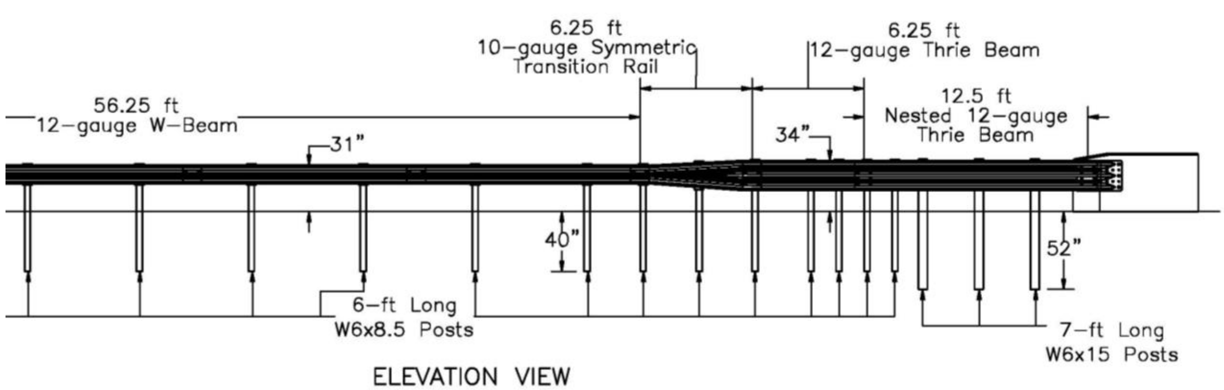



Figure 25. Nebraska DOT's 34-in. Tall AGT [26]

## 3.3 Termination of Top Tube Rail

Due to the height of the new bridge railing, efforts were made to reduce the propensity for snag during impact events by safely terminating the top bridge railing. From the literature review, it was observed that steel bridge rail systems with similar geometric sections and rail heights as the new MASH TL-4 steel-tube bridge rail terminated the top bridge railing behind the AGT thrie-beam rail. For example, the Wisconsin Thrie-Beam Transition, shown previously in Figure 18, had the top railing angled downward at a 2:1 slope and was welded onto the top of the middle railing.

A similar approach was taken for terminating the top HSS12x4x¼ railing of the MASH TL-4 steel-tube bridge rail. A top railing assembly was designed featuring a downward sloped end that was welded to a bent plate. The top railing was to be angled downward at a 2H:1V slope and terminated ½ in. from the end of the middle railing to allow for weld space. The bent plate fit over the top and back surfaces of the middle rail, and two ¾-in. diameter bolts were used to attach the plate to the middle rail. Note that the same bolts were used to attach the middle and lower rails to the bridge posts. This concept for safely terminating the top rail is shown in Figure 26.

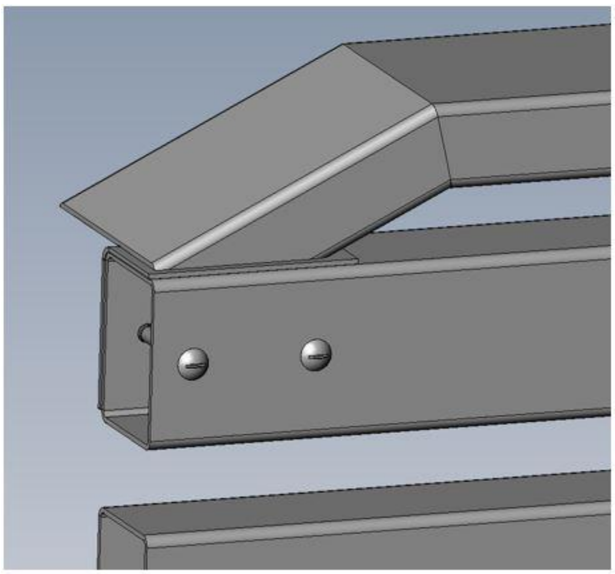
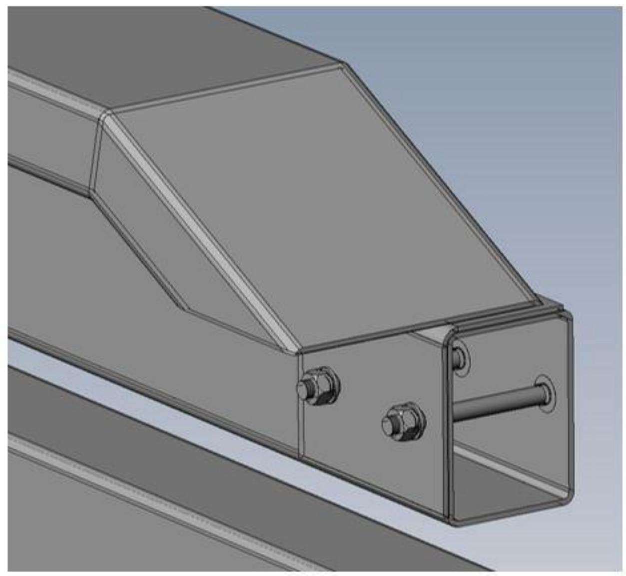



Figure 26. Termination of Top Bridge Railing

### 3.4 Vehicle Snag

Vehicle snag was a concern for impacts at the connection in both the conventional and reverse directions. For conventional impacts with the vehicle traveling toward the bridge rail, the potential for snag arises from height differences between the thrie-beam guardrail and the steel tube rails. Vehicle components snagging on the exposed ends of the tube rails could lead to excessive decelerations, occupant compartment crush, or vehicle instabilities. Therefore, a smooth height transition was needed to prevent snag. A 3H:1V taper was recommended for height transitions between the lower two tube rails and the thrie-beam guardrail. The 1V:3H rate was based on the performance of guardrail connection plates observed in the literature review.

Additionally, tires from an impacting vehicle could extend under the lower tube rail and snag on a bridge post. Minor tire snag was observed during full-scale testing of the new TL-4 steel-tube bride rail, but not enough to negatively affect the performance of the bridge rail. However, the nested thrie-beam rails of the AGT provided much less bending strength as compared to the tube rails, which could lead to increased system deflections, pocketing and/or snag. To limit system deflections and the potential for snag or pocketing, it was recommended that the bridge tube rails be extended as far upstream as possible and be terminated near the first transition post.

For reverse-direction impacts, vehicle snag could occur on the thrie-beam terminal connector between the middle and lower tube rails or on the top tube rail as it sloped downward to meet the middle tube rail. Designs found during the literature review often included a sloped face component between tube rails and adjacent to the terminal connector. This sloped face would push vehicle components out from between the tube rails to prevent snagging on the downstream edge of the terminal connector. Although none of the previous designs were crash tested with reverse-direction impacts, the concept showed promise for snag mitigation.

## 3.5 Design Concepts

The 34-in. tall thrie-beam terminal connector could not be easily bolted to the bridge rail using the standard five-bolt pattern. Several bolts were located at the top or bottom of the tube rails, as shown in Figure 27, which prevented a simple bolted connection. Thus, a unique solution was required to complete the connection for the new AGT. Two concepts were explored as possible solutions. The first included a connection assembly plate that sloped downward from the terminal connector to match the heights of the transition tube rails, while the second included modified tube rails that tapered upward to match the height of the thrie beam. These concepts are briefly discussed in the following sections.

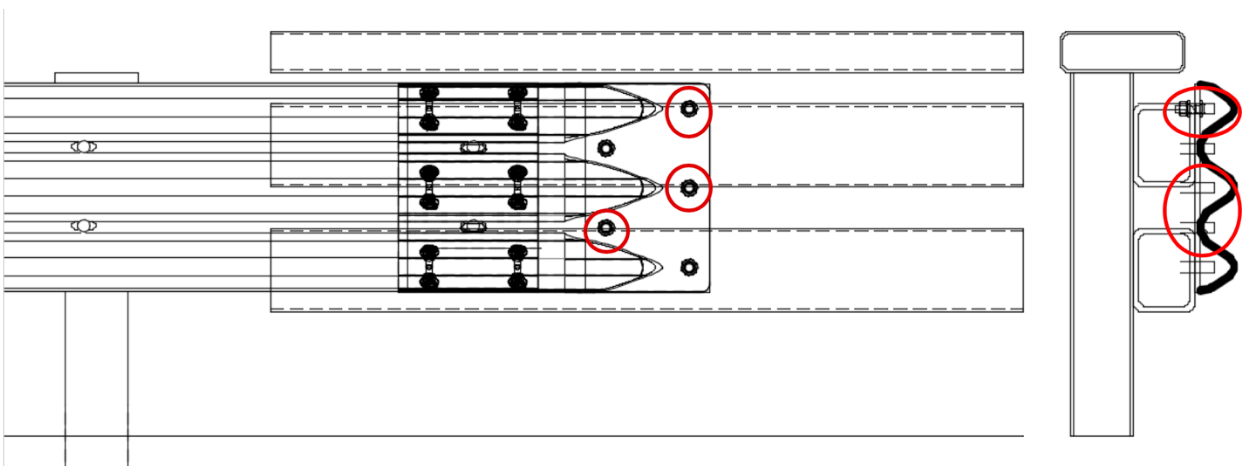


Figure 27. Thrie-Beam Rail Misaligning with Bridge Rail

### 3.5.1 Concept #1: Connection Assembly

The connection assembly featured a built-up assembly of plates and stiffeners that allowed the AGT thrie-beam terminal connector to connect to the end of the bridge rail, as shown in Figure 28. The terminal connector bolted to the front face of the connection assembly. Horizontal stiffeners were welded to the back side of the connection assembly to increase the bending capacity of the assembly and reduce the propensity for hinging at the connection during impact. All horizontal stiffeners were one piece with the same $^{5}/_{16}$-in. thickness. The vertical stiffeners served as bracing of the built-up assembly and offered additional bending capacity. All vertical stiffeners were independent stiffeners with a thickness of $^{3}/_{16}$ in.

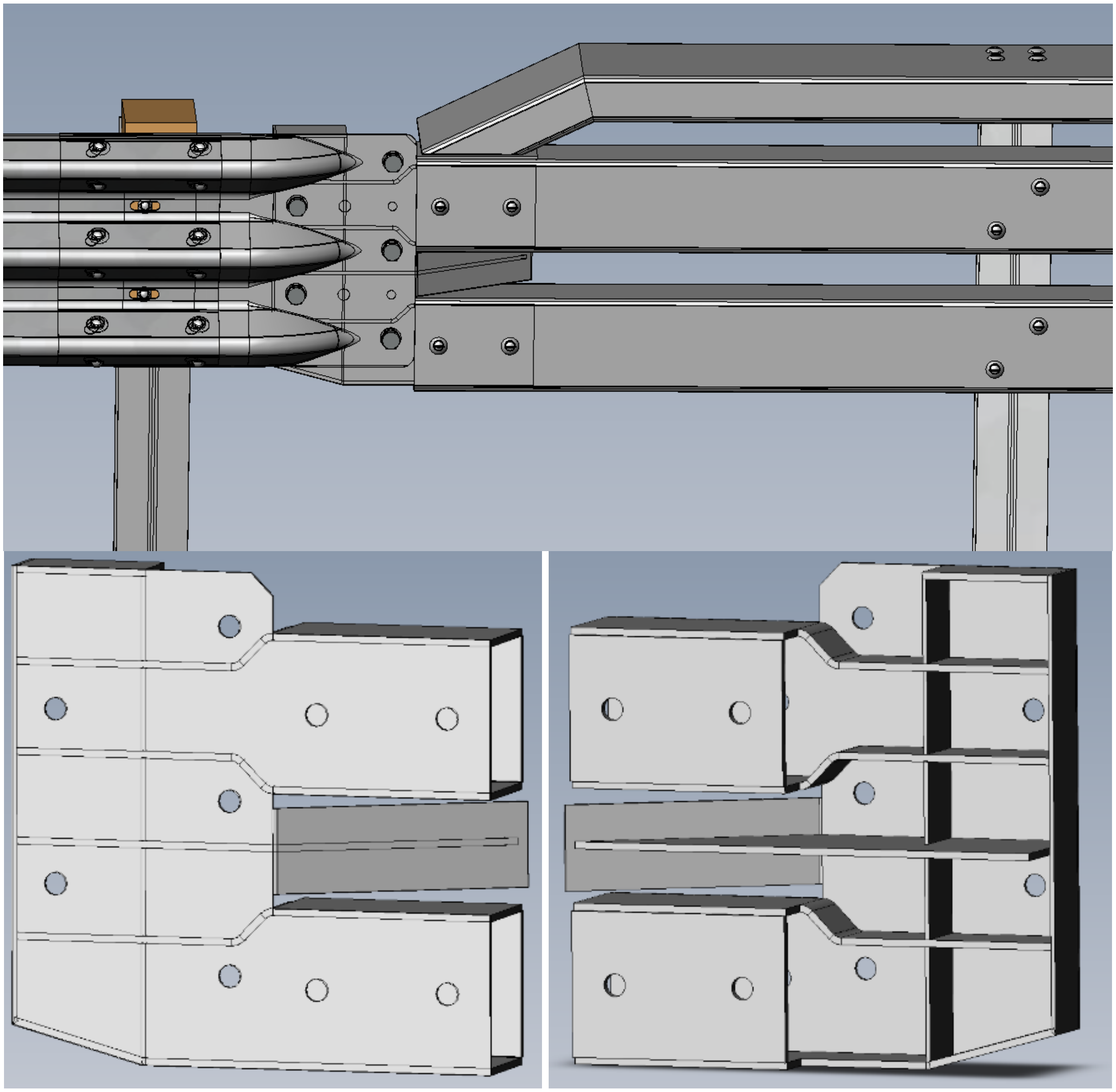


Figure 28. Concept #1: Connection Assembly

The use of horizontal and vertical stiffeners to increase the bending capacity of the connection assembly was derived from terminal connector plates utilized in New Jersey shaped concrete barriers that featured a sloped face, as shown in Figure 29. The connector plate allowed the terminal connector of an adjacent AGT thrie-beam rail to connect to the sloped face of the concrete barrier.

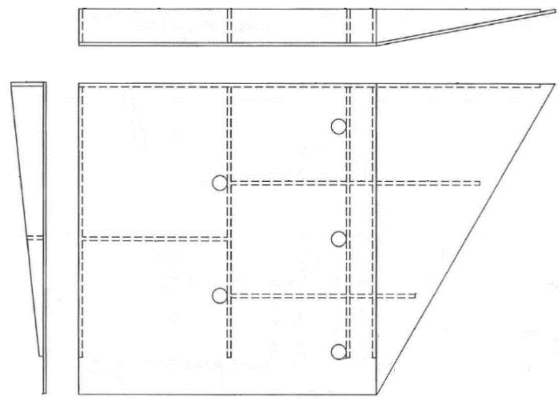


Figure 29. Terminal Connector Plate for New Jersey Shaped Barriers

The connection assembly attached to the ends of the bridge rail through built-up plates that acted as tube splices and were inserted into the middle and lower tube railings, as shown in Figure 30. The tube splice inserts were flush with the inner front face of the tube railings.

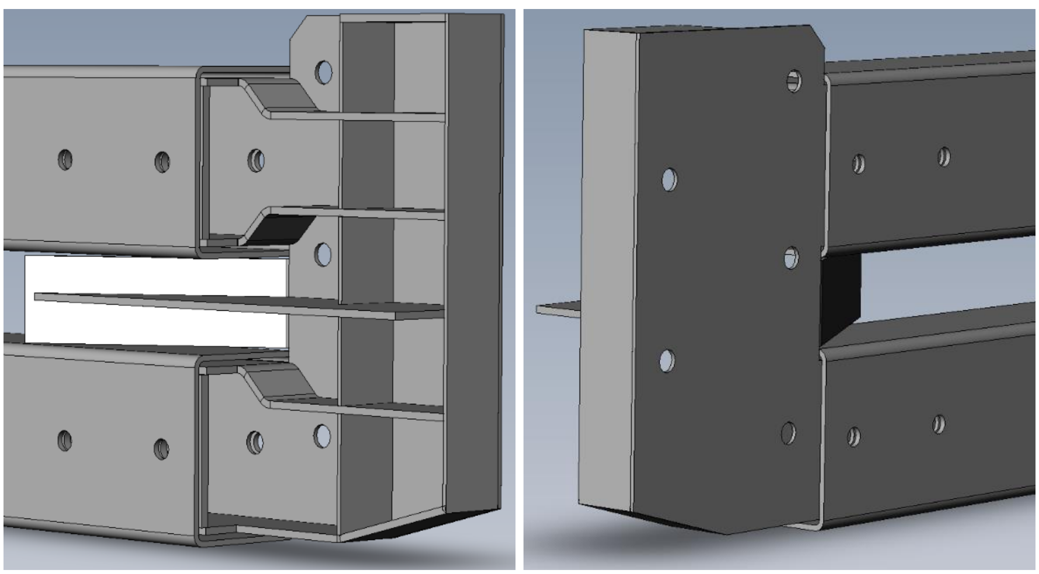


Figure 30. Connection Assembly Attached to the Bridge Rail

### 3.5.2 Concept #2: Continuous Transition Tubes

A second concept was developed which connected the terminal connector directly to the HSS tubes with the same sections as the bridge rail. The lower two HSS8x6x¼ tube rails within the bridge rail had top heights of 32 in. and 20 in. Specialized HSS8x6x¼ transition tubes were fabricated with an angled middle section that sloped up at a 6H:1V rate to achieve top heights of 34 in. and 22 in. and aligned with the top and bottom of the terminal connector, as shown in Figure 31.

A 9-ft span from the final AGT post to the first bridge rail post was selected. The transition tubes extended to 12 in. from the centerline of the last AGT post to provide a stiff section throughout the transition. The thrie-beam terminal connector bolted directly to the transition tubes, and one additional HSS6x4x¼ tube was sandwiched between the middle and lower transition tubes to provide a connection for all five terminal connector bolts. The downstream face of this additional tube was tapered back laterally to prevent reverse-direction snag on the terminal connector.

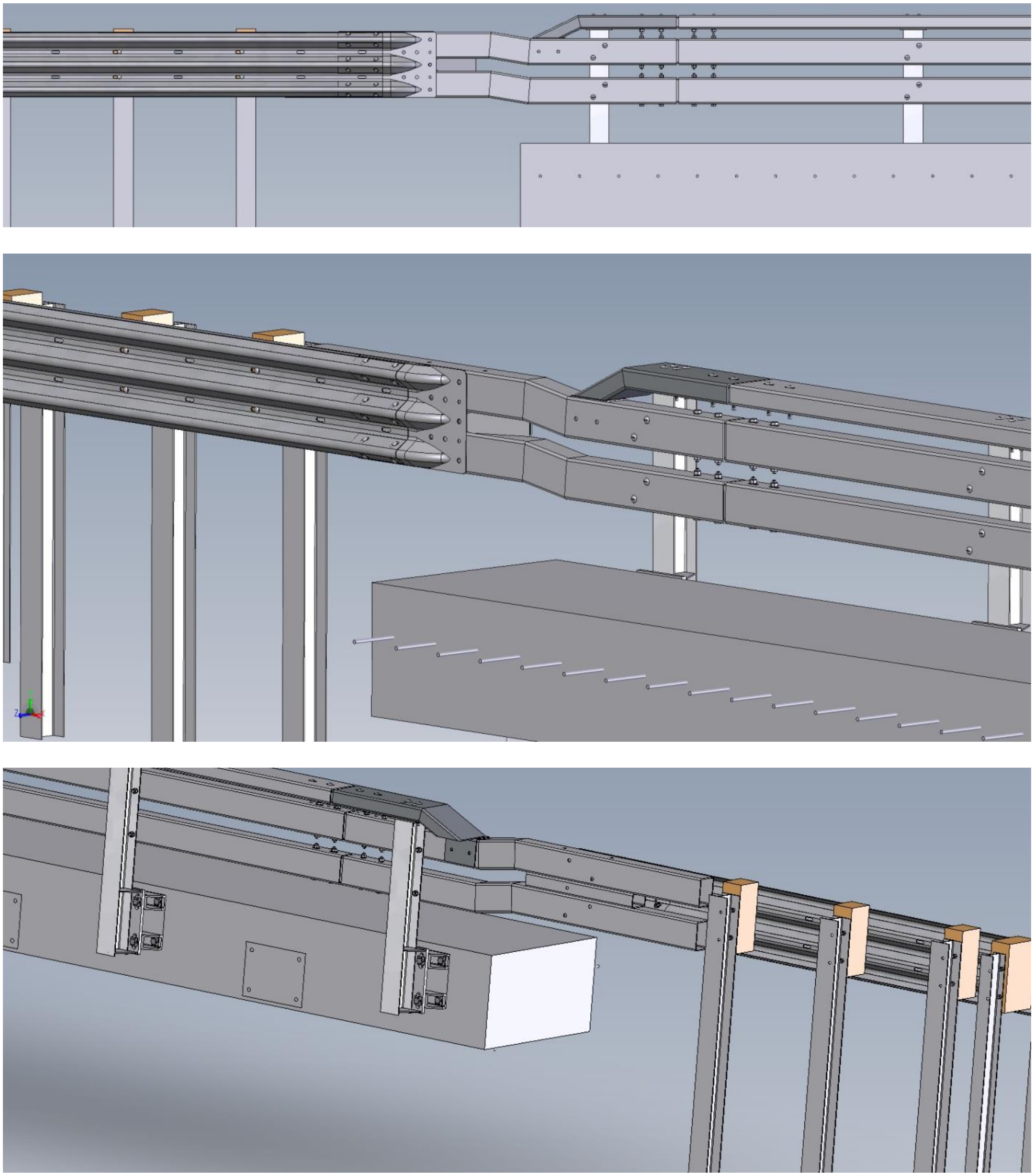


Figure 31. Concept #2: Continuous Transition Tubes

# 4 LS-DYNA MODEL DEVELOPMENT

The two transition concepts were evaluated using LS-DYNA finite element software [27] to evaluate the feasibility of each concept, assist in the design, and to select CIPs for the full-scale crash testing effort.

## 4.1 Development of the AGT model

An LS-DYNA model of an AGT consisting of a trailing end anchor, MGS, thrie-beam approach guardrail transition, and the standardized concrete buttress had been previously developed [28]. The LS-DYNA model was validated against test no. AGTB-2 on the approach guardrail transition [28-29]. This model was modified to utilize the post sections and spacing and a top rail height of 34 in. as was used in test nos. 34AGT-1 and 34AGT-2 [26], shown in Figure 32. The total system length of the LS-DYNA model was 6.25 ft shorter than length of the actual test installations, which was due to a shorter length of MGS being placed upstream of the MGS. Thus, the LS-DYNA model had 18 posts, while the test installations for test nos. 34AGT-1 and 34AGT-2 utilized 19 posts.

Two vehicle models were used in the simulations. A Dodge Ram pickup truck vehicle model was originally developed by the Center for Collision Safety and Analysis Team at George Mason University [30] and was modified by MwRSF personnel for use in roadside safety applications. A model of a 2010 Toyota Yaris was originally developed by the National Crash Analysis Center at the George Washington University and was modified by MwRSF personnel for use in roadside safety applications [31].

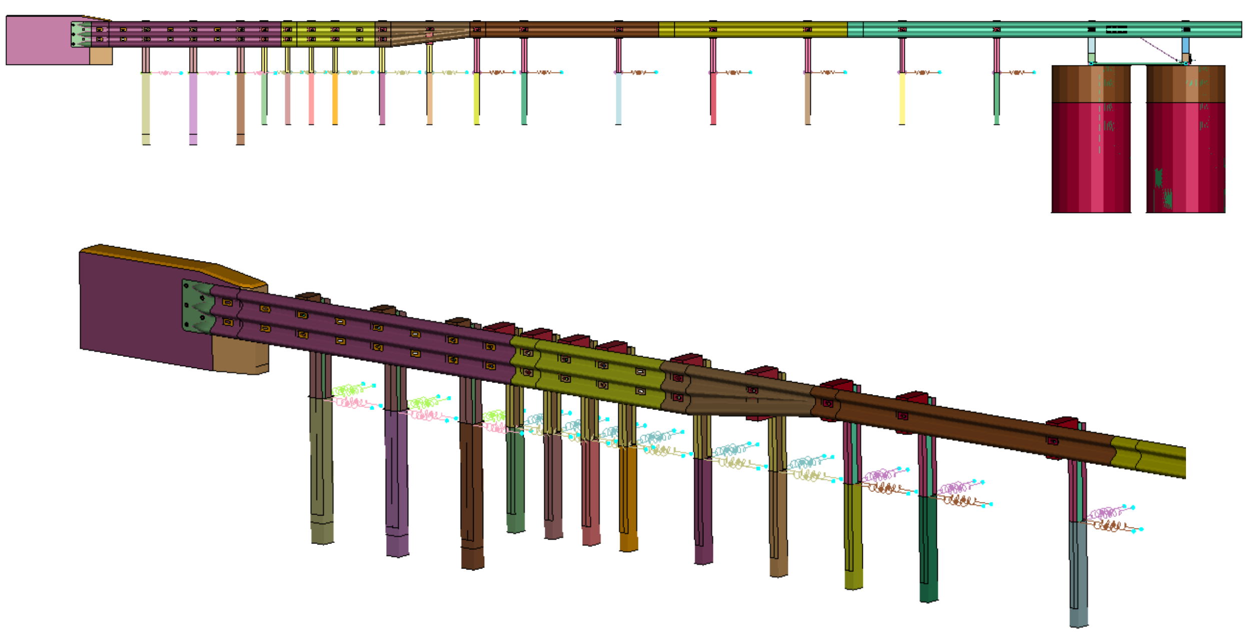


Figure 32. 34-in. Tall Approach Guardrail Transition Model

Although a complete model validation was not conducted, several key parameters were compared between test nos. 34AGT-1 and 34AGT-2, including occupant impact velocities (OIVs), occupant ridedown accelerations (ORAs), angular displacements, and dynamic deflections. A comparison of results between the simulations and test nos. 34AGT-1 and 34AGT-2 are shown in Tables 1 and 2, respectively. The metrics compared very well for the pickup truck (test no. 34AGT-1), with the simulation overpredicting longitudinal OIV and lateral ORA. However, the metrics did not compare well with the small car (test no. 34AGT-2) as the simulation overpredicted longitudinal OIV, longitudinal ORA, pitch, and dynamic deflection but underpredicted lateral ORA and roll. However, the general behavior of the small car was reasonable. Since the pickup truck simulation compared well with test no. 34AGT-1, the transition model was utilized for this study. However, the areas where the model did not compare well for both the pickup truck and small car simulations were taken into account when utilizing the model to evaluate AGT configurations as part of this study.

Table 1. Comparison of Test No. 34AGT-1 and Simulation

| Evaluation Criteria | | Test No. 34AGT-1 | Simulation (34agt1-v11) | MASH 2016 Limits |
|---|---|---|---|---|
| OIV ft/s | Longitudinal | -20.2 | -27.2 | ±40 |
| | Lateral | 25.9 | 25.4 | ±40 |
| ORA g's | Longitudinal | -10.8 | -10.2 | ±20.49 |
| | Lateral | 8.9 | 11.9 | ±20.49 |
| Maximum Angular Displacement deg. | Roll | 12.0 | 8.3 | ±75 |
| | Pitch | 4.4 | 5.1 | ±75 |
| | Yaw | 38.9 | 39.7 | N/A |
| Maximum Dynamic Deflection in. | | 7.8 | 7.7 | N/A |
| Maximum Dynamic Deflection Location | | $2^{nd}$ to last AGT post | $2^{nd}$ to last AGT post | N/A |

N/A = not applicable

Table 2. Comparison of Test No. 34AGT-2 and Simulation

| Evaluation Criteria | | Test No. 34AGT-2 | Simulation (34agt2-v3) | MASH 2016 Limits |
|---|---|---|---|---|
| OIV ft/s | Longitudinal | -6.9 | -10.1 | ±40 |
| | Lateral | 10.0 | 9.7 | ±40 |
| ORA g's | Longitudinal | -10.8 | -19.9 | ±20.49 |
| | Lateral | 14.7 | 11.3 | ±20.49 |
| Maximum Angular Displacement deg. | Roll | -10.0 | 6.9 | ±75 |
| | Pitch | -5.5 | 17.6 | ±75 |
| | Yaw | 94.9 | 61.0 | N/A |
| Maximum Dynamic Deflection in. | | 2.7 | 5.2 | N/A |
| Maximum Dynamic Deflection Location | | Last AGT post | Last AGT post | N/A |

### 4.2 Development of IL-OH Bridge Rail Model

A bridge model with 7 posts and 6 rail spans was also created, as shown in Figure 33. For evaluation of the two transition concepts, minimal vehicle interaction with the bridge rail was anticipated. Thus, the full bridge rail model was not validated against test nos. STBR-2 through

STBR-4 [6-7]. It was most important for the bridge rail posts to have accurate deflection behavior, as the impacting vehicle may contact and snag on the bridge rail posts. Therefore, the bridge rail posts and post connection, as shown in Figure 34, were previously modeled and validated by Mauricio, et al. [8-9]. The rails were created from shell elements with material properties consistent with the ASTM A500 steel material. The rail-to-splice and rail-to-post bolts were simulated with constrained nodal rigid bodies. The concrete bridge deck was not modeled, and the embedded plate on the bridge rail posts was rigid and constrained, similar to how the actual connection behaves.

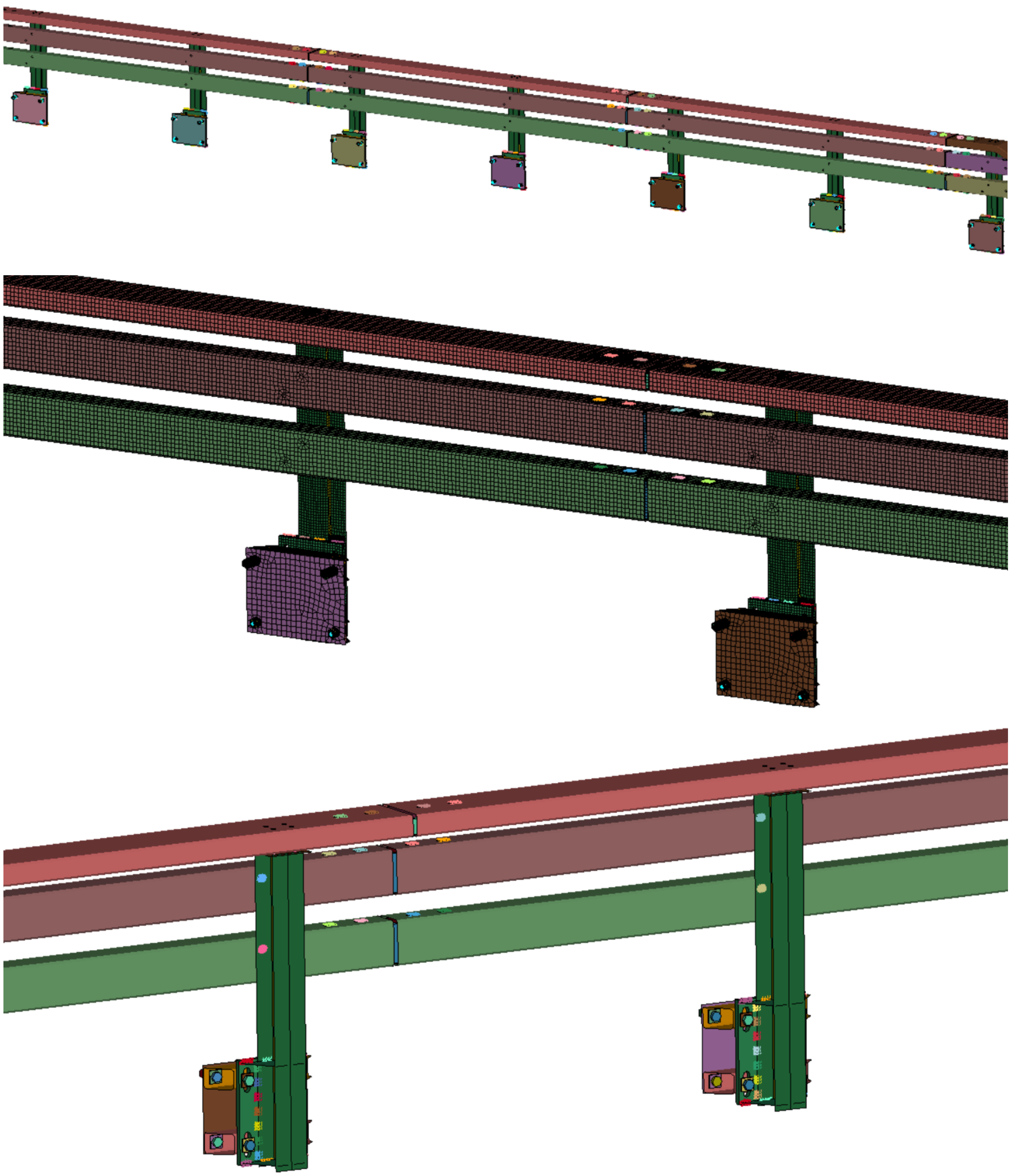


Figure 33. Bridge Rail Model

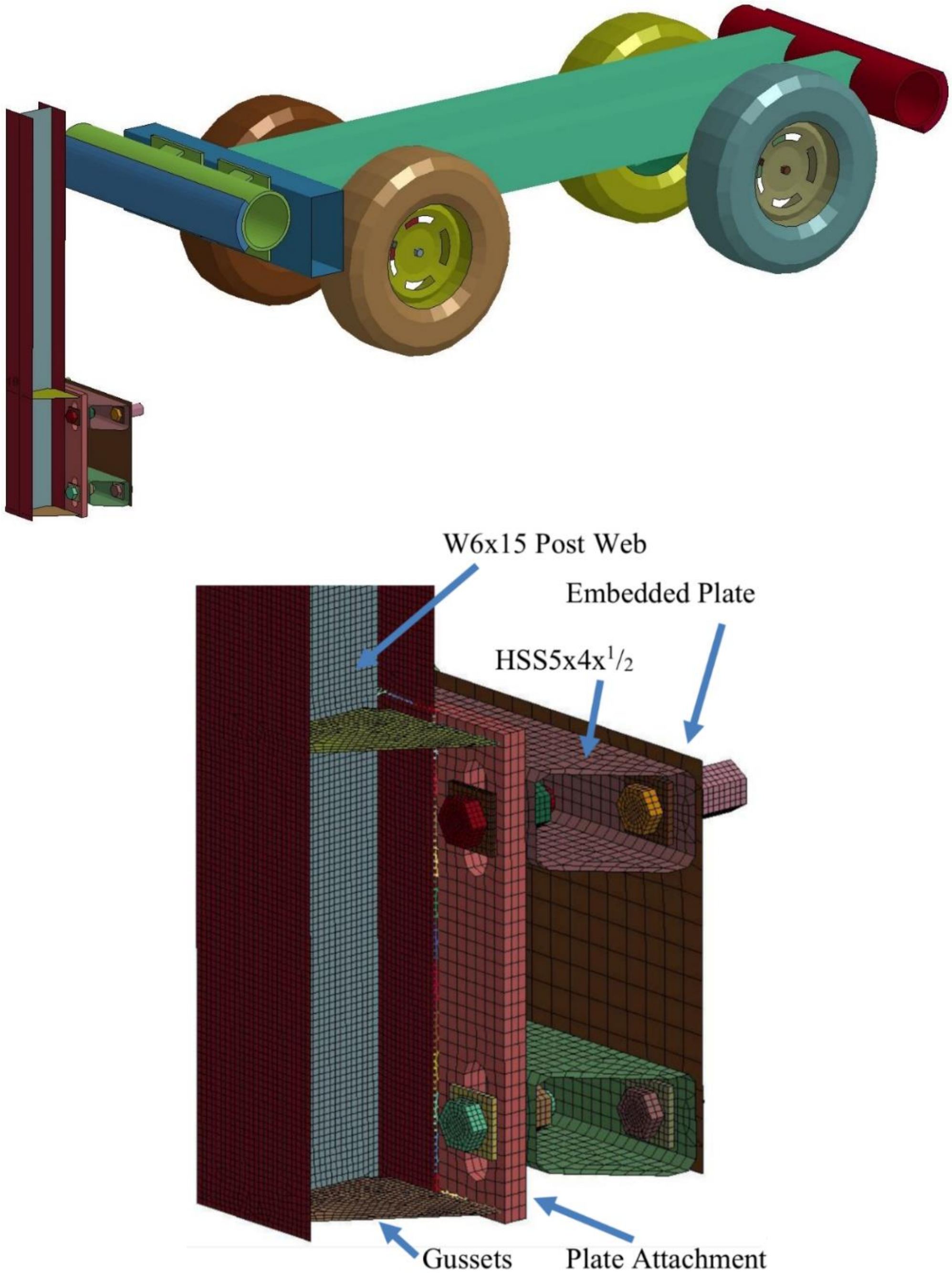



Figure 34. Bridge Post Model [8-9]

## 4.3 Connection Model

### 4.3.1 Concept #1

The concept #1 connection assembly model is shown in Figure 35. The model utilized shell elements for the connection assembly, wedge middle tube, and top tube transition with material properties consistent with those steel sections. Bolts were modeled as constrained nodal rigid bodies or tied rigid bodies.

The connection assembly was initially designed and evaluated utilizing $^{3}/_{16}$-in. vertical and horizontal gusset plates. Another model evaluated $^{3}/_{16}$-in. vertical gusset plates and $^{5}/_{16}$-in. horizontal gusset plates. Three post configurations were evaluated, as shown in Figure 36. The first configuration utilized the three standard W6x15 AGT posts with a 9-ft span length between the last AGT post and the first bridge rail post. The second configuration utilized four W6x15 AGT posts with a 6-ft span length between the last AGT post and the first bridge post. The third configuration utilized four W6x15 AGT posts with a 9-ft span length between the last AGT post and the first bridge rail post.

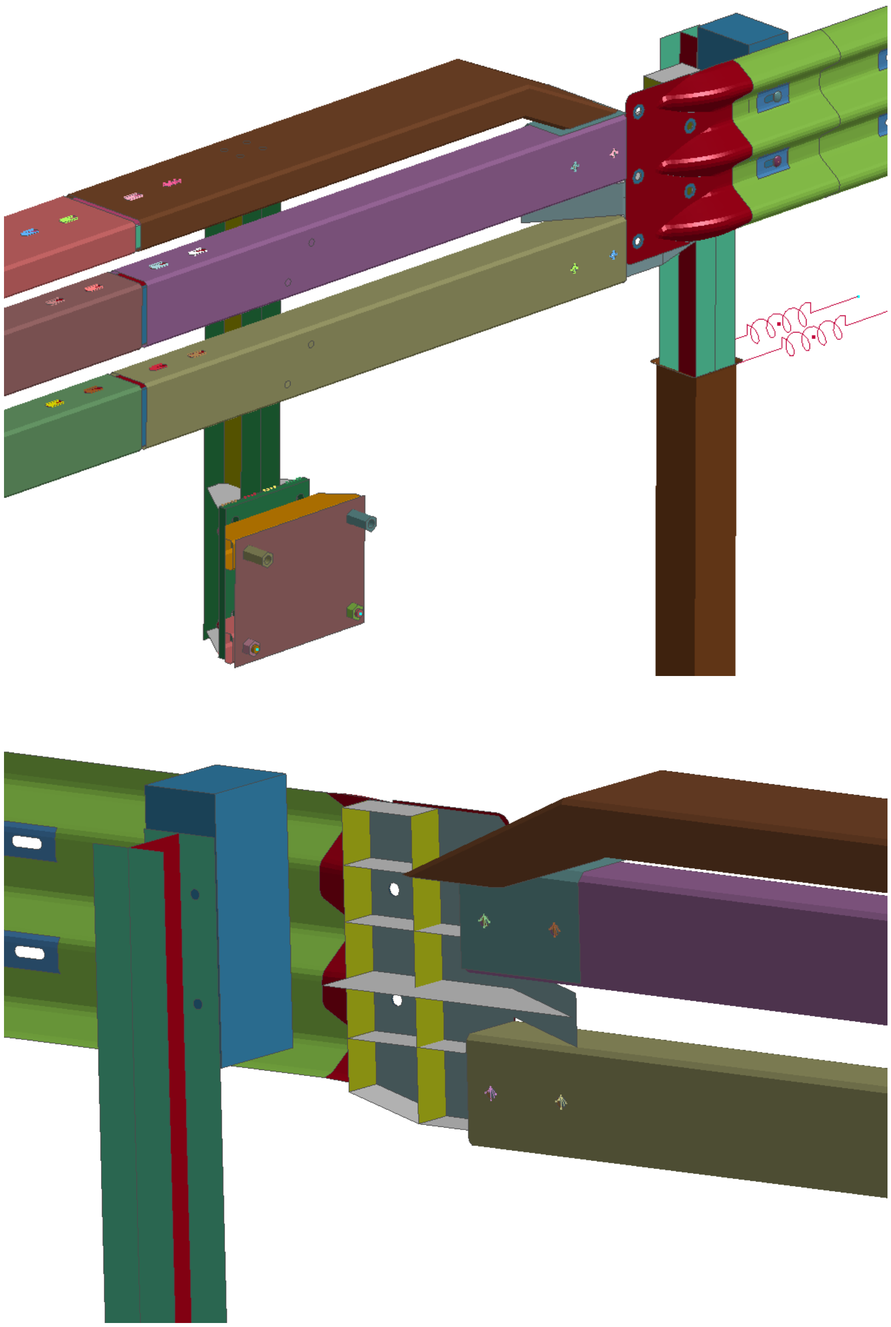


Figure 35. Concept #1 Connection Assembly Model

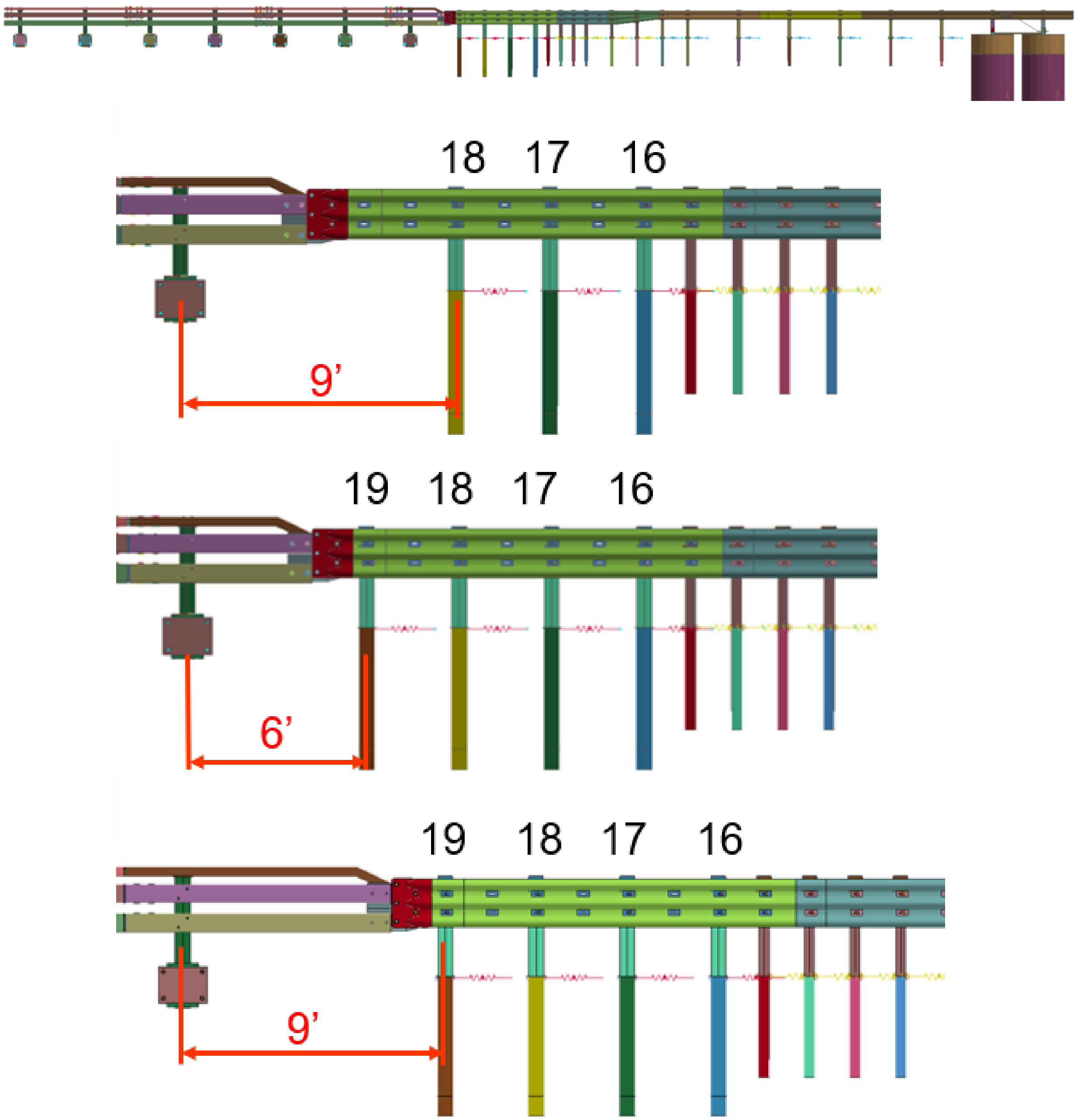



Figure 36. Concept #1 Models

**4.3.2 Concept #2**

The concept #2 continuous tubes transition model is shown in Figure 37. The model utilized shell elements for the lower and middle transition tubes, wedge middle tube, and top tube transition with material properties consistent with those steel sections. Bolts were modeled as constrained nodal rigid bodies or tied rigid bodies. Only one configuration was evaluated with three standard W6x15 AGT posts and a 9-ft span between the last AGT post and the first bridge rail post.

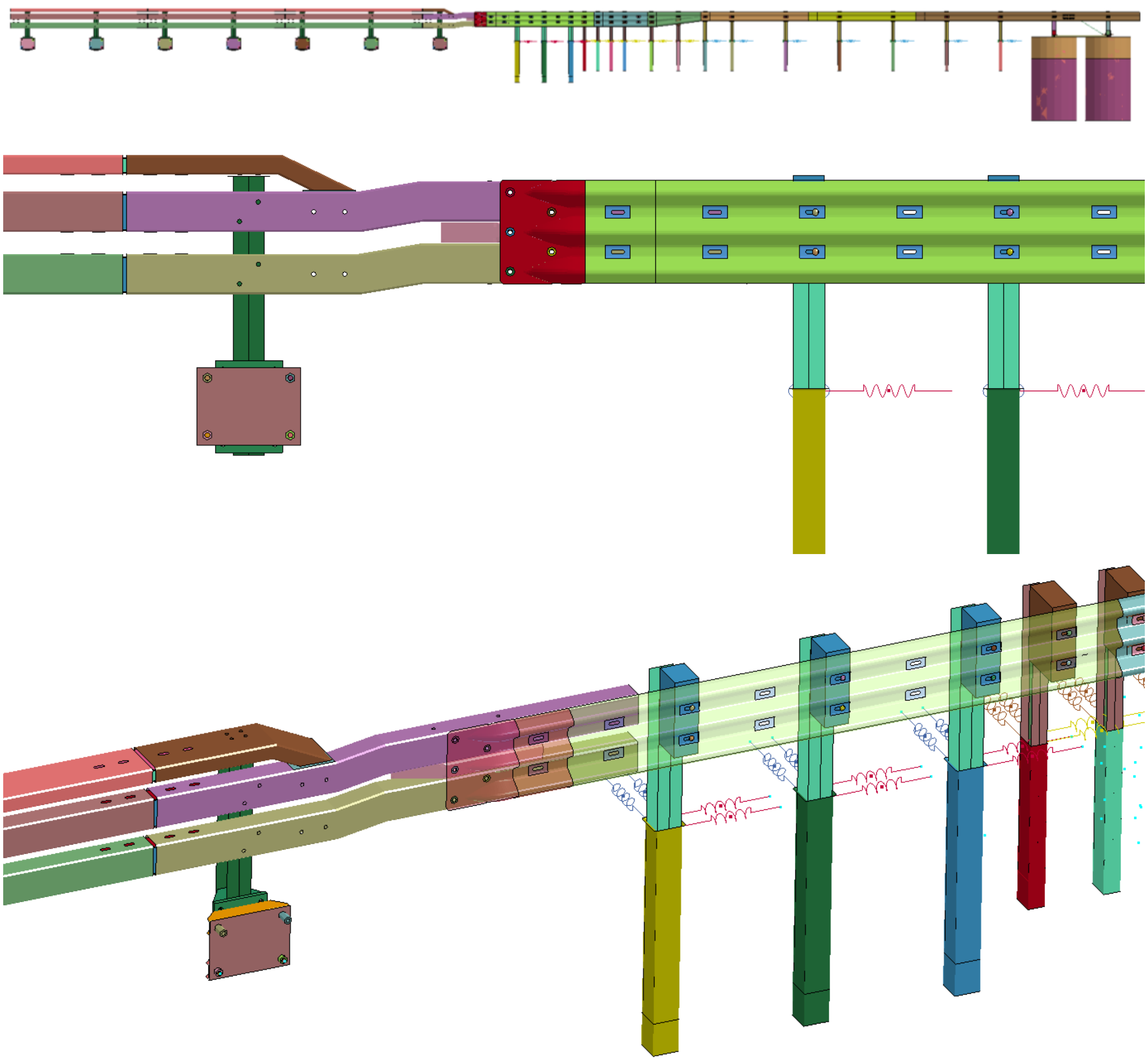


Figure 37. Concept #2 Model

# 5 LS-DYNA TRANSITION MODEL RESULTS

## 5.1 Simulation of Concept #1

Concept #1 was first evaluated with the MASH test designation no. 3-21 (pickup truck) impacts. Several parameters were utilized to evaluate the feasibility of the concept:

1) General vehicle behavior and snag on any system components

2) Occupant risk – longitudinal and lateral OIV and ORA

3) Angle of connection assembly – as the connection assembly deformed and bent backward, the angle that was formed relative to the bridge rail tubes

4) Stresses in various components compared to yield and ultimate stresses

5) Other MASH metrics

As mentioned previously, three post configurations and two connection assembly thicknesses were evaluated. Table 3 shows the simulation matrix of these configurations at several different impact points listed by simulation name (V#) and impact location in inches upstream from the last transition post.

Table 3. Summary of Simulations on Concept #1, Test Designation No. 3-21

| Span | Connector – $^3/_{16}$-in. plates | Connector – $^3/_{16}$-in. vertical, $^5/_{16}$-in. horizontal |
|---|---|---|
| 9-ft span (3 AGT posts) | V10 – 54.6” | V18 – 54.6” |
| | V11 – 73.4” | V19 – 73.4” |
| | V12 – 35.9” | V20 – 35.9” |
| | V13 – 17.1” | V21 – 17.1” |
| 6-ft span (4 AGT posts) | V14 – 54.6” | V22 – 54.6” |
| | V15 – 73.4” | V23 – 73.4” |
| | V16 – 35.9” | V24 – 35.9” |
| | V17 – 17.1” | V25 – 17.1” |
| 9-ft span (4 AGT posts | V26 – 54.6” | N/A |
| | V27 – 73.4” | N/A |
| | V28 – 35.9” | N/A |
| | V29 – 17.1” | N/A |

N/A – Not applicable

Occupant risk values and the angle of connection assembly for each simulation are shown in Table 4. General vehicle and system behavior for each simulation is shown in Figures 38 through 57. All occupant risk values were below MASH thresholds. However, several simulations did not run to completion, as denoted with an asterisk in Table 4, so ORAs may have been higher in those simulations had they not terminated early. The errors that caused the simulations to terminate early were not resolvable. However, early termination is likely linked to areas where large deformations were occurring within the simulation, which may indicate vehicle snag on system components.

Table 4. Summary of Concept #1 Simulation Results

| Concept Description | Simulation Name | Impact Distance US from last transition post (in.) | Occupant Impact Velocity (m/s) | | Occupant Ridedown Acceleration (g's) | | Angle of Connection Assembly (deg.) |
|---|---|---|---|---|---|---|---|
| | | | Lateral | Long. | Lateral | Long. | |
| 3 AGT Posts 9-ft span $^{3}/_{16}$-in. connector plates | V10* | 54.6 | 6.0 | -5.7 | 9.0 | -11.6 | 19.8 |
| | V11 | 73.4 | 6.0 | -5.6 | 12.4 | -8.6 | 21.1 |
| | V12* | 35.9 | 6.3 | -6.4 | 10.8 | -13.1 | 20.1 |
| | V13* | 17.1 | 6.5 | -6.9 | 0.0 | 0.0 | 19.7 |
| 4 AGT Posts 6-ft span $^{3}/_{16}$-in. connector plates | V14 | 54.6 | 6.7 | -6.3 | 11.0 | -11.4 | 15.7 |
| | V15 | 73.4 | 6.7 | -6.3 | 10.4 | -7.8 | 12.9 |
| | V16* | 35.9 | 6.8 | -7.2 | 8.5 | -9.8 | 15.8 |
| | V17 | 17.1 | 7.3 | -7.1 | 8.3 | -12.0 | 16.2 |
| 3 AGT Posts 9-ft span $^{3}/_{16}$-in. vertical and $^{5}/_{16}$-in. horizontal connector plates | V18* | 54.6 | 6.1 | -5.7 | 11.2 | -12.5 | 14.4 |
| | V19 | 73.4 | 6.1 | -5.7 | 10.8 | -8.8 | 15.3 |
| | V20* | 35.9 | 6.4 | -6.4 | 9.8 | -7.0 | 16.6 |
| | V21 | 17.1 | 6.5 | -7.0 | 9.5 | -14.7 | 12.4 |
| 4 AGT Posts 6-ft span $^{3}/_{16}$-in. vertical and $^{5}/_{16}$-in. horizontal connector plates | V22 | 54.6 | 6.6 | -6.5 | 12.0 | -12.9 | 11.6 |
| | V23 | 73.4 | 6.5 | -6.4 | 10.3 | -10.0 | 9.5 |
| | V24 | 35.9 | 6.8 | -7.2 | 9.8 | -12.0 | 13.2 |
| | V25 | 17.1 | 7.1 | -7.1 | 7.5 | -9.2 | 12.3 |
| 4 AGT Posts 9-ft span $^{3}/_{16}$-in. connector plates | V26 | 54.6 | 6.4 | -6.6 | 12.1 | -13.8 | 14.1 |
| | V27 | 73.4 | 6.5 | -6.4 | 10.6 | -11.0 | 12.1 |
| | V28 | 35.9 | 6.9 | -6.5 | 8.6 | -12.4 | 13.8 |
| | V29* | 17.1 | 6.6 | -6.3 | 12.5 | -15.6 | 9.3 |

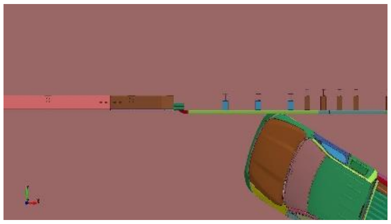
*Simulation terminated early – ORAs may be greater than recorded

The connection assembly had stresses that exceeded yield in every simulation as the connection assembly bent. When the connection assembly bent, especially with a higher bend angle, there was increased potential for the vehicle to snag on the ends of the bridge rail tube. However, the connection assembly performed as intended and remained intact to connect the AGT and bridge rail systems. Since the bolts were not modeled explicitly, their capacity was not evaluated. Additionally, the potential for rupture and tearing of the guardrail and connection assembly was not fully evaluated as it would have been difficult to accurately model.

The simulations with four W6x15 AGT posts performed better than the simulations with three W6x15 AGT posts, as the general behavior and potential for snag appeared less with four AGT posts. Additionally, simulations with the $^{5}/_{16}$-in. thick horizontal gusset plates performed better than those with the $^{3}/_{16}$-in. thick horizontal gusset plates. In the simulations with three AGT posts and $^{3}/_{16}$-in. thick connection assembly gusset plates, larger angles formed with the connection assembly, which indicated rail pocketing and the potential for vehicle snag. Still frames from simulations V10 and V13 are shown in Figures 58 and 59, respectively, which show the right-front wheel riding underneath the rail and snagging on the connection assembly, which could produce an undesirable test outcome. Three AGT posts with a 9-ft span to the first bridge rail post with $^{5}/_{16}$-in. thick horizontal gusset plates on the connection assembly also indicated the potential for vehicle snag. Still frames from simulations V18 and V20 are shown in Figures 60 and 61, respectively, also show the right-front wheel snagging on the connection assembly. Thus, the configurations with three AGT posts were not recommended for further evaluation.

Still frames from the configuration with four AGT posts, a 9-ft span to the first bridge rail post, and $^{5}/_{16}$-in. thick horizontal gusset plates in the connection assembly (simulations V28 and V29) also showed the right-front wheel interacting with and snagging on the lower side of the connection assembly. Thus, the $^{3}/_{16}$-in. thick horizontal gusset plates were not recommended for further evaluation.

The configuration with four AGT posts, a 9-ft span to the first bridge rail post, and $^{5}/_{16}$-in. thick horizontal gusset plates in the connection assembly performed the best and appeared to have a potential to pass MASH test designation no. 3-21, with the occupant risk values well below MASH thresholds. However, it was desired to utilize the standard AGT configuration with three W6x15 AGT posts, and concept #2 was further pursued to be evaluated for feasibility.



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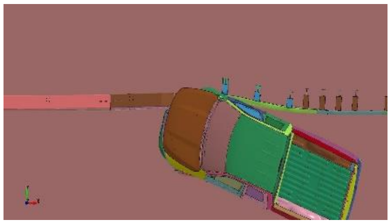

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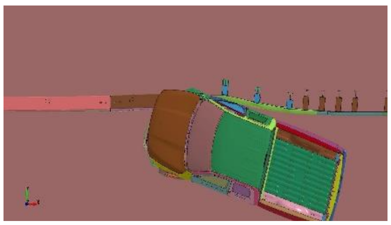

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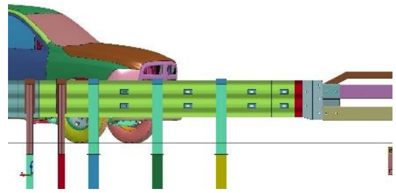
Overhead View



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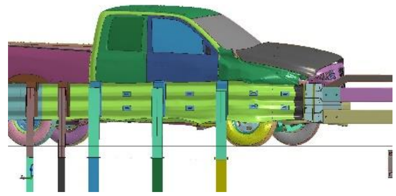

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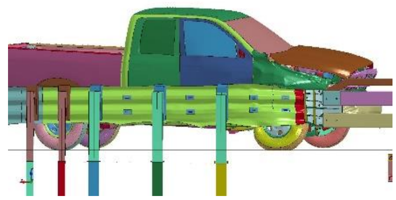

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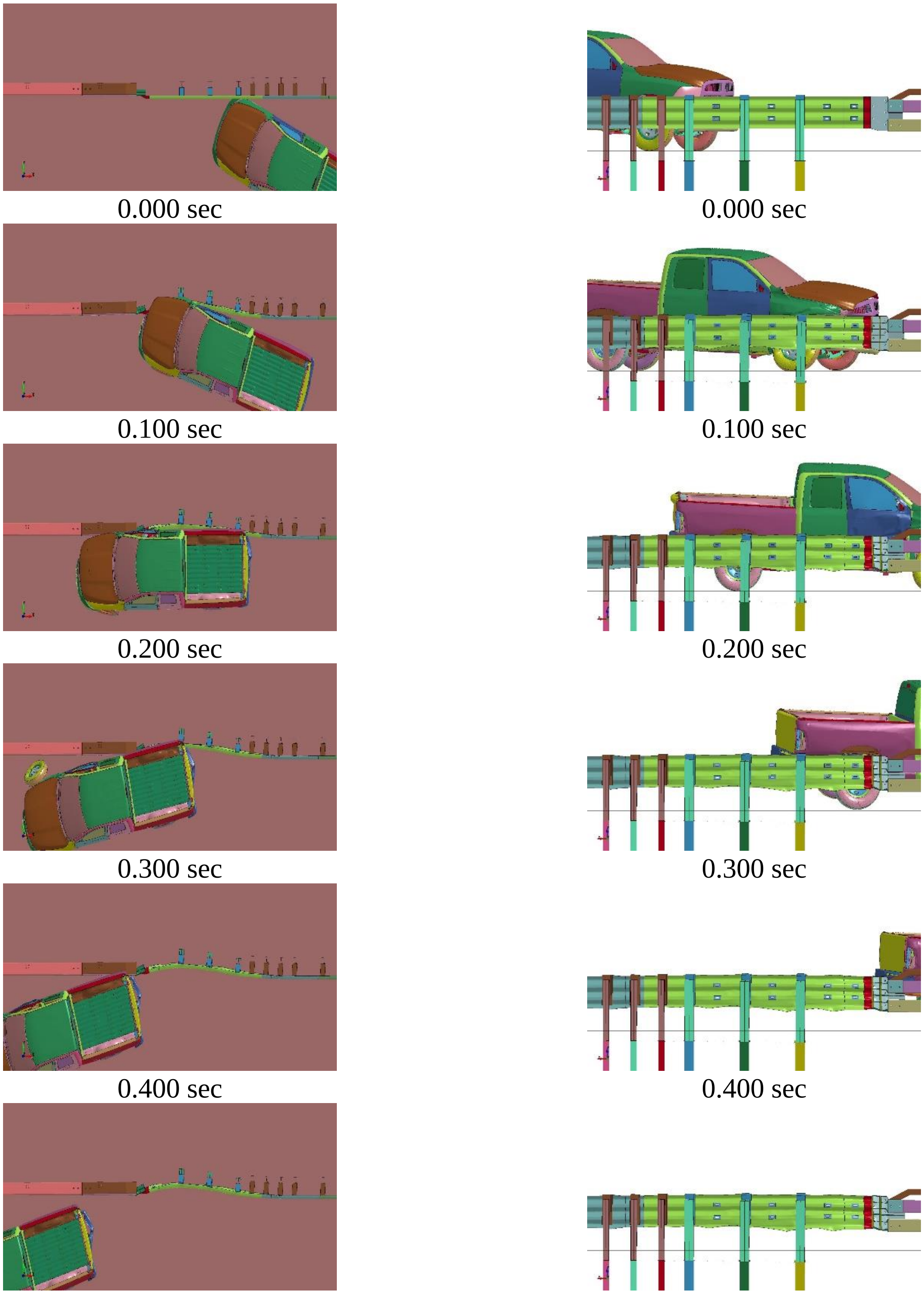
Perpendicular View

Figure 38. Sequential Photographs, Concept #1, Simulation v10



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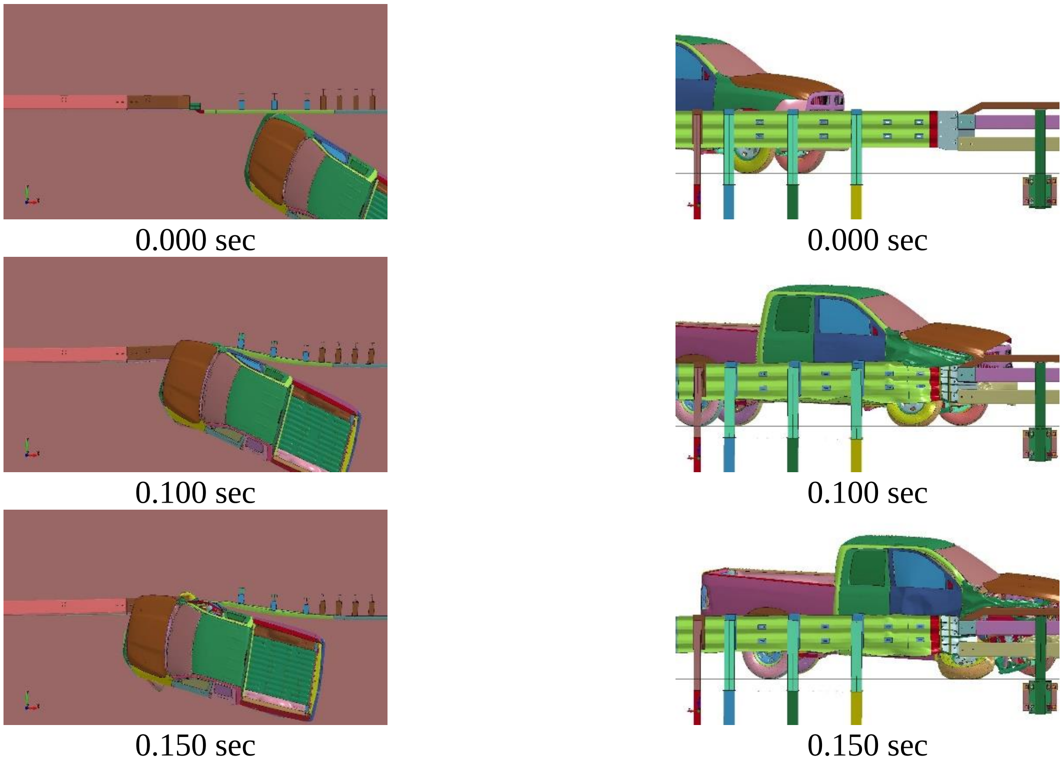
Overhead View | Perpendicular View

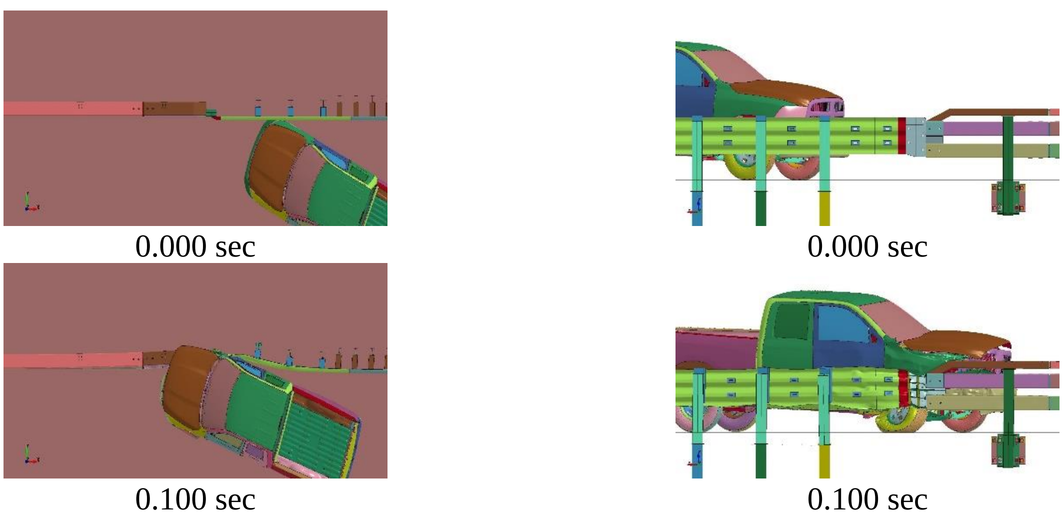
Figure 39. Sequential Images, Concept #1, Simulation v11




Overhead View

Perpendicular View

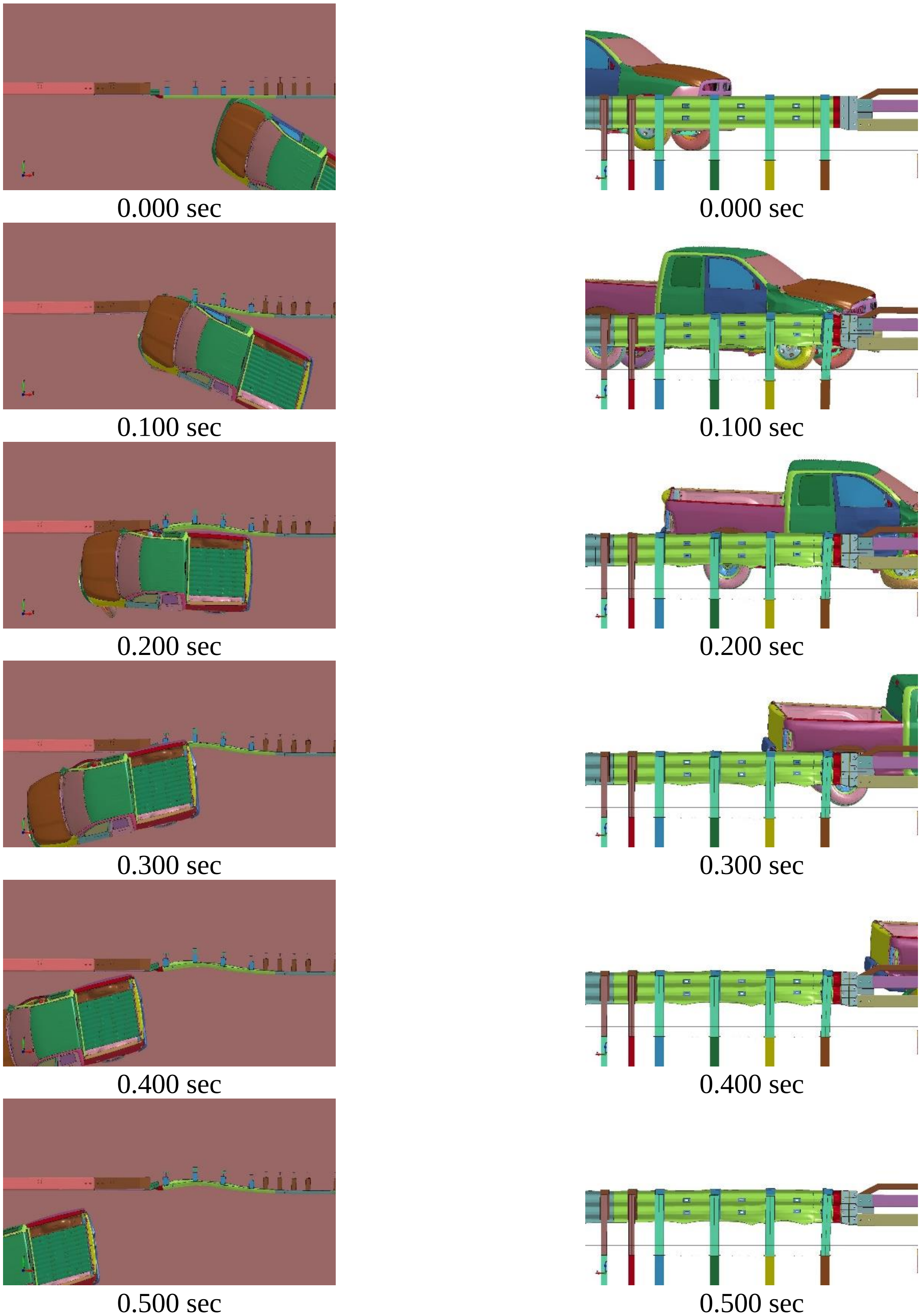
Figure 40. Sequential Images, Concept #1, Simulation v1




Overhead View

Perpendicular View

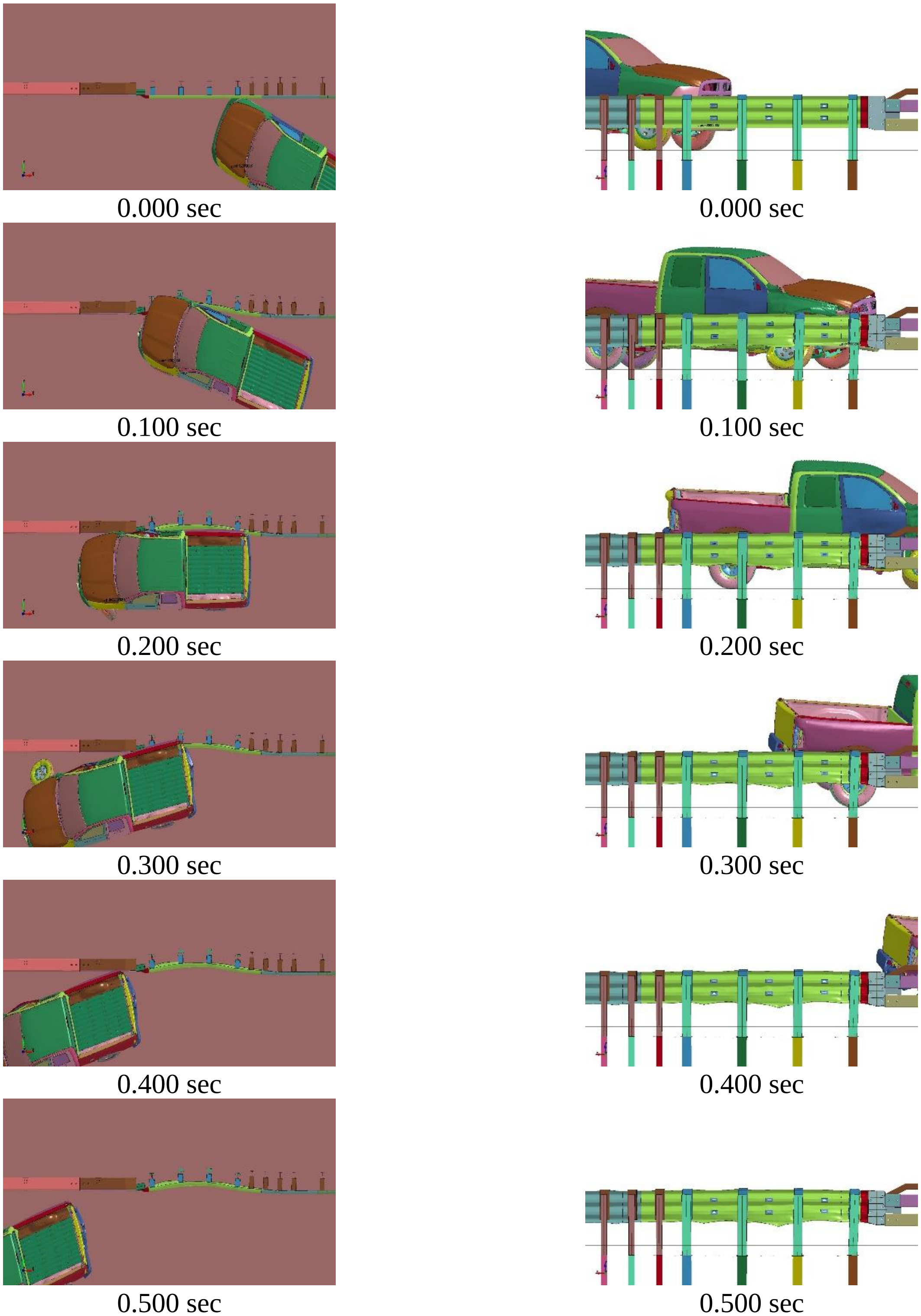
Figure 41. Sequential Images, Concept #1, Simulation v13




Overhead View

Perpendicular View

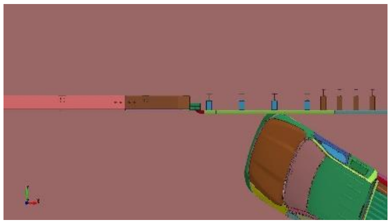
Figure 42. Sequential Images, Concept #1, Simulation v14




Overhead View

Perpendicular View

Figure 43. Sequential Images, Concept #1, Simulation v15



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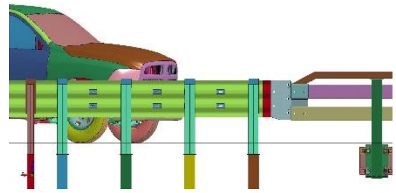

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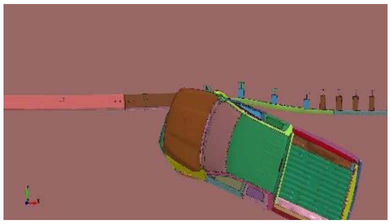

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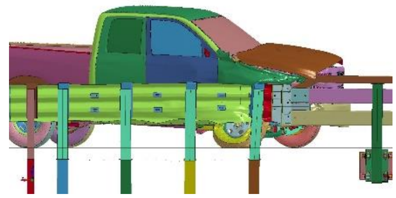

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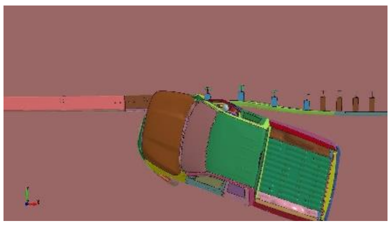

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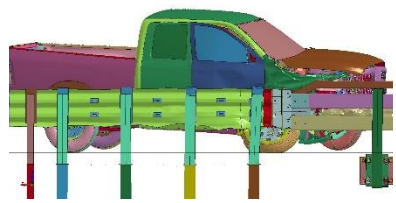

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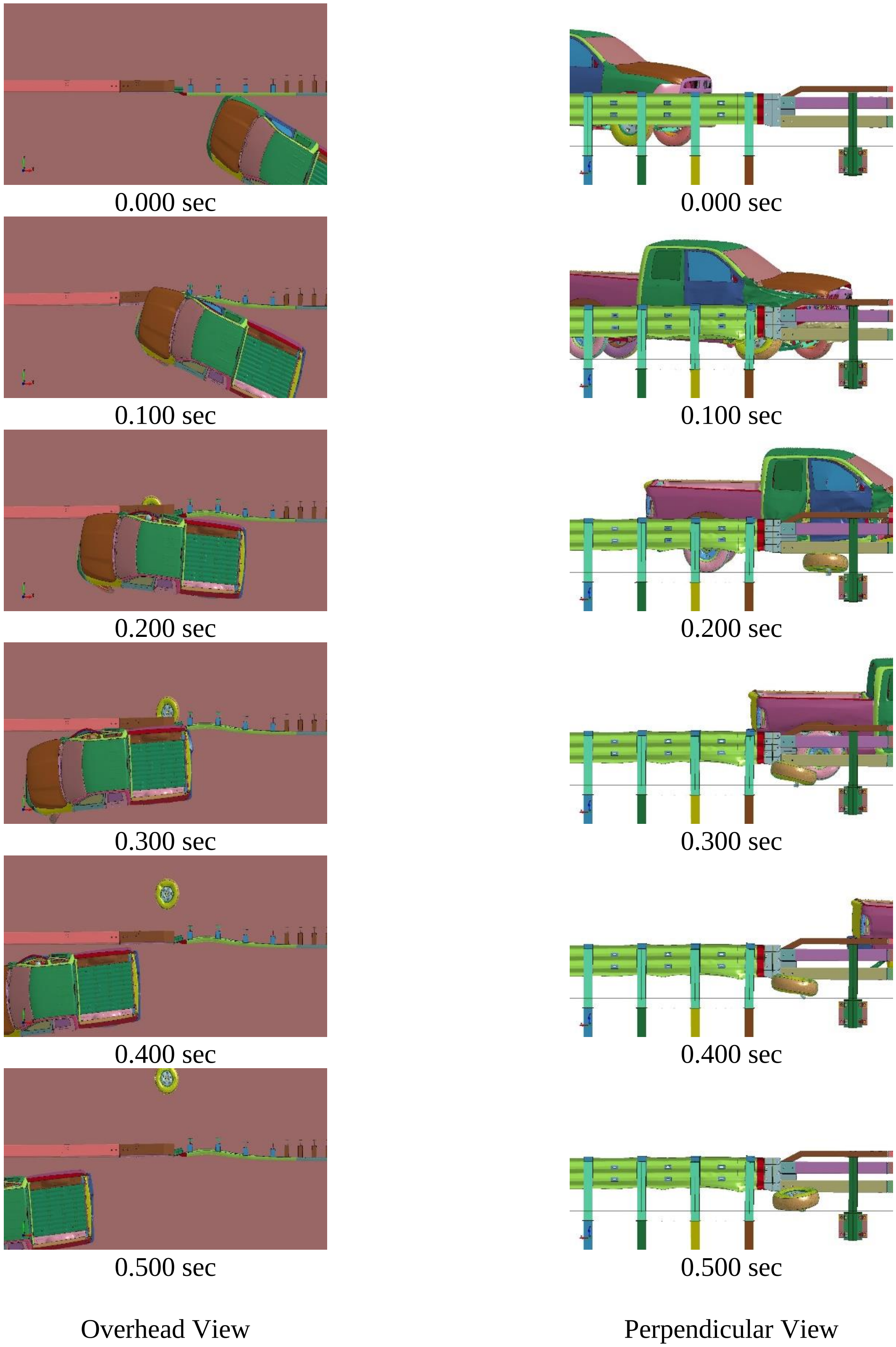
Overhead View

Perpendicular View

Figure 44. Sequential Images, Concept #1, Simulation v16

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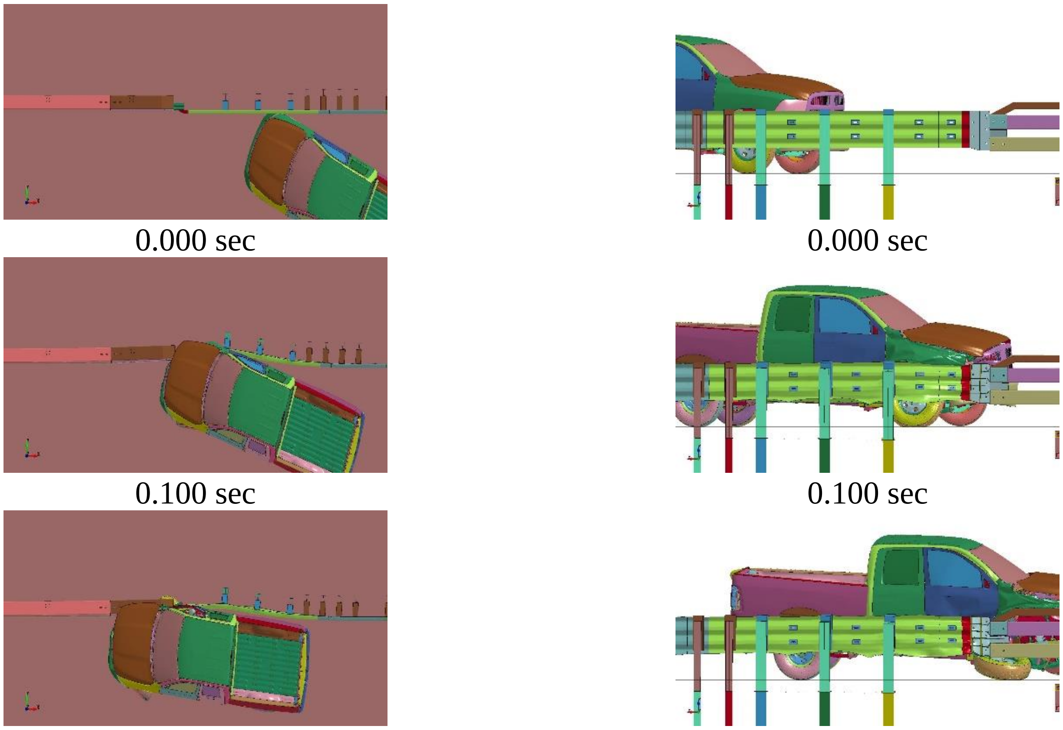

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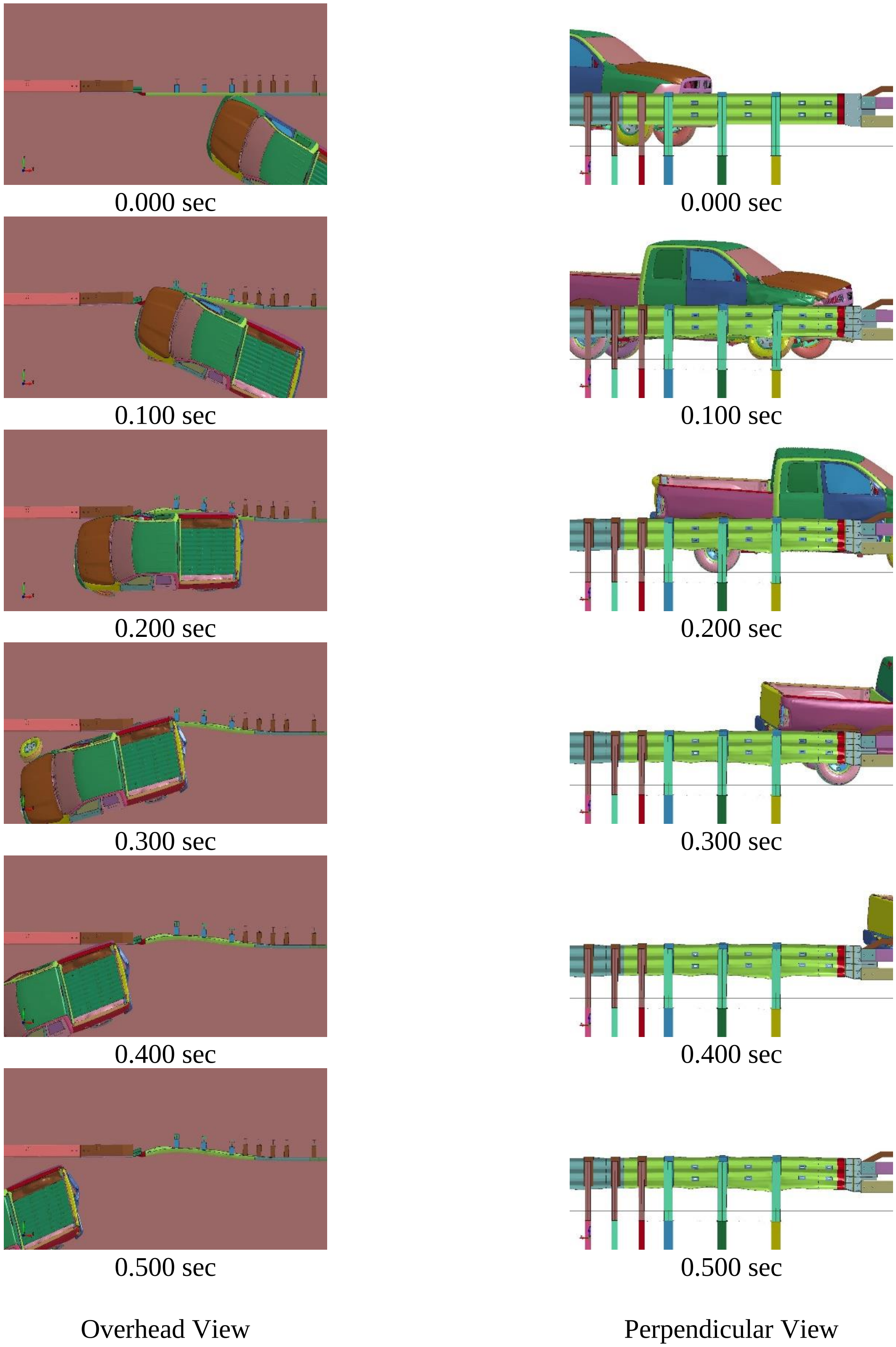
Overhead View | Perpendicular View

Figure 46. Sequential Images, Concept #1, Simulation v18

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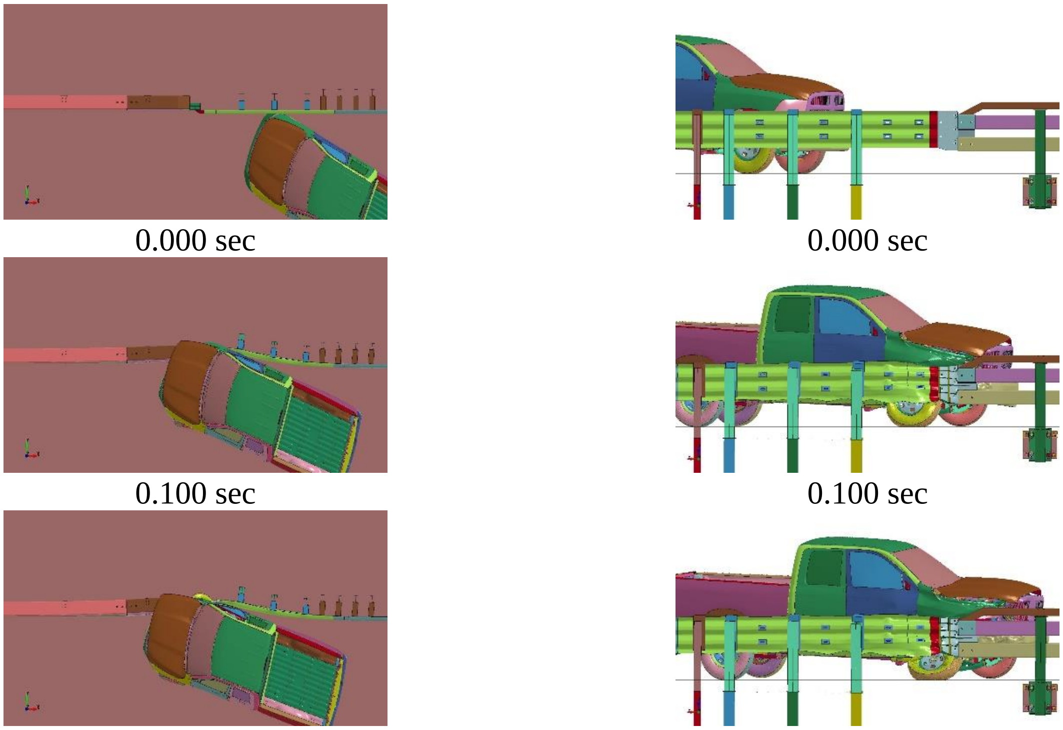

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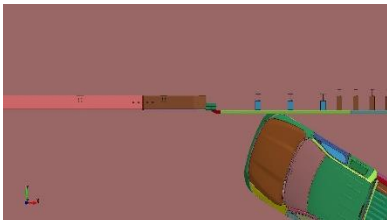
Overhead View | Perpendicular View

Figure 48. Sequential Images, Concept #1, Simulation v20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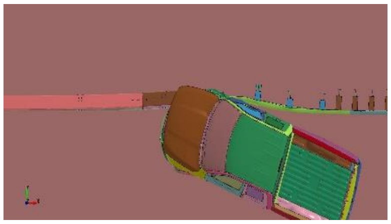
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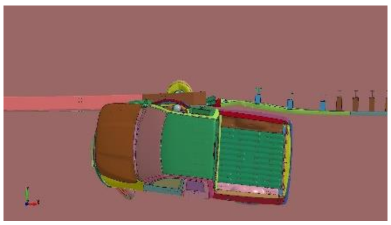
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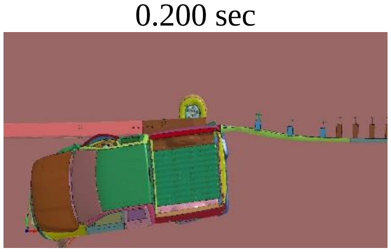
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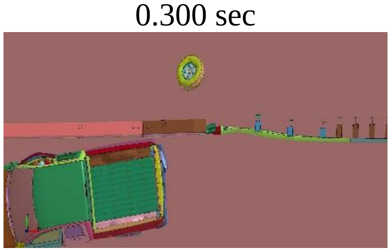
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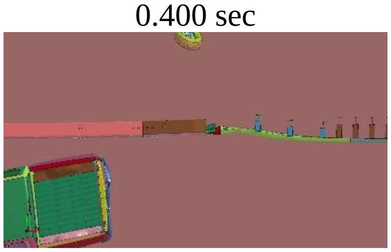
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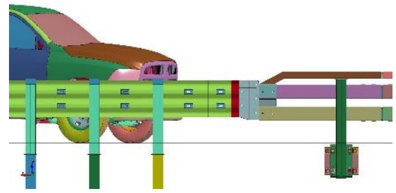
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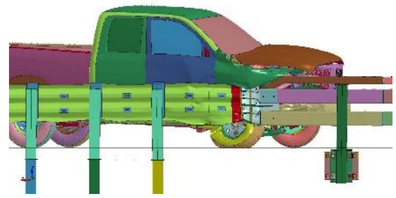
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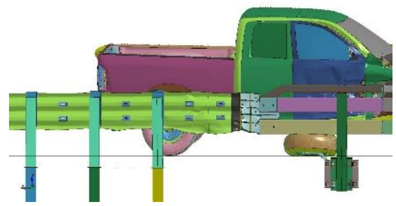
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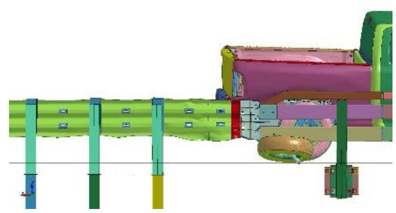
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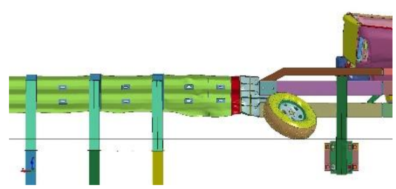
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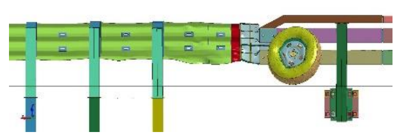
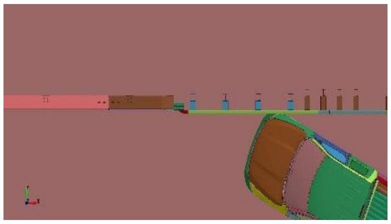

0.500 sec

Perpendicular View

Figure 49. Sequential Images, Concept #1, Simulation v21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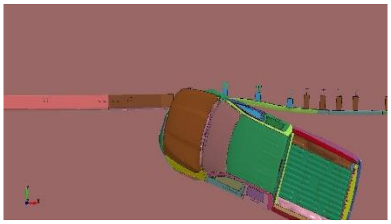
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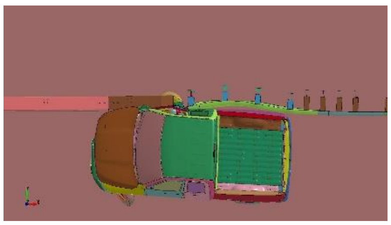
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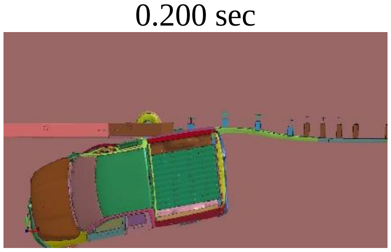
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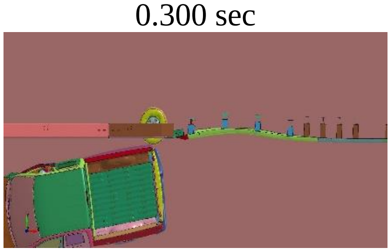
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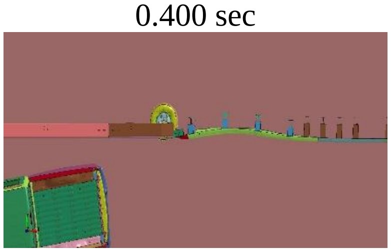
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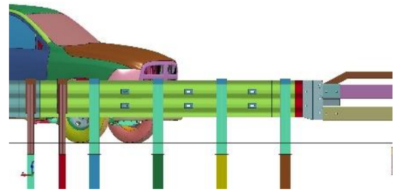
Overhead View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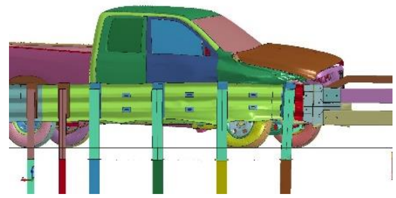
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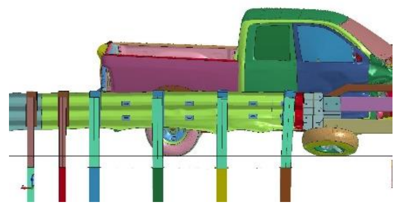
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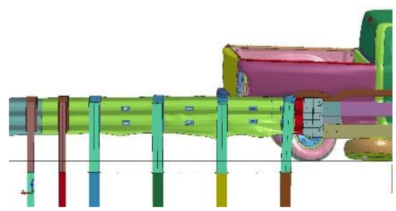
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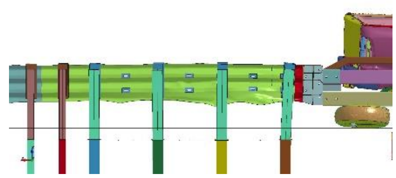
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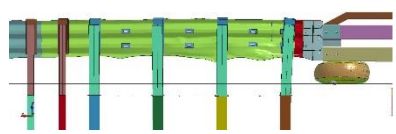

0.500 sec

Perpendicular View

Figure 50. Sequential Images, Concept #1, Simulation v22

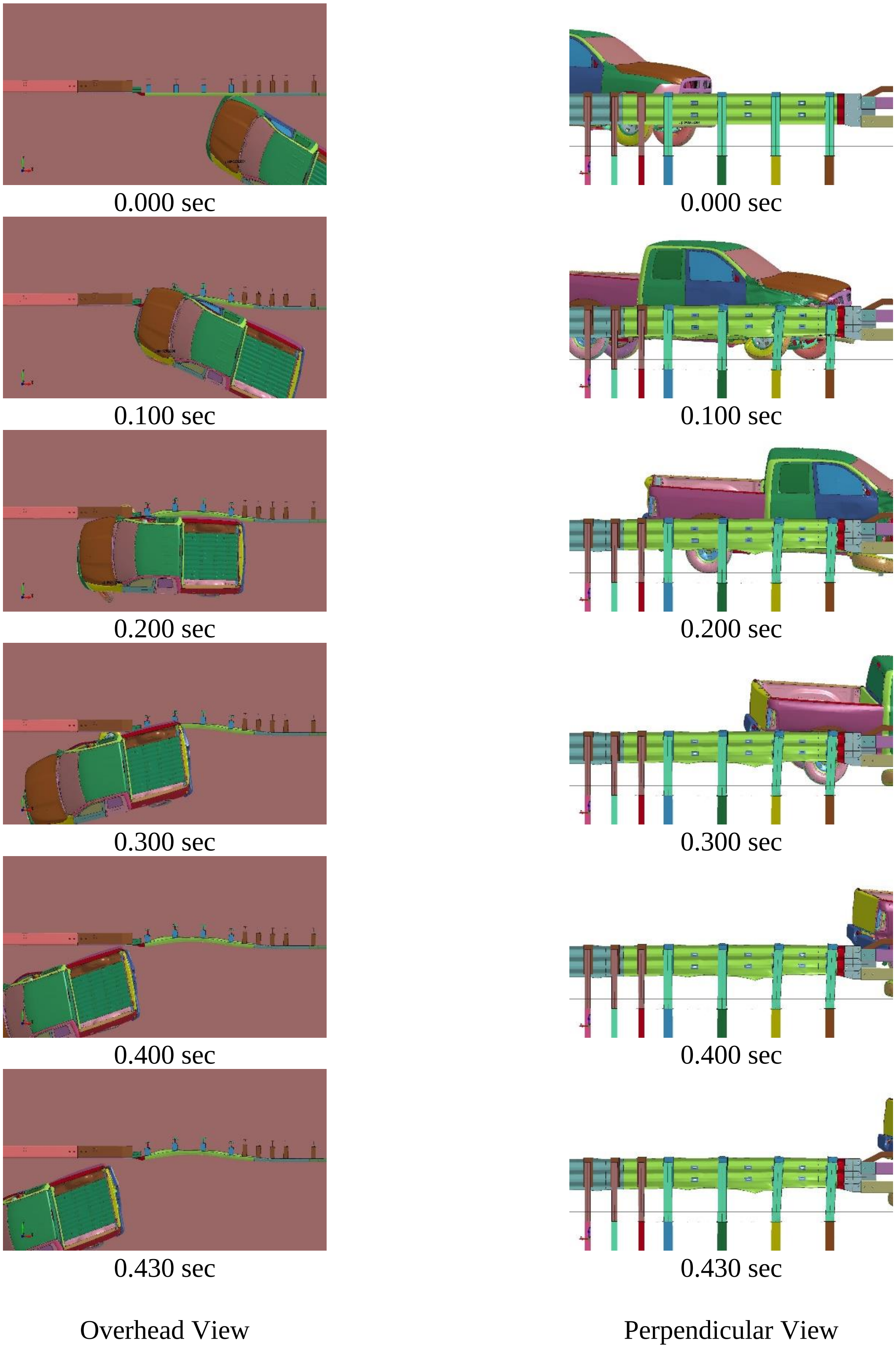
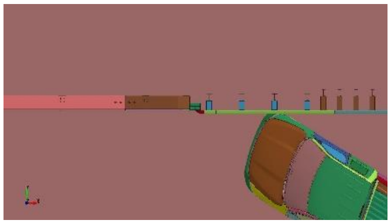



Figure 51. Sequential Images, Concept #1, Simulation v23



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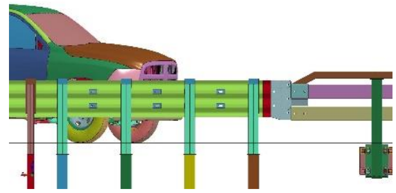

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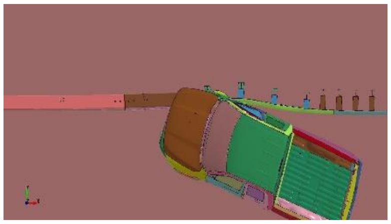

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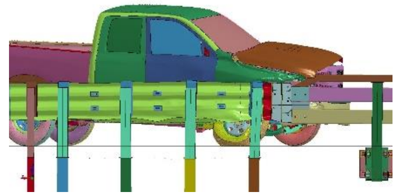

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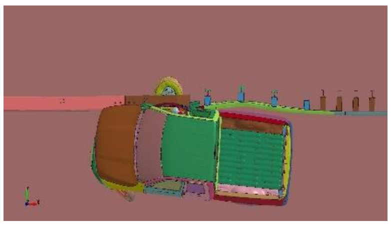

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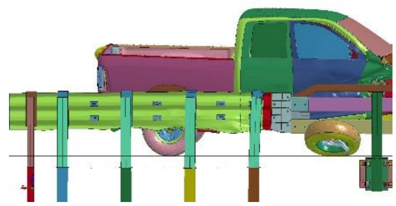

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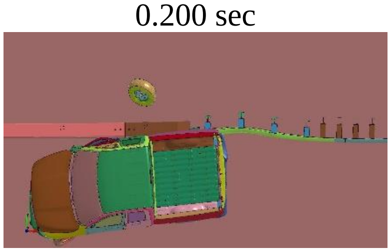

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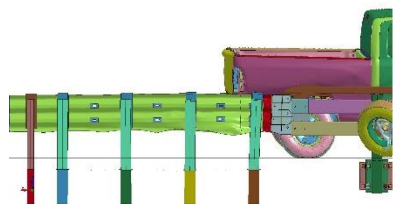

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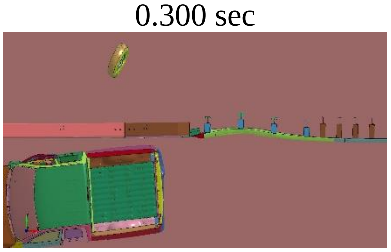

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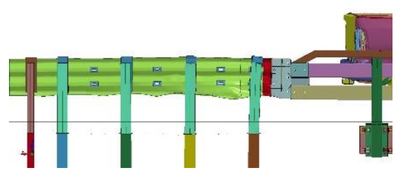

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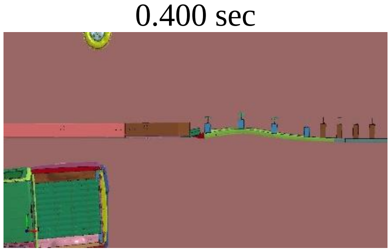
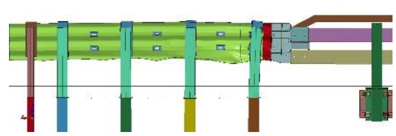


0.500 sec

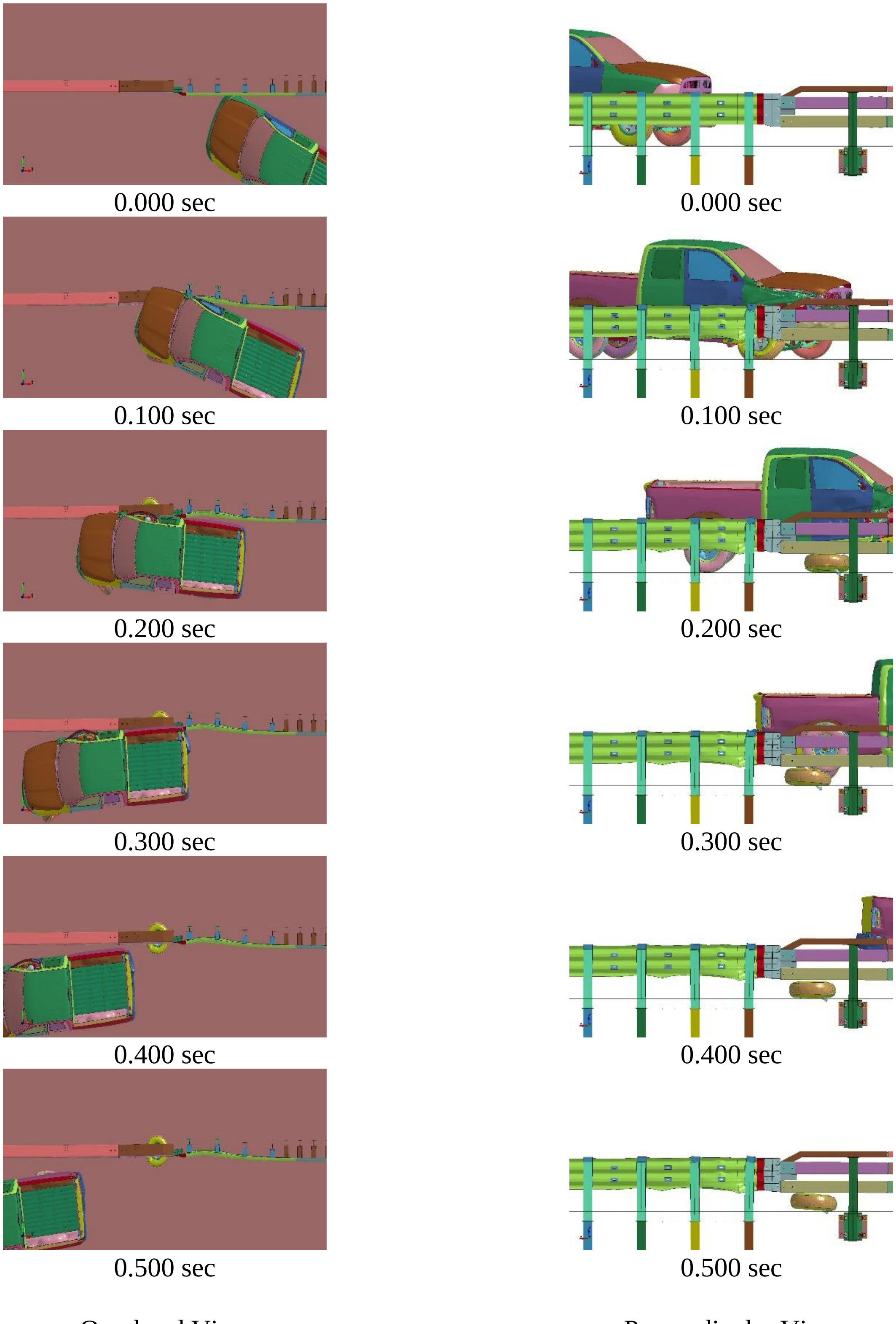


0.500 sec

Overhead View

Perpendicular View

Figure 52. Sequential Images, Concept #1, Simulation v24



0.000 sec 0.100 sec 0.200 sec 0.300 sec 0.400 sec 0.500 sec

Overhead View | Perpendicular View

Figure 53. Sequential Images, Concept #1, Simulation v25

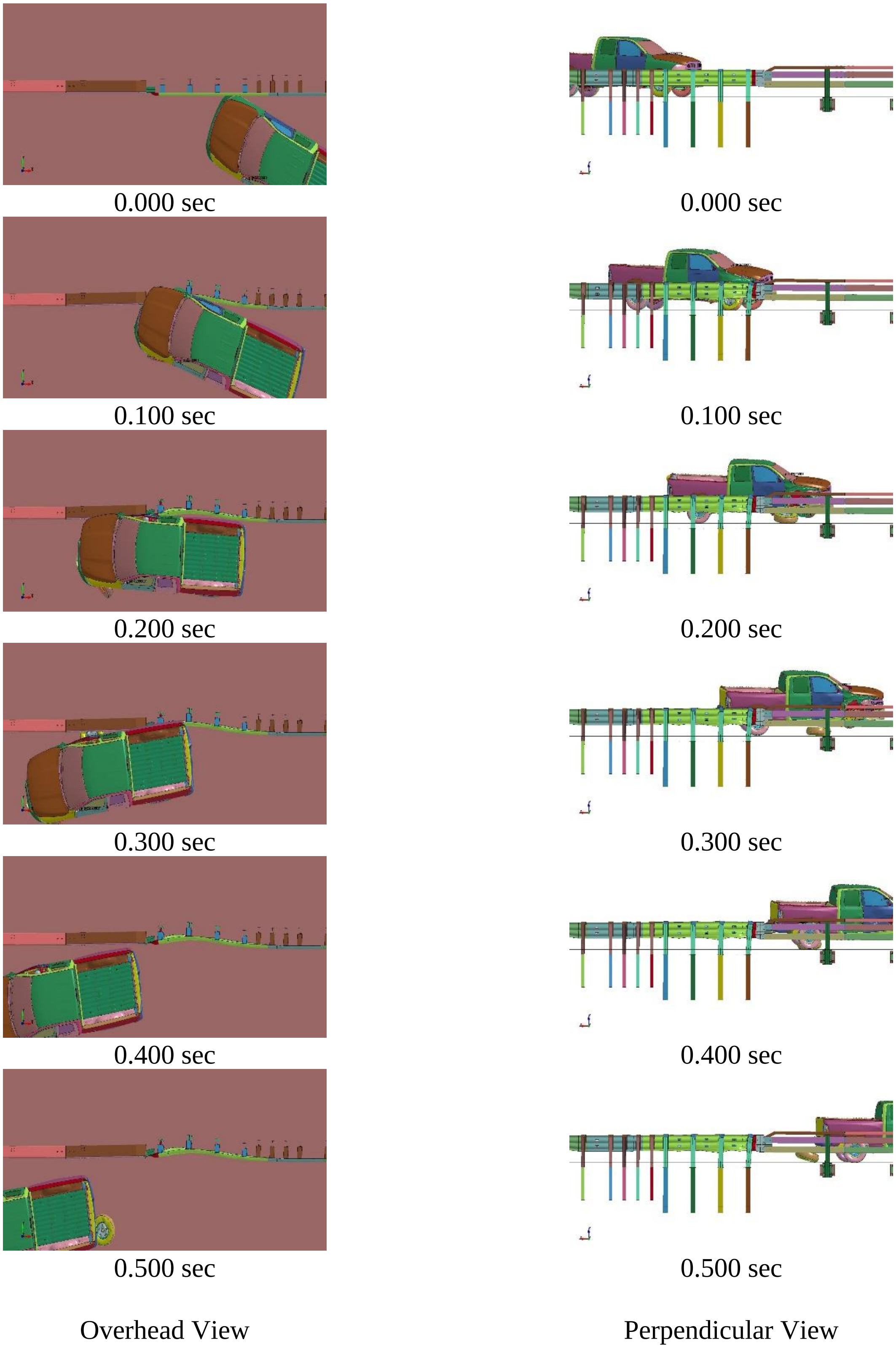
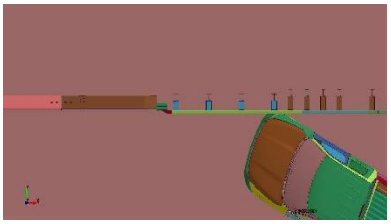



Figure 54. Sequential Images, Concept #1, Simulation v26



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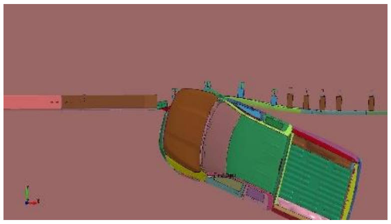

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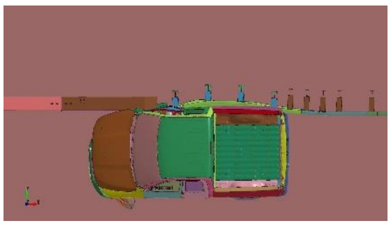

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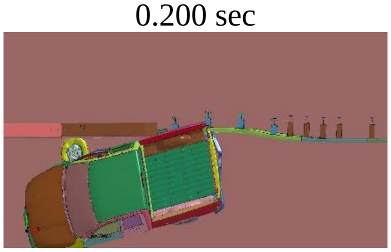

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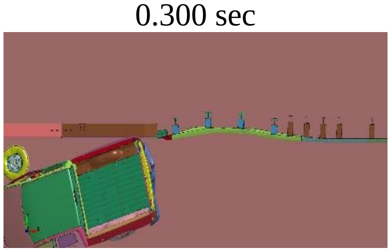

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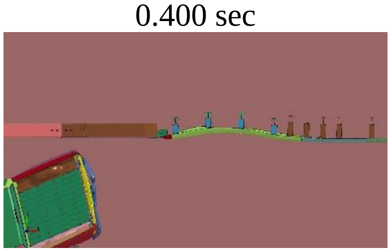
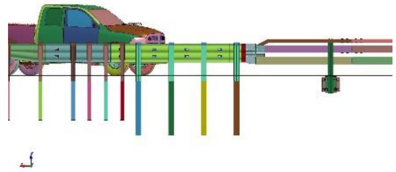


0.500 sec

Overhead View



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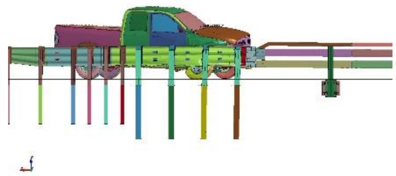

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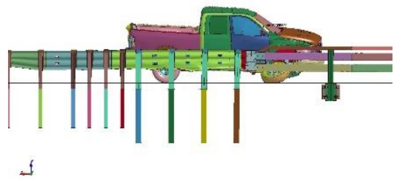

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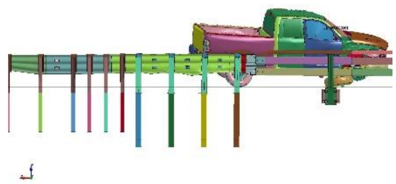

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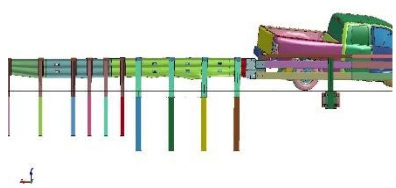

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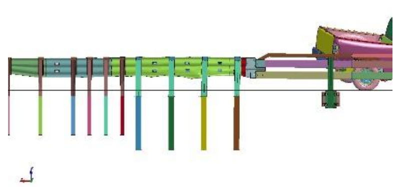
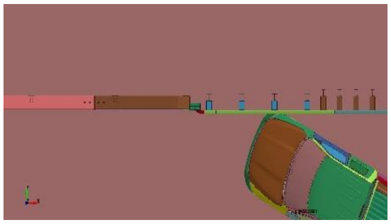


0.500 sec

Perpendicular View

Figure 55. Sequential Images, Concept #1, Simulation v27



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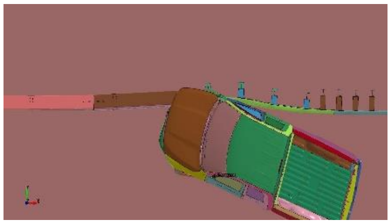

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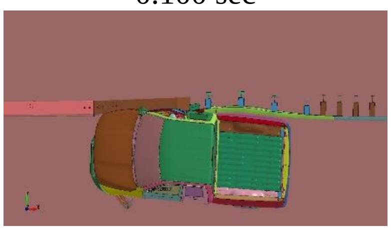

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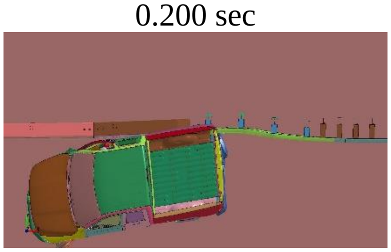

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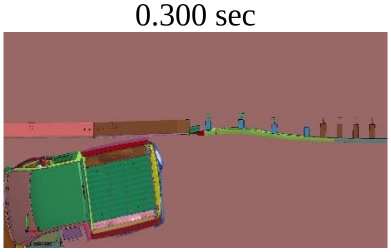
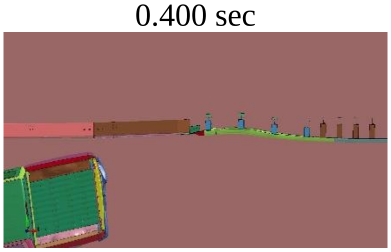
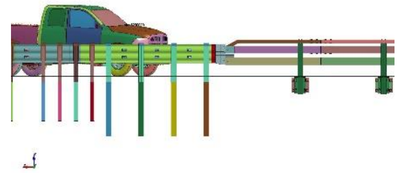


0.400 sec



0.500 sec

Overhead View



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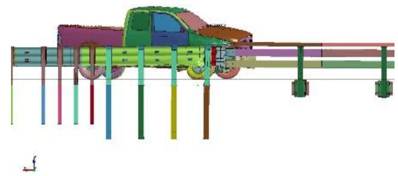

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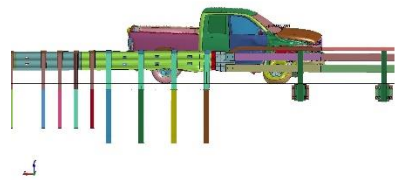

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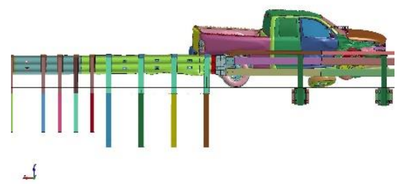

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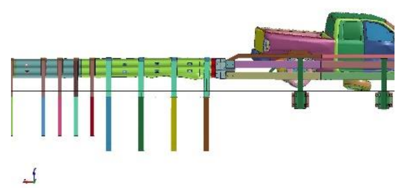

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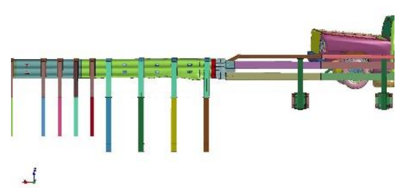
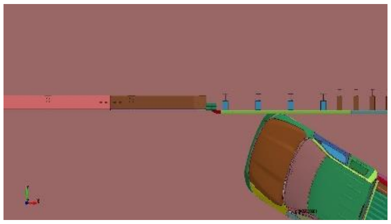


0.500 sec

Perpendicular View

Figure 56. Sequential Images, Concept #1, Simulation v28



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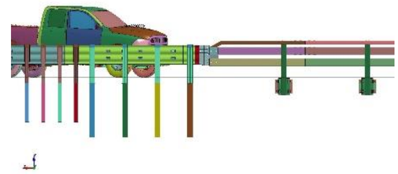

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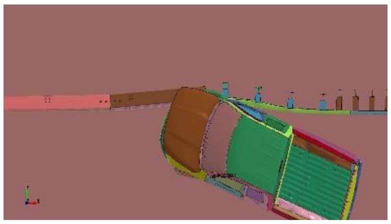

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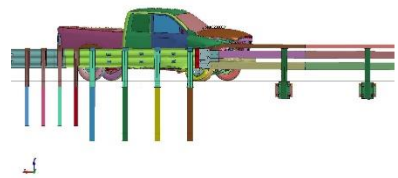

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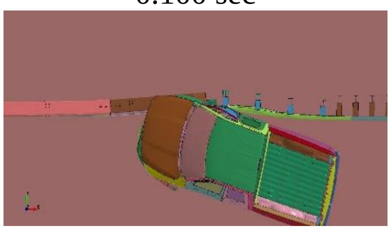

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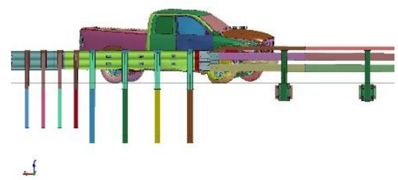


0.130 sec

Overhead View

Perpendicular View

Figure 57. Sequential Images, Concept #1, Simulation v29

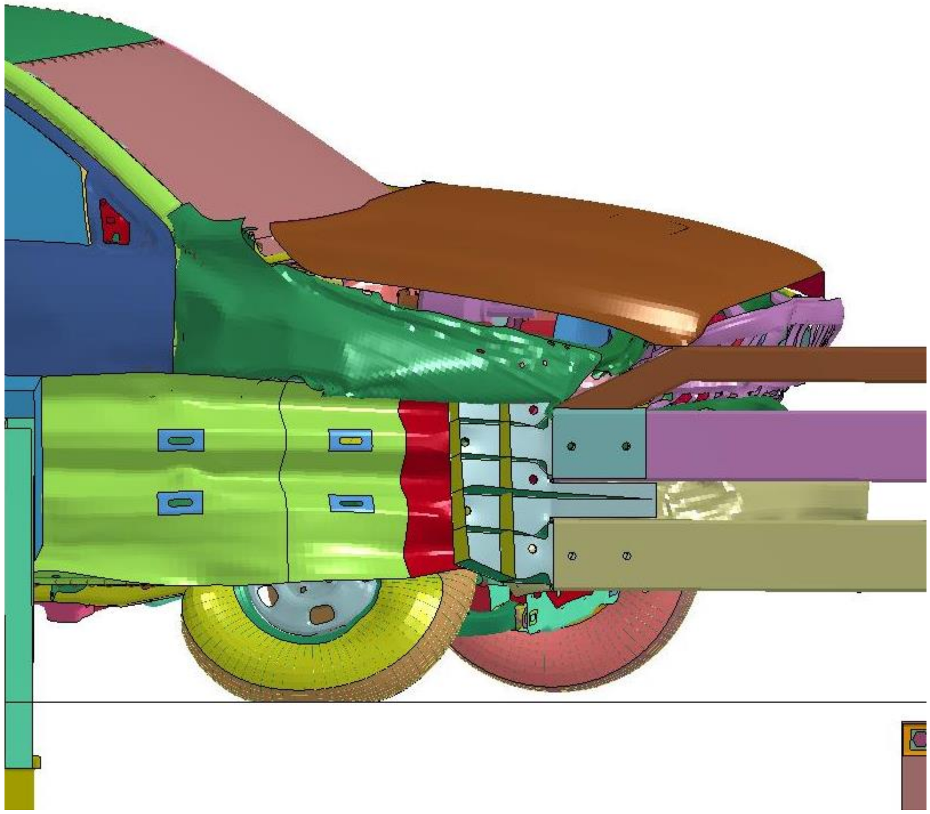


Figure 58. Vehicle Interaction with System, Simulation V10

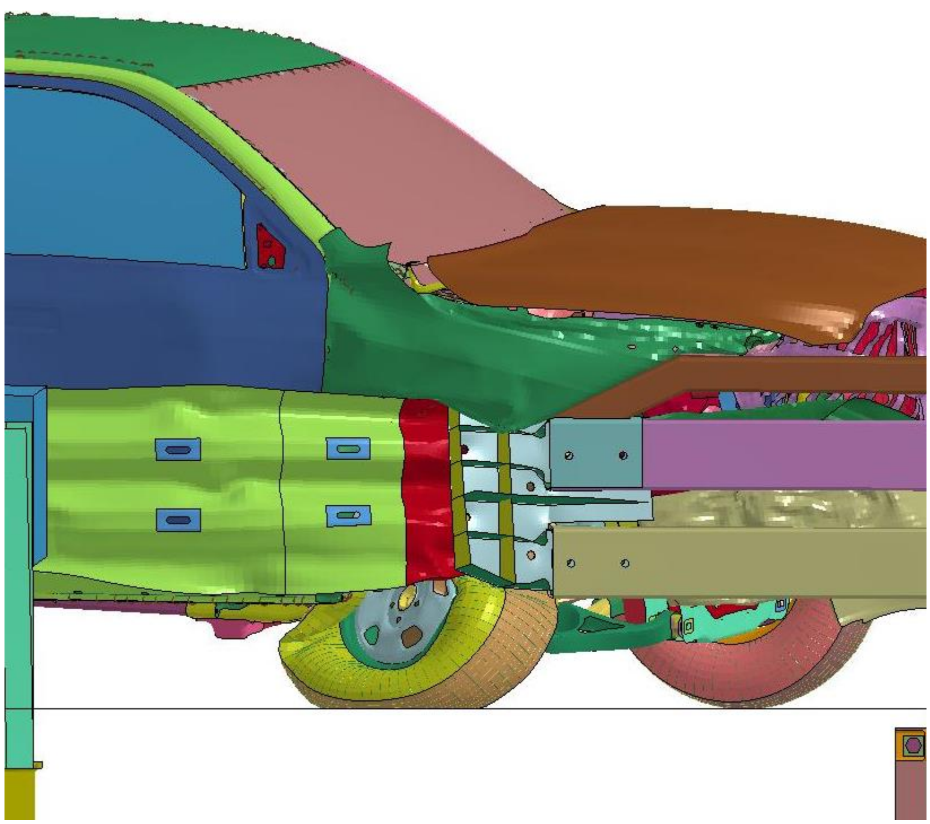


Figure 59. Vehicle Interaction with System, Simulation V13

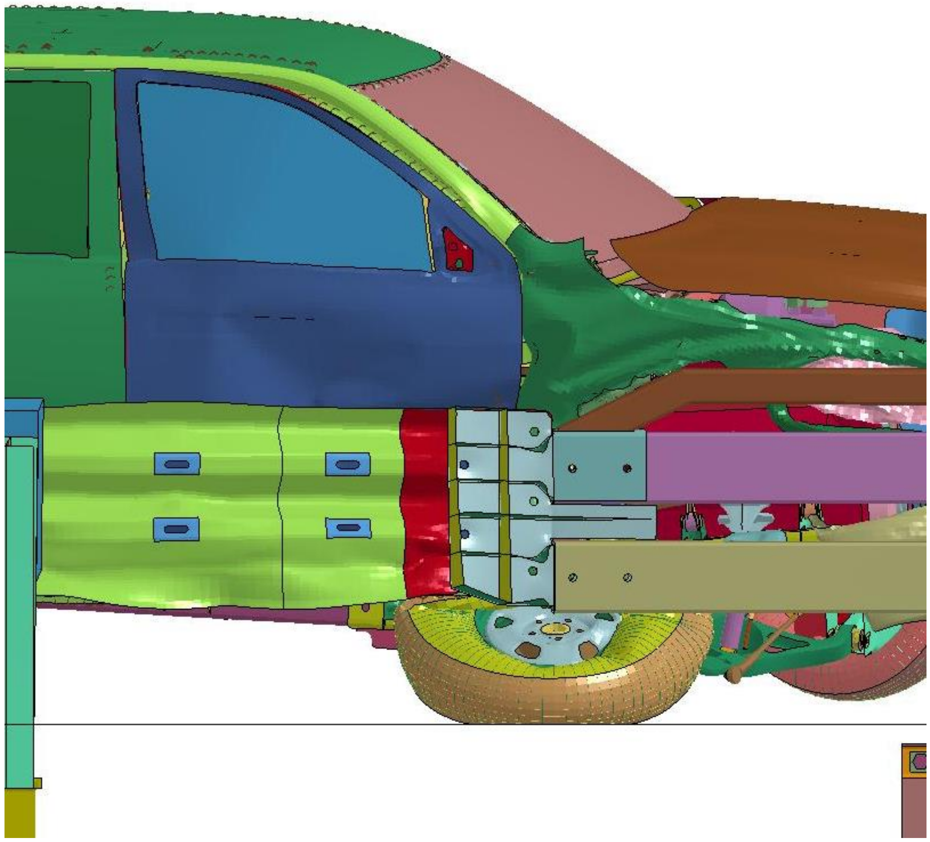


Figure 60. Vehicle Interaction with System, Simulation V18

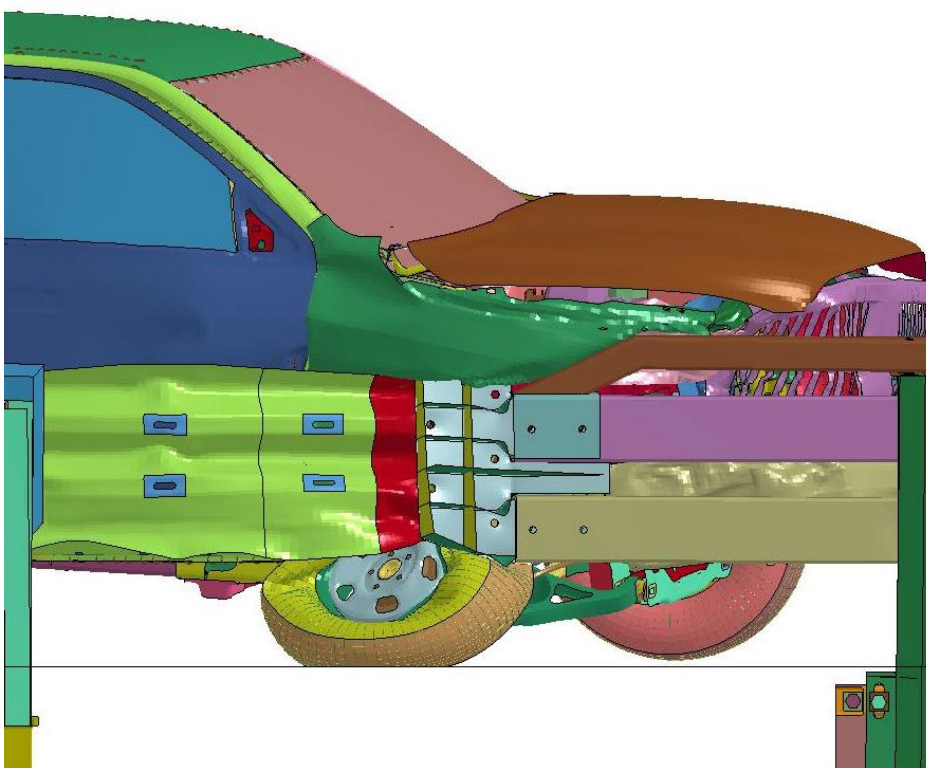


Figure 61. Vehicle Interaction with System, Simulation V20

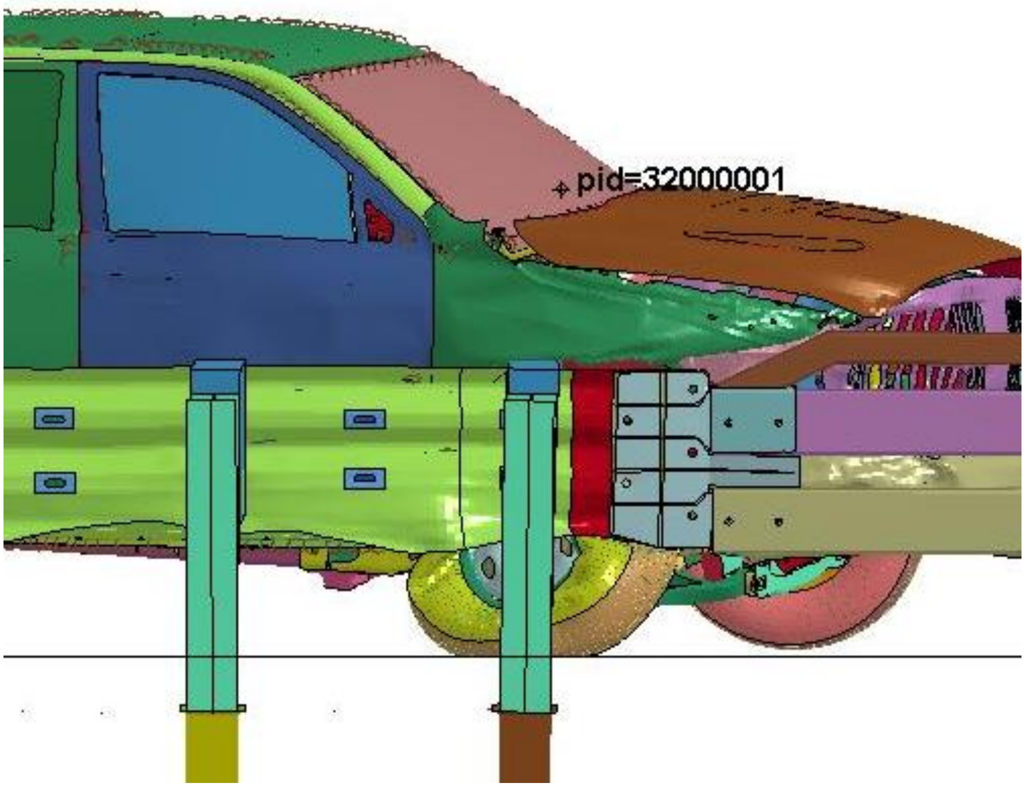



Figure 62. Vehicle Interaction with System, Simulation V28

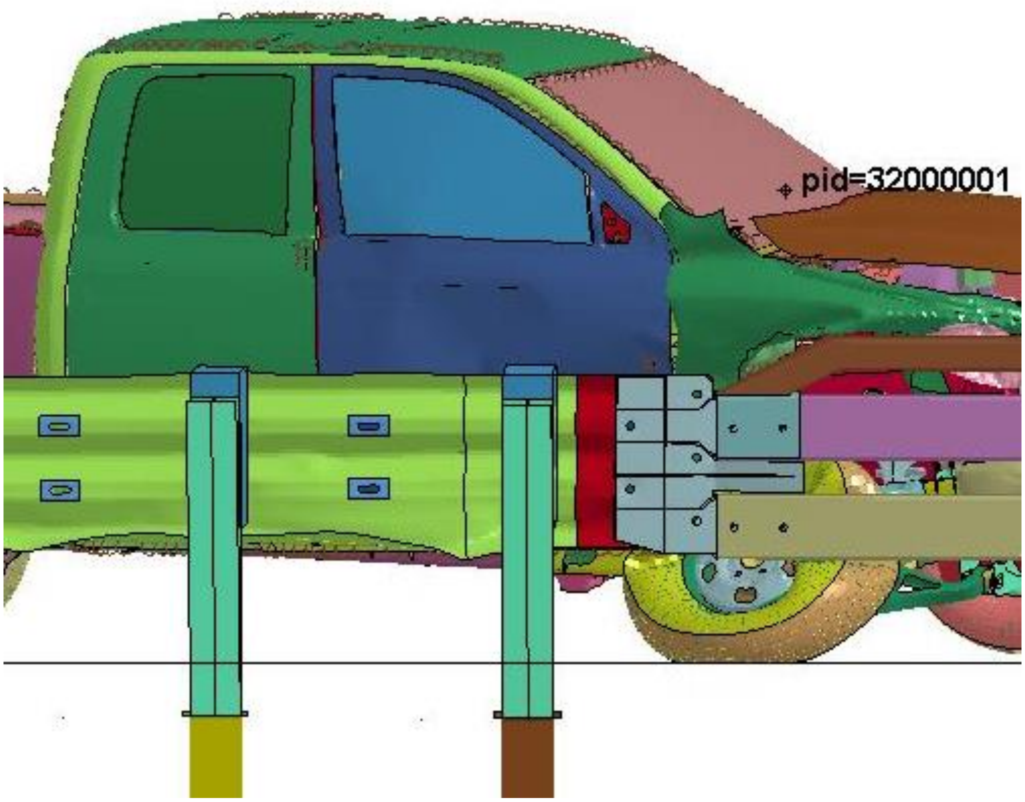



Figure 63. Vehicle Interaction with System, Simulation V29

## 5.2 Simulation of Concept #2

Concept #2 was evaluated with MASH test designation nos. 3-21 (pickup truck) and 3-20 (small car) impacts. MASH test designation no. 3-21 was simulated with conventional impacts originating from the thrie beam to the bridge rail (TB to BR) as well as with reverse-direction impacts from the bridge rail to the thrie beam (BR to TB).

Several parameters were utilized to evaluate the feasibility of the concept:

1) General vehicle behavior and snag on any system components

2) Occupant risk – longitudinal and lateral OIV and ORA

3) Stresses in various components compared to yield and ultimate stresses

4) Other MASH metrics

### 5.2.1 Test Designation No. 3-21 (Conventional Impact Direction)

Table 5 shows the matrix of the concept #2, test designation no. 3-21, thrie beam to bridge rail simulations at several different impact points listed by simulation name and impact location in inches upstream (US) from the last AGT post (post no. 18).

Table 5. Summary of Simulations on Concept #2, Test Designation No. 3-21 (TB to BR)

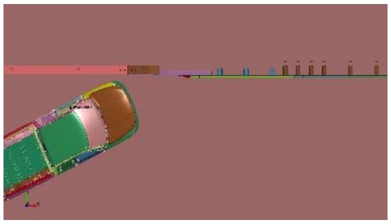
| Simulation Name | Impact Point |
|---|---|
| New-v1 | 54.6” US post no. 18 |
| New-v2 | 73.4” US post no. 18 |
| New-v3 | 35.9” US post no. 18 |
| New-v4 | 17.1” US post no. 18 |
| New-v5 | 63.5” US post no. 18 |

Occupant risk values for each simulation are shown in Table 6. General vehicle and system behavior for each simulation is shown in Figures 64 through 68. The vehicle was redirected in all simulations except New-V4, which terminated early. All the occupant risk values were below MASH thresholds. However, simulation New-V4 did not run to completion, as denoted with an asterisk in Table 6, so ORAs may have been higher had the simulation not terminated early. The errors that caused the simulation to terminate early were not resolvable. However, the early termination is likely linked to areas where large deformations were occurring within the simulation, which may indicate vehicle snag on system components. A still frame of the vehicle interaction with the system in simulation New-V4 is shown in Figure 69. The right-front wheel rode underneath the rail and interacted with and snagged on the sloped portion of the transition tube, which resulted in the model’s termination shortly thereafter. A larger lateral ORA also occurred at this time. Based on the results of the simulation effort, the impact point associated with simulation New-v4, or 17.1 in. upstream from the last AGT post, would be selected as the CIP to maximize the potential for wheel snag on the transition tubes.

Table 6. Summary of Concept #2 Simulation Results, Test Designation No. 3-21 (TB to BR)

| Simulation No. | Occupant Impact Velocity m/s | | Occupant Ridedown Acceleration g's | |
|---|---|---|---|---|
| | Lateral | Longitudinal | Lateral | Longitudinal |
| New-v1 | 6.7 | -5.9 | 9.6 | -6.5 |
| New-v2 | 6.9 | -6.2 | 8.4 | -5.1 |
| New-v3 | 6.9 | -5.6 | 8.9 | -10.2 |
| New-v4* | 6.6 | -5.6 | 15.2 | -9.7 |
| New-v5 | 6.9 | -6.1 | 8.5 | -7.6 |

*Simulation terminated early – ORAs may be greater than recorded



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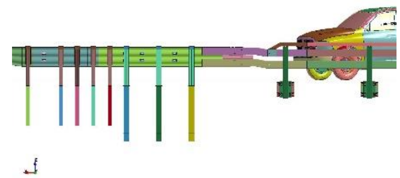

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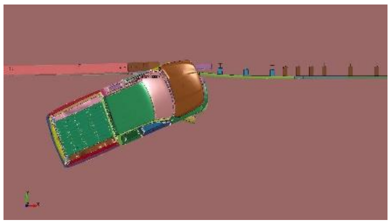

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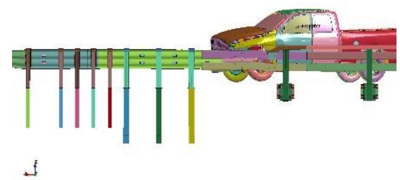

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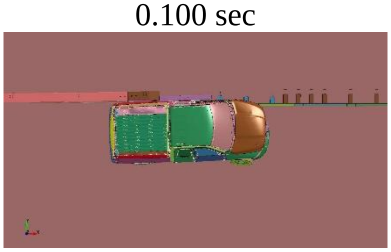

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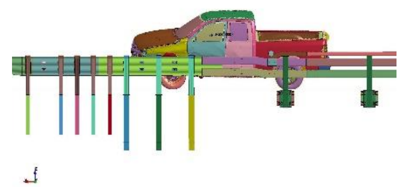

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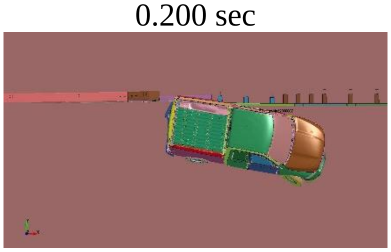

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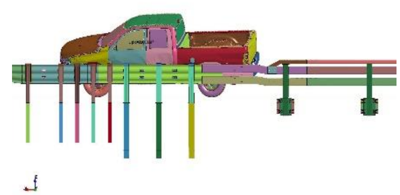

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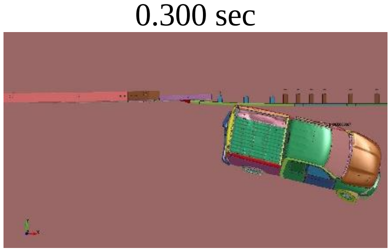

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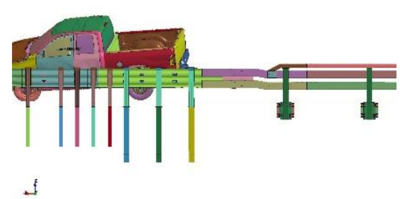

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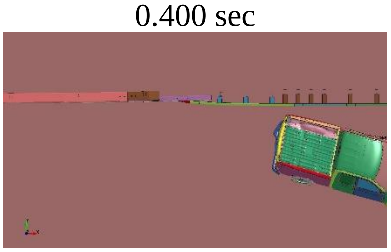

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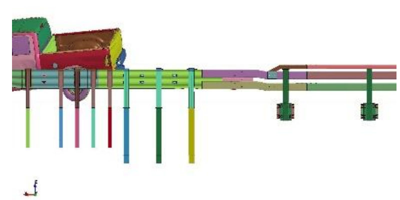

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Overhead View

Perpendicular View

Figure 64. Sequential Images, Concept #2, Simulation New-v1

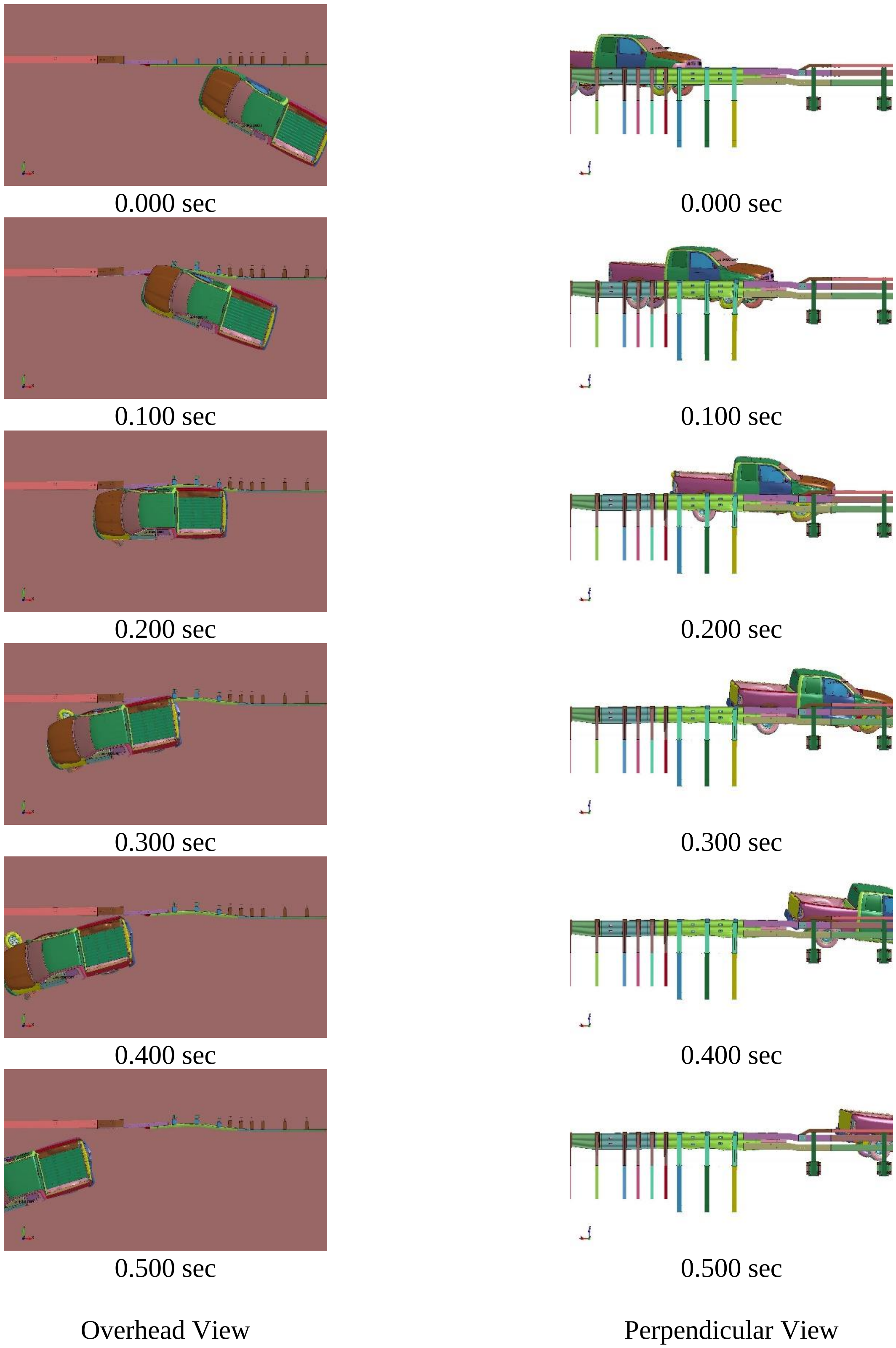



Figure 65. Sequential Images, Concept #2, Simulation New-v2

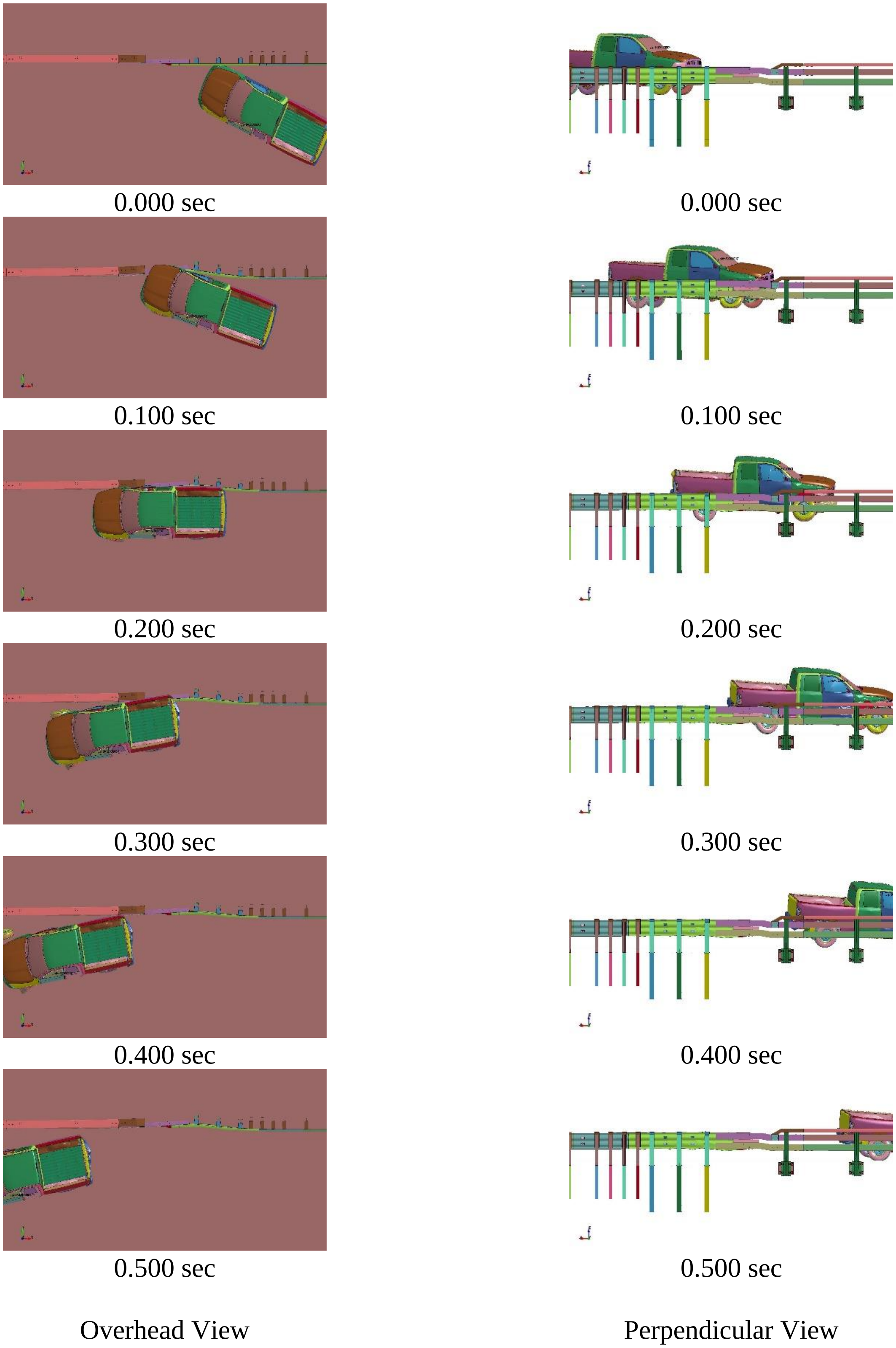



Figure 66. Sequential Images, Concept #2, Simulation New-v3

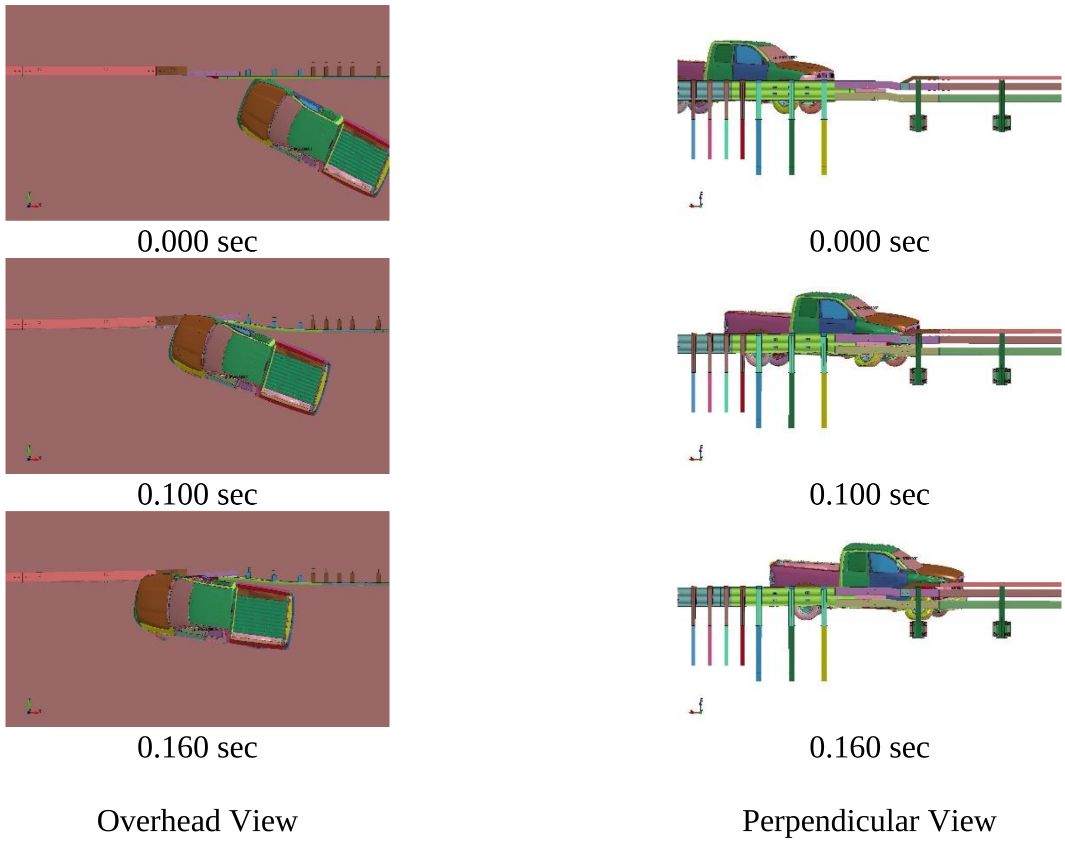
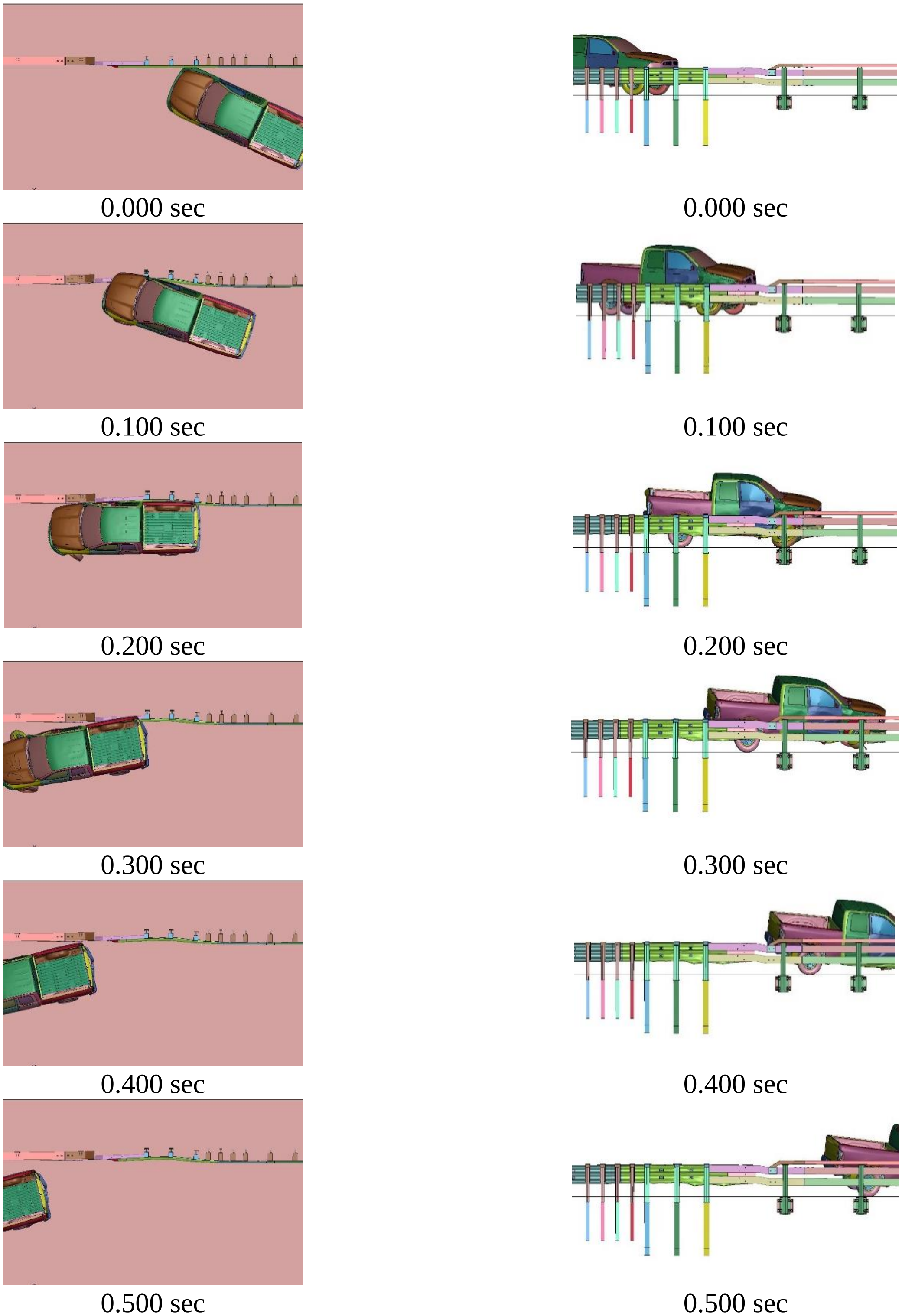



Figure 67. Sequential Images, Concept #2, Simulation New-v4




Overhead View

Perpendicular View

Figure 68. Sequential Images, Concept #2, Simulation New-v5

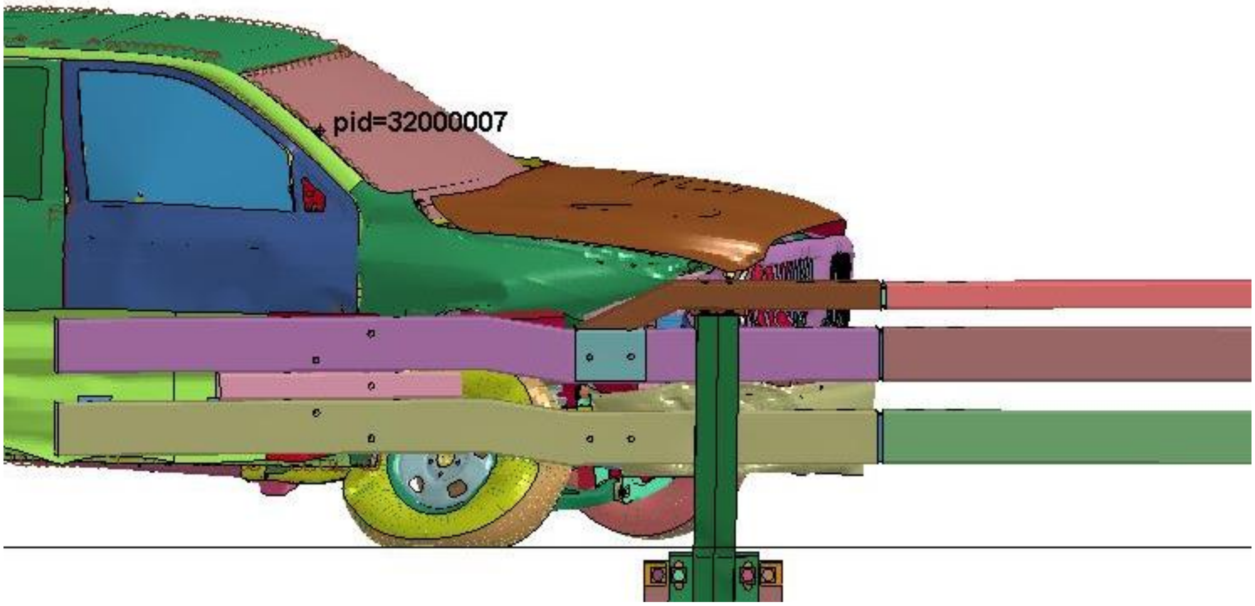



Figure 69. Vehicle Interaction with System, Simulation new-V4

### 5.2.2 Test Designation No. 3-20 (Conventional Impact Direction)

Table 7 shows the matrix of the concept #2, test designation no. 3-20, thrie beam to bridge rail simulation at several different impact points listed by simulation name and impact location in inches upstream (US) from the last AGT post (post no. 18).

Table 7. Summary of Simulations on Concept #2, Test Designation No. 3-20 (TB to BR)

| Simulation Name | Impact Point |
|---|---|
| New-sc-v1 | 37.5” US post no. 18 |
| New-sc-v2 | 56.3” US post no. 18 |
| New-sc-v3 | 50.5” US post no. 18 |
| New-sc-v4 | 29.6” US post no. 18 |
| New-sc-v5 | 21.7” US post no. 18 |

Occupant risk values for each simulation are shown in Table 8. General vehicle and system behavior for each simulation is shown in Figures 70 through 74. The vehicle was redirected in all simulations except New-sc-V3 and New-sc-V4, which terminated early. All the occupant risk values were below MASH thresholds. However, simulations New-sc-V3 and New-sc-V4 did not run to completion, as denoted with an asterisk in Table 8, so ORAs may have been higher had the simulations not terminated early. The errors that caused the simulation to terminate early were not resolvable. However, the termination is likely linked to areas where large deformations were happening within the simulation which may indicate vehicle snag on system components.

A still frame of the vehicle interaction with the system in simulation New-sc-V3 is shown in Figure 75. The right-front wheel rode underneath the rail and interacted with the front face of the last AGT post, which resulted in model termination. A larger lateral ORA also occurred at this time.

A still frame of the vehicle interaction with the system in simulation New-sc-V4 is shown in Figure 76. The right-front wheel extended and rode underneath the transition tubes with the potential to interact with and snag on the sloped portion of the transition tube, which resulted in model termination. Due to the early model termination, it is believed that the lateral and longitudinal ORA values would be much greater if the right-front wheel snagged on the sloped portion of the transition tubes.

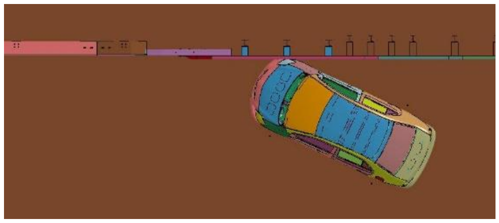
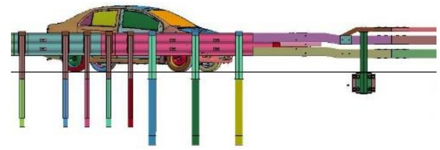
A still frame of the vehicle interaction with the system in simulation New-sc-V5 is shown in Figure 77. The right-front wheel extended underneath the transition tubes and slightly contacted the first bridge rail post before traversing past it. Since the small car tire in test no. STBR-3 overlapped with the bridge rail post several inches, this tire snag on the bridge rail post was believed to be less severe and not of concern.

Simulations New-sc-v1 and New-sc-v2 were similar to simulations New-sc-v4 and New-sc-v3, respectively, but resulted in decreased snag potential. Thus, the impact points in simulations New-sc-v1 and New-sc-v2 were not believed to be critical. Based on the results of the simulation effort, the impact point associated with simulation New-sc-v4, or 29.6 in. upstream from the final AGT post, would be selected as the CIP to maximize the potential for wedging the wheel underneath the transition tubes and snagging on the sloped portion of the transition tubes.

Table 8. Summary of Concept #2 Simulation Results, Test Designation No. 3-20 (TB to BR)

| Simulation No. | Occupant Impact Velocity m/s | | Occupant Ridedown Acceleration g's | |
|---|---|---|---|---|
| | Lateral | Longitudinal | Lateral | Longitudinal |
| New-sc-v1 | 9.1 | -6.9 | 10.7 | -11.8 |
| New-sc-v2 | 8.6 | -7.9 | 15.7 | -12.0 |
| New-sc-v3* | 8.1 | -7.6 | 18.3 | -11.0 |
| New-sc-v4* | 8.8 | -7.1 | 5.8 | -8.5 |
| New-sc-v5 | 8.4 | -7.1 | 11.7 | -12.6 |

*Simulation terminated early - ORAs may be greater than recorded

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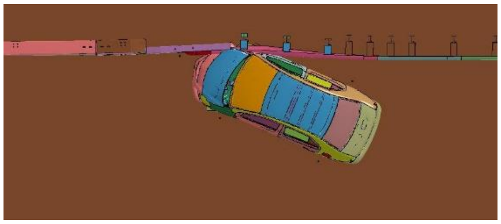 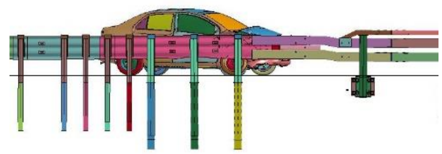

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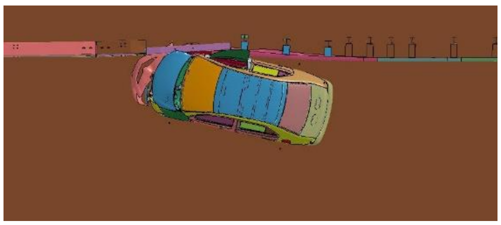 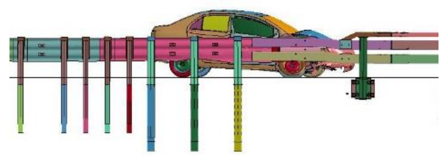

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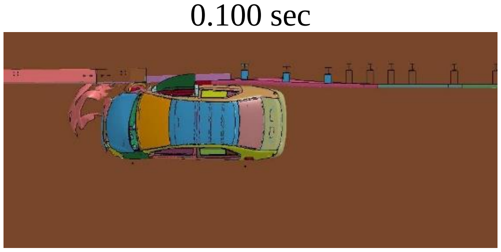 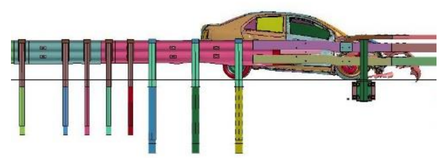

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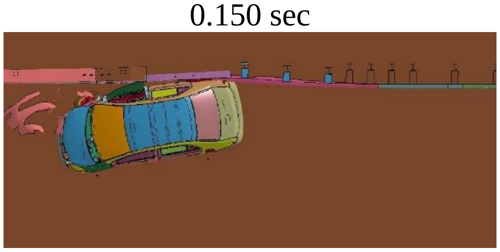 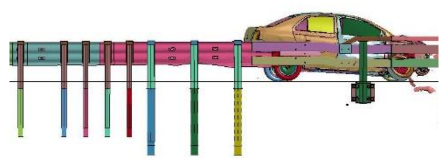

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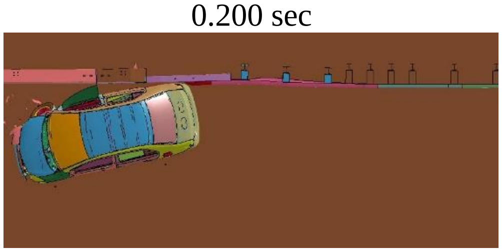 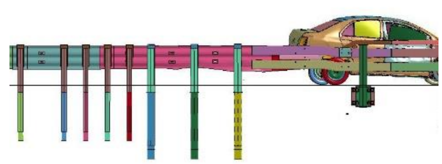

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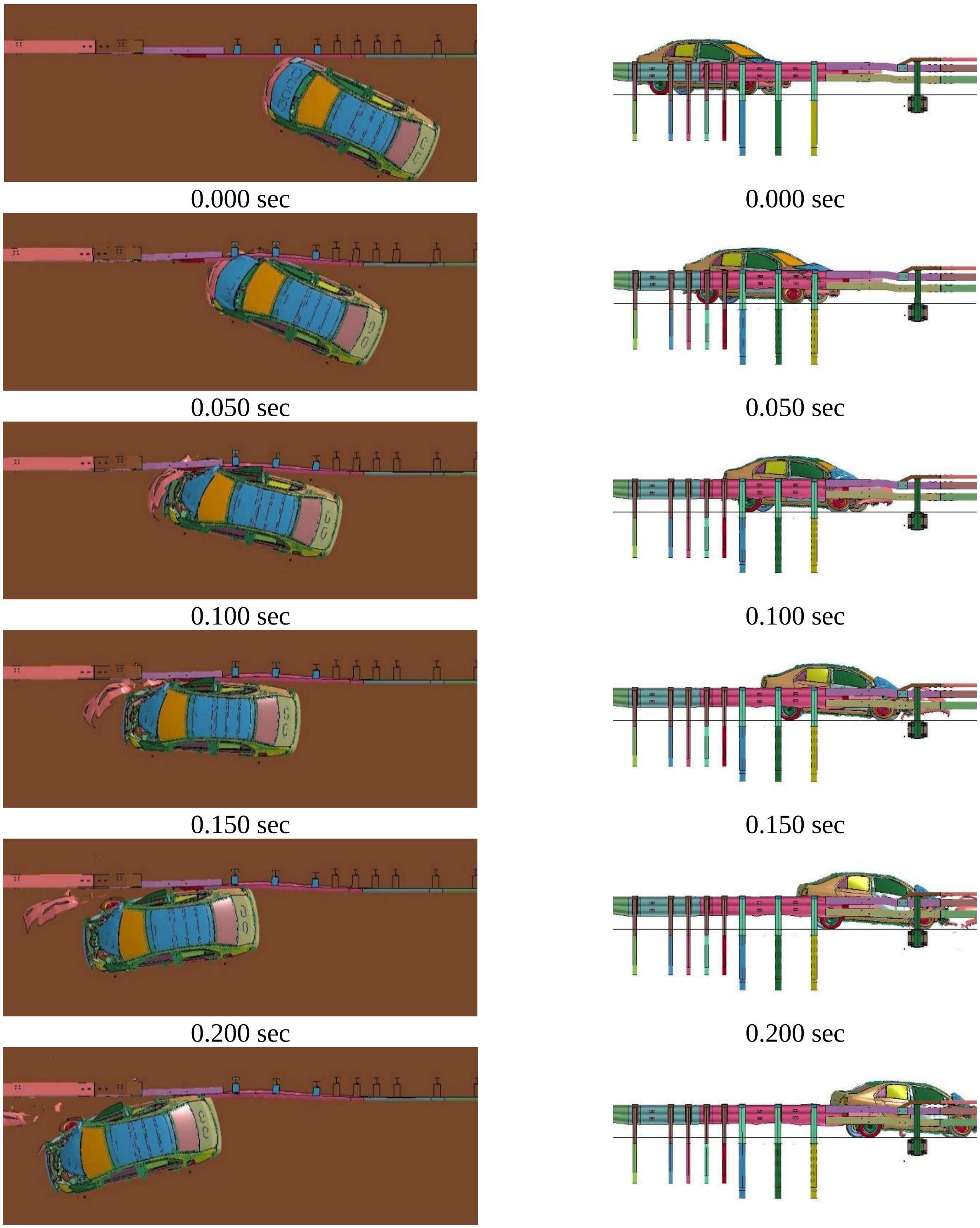
Overhead View Perpendicular View

Figure 70. Sequential Images, Concept #2, Simulation New-sc-v1




0.250 sec　　0.250 sec

Overhead View　　Perpendicular View

Figure 71. Sequential Images, Concept #2, Simulation New-sc-v2

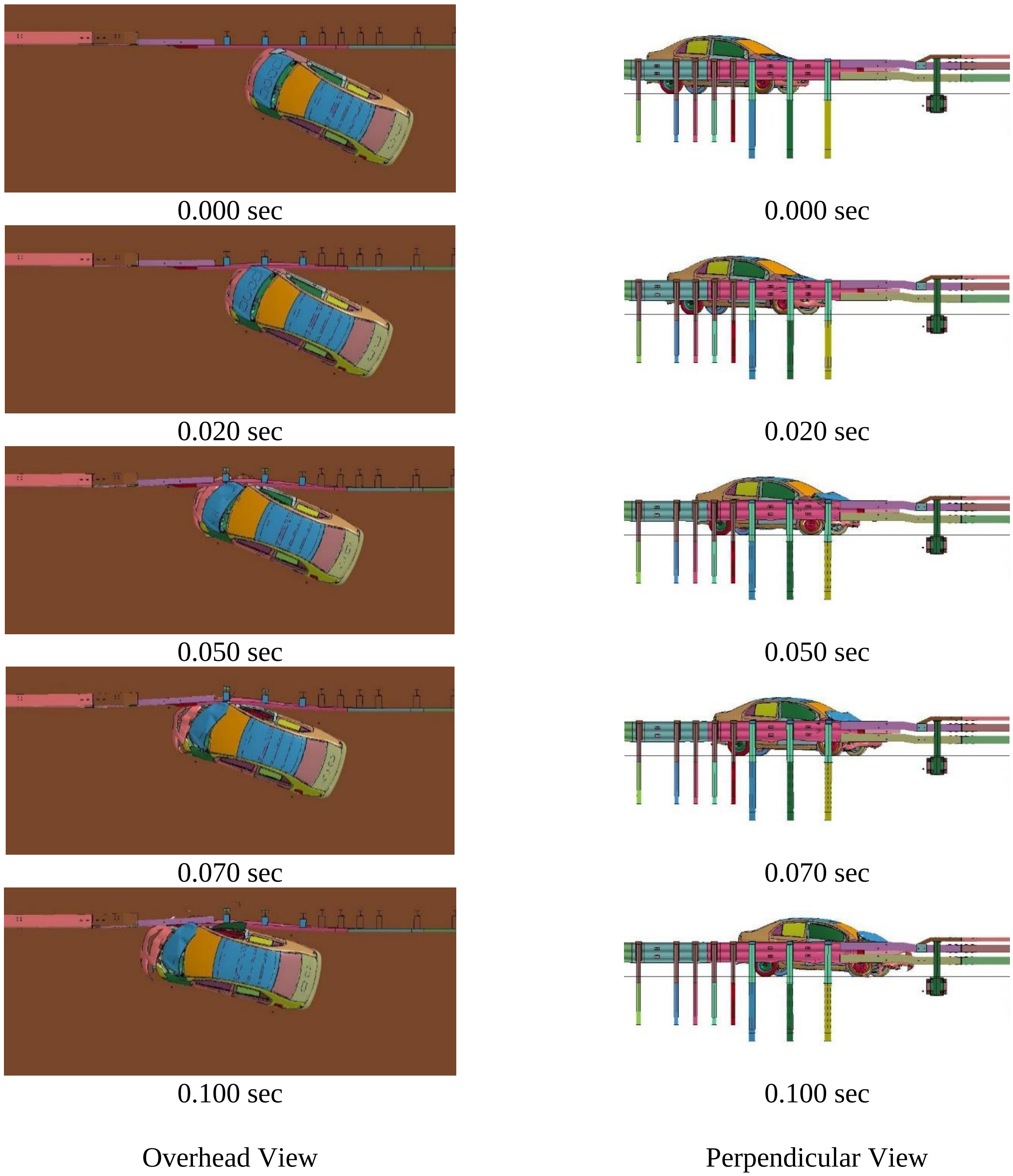



Figure 72. Sequential Images, Concept #2, Simulation New-sc-v3

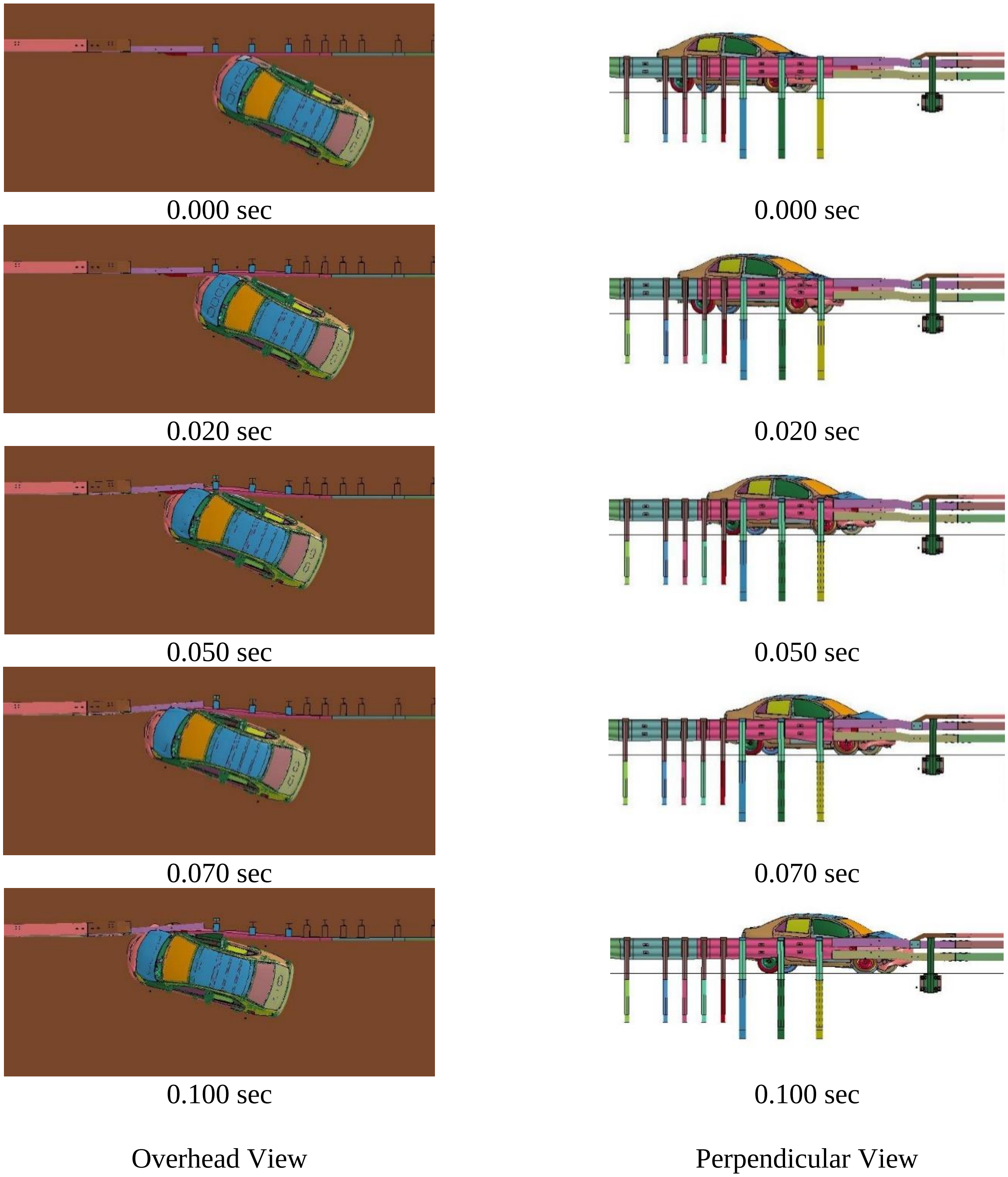
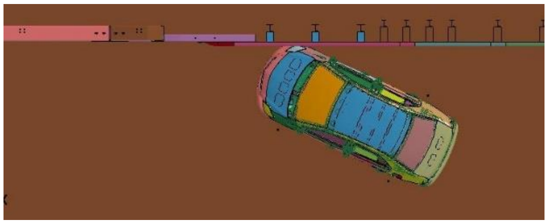



Figure 73. Sequential Images, Concept #2, Simulation New-sc-v4



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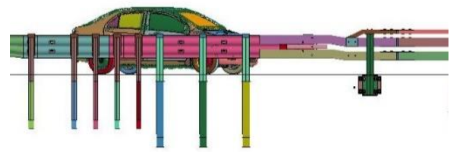

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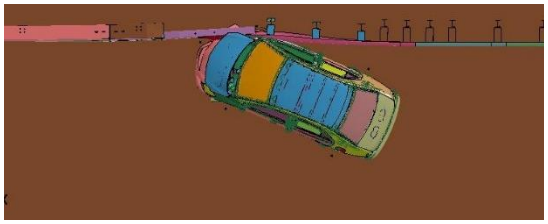

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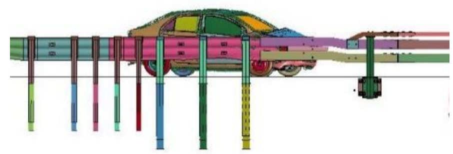

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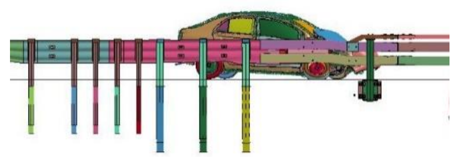

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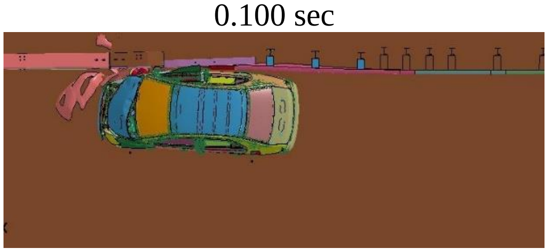

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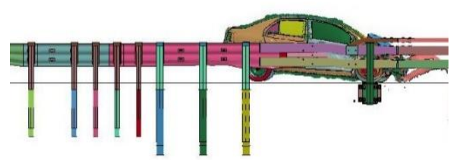

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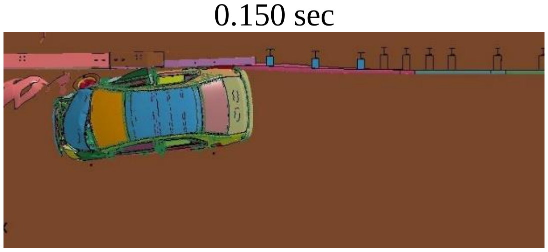

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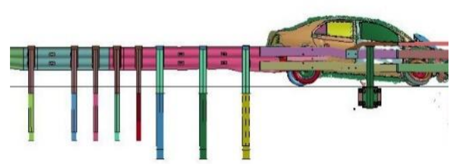

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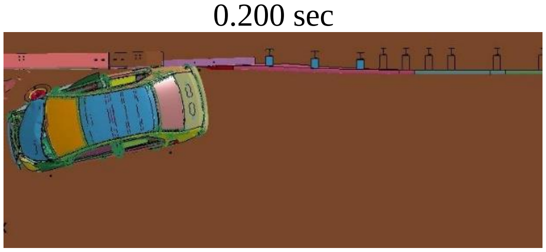

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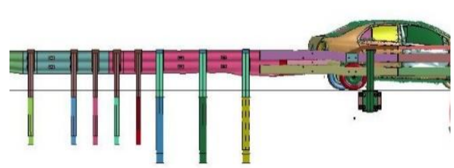

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Overhead View

Perpendicular View

Figure 74. Sequential Images, Concept #2, Simulation New-sc-v5

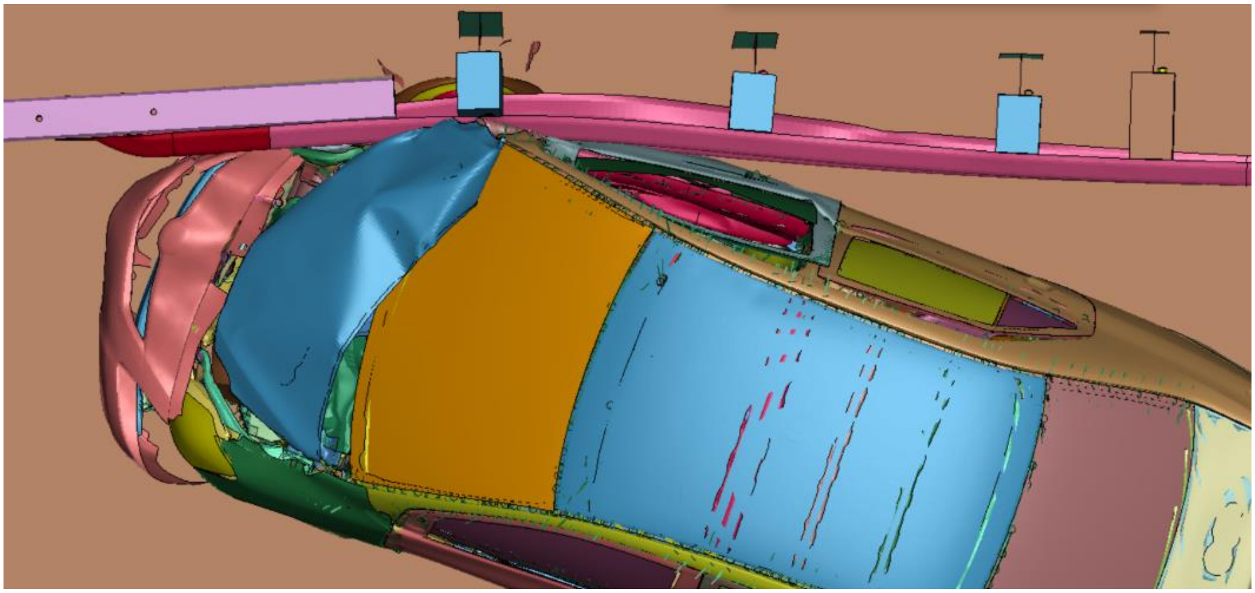


Figure 75. Vehicle Interaction with System, Simulation New-sc-v3

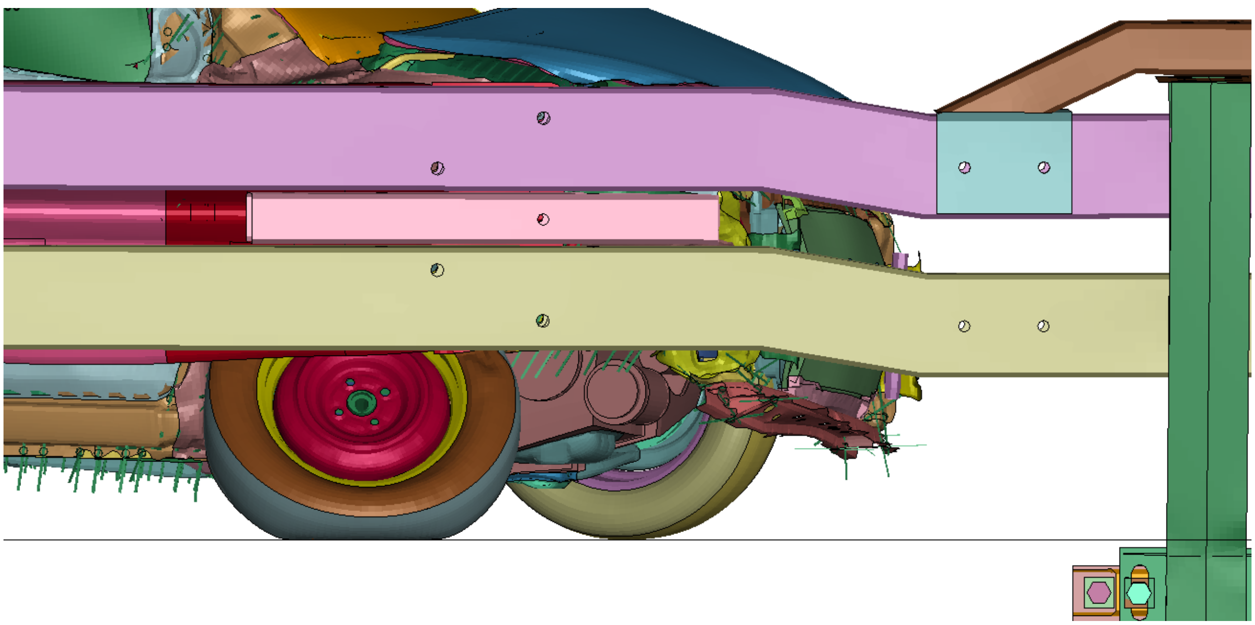


Figure 76. Vehicle Interaction with System, Simulation New-sc-v4

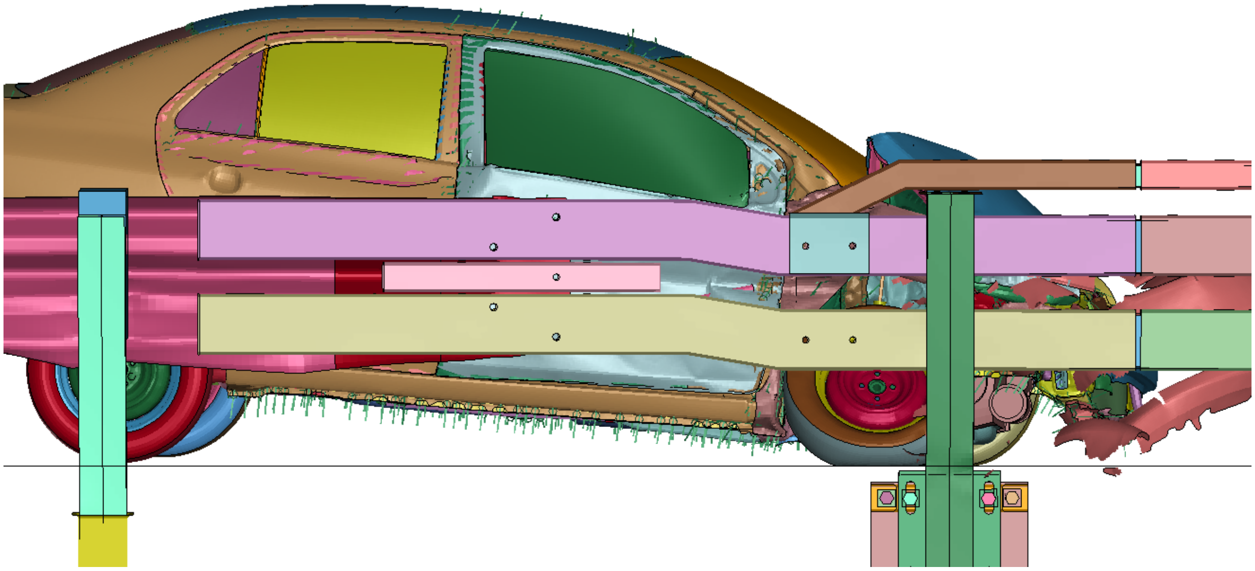


Figure 77. Vehicle Interaction with System, Simulation New-sc-v5

### 5.2.3 Test Designation No. 3-21 (Reverse Direction)

Table 9 shows the matrix of the concept #2, test designation no. 3-21, bridge rail to thrie beam simulation at several different impact points listed by simulation name and impact location in inches upstream (US) from the thrie-beam terminal connector.

Table 9. Summary of Simulations on Concept #2, Test Designation No. 3-21 (BR to TB)

| Simulation Name | Impact Point |
|---|---|
| New-rev-v1 | 72” US from end shoe |
| New-rev-v2 | 125” US from end shoe |
| New-rev-v3 | 84” US from end shoe |

Occupant risk values for each simulation are shown in Table 10. General vehicle and system behavior for each simulation are shown in Figures 78 through 80. The vehicle was redirected in all the simulations. All the occupant risk values were below MASH thresholds.

Since there were no system components that showed the potential for snag in impacts from the bridge rail to the thrie beam (from a stiff system to a less stiff system), testing was not deemed critical.

Table 10. Summary of Concept #2 Simulation Results, Test Designation No. 3-21 (BR to TB)

| Simulation Name | Occupant Impact Velocity m/s | | Occupant Ridedown Acceleration g's | |
|---|---|---|---|---|
| | Lateral | Longitudinal | Lateral | Longitudinal |
| New-rev-v1 | -7.3 | -8.5 | -12.9 | -10.2 |
| New-rev-v2 | -8.5 | -5.8 | -11.6 | -3.4 |
| New-rev-v3 | -7.7 | -5.1 | -14.3 | -9.8 |

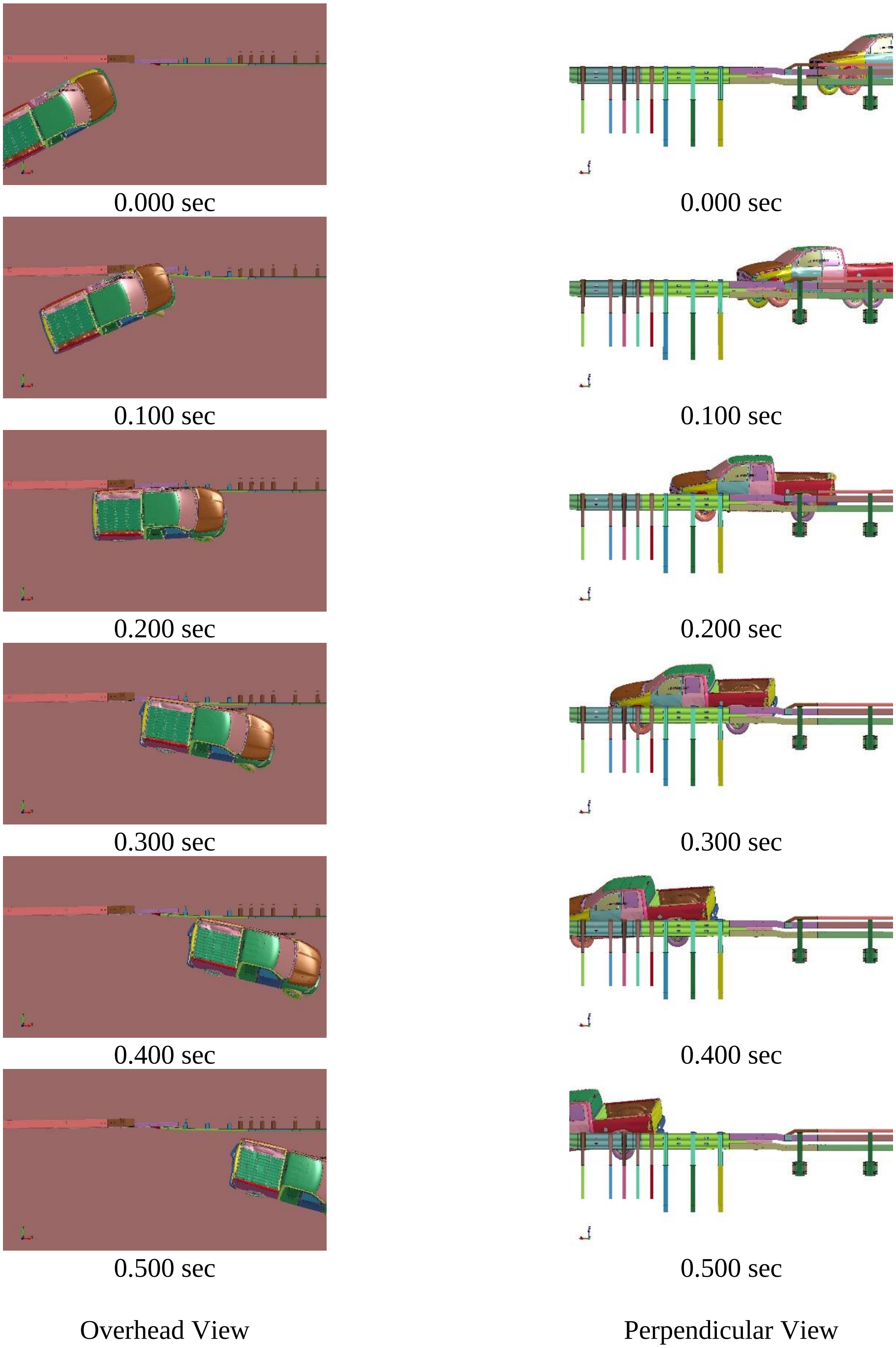
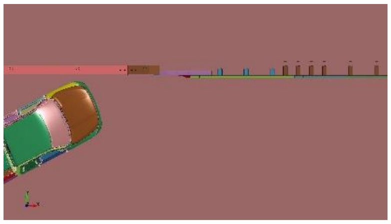



Figure 78. Sequential Images, Concept #2, Simulation New-rev-v1



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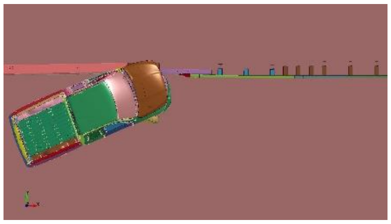

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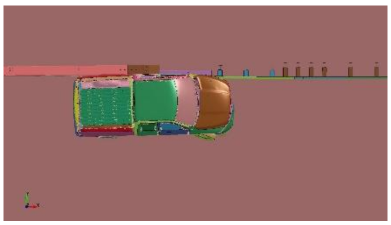

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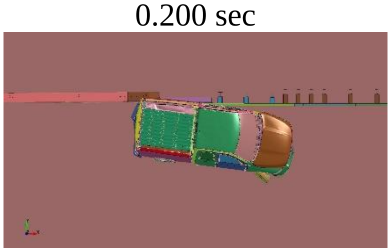

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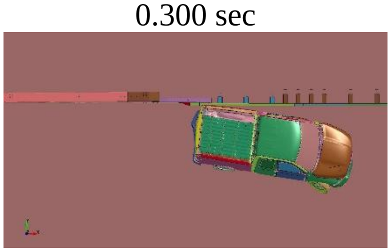

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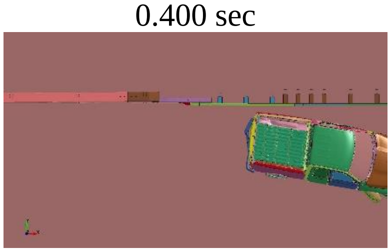
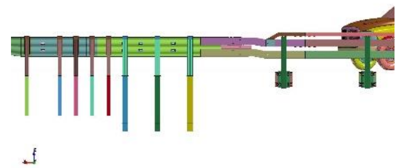


0.500 sec

Overhead View



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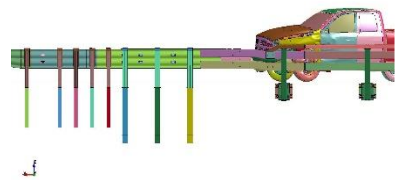
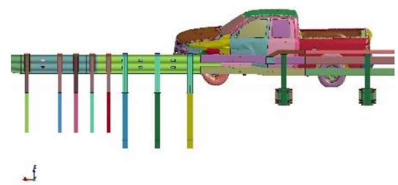


0.100 sec



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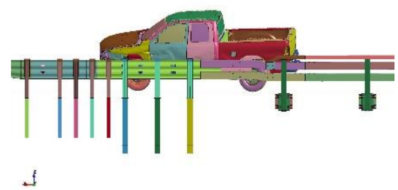

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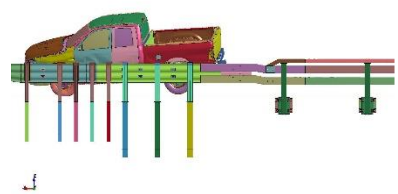
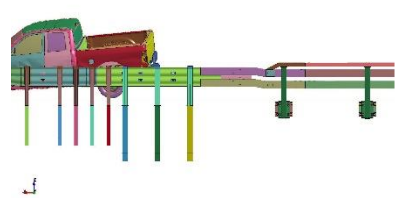


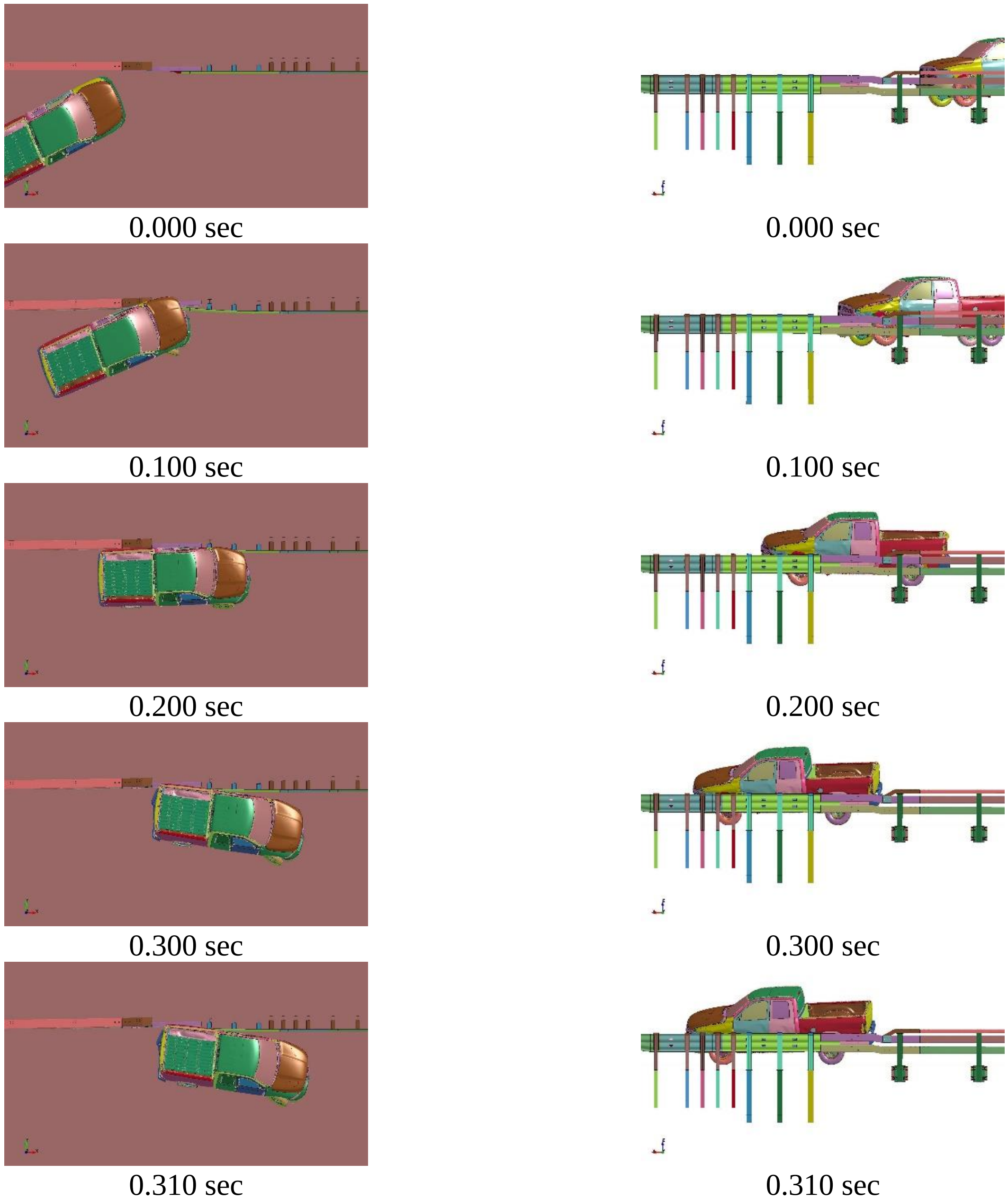
0.400 sec



0.500 sec

Perpendicular View

Figure 79. Sequential Images, Concept #2, Simulation New-rev-v2




Overhead View Perpendicular View

Figure 80. Sequential Images, Concept #2, Simulation New-rev-v3

### 5.3 Discussion and CIP Selection

The CIP for test designation no. 3-21 in the conventional direction was determined from computer simulation to be 17 in. upstream from the last W6x15 AGT post to maximize occupant risk values and the potential for snagging on sloped end of the upper transition tube and the first bridge rail post.

The CIP for test designation no. 3-20 in the conventional direction was determined from computer simulation to be 30 in. upstream from the last AGT post to maximize wedging of the small car tire underneath the sloped transition tubes and the potential for snagging on the posts. Although the occupant risk values were lower in this simulation compared to other simulations, the accelerations with the small car were less reliable, and thus were not used to evaluate the small car simulations.

Reverse-direction impacts with test designation no. 3-21 showed no indication of significant pocketing or snag. Additionally, the system behaved similar to the bridge rail length-of-need impacts. Since test no. STBR-2 on the length-of-need bridge rail was successful, the test on the transition from the bridge rail to the thrie beam should also be successful [6-7]. The simulated occupant risk values were all below MASH limits, and the reverse-direction simulation results were less severe than those of the conventional-direction impacts. Thus, this test was deemed not critical for testing.

Reverse-direction impacts with test designation no. 3-20 were not simulated. However, it was believed that a reverse-direction impact to the transition tube rails would behave similarly as the bridge rail length-of-need impacts. Since test no. STBR-3 on the length-of-need bridge rail was successful, the test on the transition from the bridge rail to the thrie beam should also be successful [6-7]. Thus, this test was deemed not critical for testing.

# 6 TEST REQUIREMENTS AND EVALUATION CRITERIA

## 6.1 Test Requirements

AGTs must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the FHWA for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH 2016 [5]. Note that there is no difference between MASH 2009 and MASH 2016 for AGTs like the system developed and tested herein except that additional occupant compartment deformation measurements, photographs, and documentation are required by MASH 2016. According to TL-3 of MASH 2016, AGT systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 11. Both crash tests are recommended for evaluation of the AGT with the CIPs as recommended by the computer simulation effort.

Table 11. MASH 2016 TL-3 Crash Test Conditions for Approach Guardrail Transitions [5]

| Test Article | Test Designation No. | Test Vehicle | Vehicle Weight (lb) | Impact Conditions | | Evaluation Criteria [1] |
|---|---|---|---|---|---|---|
| | | | | Speed (mph) | Angle (deg.) | |
| Longitudinal Barrier | 3-20 | 1100C | 2,420 | 62 | 25 | A,D,F,H,I |
| | 3-21 | 2270P | 5,000 | 62 | 25 | A,D,F,H,I |

[1] Evaluation criteria explained in Table 12

Recent testing of AGTs has illustrated the importance of evaluating two different transition regions along the length of the AGT: (1) the downstream transition where the thrie beam connects to the bridge rail and (2) the upstream stiffness transition where the W-beam guardrail transitions to a stiffer thrie beam barrier. Additionally, the 34-in. tall AGT described herein was designed for use both before and after roadway overlays, which effectively changes the barrier height relative to the roadway surface. The combination of these MASH tests, different transition regions, and pre- and post-overlay barrier configurations resulted in a total of eight recommended tests, but not all of them were considered critical or necessary to evaluate the performance of the new AGT.

The upstream stiffness transition of the 34-in. tall AGT was specifically designed to replicate the MASH-crashworthy MGS stiffness transition [32-33]. Upon initial installation, the only difference between the two systems was that the 34-in. tall AGT utilized a symmetric W-to-thrie transition rail instead of an asymmetric transition rail. Since the W-beam upstream from the transition rail was mounted at its nominal 31-in. height, vehicles impacting this region of the barrier should not extend over the rail and roll excessively. Additionally, the bottom of the symmetric transition rail has a shallower slope, which would produce less snag if a small vehicle tried to wedge underneath the rail. Thus, there were no concerns about vehicle stability and/or snag on the upstream stiffness transition of the 34-in. tall AGT prior to a roadway overlay.

After the roadway overlay, the symmetric rail segment is replaced by an asymmetric rail and the W-beam is raised 3 in. on the post to maintain its nominal 31-in. mounting height. Thus, after an overlay, the upstream stiffness transition is essentially identical to the MGS stiffness transition. Since the MGS stiffness transition was previously subjected to and successfully passed MASH TL-3 criteria, the upstream stiffness transition within the 34-in. tall AGT would be MASH TL-3 crashworthy as well. Therefore, all crash testing of the upstream stiffness transition, both before and after an overlay, was deemed non-critical.

At the downstream end of the AGT, there were concerns about the strength of the connection hardware, the stiffness of the system within the 9-ft span between adjacent transition and bridge rail posts, and the potential for vehicle snag on the system components. Although these concerns applied to the AGT both before and after a roadway overlay, the increased height of the 34-in. tall thrie beam prior to an overlay increased the propensity for vehicle snag. The front ends and wheels of both small cars and pickup trucks were susceptible to excessive snag by extending below the rail and impacting the sloped portions of the transition tubes rails and the bridge rail posts. As such, both MASH crash tests were determined to be critical in evaluating the crashworthiness of the downstream end of the 34-in. tall AGT.

After a 3-in. overlay, the thrie beam would be at its nominal 31-in. height relative to the roadway surface and the opening below the rails would be smaller. As such, the potential for vehicle snag on the system components would be decreased. Subsequently, testing of the downstream end of the AGT after the application of a roadway overlay was deemed non-critical, as testing with the taller rails (before overlay) would be more critical for vehicle snag. Thus, only two full-scale tests were recommended for evaluating the crashworthiness of the AGT, and MASH test designation nos. 3-20 and 3-21 were conducted on the downstream end of the transition with the rail mounted 34 in. above the roadway surface (pre-overlay configuration).

It should be noted that the test matrix detailed herein represents the researchers' best engineering judgement with respect to the MASH 2016 safety requirements and their internal evaluation of critical tests necessary to evaluate the crashworthiness of the guardrail transition. However, these opinions may change in the future due to the development of new knowledge (crash testing, real-world performance, etc.) or changes to the evaluation criteria. Thus, any tests within the evaluation matrix deemed non-critical may eventually need to be evaluated based on additional knowledge gained over time or revisions to the MASH 2016 criteria.

## 6.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the transition to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 12 and defined in greater detail in MASH 2016. The full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in MASH 2016. In addition to the standard occupant risk measures, the Post-Impact Head Deceleration (PHD), the Theoretical Head Impact Velocity (THIV), and the Acceleration Severity Index (ASI) were determined and reported. Additional discussion on PHD, THIV and ASI is provided in MASH 2016.

Table 12. MASH 2016 Evaluation Criteria for Approach Guardrail Transitions [5]

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">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.</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">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. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s</td><td>40 ft/s</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

### 6.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH 2016, foundation soil strength must be verified before any full-scale crash testing can occur. During the installation of a soil dependent system, W6x16 posts are installed near the impact region utilizing the same installation procedures as the system itself. Prior to full-scale testing, a dynamic impact test must be conducted to verify a minimum dynamic soil resistance of 7.5 kips at post deflections between 5 and 20 in. measured at a height of 25 in. If dynamic testing near the system is not desired, MASH 2016 permits a static test to be conducted instead and compared against the results of a previously established baseline test. In this situation, the soil must provide a resistance of at least 90% of the static baseline test at deflections of 5, 10, and 15 in. Further details can be found in Appendix B of MASH 2016.

# 7 DESIGN DETAILS

The AGT test installation was approximately 137 ft – 9 in. long and consisted of five major components: (1) a guardrail anchorage system; (2) standard Midwest Guardrail System (MGS); (3) a 34-in. tall approach guardrail transition; (4) a 39-in. tall steel-tube bridge rail; and (5) the AGT connection hardware developed herein to attach thrie beam guardrail to the bridge rail. Design details for test nos. STBRT-1 and STBRT-2 are shown in Figures 81 through 115. Photographs of the test installation are shown in Figures 116 and 118. Material specifications, mill certifications, and certificates of conformity for the system are shown in Appendix B.

The breakaway cable terminal (BCT) guardrail anchorage system utilized to anchor the upstream region of the test installation consisted of timber posts, connection hardware, foundation tubes, anchor cable, bearing plate, rail bracket, and channel strut. BCT posts consisted of wooden posts embedded in 72-in. long foundation tubes. Longitudinal stiffness and strength were provided to the guardrail by the BCT ground strut and anchorage assembly. The guardrail anchorage system has been MASH TL-3 crash tested as a downstream trailing end terminal [34-37].

The MGS section was 43.75 ft long and consisted of 12-gauge W-beam mounted to W6x8.5 guardrail posts spaced at 75 in. on-center. The W-beam had a top mounting height of 31 in. The MGS section utilized 12-in. deep timber blockouts.

The 34-in. tall AGT consisted of a 10-gauge, symmetric, W-to-thrie beam rail transition rail segment; 6.25 ft of 12-gauge thrie beam; and 12.5 ft of nested 12-gauge thrie beam. A 10-gauge thrie beam terminal connector was sandwiched between the nested thrie beam rails at the downstream end of the guardrail and connected to the upstream end of the steel bridge rail transition tubes. The AGT posts used a combination of standard W6x8.5 guardrail posts at various spacings and W6x15 posts spaced at 37.5 in. on-center. Post details, including lengths, embedment depths, and spacings for the 34-in. tall AGT are shown in Figure 99.

The transition to the steel bridge rail consisted of four specialized transition tubes. Two 119⅝-in. long HSS8x6x¼ steel rails were used to connect the thrie beam terminal connector to the bridge rails. These transition rails included a 2-in. height transition near their middle to match up with the heights of the AGT rail and the bridge rail tubes. A 6H:1V vertical taper was used on the height transition to reduce snag severity. A 36-in. long HSS6x4x¼ tube was sandwiched between the lower and middle transition rails and incorporated a 3:1 lateral taper to mitigate vehicle snag on the terminal connector during reverse-direction impacts. The top transition rail assembly was 44¼ in. long and consisted of HSS12x4x¼ segments and a ¼-in. thick bent plate. The top transition rail was sloped downward at a 2H:1V slope and welded to the bent plate. The bent plate fit against the top and back sides of the middle transition rail and was secured with two ¾-in. diameter bolts. The three transition rails were connected to the bridge rail tubes using the same hardware as the bridge rail splices.

Two fabricators were consulted about the best practice to assemble the welded tube assemblies, and two sets of the transition tube rails were obtained, one from each manufacturer. Both fabricators used full penetration welds with backing plates on the inside of the lower and middle transition tubes in lieu of bevel welds. The final fabricator details of the transition components utilized in test no. STBRT-1 are shown in Appendix C. For test no. STBRT-2, the fabricator specified these welds with weld detail B-U2a-GF. It is recommended that full penetration welds are utilized on the lower and middle transition tube assemblies to ensure adequate system capacity.

The 39-in. tall steel bridge rail was approximately 50 ft long and consisted of seven W6x15 bridge rail posts, an HSS12x4x¼ top tube rail, and two HSS6x8x¼ (lower and middle) tube rails. The bridge rail posts were spaced at 8 ft on-center and mounted to the side of a simulated bridge deck used previously in the full-scale crash testing of the new steel-tube bridge rail.

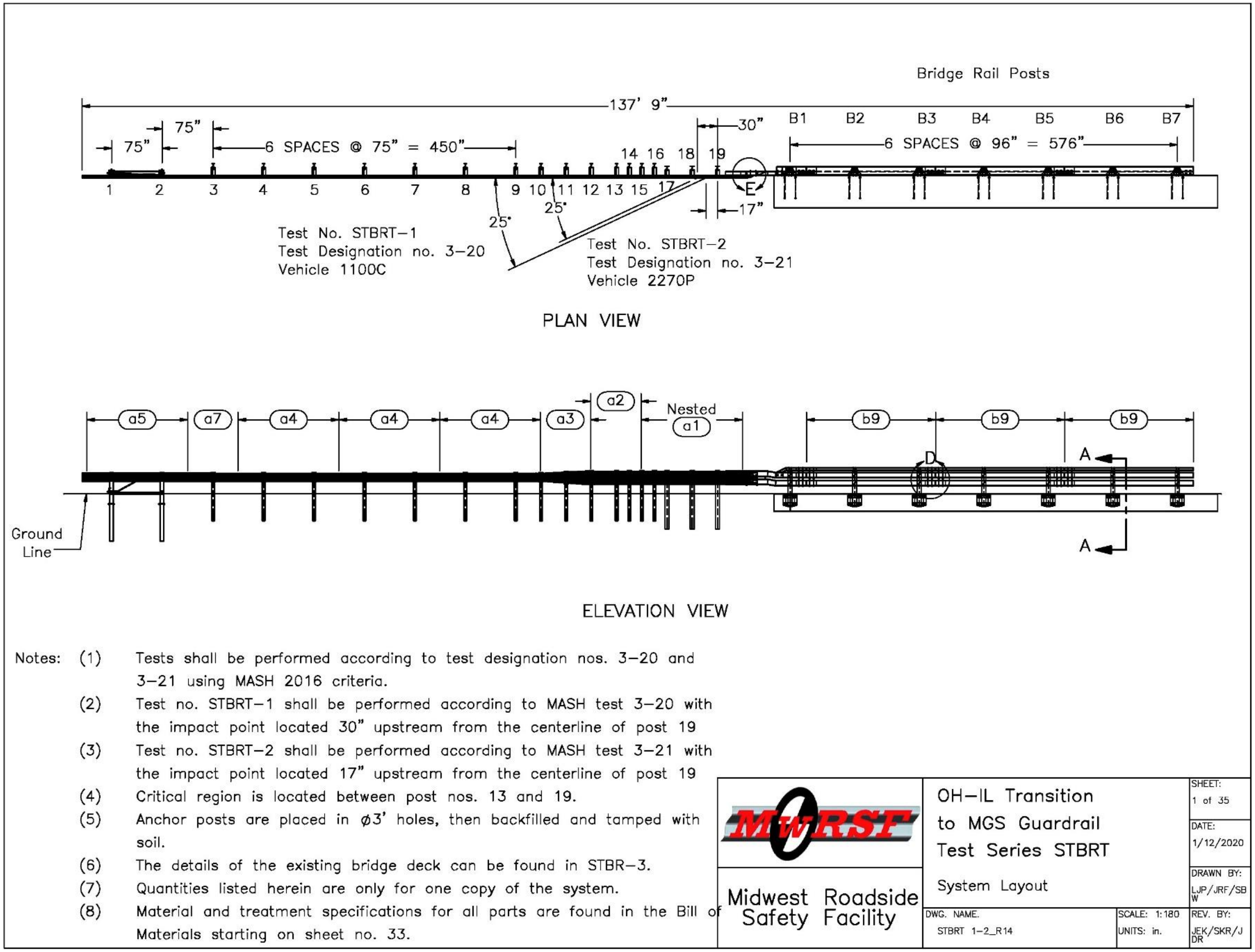
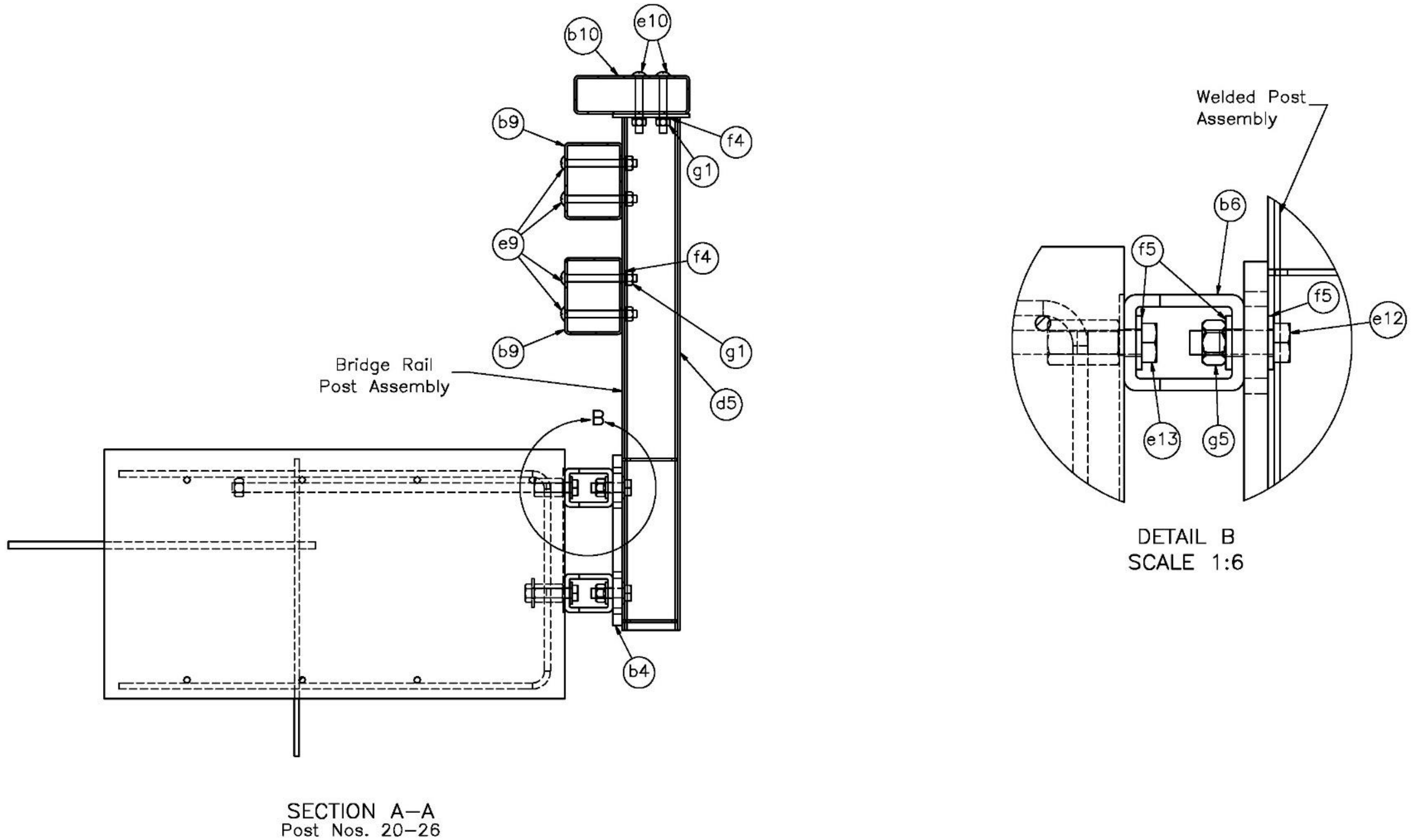


Figure 81. Test Installation Layout, Test Nos. STBRT-1 and STBRT-2




Notes: (1) Two f4 washers can be used if e10 bolt thread length exists, which is necesssary to properly tighten nut.
(2) Material and treatment specifications for all parts are found in the Bill of Materials starting on sheet no. 33.

| | | |
|---|---|---|
| MwRSF Midwest Roadside Safety Facility | OH–IL Transition to MGS Guardrail Test Series STBRT | SHEET: 2 of 35 |
| | | DATE: 1/12/2020 |
| | Bridge Rail Post Sections | DRAWN BY: LJP/JRF/SBW |
| | DWG. NAME. STBRT 1–2_R14 / SCALE: 1:15 UNITS: in. | REV. BY: JEK/SKR/JDR/JDR |

Figure 82. Bridge Rail Post Sections, Test Nos. STBRT-1 and STBRT-2

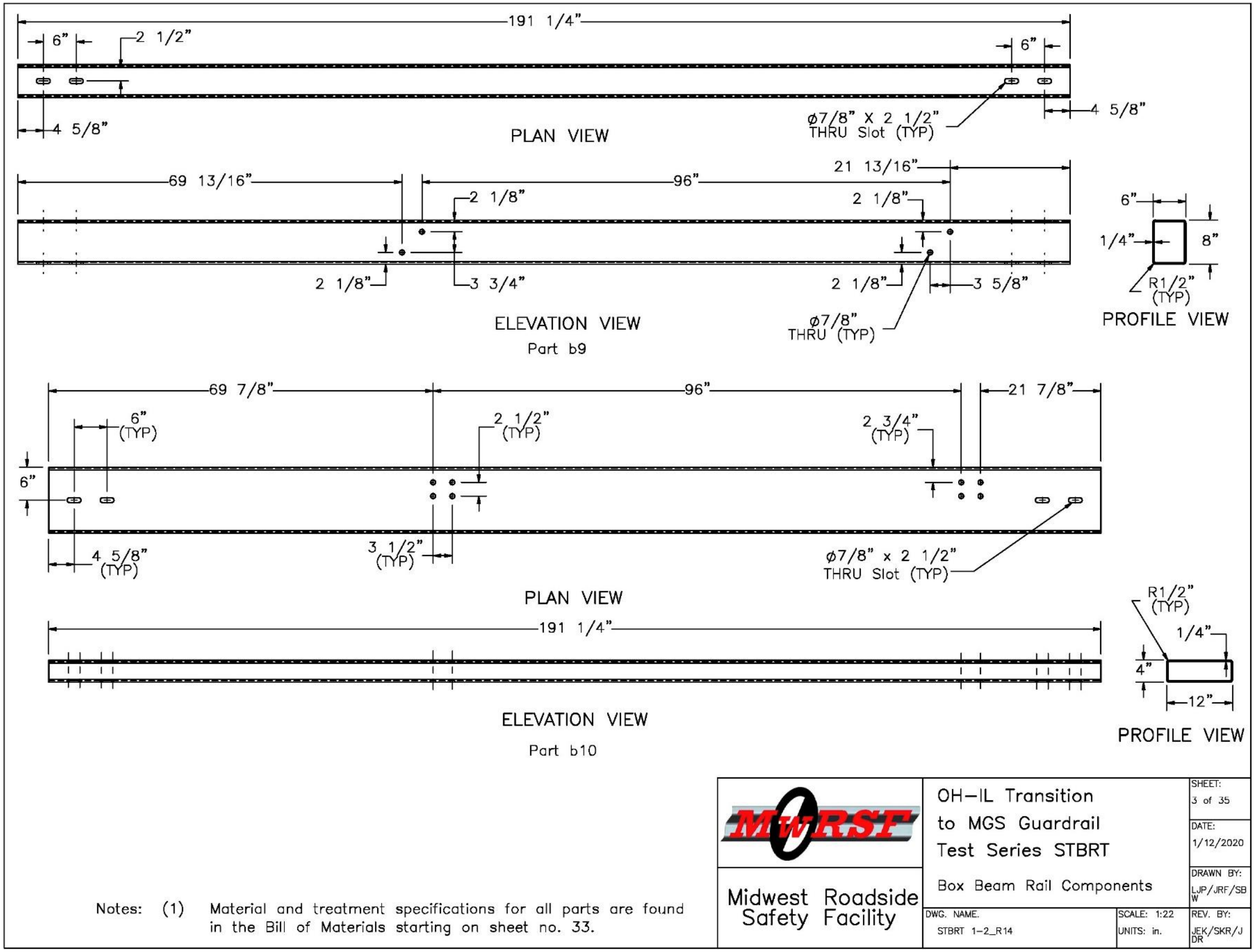



Figure 83. Box Beam Rail Components, Test Nos. STBRT-1 and STBRT-2

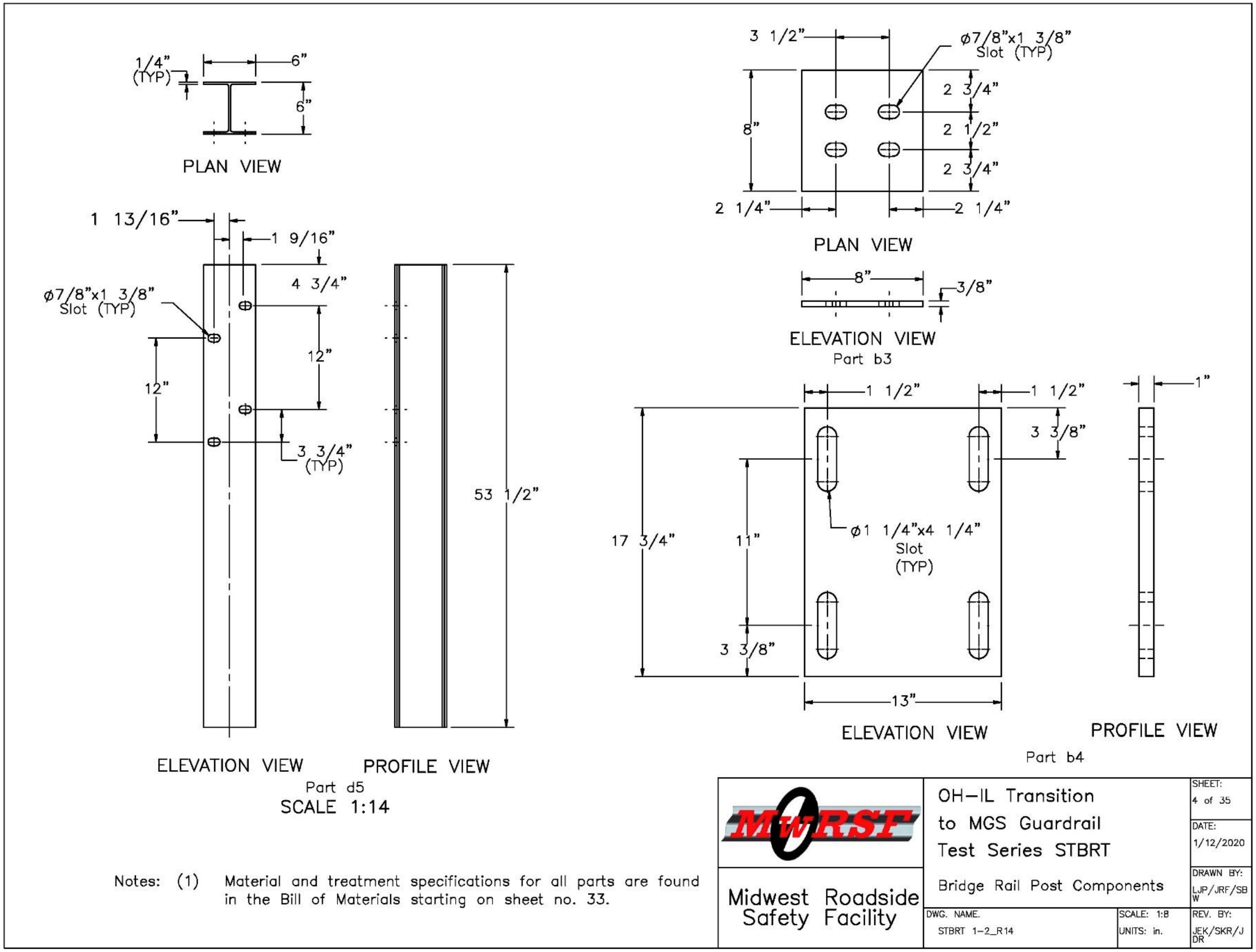
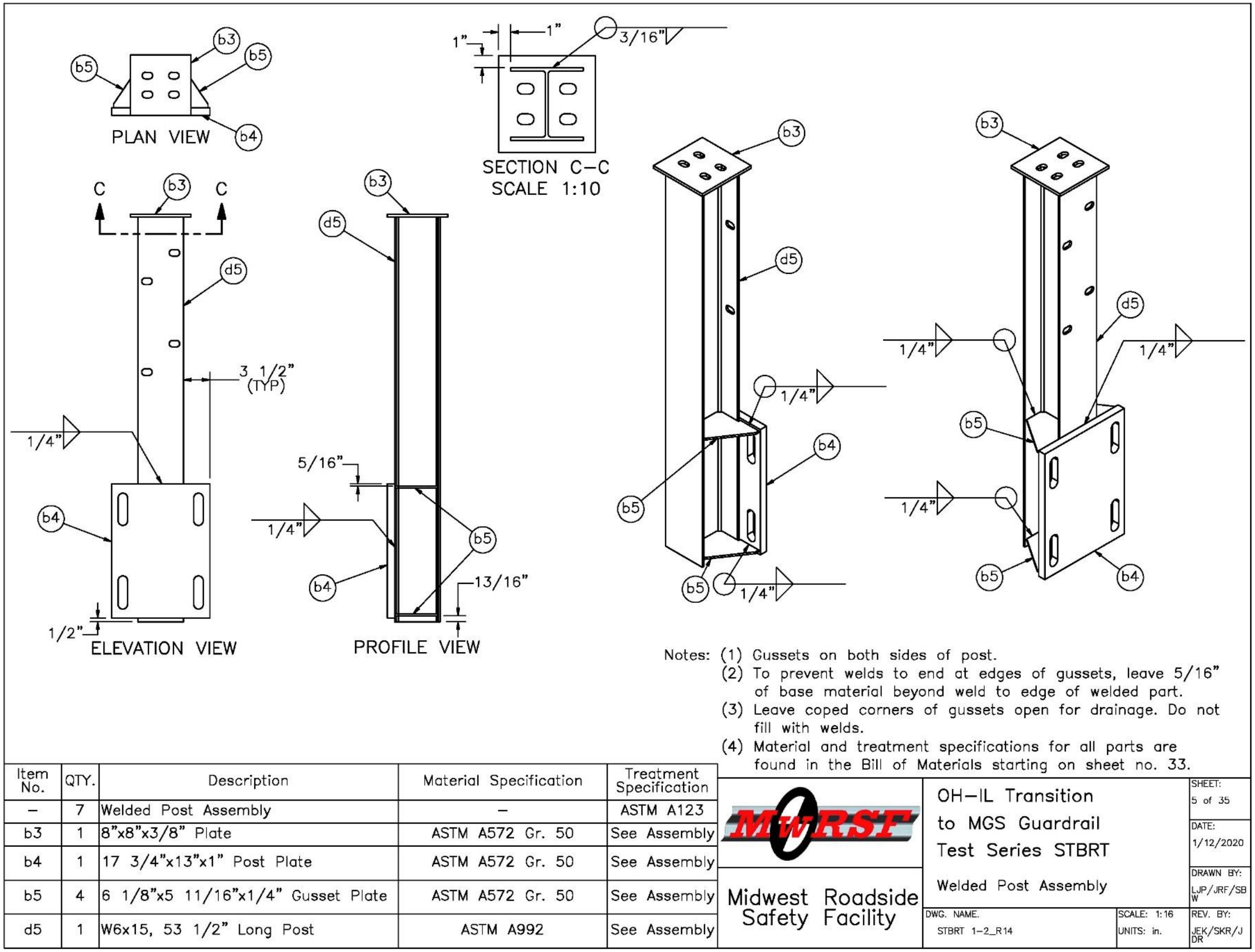



Figure 84. Bridge Rail Post Components, Test Nos. STBRT-1 and STBRT-2




| Item No. | QTY. | Description | Material Specification | Treatment Specification |
|---|---|---|---|---|
| – | 7 | Welded Post Assembly | – | ASTM A123 |
| b3 | 1 | 8"x8"x3/8" Plate | ASTM A572 Gr. 50 | See Assembly |
| b4 | 1 | 17 3/4"x13"x1" Post Plate | ASTM A572 Gr. 50 | See Assembly |
| b5 | 4 | 6 1/8"x5 11/16"x1/4" Gusset Plate | ASTM A572 Gr. 50 | See Assembly |
| d5 | 1 | W6x15, 53 1/2" Long Post | ASTM A992 | See Assembly |

Figure 85. Welded Post Assembly, Test Nos. STBRT-1 and STBRT-2

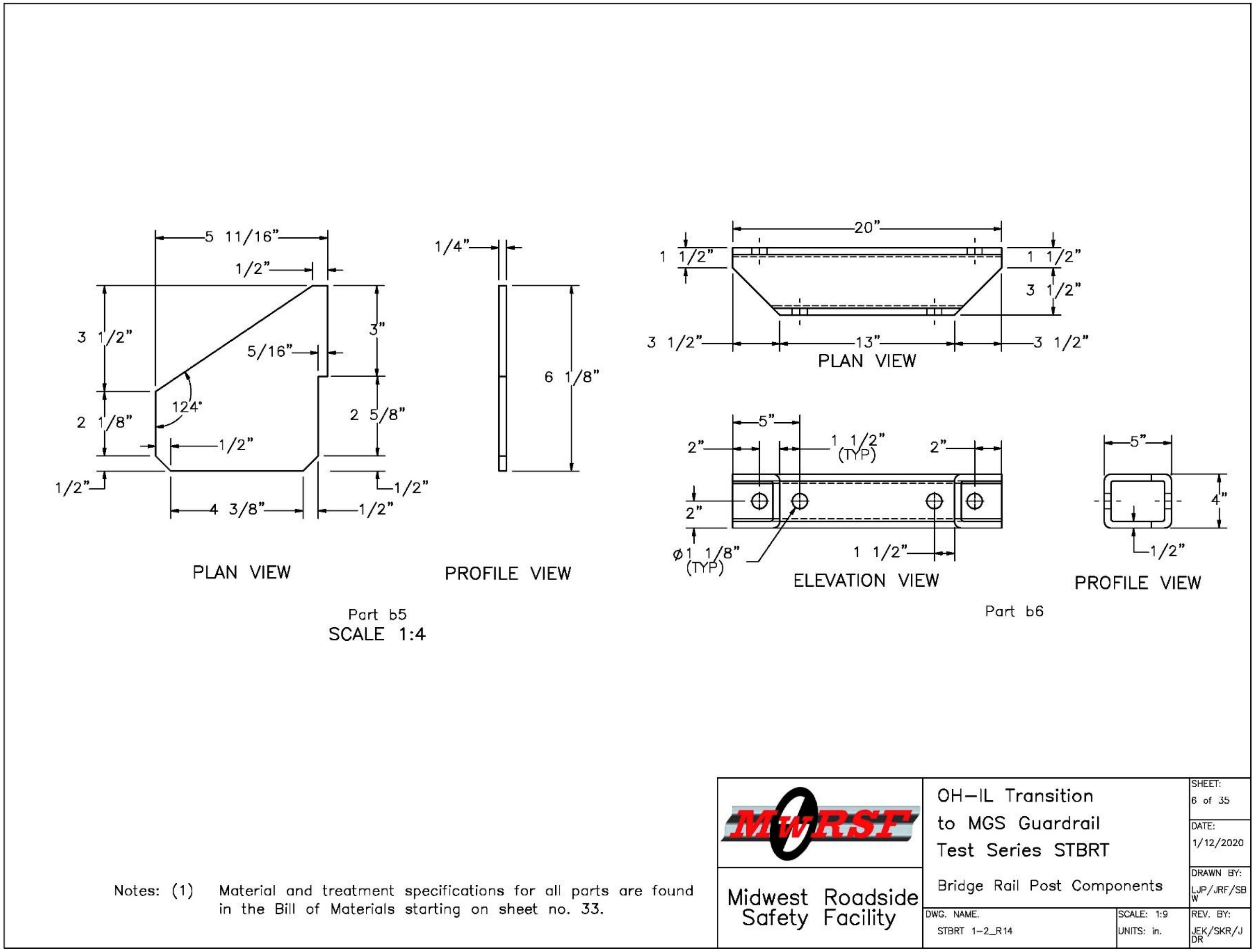
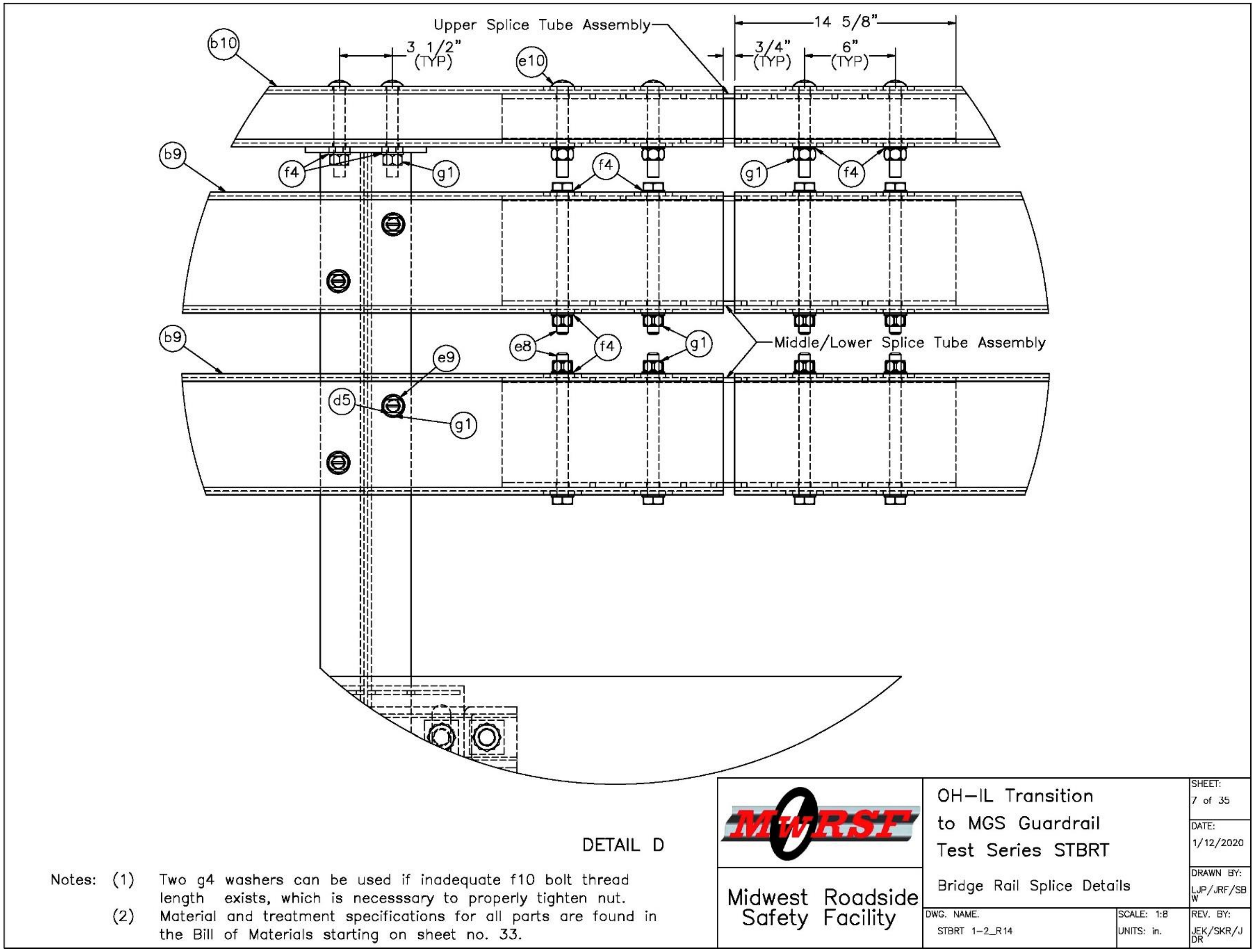
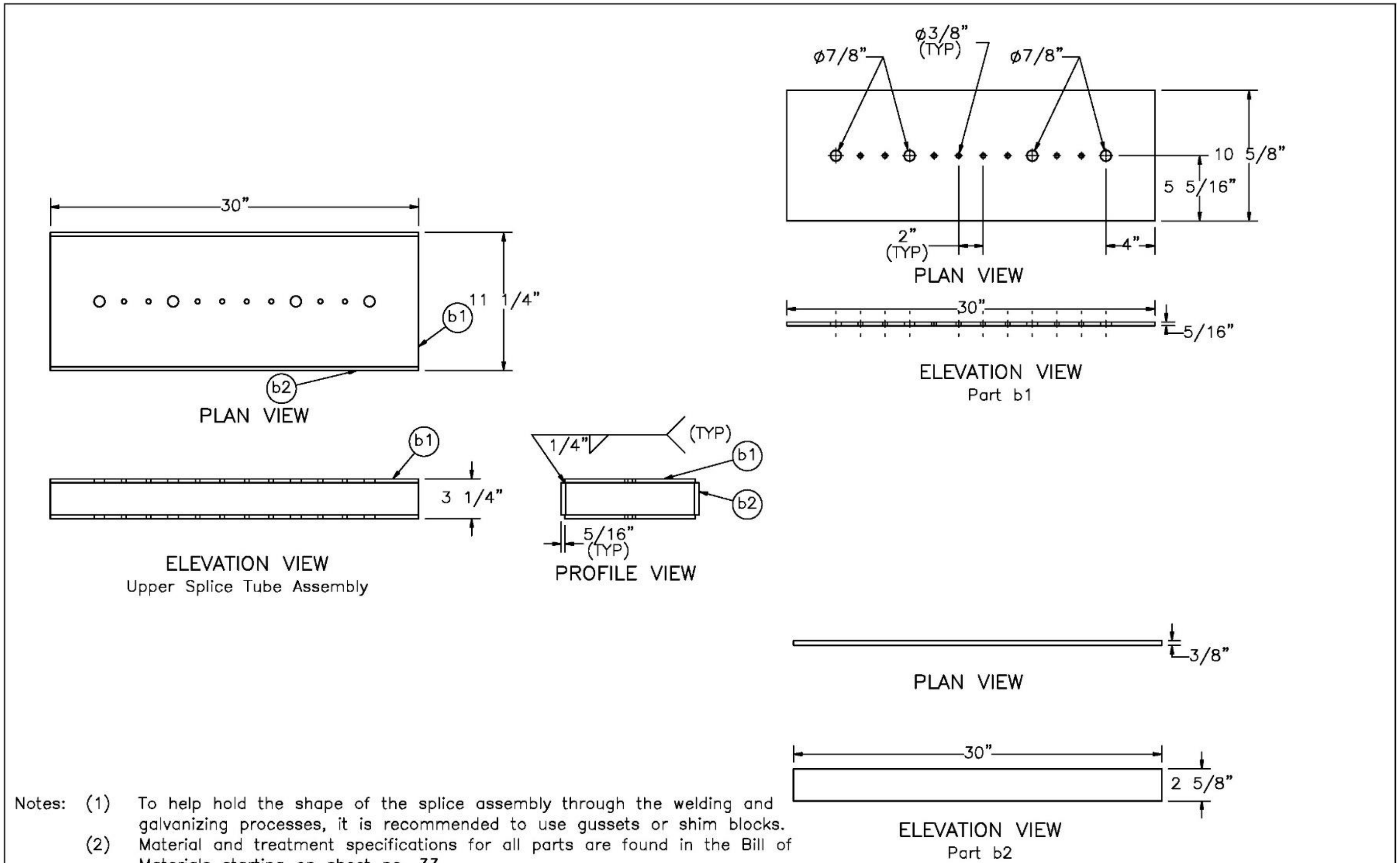



Figure 86. Bridge Rail Post Components, Test Nos. STBRT-1 and STBRT-2




Notes: (1) Two g4 washers can be used if inadequate f10 bolt thread length exists, which is necesssary to properly tighten nut.
(2) Material and treatment specifications for all parts are found in the Bill of Materials starting on sheet no. 33.

Figure 87. Detail D, Test Nos. STBRT-1 and STBRT-2




Notes: (1) To help hold the shape of the splice assembly through the welding and galvanizing processes, it is recommended to use gussets or shim blocks.
(2) Material and treatment specifications for all parts are found in the Bill of Materials starting on sheet no. 33.

| Item No. | QTY. | Description | Material Specification | Treatment Specification |
|---|---|---|---|---|
| – | 3 | Upper Splice Tube Assembly – Option 1 | – | ASTM A123 |
| b1 | 2 | 30"x10 5/8"x5/16" Plate | ASTM A572 Gr. 50 | See Assembly |
| b2 | 2 | 30"x2 5/8"x3/8" Plate | ASTM A572 Gr. 50 | See Assembly |

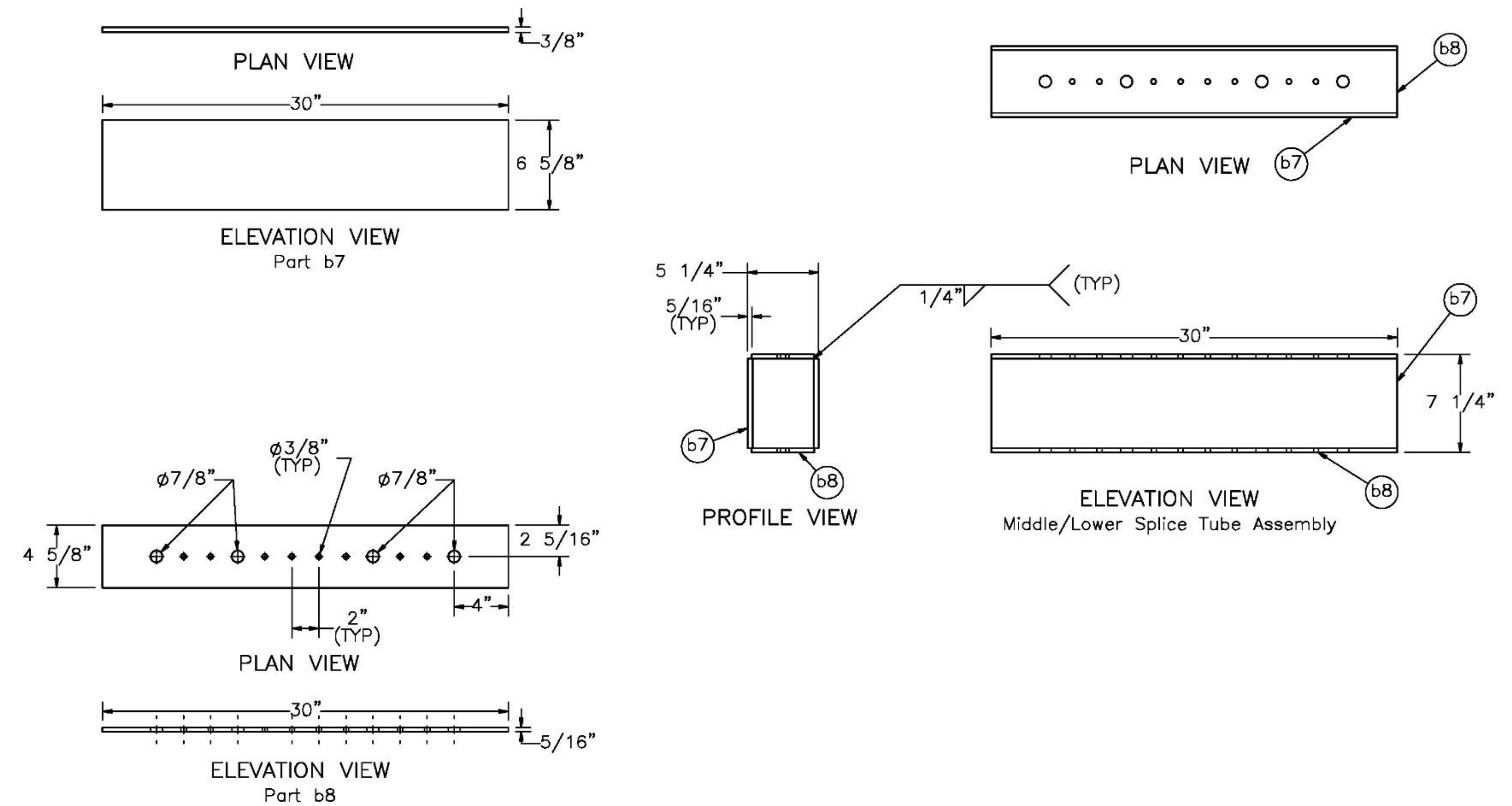
Midwest Roadside Safety Facility

OH–IL Transition to MGS Guardrail Test Series STBRT

Upper Splice Tube Assembly

| SHEET: | DATE: | DRAWN BY: | DWG. NAME. | SCALE: | UNITS: | REV. BY: |
|---|---|---|---|---|---|---|
| 8 of 35 | 1/12/2020 | LJP/JRF/SBW | STBRT 1–2_R14 | 1:11 | in. | JEK/SKR/JDR |

Figure 88. Upper Splice Tube Assembly, Test Nos. STBRT-1 and STBRT-2




Notes: (1) To help hold the shape of the splice assembly through the welding and galvanizing processes, it is recommended to use gussets or shim blocks.
(2) Material and treatment specifications for all parts are found in the Bill of Materials starting on sheet no. 33.

| Item No. | QTY. | Description | Material Specification | Treatment Specification |
|---|---|---|---|---|
| – | 6 | Middle/Lower Splice Tube Assembly – Option 1 | – | ASTM A123 |
| b7 | 2 | 30"x6 5/8"x3/8" Plate | ASTM A572 Gr. 50 | See Assembly |
| b8 | 2 | 30"x4 5/8"x5/16" Plate | ASTM A572 Gr. 50 | See Assembly |

MwRSF
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OH–IL Transition to MGS Guardrail Test Series STBRT

Middle/Lower Splice Tube Assembly

SHEET: 9 of 35
DATE: 1/12/2020
DRAWN BY: LJP/JRF/SBW
REV. BY: JEK/SKR/JDR
DWG. NAME. STBRT 1–2_R14
SCALE: 1:11
UNITS: in.

Figure 89. Middle/Lower Splice Tube Assembly, Test Nos. STBRT-1 and STBRT-2

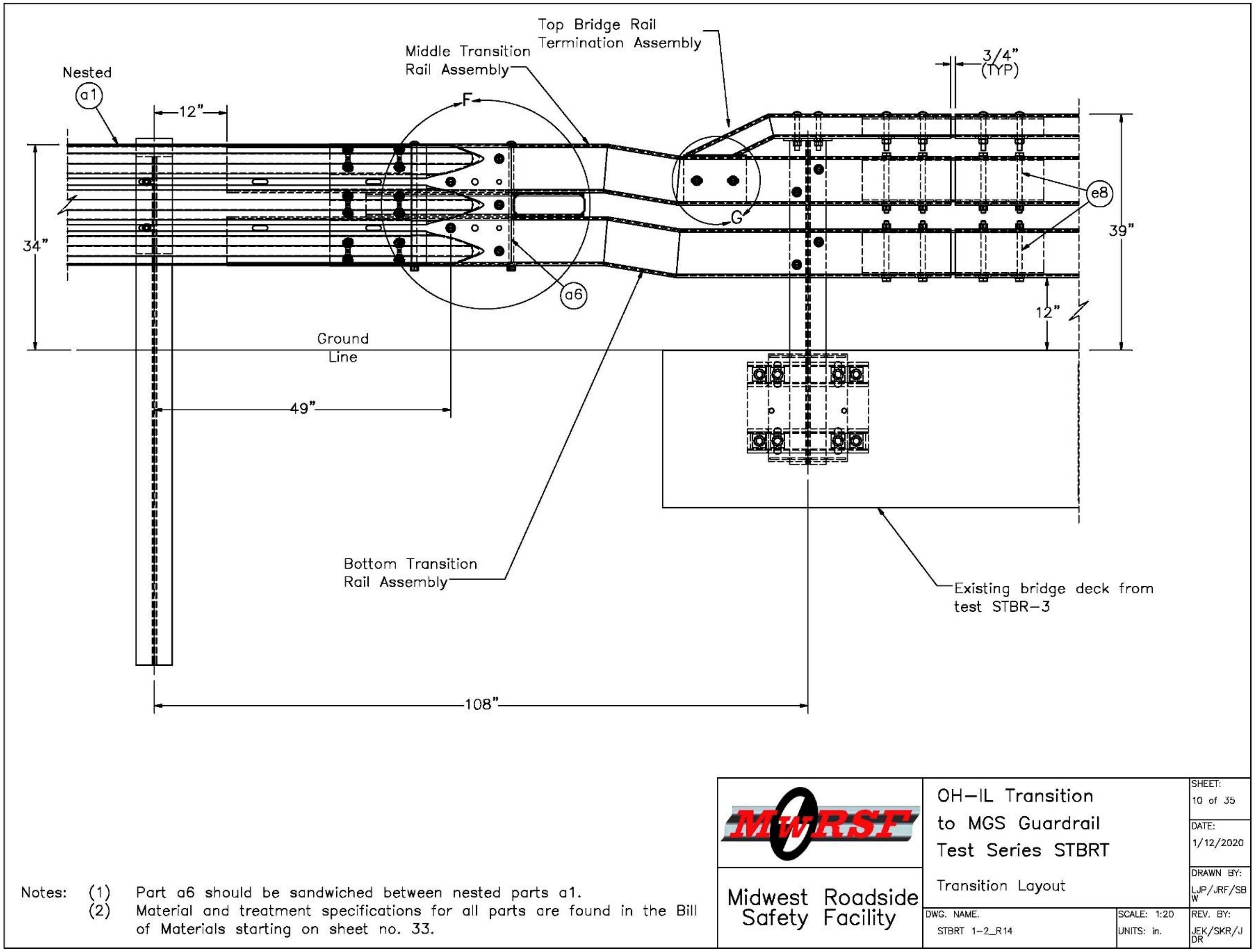



Figure 90. Transition Layout, Test Nos. STBRT-1 and STBRT-2

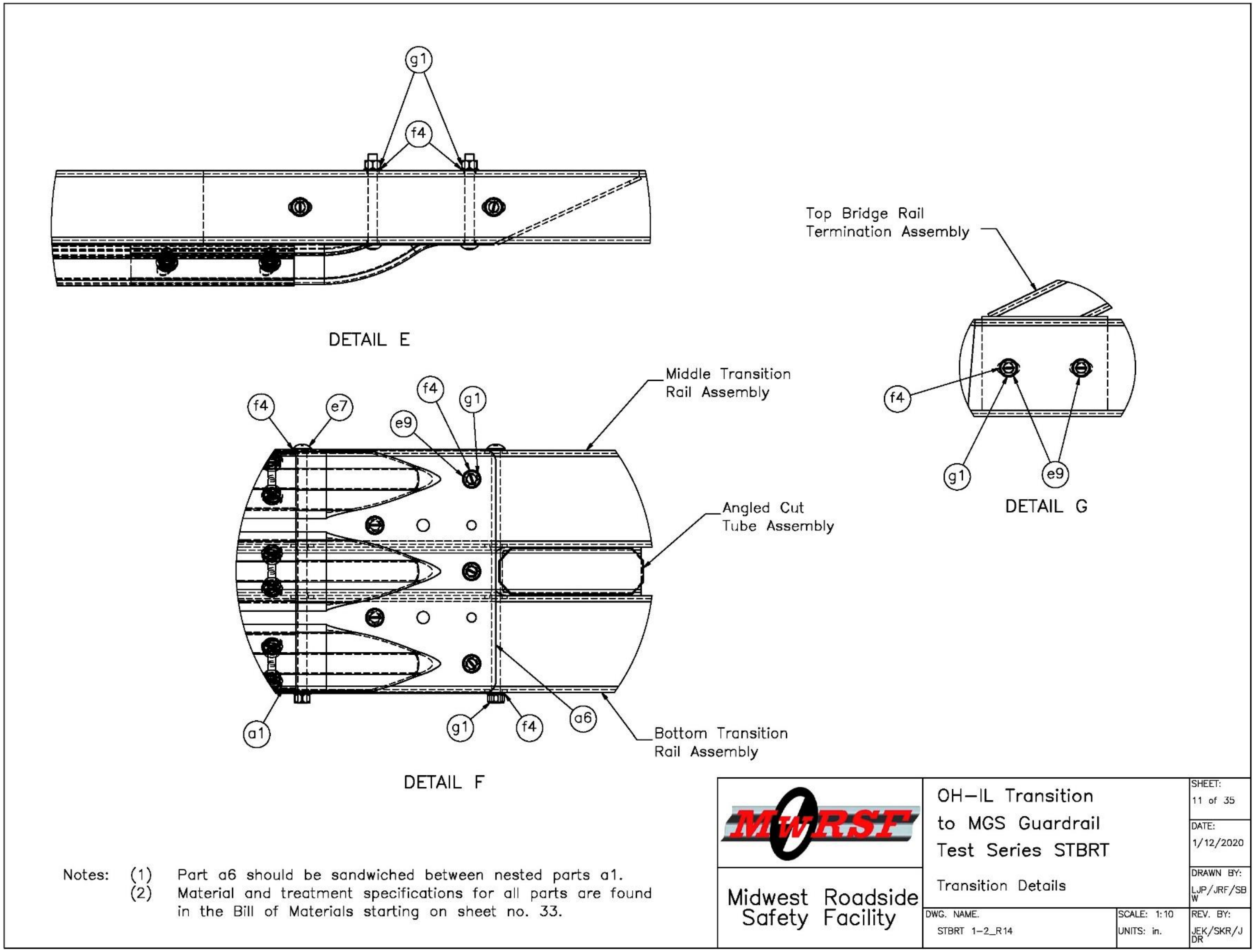
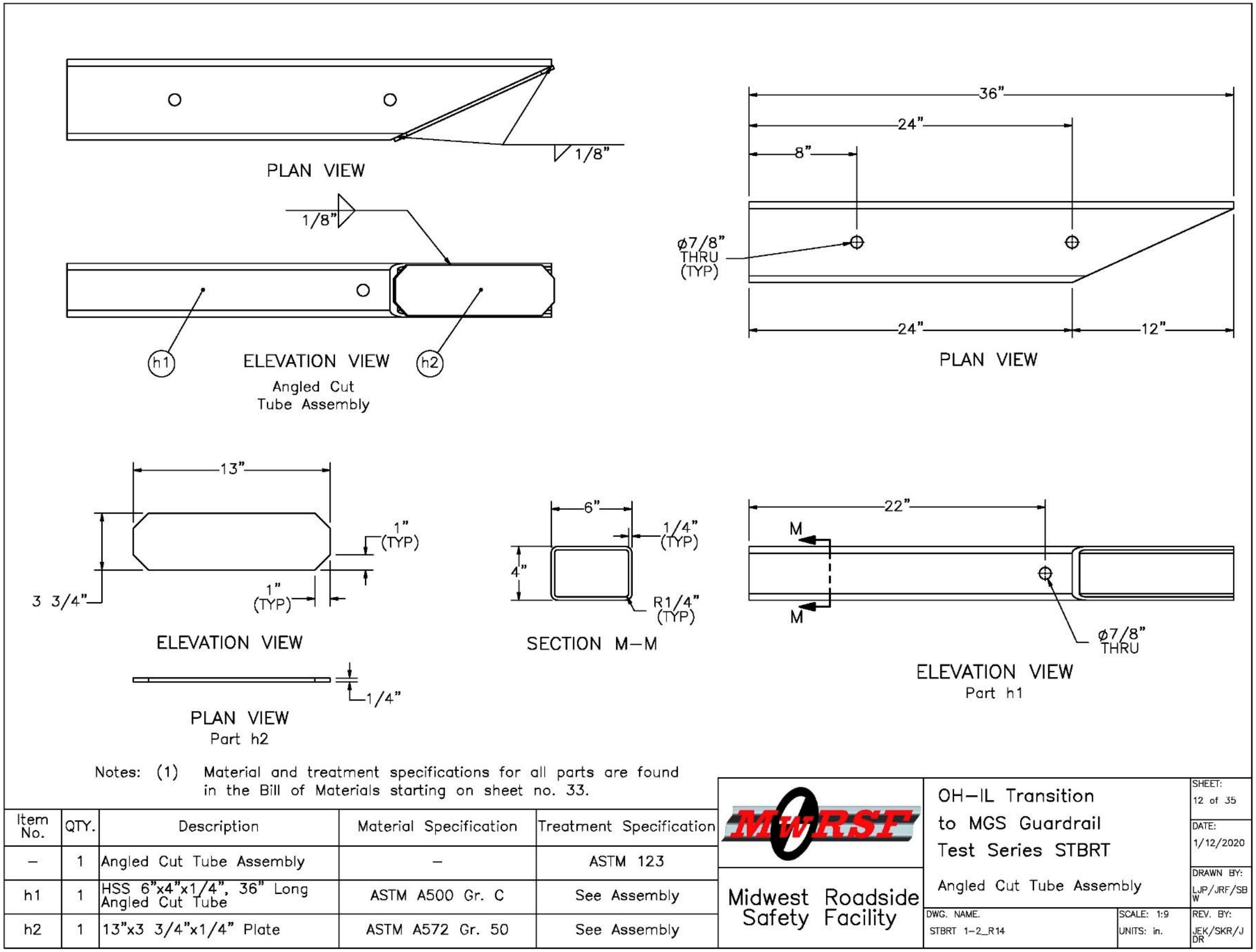
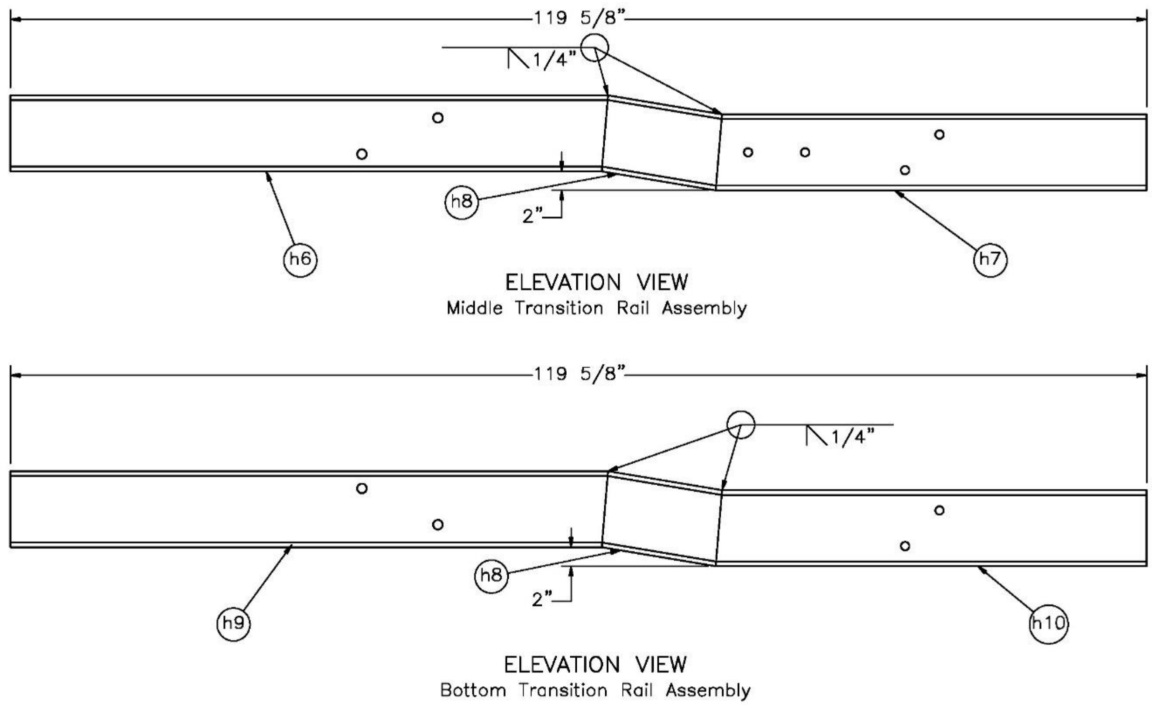



Figure 91. Transition Details, Test Nos. STBRT-1 and STBRT-2




| Item No. | QTY. | Description | Material Specification | Treatment Specification |
|---|---|---|---|---|
| – | 1 | Angled Cut Tube Assembly | – | ASTM 123 |
| h1 | 1 | HSS 6"x4"x1/4", 36" Long Angled Cut Tube | ASTM A500 Gr. C | See Assembly |
| h2 | 1 | 13"x3 3/4"x1/4" Plate | ASTM A572 Gr. 50 | See Assembly |

Figure 92. Angled Cut Tube Assembly, Test Nos. STBRT-1 and STBRT-2




| Item No. | QTY. | Description | Material Specification | Treatment Specification |
|---|---|---|---|---|
| – | 1 | Middle Transition Rail Assembly | ASTM A500 Gr. C | ASTM A123 |
| h6 | 1 | HSS 8"x6"x1/4", 62 15/16" Long Middle Transition Rail | ASTM A500 Gr. C | See Assembly |
| h7 | 1 | HSS 8"x6"x1/4", 45 3/8" Long Middle Transition Rail | ASTM A500 Gr. C | See Assembly |
| h8 | 1 | HSS 8"x6"x1/4", 12 7/8" Long Transition Rail | ASTM A500 Gr. C | See Assembly |

| Item No. | QTY. | Description | Material Specification | Treatment Specification |
|---|---|---|---|---|
| – | 1 | Bottom Transition Rail Assembly | ASTM A500 Gr. C | ASTM A123 |
| h8 | 1 | HSS 8"x6"x1/4", 12 7/8" Long Transition Rail | ASTM A500 Gr. C | See Assembly |
| h9 | 1 | HSS 8"x6"x1/4", 62 15/16" Long Bottom Transition Rail | ASTM A500 Gr. C | See Assembly |
| h10 | 1 | HSS 8"x6"x1/4", 45 3/8" Long Bottom Transition Rail | ASTM A500 Gr. C | See Assembly |

Notes: (1) Fabricator–Please provide opinion if the specified bevel welds will obtain full strength of the section or if an alternate weld would provide better strength. These will be critically loaded parts.

(2) Material and treatment specifications for all parts are found in the Bill of Materials starting on sheet no. 33.

Midwest Roadside Safety Facility

OH–IL Transition to MGS Guardrail Test Series STBRT

Middle/Bottom Transition Rail Assemblies

| | |
|---|---|
| SHEET: | 13 of 35 |
| DATE: | 1/12/2020 |
| DRAWN BY: | LJP/JRF/SBW |
| DWG. NAME. | STBRT 1-2_R14 |
| SCALE: | 1:16 |
| UNITS: | in. |
| REV. BY: | JEK/SKR/JDR |

Figure 93. Middle/Bottom Transition Rail Assemblies, Test Nos. STBRT-1 and STBRT-2

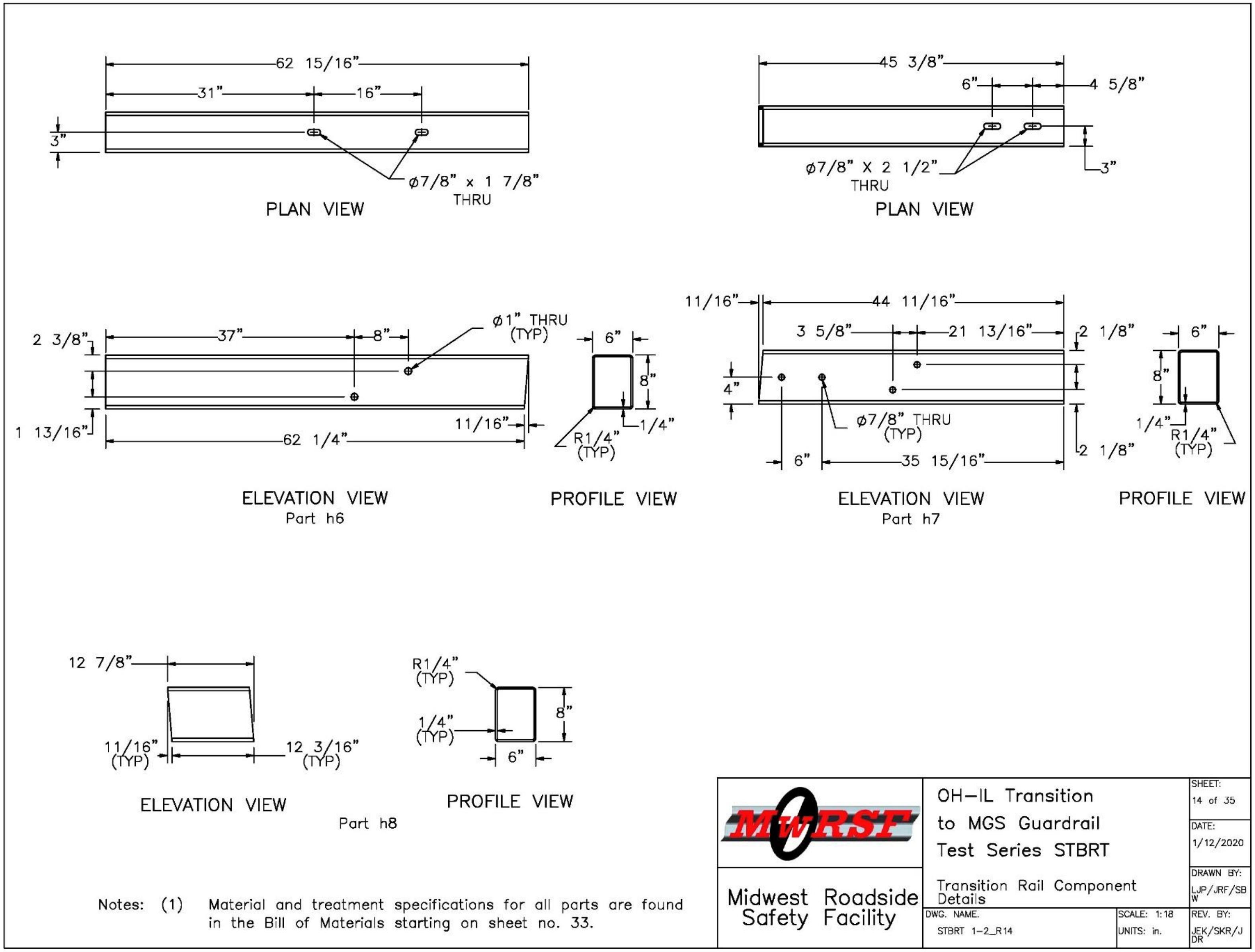



Figure 94. Transition Rail Component Details, Test Nos. STBRT-1 and STBRT-2

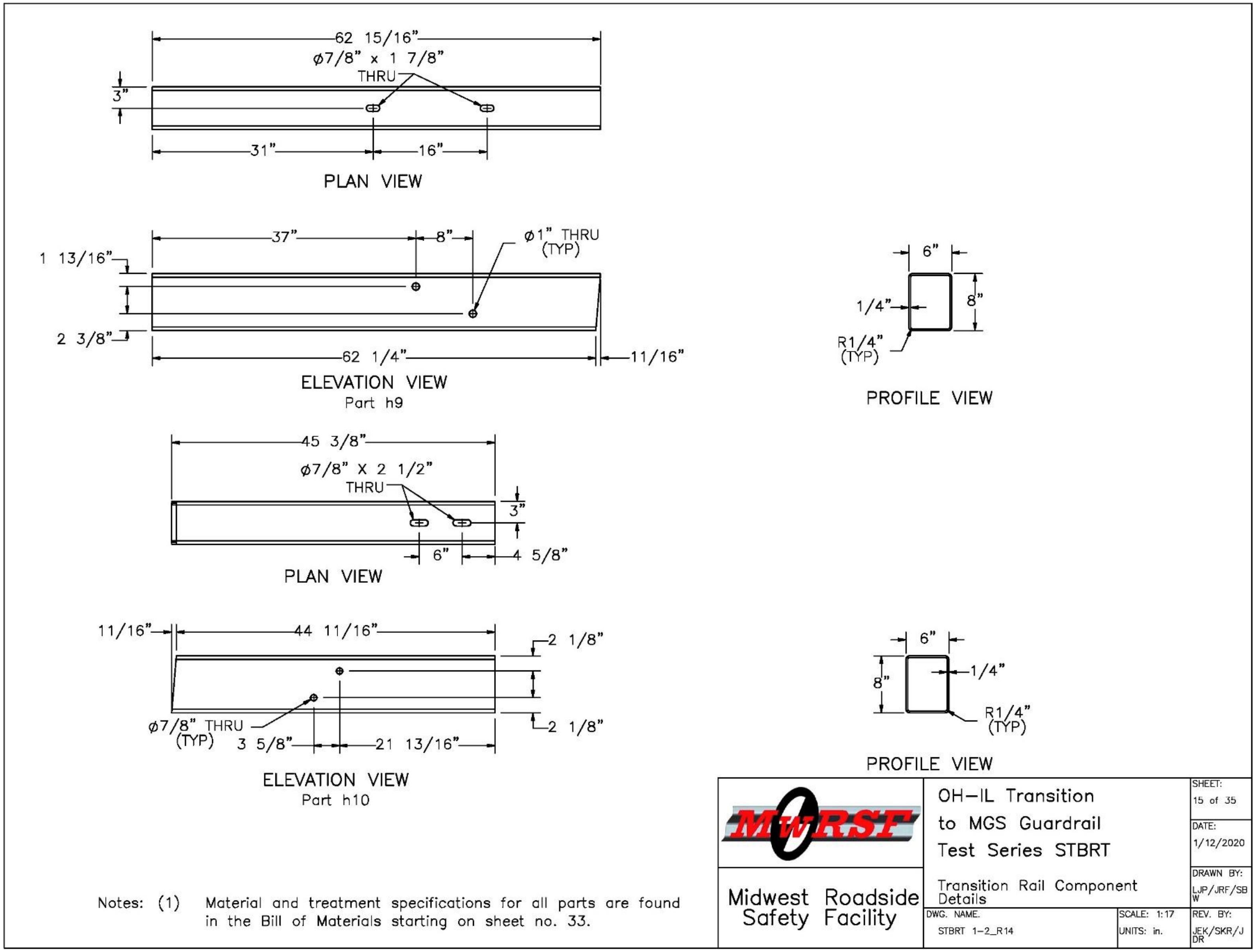
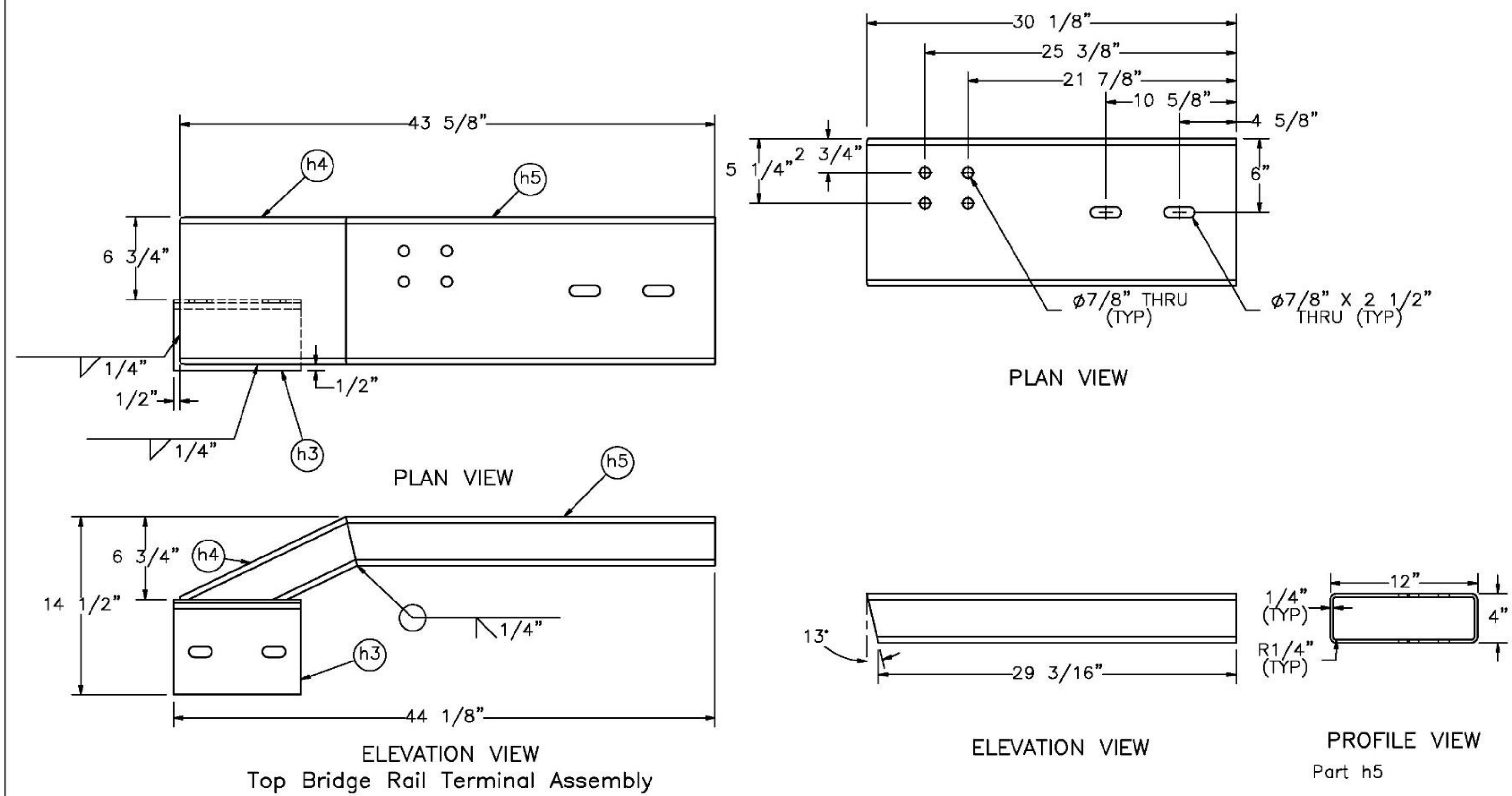



Figure 95. Transition Rail Component Details, Test Nos. STBRT-1 and STBRT-2




Notes: (1) Fabricator—Please provide opinion if the specified bevel welds will obtain full strength of the section or if an alternate weld would provide better strength. These will be critically loaded parts.

(2) Material and treatment specifications for all parts are found in the Bill of Materials starting on sheet no. 33.

| Item No. | QTY. | Description | Material Specification | Treatment Specification |
|---|---|---|---|---|
| – | 1 | Top Bridge Rail Termination Assembly | – | ASTM A123 |
| h3 | 1 | 13"x10 3/8"x1/4" Bent Plate | ASTM A572 Gr. 50 | See Assembly |
| h4 | 1 | 12"x4"x1/4", 15" Long Sloped Transition Rail | ASTM A500 Gr. C | See Assembly |
| h5 | 1 | 12"x4"x1/4", 30 1/8" Long Transition Rail | ASTM A500 Gr. C | See Assembly |

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Top Bridge Rail Termination Assembly

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DWG. NAME. STBRT 1–2_R14

SCALE: 1:12

UNITS: in.

REV. BY: JEK/SKR/JDR

Figure 96. Top Bridge Rail Termination Assembly, Test Nos. STBRT-1 and STBRT-2

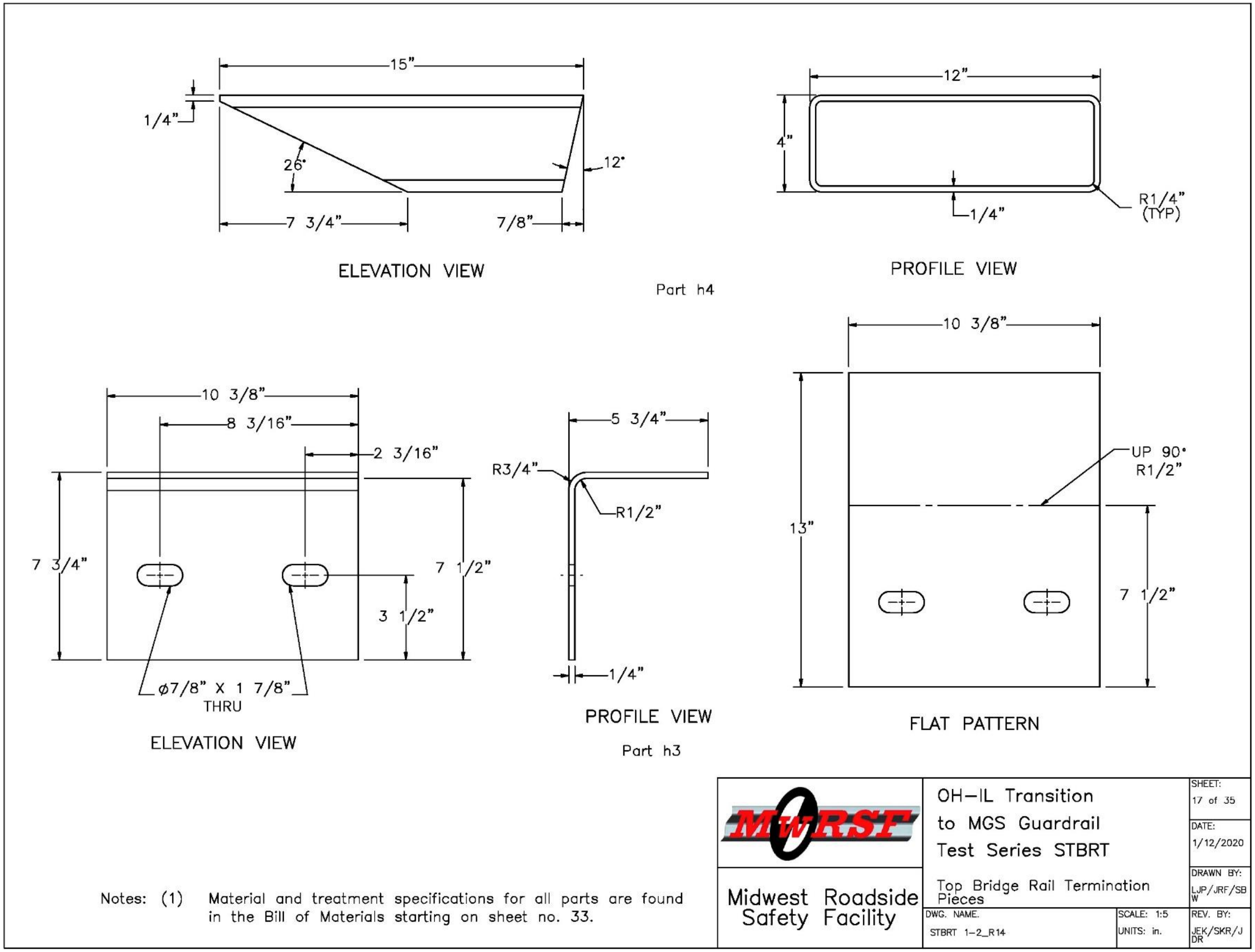



Figure 97. Top Bridge Rail Termination Pieces, Test Nos. STBRT-1 and STBRT-2

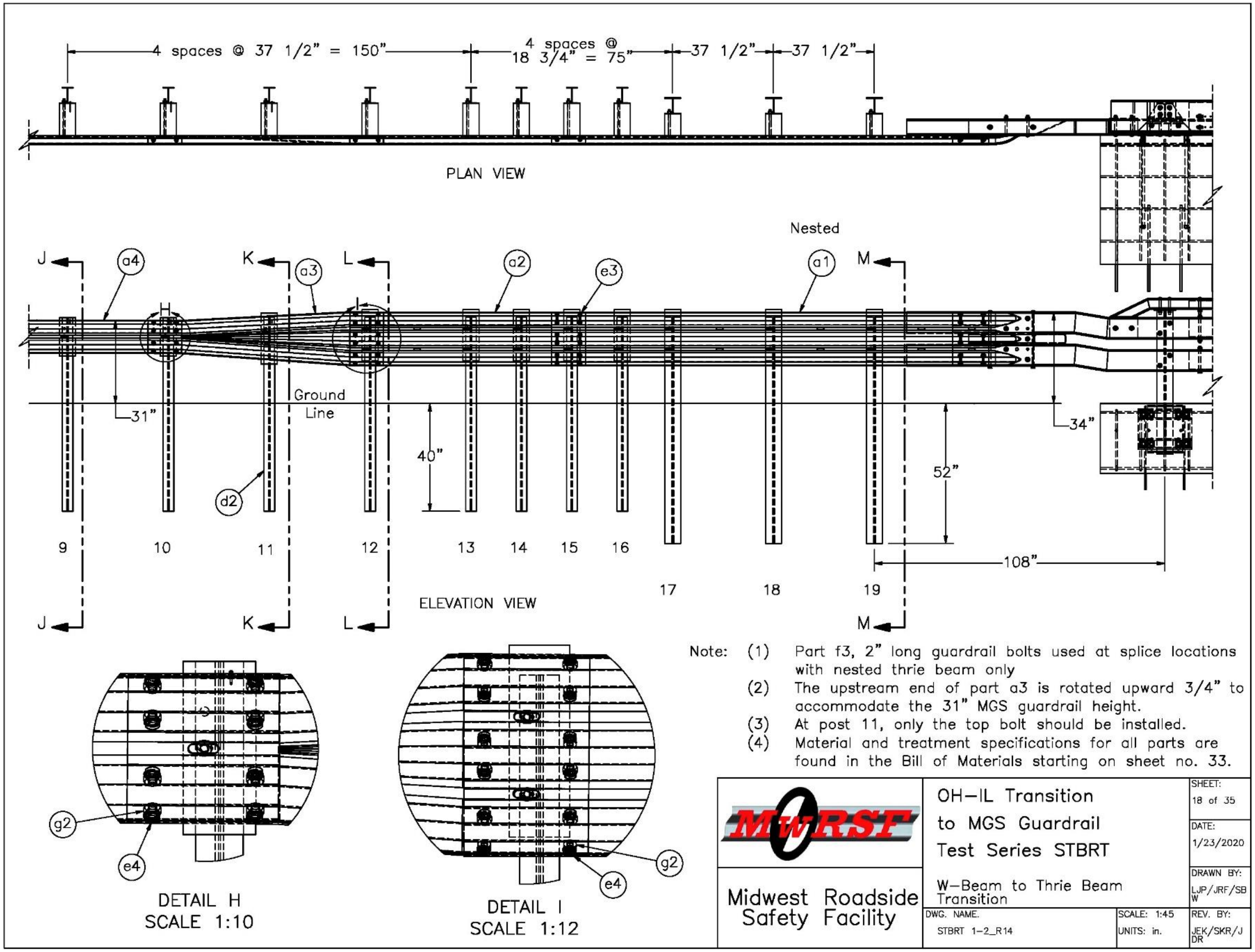



Figure 98. W-Beam to Thrie Beam Transition, Test Nos. STBRT-1 and STBRT-2

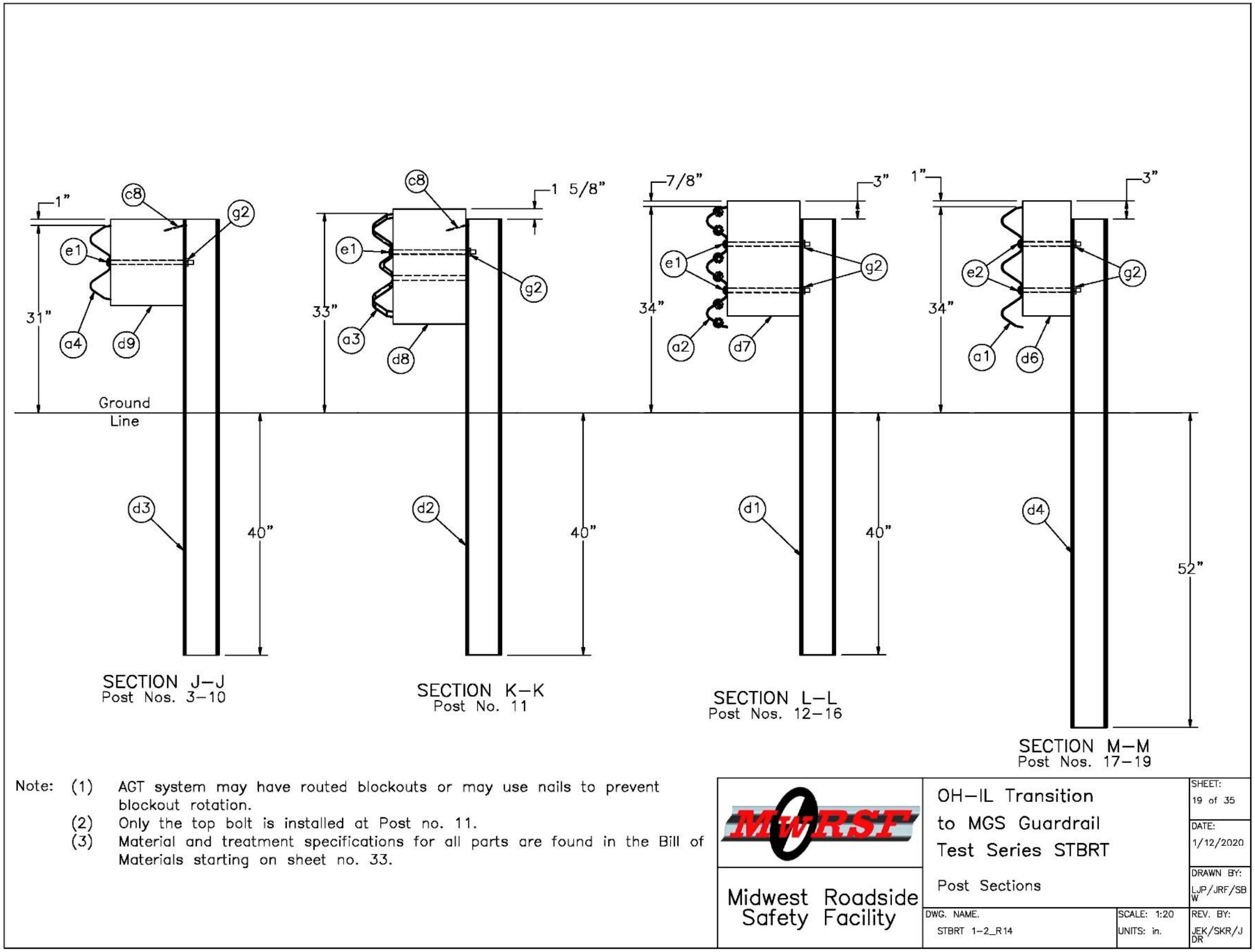



Figure 99. Post Sections, Test Nos. STBRT-1 and STBRT-2

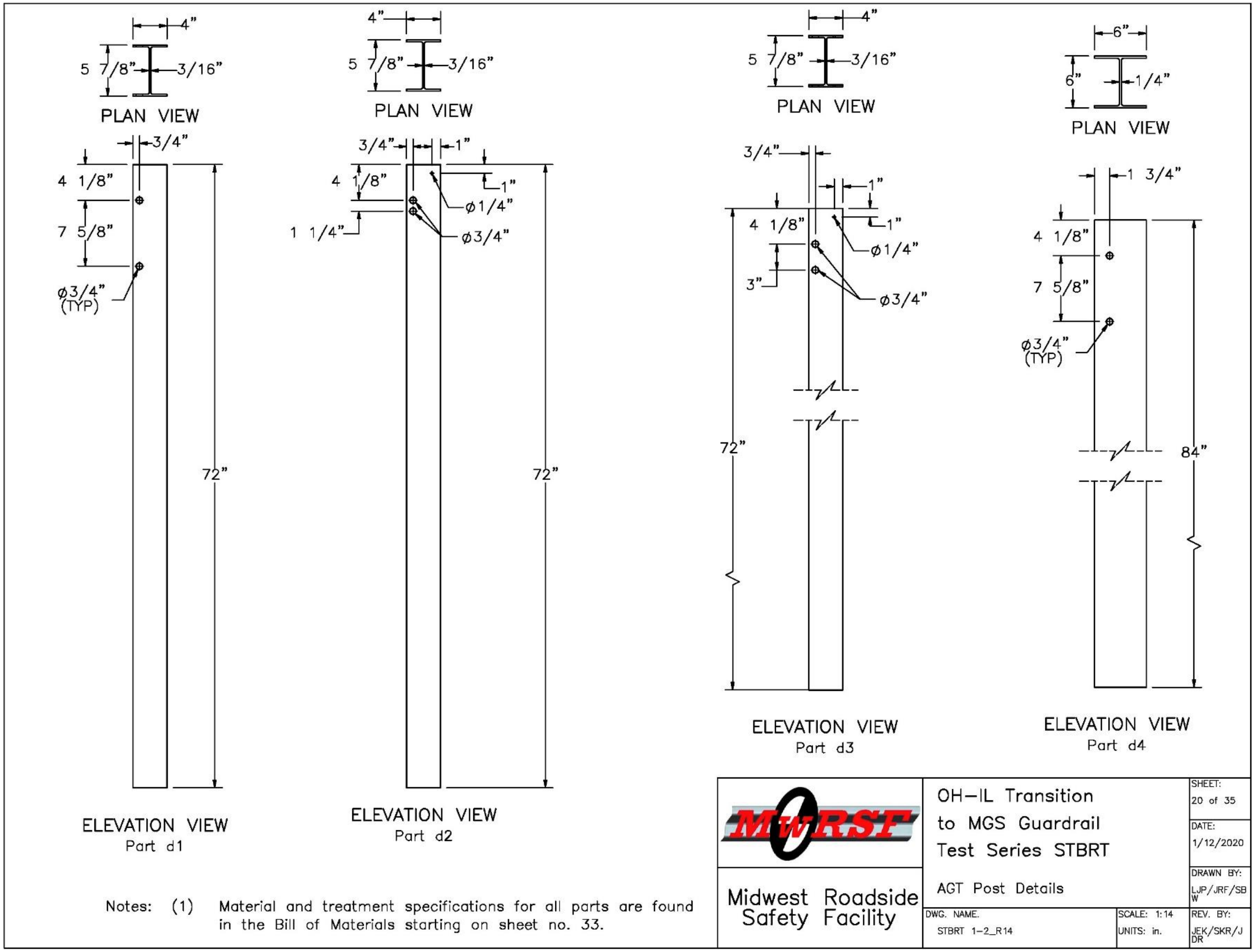



Figure 100. AGT Post Details, Test Nos. STBRT-1 and STBRT-2

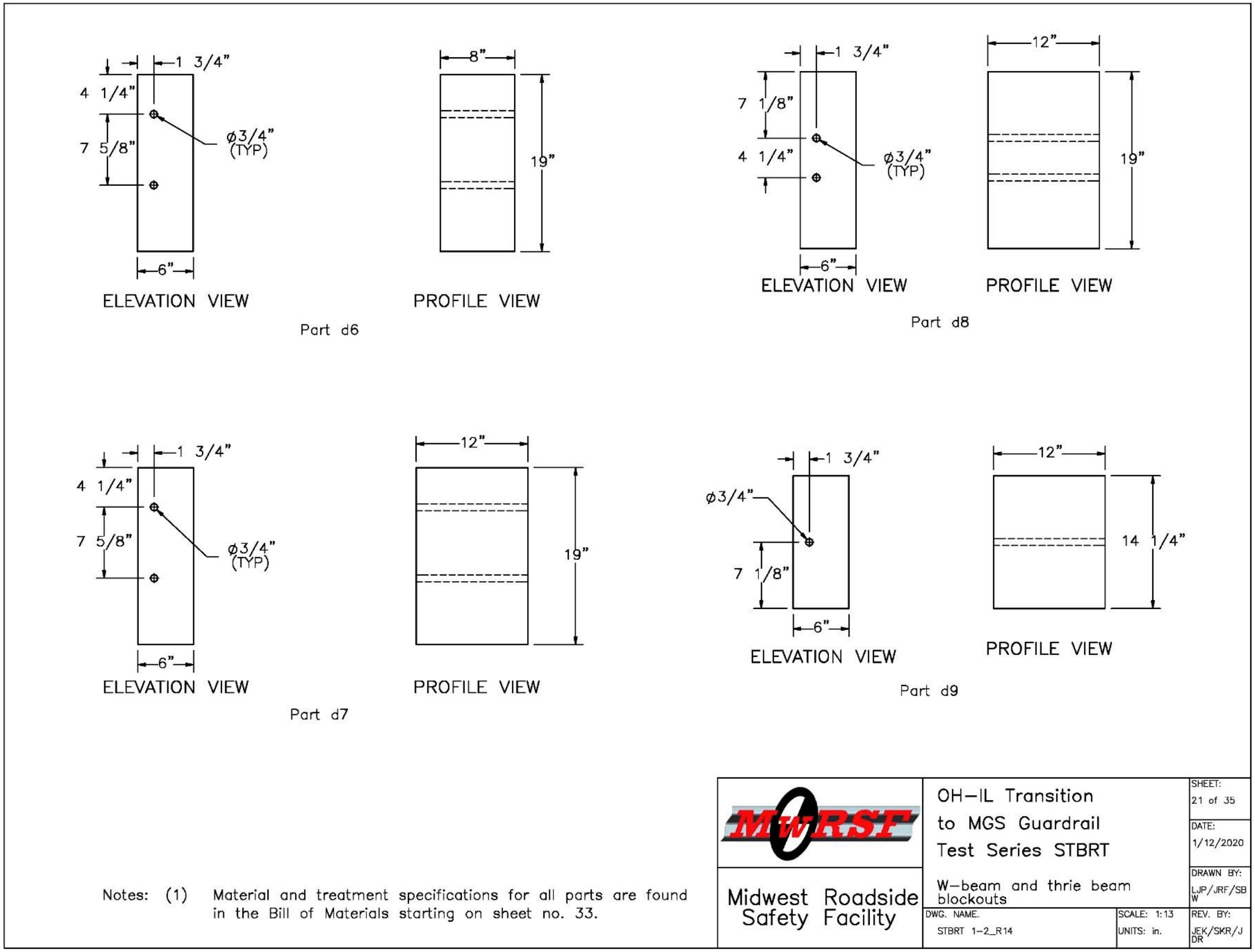



Figure 101. W-Beam and Thrie Beam Blockouts, Test Nos. STBRT-1 and STBRT-2

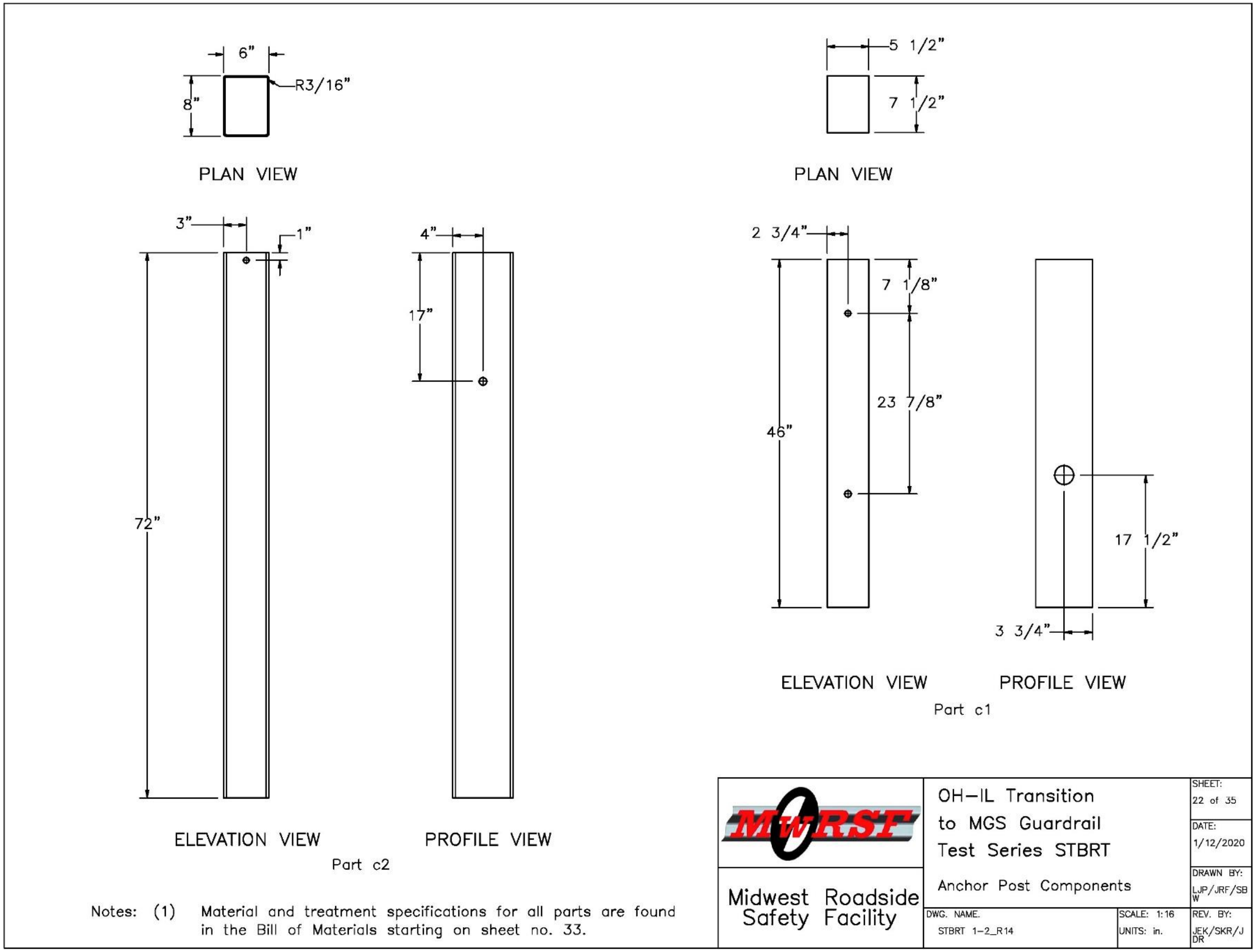
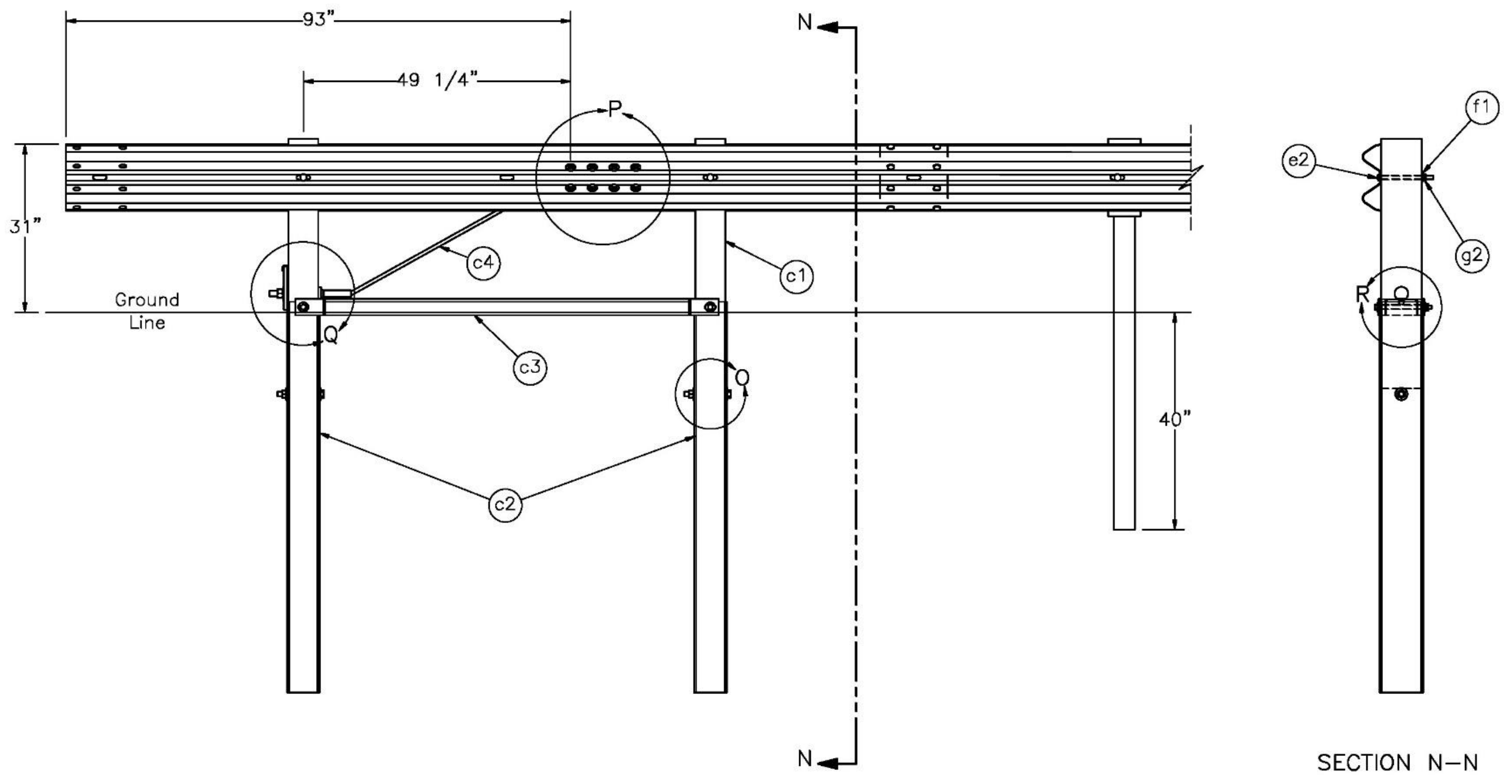



Figure 102. Anchor Components, Test Nos. STBRT-1 and STBRT-2




Notes: (1) Material and treatment specifications for all parts are found in the Bill of Materials starting on sheet no. 33.

| | | | |
|---|---|---|---|
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| | | | DATE: 1/12/2020 |
| | Upstream Anchorage | | DRAWN BY: LJP/JRF/SBW |
| | DWG. NAME. STBRT 1–2_R14 | SCALE: 1:28 UNITS: in. | REV. BY: JEK/SKR/JDR |

Figure 103. Upstream Anchorage, Test Nos. STBRT-1 and STBRT-2

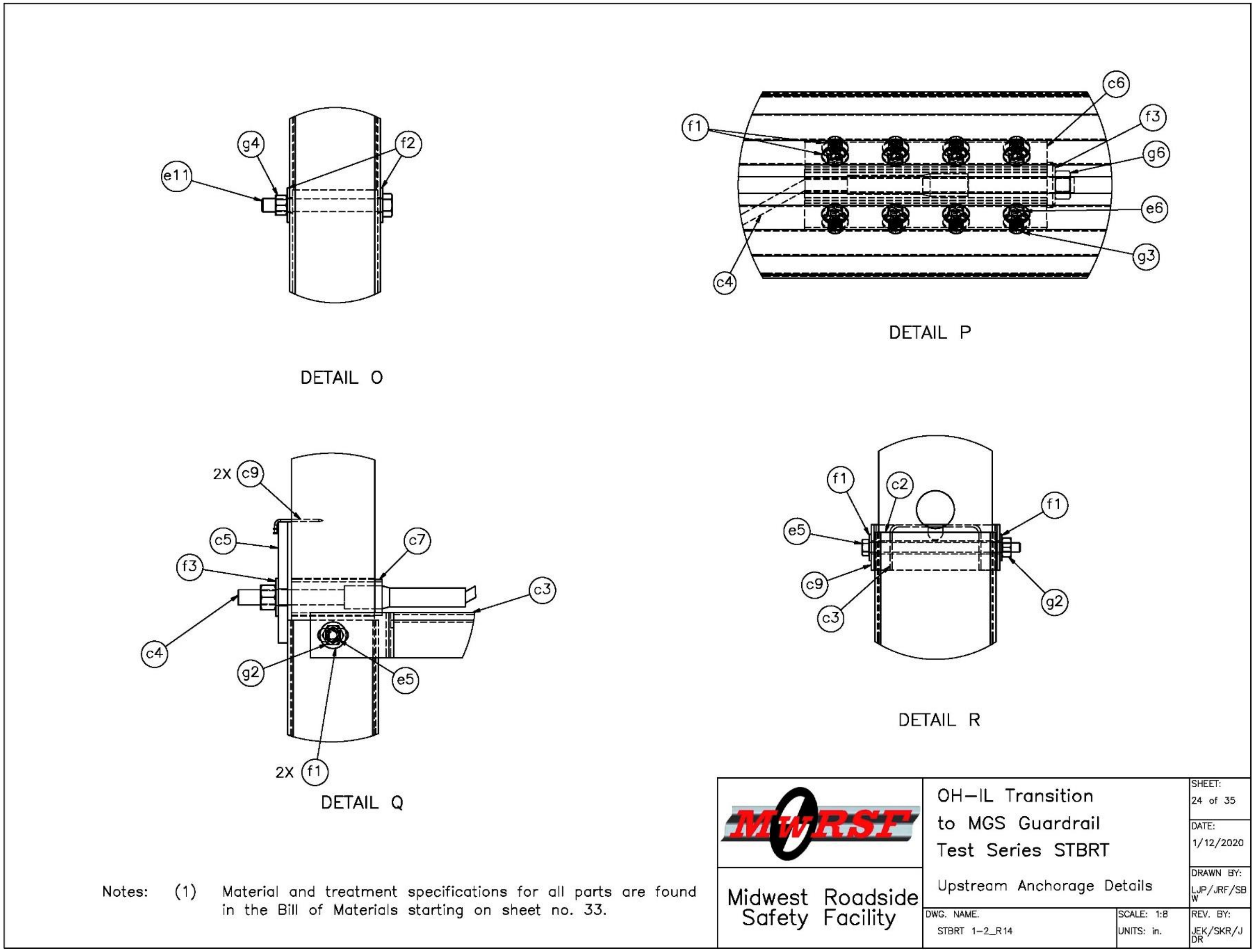

Figure 104. Upstream Anchorage Details, Test Nos. STBRT-1 and STBRT-2

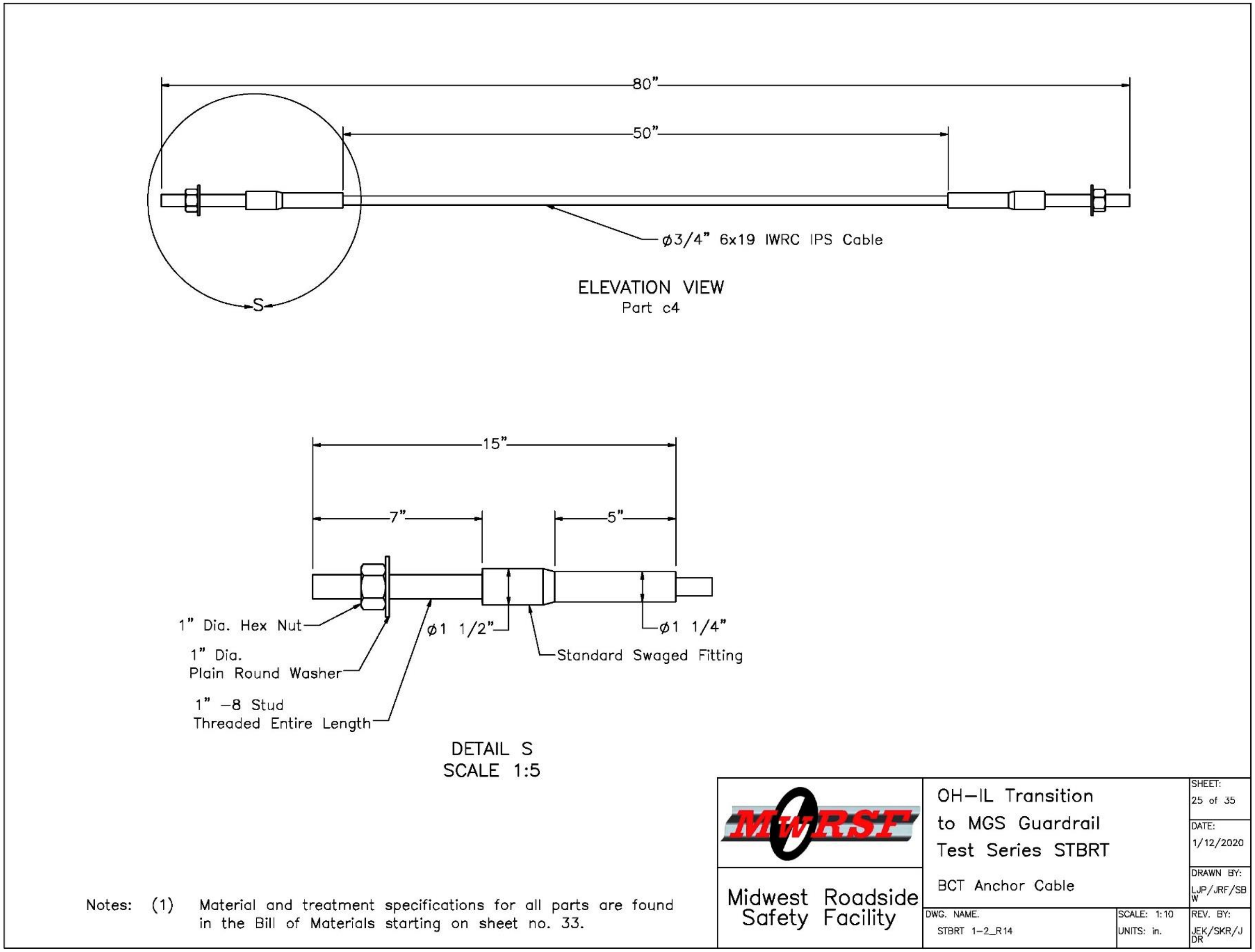


Figure 105. BCT Anchor Cable, Test Nos. STBRT-1 and STBRT-2

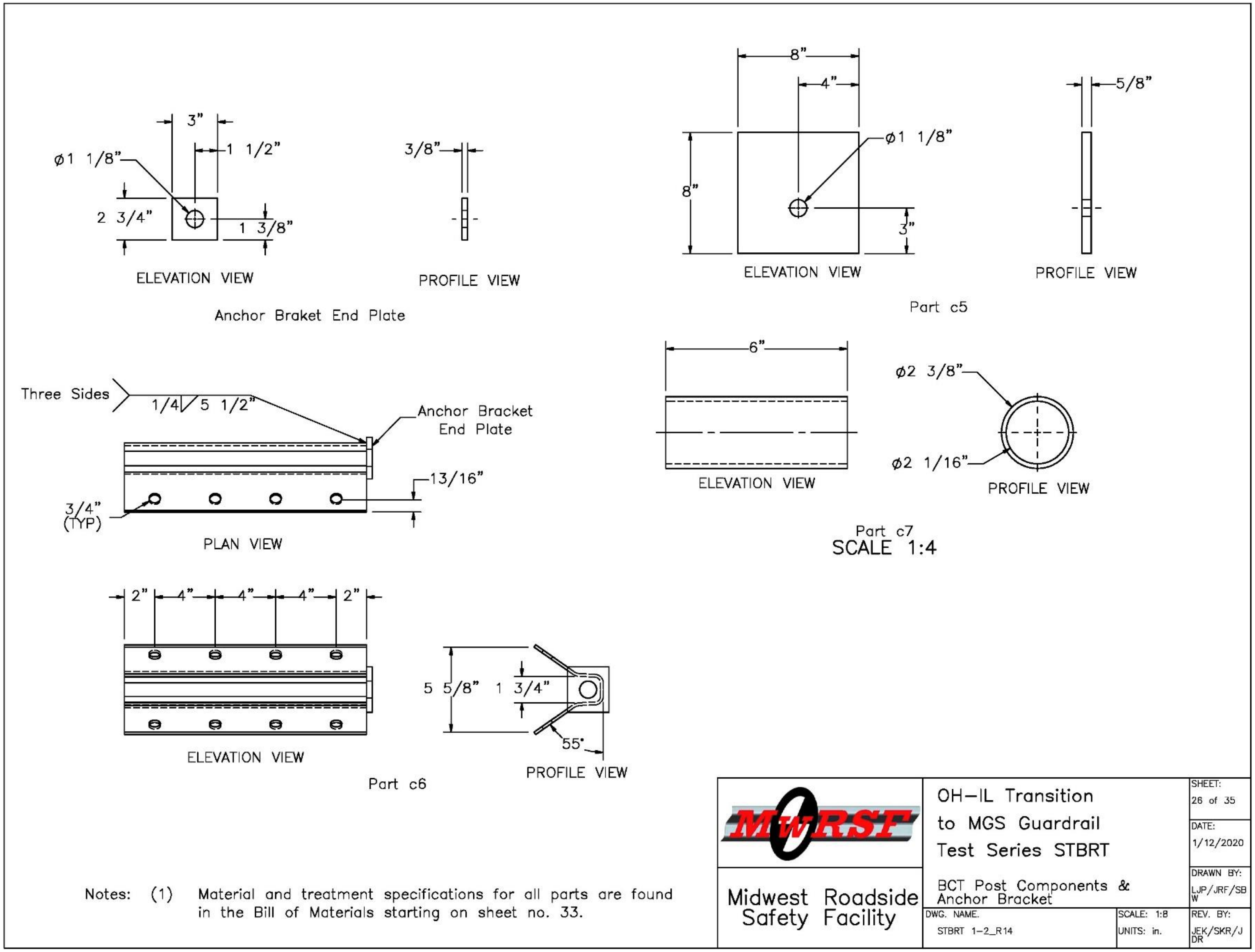


Figure 106. BCT Post Components and Anchor Bracket, Test Nos. STBRT-1 and STBRT-2

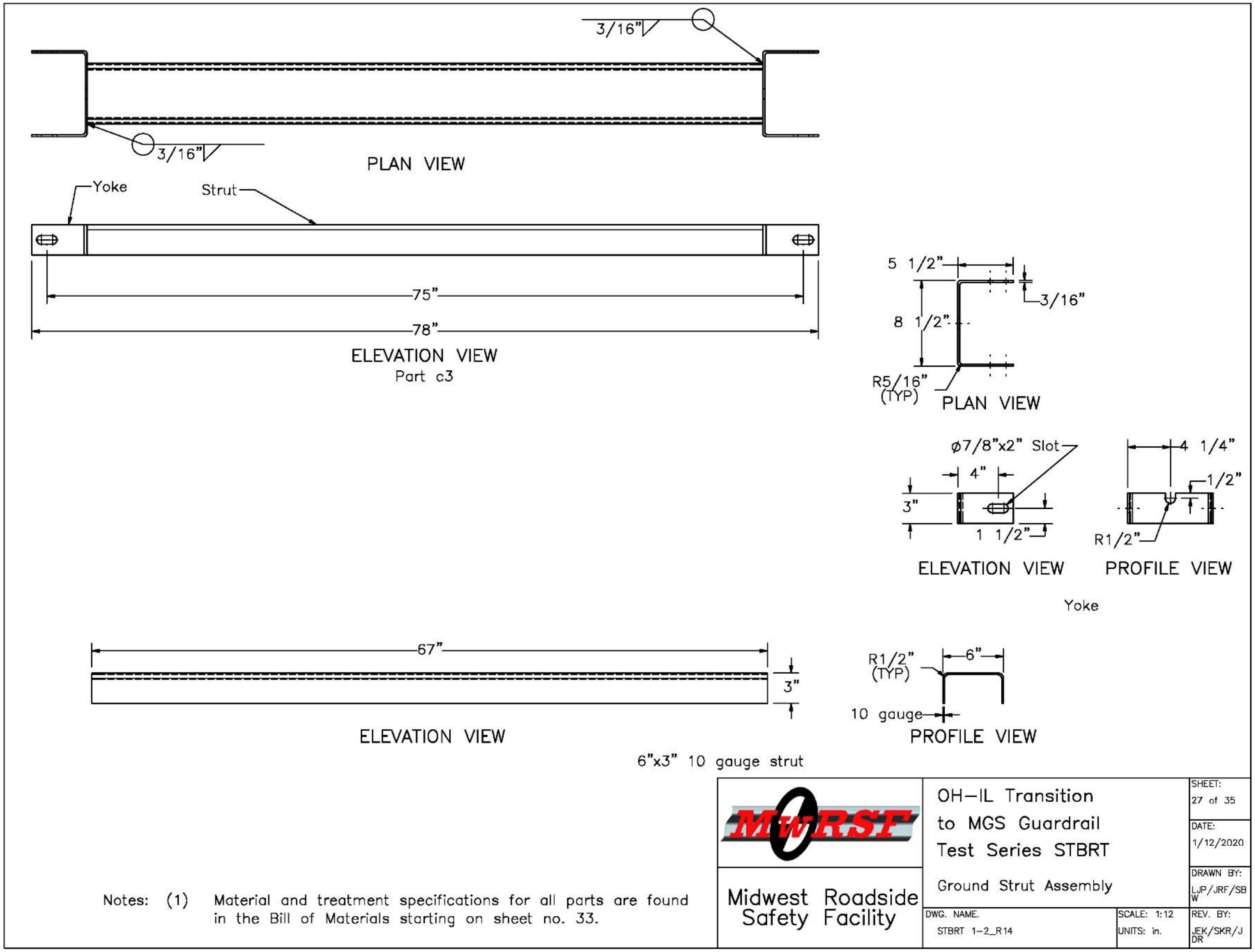


Figure 107. Ground Strut Assembly, Test Nos. STBRT-1 and STBRT-2

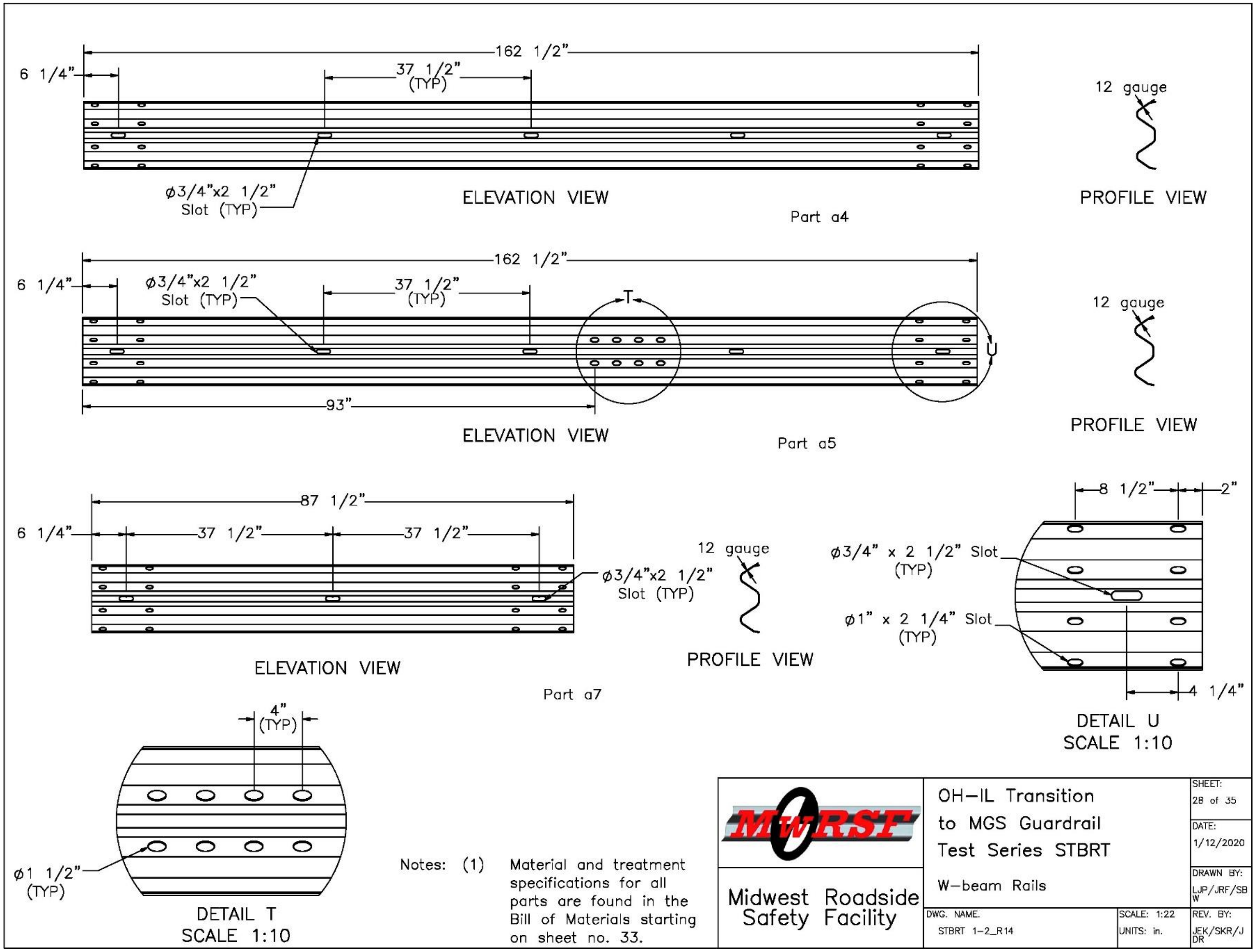


Figure 108. W-Beam Rails, Test Nos. STBRT-1 and STBRT-2

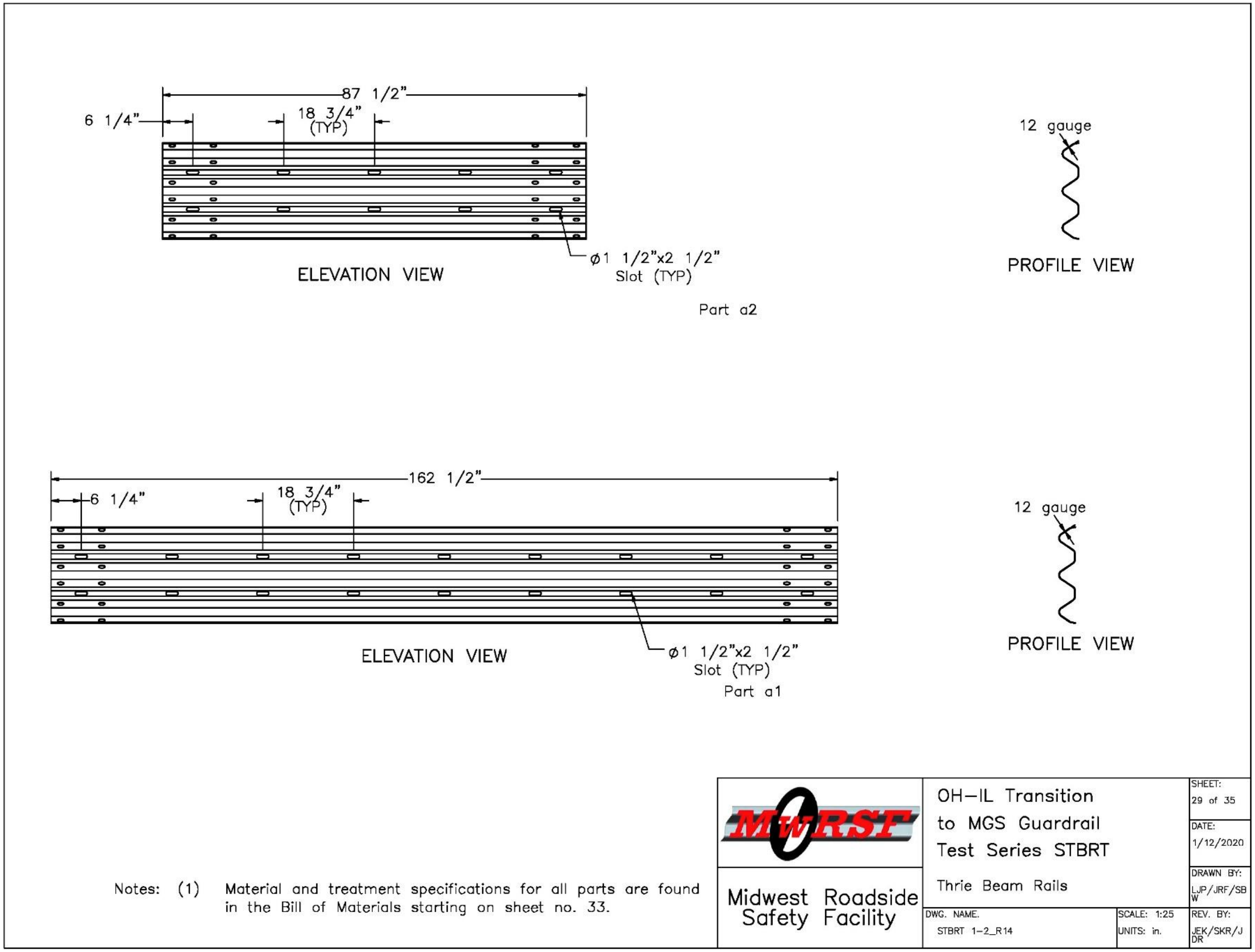


Figure 109. Thrie Beam Rails, Test Nos. STBRT-1 and STBRT-2

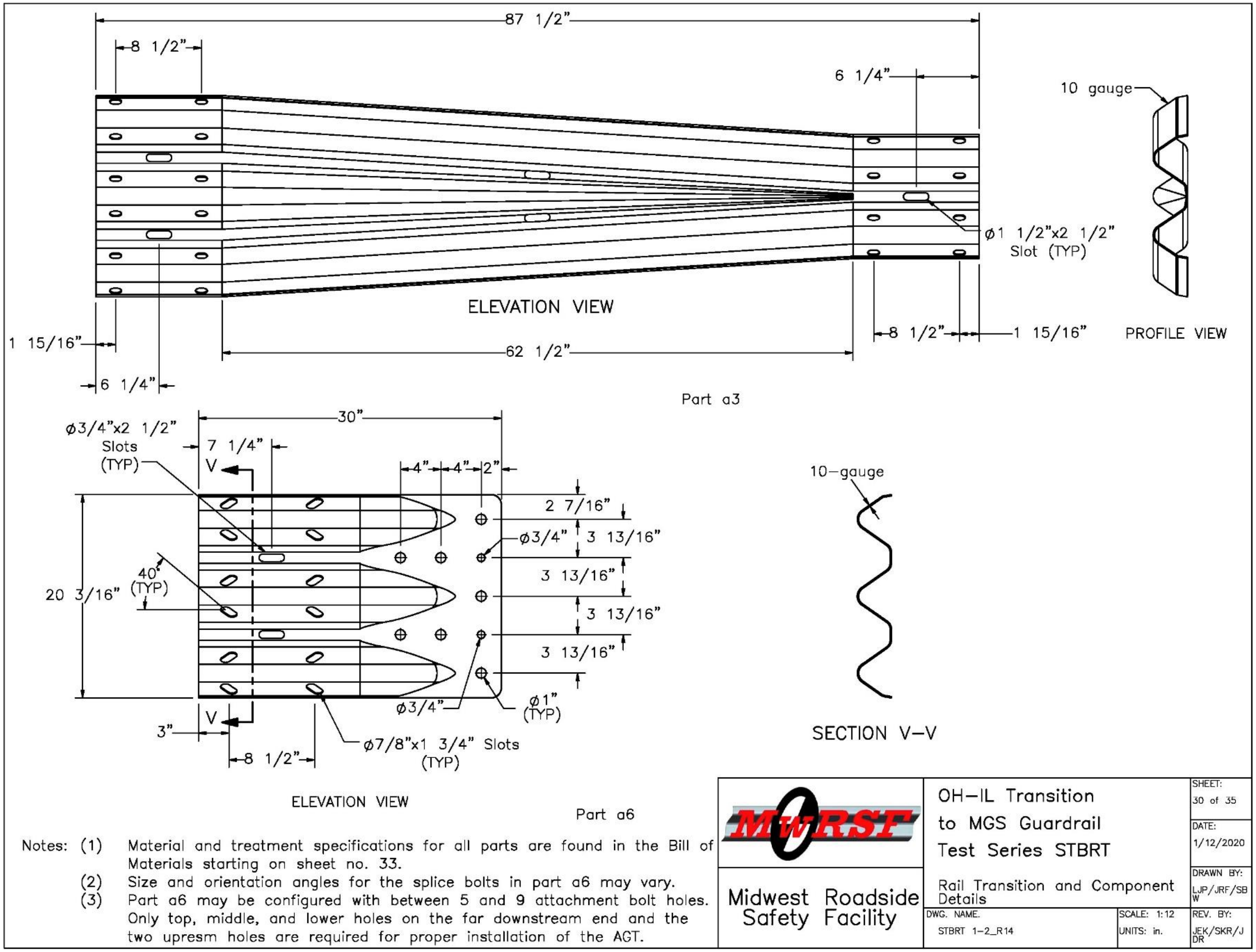


Figure 110. Rail Transition and Component Details, Test Nos. STBRT-1 and STBRT-2

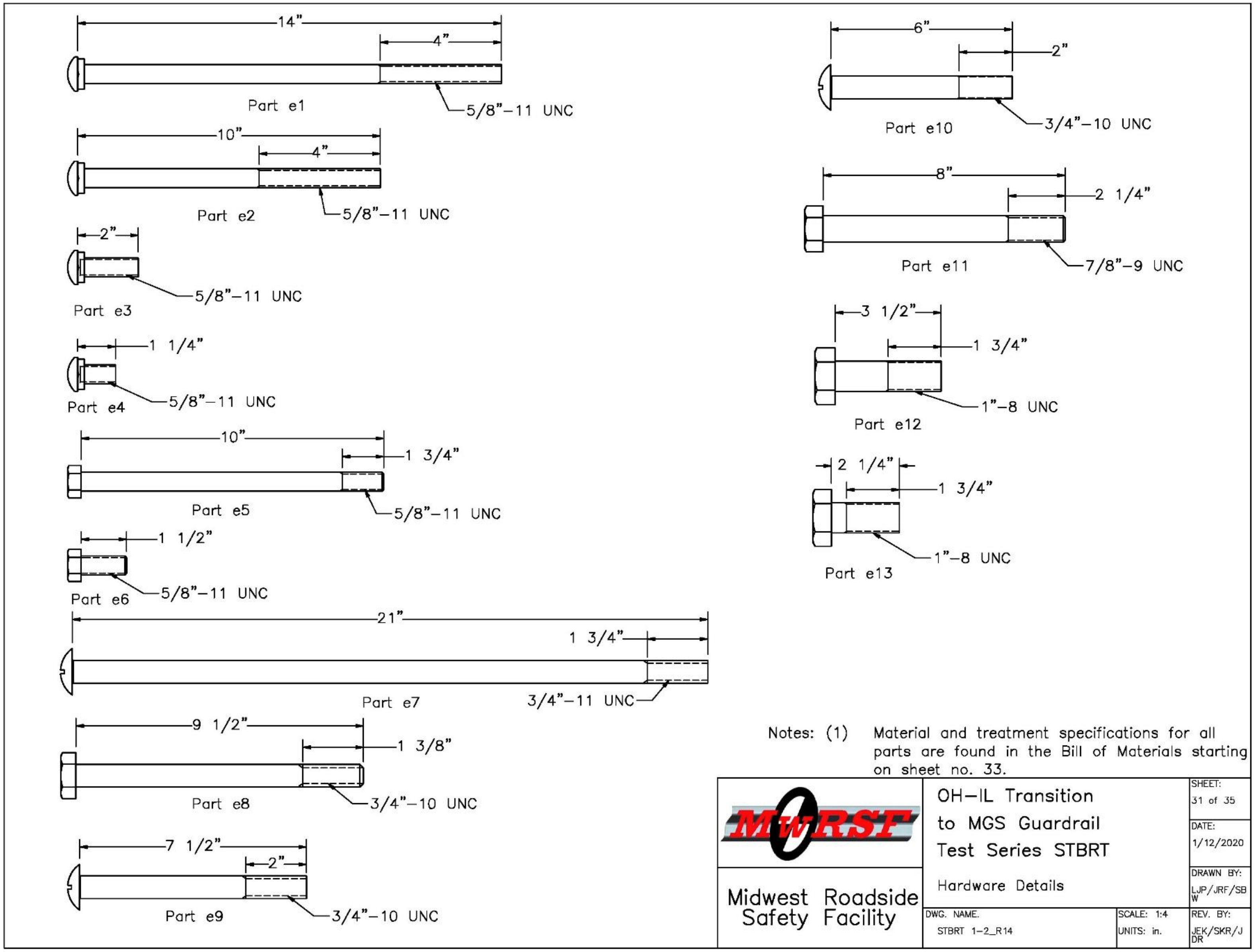


Figure 111. Hardware Details, Test Nos. STBRT-1 and STBRT-2

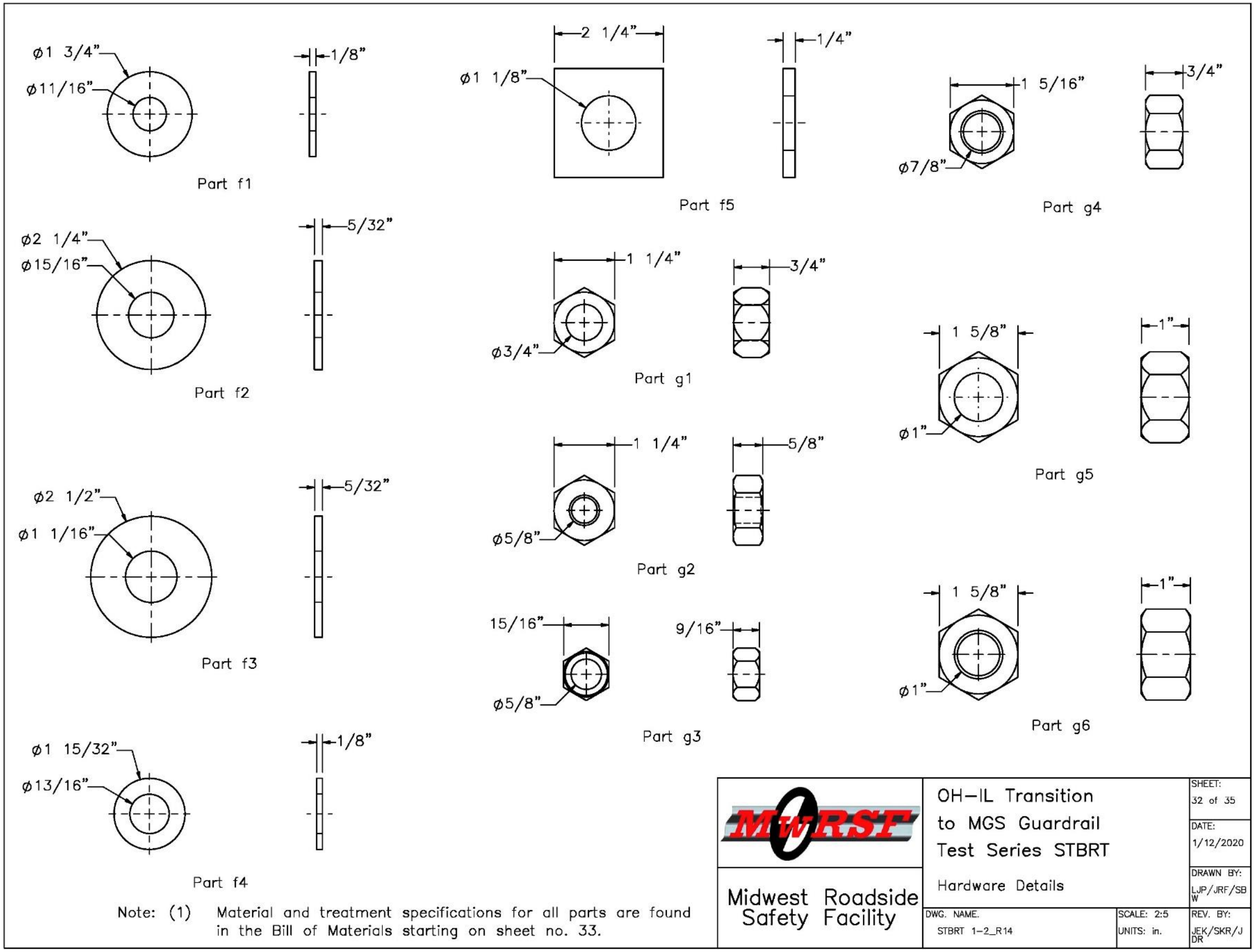


Figure 112. Hardware Details, Test Nos. STBRT-1 and STBRT-2

| Item No. | QTY. | Description | Material Specification | Treatment Specification | Hardware Guide |
|---|---|---|---|---|---|
| – | – | MASH Strong Soil in Critical Region | – | – | – |
| – | – | Existing Bridge Deck | – | – | – |
| a1 | 24 | 12'–6" 12–gauge Thrie Beam Section | AASHTO M180 | A123 or ASTM A653 | RTM08a |
| a2 | 1 | 6'–3" 12–gauge Thrie Beam Section | AASHTO M180 | A123 or ASTM A653 | RTM19a |
| a3 | 1 | 10–gauge Symmetrical W–beam to Thrie Beam Transition | AASHTO M180 | A123 or ASTM A653 | RWT01b |
| a4 | 3 | 12'–6" 12–gauge W–Beam Section | AASHTO M180 | A123 or ASTM A653 | RWM04a |
| a5 | 1 | 12'–6" 12–gauge W–Beam MGS End Section | AASHTO M180 | A123 or ASTM A653 | RWM14a |
| a6 | 1 | 10–gauge Thrie Beam Terminal Connector | AASHTO M180 (Min yield strength = 50 ksi Min. ultimate strength = 70 ksi) | A123 or ASTM A653 | RTE01b |
| a7 | 1 | 6'–3" 12–gauge W–Beam MGS Section | AASHTO M180 | A123 or ASTM A653 | RWM04a |
| b1 | 6 | 30"x10 5/8"x5/16" Plate | ASTM A572 Gr. 50 | See Assembly | – |
| b2 | 6 | 30"x2 5/8"x3/8" Plate | ASTM A572 Gr. 50 | See Assembly | – |
| b3 | 7 | 8"x8"x3/8" Plate | ASTM A572 Gr. 50 | See Assembly | – |
| b4 | 7 | 17 3/4"x13"x1" Post Plate | ASTM A572 Gr. 50 | See Assembly | – |
| b5 | 28 | 6 1/8"x5 11/16"x1/4" Gusset Plate | ASTM A572 Gr. 50 | See Assembly | – |
| b6 | 14 | HSS 5"x4"x1/2", 20" Long | ASTM A500 Gr. C | ASTM A123 | – |
| b7 | 12 | 30"x6 5/8"x3/8" Plate | ASTM A572 Gr. 50 | See Assembly | – |
| b8 | 12 | 30"x4 5/8"x5/16" Plate | ASTM A572 Gr. 50 | See Assembly | – |
| b9 | 6 | HSS 8"x6"x1/4", 191 1/4" Long | ASTM A500 Gr. C | ASTM A123 | – |
| b10 | 3 | HSS 12"x4"x1/4", 191 1/4" Long | ASTM A500 Gr. C | ASTM A123 | – |
| b11 | 14 | 20"x15"x3/16" Steel Plate | ASTM A572 Gr. 50 | See Assembly | – |
| c1 | 2 | BCT Timber Post – MGS Height | SYP Grade No. 1 or better (No knots +/– 9" from weakening hole on tension face) | – | PDF01 |
| c2 | 2 | 72" Long Foundation Tube | ASTM A500 Gr. B | ASTM A123 | PTE06 |
| c3 | 1 | Ground Strut Assembly | ASTM A36 | ASTM A123 | PFP02 |
| c4 | 1 | BCT Cable Anchor Assembly | – | – | FCA01 |
| c5 | 1 | 8"x8"x5/8" Anchor Bearing Plate | ASTM A36 | ASTM A123 | FPB01 |
| c6 | 1 | Anchor Bracket Assembly | ASTM A36 | ASTM A123 | FPA01 |
| c7 | 1 | 2 3/8" O.D. x 6" Long BCT Post Sleeve | ASTM A53 Gr. B Schedule 40 | ASTM A123 | FMM02 |

Note: (1) Quantities listed herein are only for one copy of the system.

Midwest Roadside Safety Facility

OH–IL Transition to MGS Guardrail Test Series STBRT

Bill of Materials

SHEET: 33 of 35
DATE: 1/12/2020
DRAWN BY: LJP/JRF/SBW
DWG. NAME. STBRT 1–2_R14
SCALE: None
UNITS: in.
REV. BY: JEK/SKR/JDR

Figure 113. Bill of Materials, Test Nos. STBRT-1 and STBRT-2

| Item No. | QTY. | Description | Material Specification | Treatment Specification | Hardware Guide |
| --- | --- | --- | --- | --- | --- |
| c8 | 11 | Bent 16D Double Head Nail | – | – | – |
| d1 | 5 | W6x9 or W6x8.5, 72" Long Steel Post | ASTM A992 | ASTM A123 | – |
| d2 | 1 | W6x9 or W6x8.5, 72" Long Steel Post | ASTM A992 | ASTM A123 | – |
| d3 | 8 | W6x9 or W6x8.5, 72" Long Steel Post | ASTM A992 | ASTM A123 | – |
| d4 | 3 | W6x15, 84" Long Steel Post | ASTM A992 | ASTM A123 | PWE12 |
| d5 | 7 | W6x15, 53 1/2" Long Post | ASTM A992 | See Assembly | – |
| d6 | 3 | 6"x8"x19" Timber Blockout | SYP Grade No.1 or better | – | PDB17 |
| d7 | 5 | 6"x12"x19" Timber Blockout | SYP Grade No.1 or better | – | – |
| d8 | 1 | 6"x12"x19" Timber Blockout | SYP Grade No.1 or better | – | PDB18 |
| d9 | 8 | 6"x12"x14 1/4" Timber Blockout | SYP Grade No.1 or better | – | PDB10a |
| e1 | 19 | 5/8" Dia. UNC, 14" Long Guardrail Bolt | ASTM A307 Gr. A | ASTM A153 or B695 Class 55 or F1941 or F2329 | FBB06 |
| e2 | 8 | 5/8" Dia. UNC, 10" Long Guardrail Bolt | ASTM A307 Gr. A | ASTM A153 or B695 Class 55 or F1941 or F2329 | FBB03 |
| e3 | 24 | 5/8" Dia. UNC, 2" Long Guardrail Bolt | ASTM A307 Gr. A | ASTM A153 or B695 Class 55 or F1941 or F2329 | FBB02 |
| e4 | 52 | 5/8" Dia. UNC, 1 1/4" Long Guardrail Bolt | ASTM A307 Gr. A | ASTM A153 or B695 Class 55 or F1941 or F2329 | FBB01 |
| e5 | 2 | 5/8" Dia. UNC, 10" Long Hex Head Bolt | ASTM A307 Gr. A | ASTM A153 or B695 Class 55 or F1941 or F2329 | FBX16a |
| e6 | 8 | 5/8" Dia. UNC, 1 1/2" Long Hex Head Bolt | ASTM A307 Gr. A | ASTM A153 or B695 Class 55 or F1941 or F2329 | FBX16a |
| e7 | 2 | 3/4"–11 UNC, 21" Long Round Head Bolt | ASTM A449 | ASTM A153 or B695 Class 55 or F1941 or F2329 | FBB08 |
| e8 | 24 | 3/4"–10 UNC, 9 1/2" Long Heavy Hex Head Bolt | ASTM F3125 Gr. A325 Type 1 | ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F1941 or F2329 or F2833 Gr. 1 | FBX20b |
| e9 | 35 | 3/4"–10 UNC, 7 1/2" Long Round Head Bolt | ASTM A449 | ASTM A153 or B695 Class 55 or F1941 or F2329 | FBB08 |
| e10 | 40 | 3/4"–10 UNC, 6" Long Round Head Bolt | ASTM A449 | ASTM A153 or B695 Class 55 or F1941 or F2329 | FBB08 |
| e11 | 2 | 7/8" Dia. UNC, 8" Long Hex Head Bolt | ASTM A307 Gr. A | ASTM A153 or B695 Class 55 or F1941 or F2329 | FBX22a |
| e12 | 28 | 1"–8 UNC, 3 1/2" Long Heavy Hex Head Bolt | ASTM F3125 Gr. A325 Type 1 | ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F1941 or F2329 or F2833 Gr. 1 | FBX24b |

Note: (1) Quantities listed herein are only for one copy of the system.

MwRSF
Midwest Roadside Safety Facility

OH–IL Transition to MGS Guardrail Test Series STBRT

Bill of Materials

| | |
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| SHEET: | 34 of 35 |
| DATE: | 1/12/2020 |
| DRAWN BY: | LJP/JRF/SBW |
| REV. BY: | JEK/SKR/JDR |
| DWG. NAME. | STBRT 1–2_R14 |
| SCALE: | None |
| UNITS: | in. |

Figure 114. Bill of Materials, Test Nos. STBRT-1 and STBRT-2

| Item No. | QTY. | Description | Material Specification | Treatment Specification | Hardware Guide |
|---|---|---|---|---|---|
| e13 | 28 | 1"–8 UNC, 2 1/4" Long Heavy Hex Head Bolt | ASTM F3125 Gr. A325 Type 1 | ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F1941 or F2329 or F2833 Gr. 1 | FBX24b |
| f1 | 34 | 5/8" Dia. SAE Plain Round Washer | ASTM F844 | ASTM A123 or A153 or F2329 | FWC16a |
| f2 | 4 | 7/8" Dia. USS Plain Round Washer | ASTM F844 | ASTM A123 or A153 or F2329 | – |
| f3 | 2 | 1" Dia. USS Plain Round Washer | ASTM F844 | ASTM A123 or A153 or F2329 | FWC24a |
| f4 | 127 | 3/4" Dia. SAE Hardened Flat Washer | ASTM F436 | ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F2329 | FWC20b |
| f5 | 84 | 2 1/4"x2 1/4"x1/4" Square Washer | ASTM A36 | ASTM A123 | – |
| g1 | 101 | 3/4 –10 UNC Heavy Hex Nut | ASTM A563DH | ASTM A153 or B695 Class 55 or F2329 | FNX20b |
| g2 | 105 | 5/8" Dia. Guardrail Nut | ASTM A563A | ASTM A153 or B695 Class 55 or F2329 | – |
| g3 | 8 | 5/8" Dia. Hex Nut | ASTM A563A | ASTM A153 or B695 Class 55 or F2329 | FBX22a |
| g4 | 2 | 7/8" Dia. Hex Nut | ASTM A563A | ASTM A153 or B695 Class 55 or F2329 | FBX22a |
| g5 | 56 | 1"–8 UNC Heavy Hex Nut | ASTM A563DH | ASTM A153 or B695 Class 55 or F2329 | FNX24b |
| g6 | 2 | 1" Dia. Hex Nut | ASTM A563DH | ASTM A153 or B695 Class 55 or F2329 | FBX24a |
| h1 | 1 | HSS 6"x4"x1/4", 36" Long Angled Cut Tube | ASTM A500 Gr. C | See Assembly | – |
| h2 | 1 | 13"x3 3/4"x1/4" Plate | ASTM A572 Gr. 50 | See Assembly | – |
| h3 | 1 | 13"x10 3/8"x1/4" Bent Plate | ASTM A572 Gr. 50 | See Assembly | – |
| h4 | 1 | 12"x4"x1/4", 15" Long Sloped Transition Rail | ASTM A500 Gr. C | See Assembly | – |
| h5 | 1 | 12"x4"x1/4", 30 1/8" Long Transition Rail | ASTM A500 Gr. C | See Assembly | – |
| h6 | 1 | HSS 8"x6"x1/4", 62 15/16" Long Middle Transition Rail | ASTM A500 Gr. C | See Assembly | – |
| h7 | 1 | HSS 8"x6"x1/4", 45 3/8" Long Middle Transition Rail | ASTM A500 Gr. C | See Assembly | – |
| h8 | 2 | HSS 8"x6"x1/4", 12 7/8" Long Transition Rail | ASTM A500 Gr. C | See Assembly | – |
| h9 | 1 | HSS 8"x6"x1/4", 62 15/16" Long Bottom Transition Rail | ASTM A500 Gr. C | See Assembly | – |
| h10 | 1 | HSS 8"x6"x1/4", 45 3/8" Long Bottom Transition Rail | ASTM A500 Gr. C | See Assembly | – |

Note: (1) Quantities listed herein are only for one copy of the system.

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OH–IL Transition to MGS Guardrail Test Series STBRT

Bill of Materials

SHEET: 35 of 35
DATE: 1/12/2020
DRAWN BY: LJP/JRF/SBW
REV. BY: JEK/SKR/JDR
DWG. NAME. STBRT 1–2_R14
SCALE: None
UNITS: in.

Figure 115. Bill of Materials, Test Nos. STBRT-1 and STBRT-2


Figure 116. Test Installation Photographs, Test No. STBRT-1


Figure 117. Test Installation Photographs – AGT Connection Hardware, Test No. STBRT-1


Figure 118. Test Installation Photographs, Test No. STBRT-2

# 8 TEST CONDITIONS

## 8.1 Test Facility

The Outdoor Test Site is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 5 miles northwest of the University of Nebraska-Lincoln.

## 8.2 Vehicle Tow and Guidance System

A reverse-cable, tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the barrier system. A digital speedometer on the tow vehicle increased the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch [38] was used to steer the test vehicle. A guide flag, attached to the right-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. diameter guide cable was tensioned to approximately 3,500 lb and supported both laterally and vertically every 100 ft by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

## 8.3 Test Vehicles

For test no. STBRT-1, a 2009 Hyundai Accent four door sedan was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,447 lb, 2,404 lb, and 2,568 lb, respectively. The test vehicle is shown in Figures 119 and 120, and vehicle dimensions are shown in Figure 121.

For test no. STBRT-2, a 2014 Dodge Ram 1500 quad cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,133 lb, 5,007 lb, and 5,160 lb, respectively. The test vehicle is shown in Figures 122 and 123, and vehicle dimensions are shown in Figure 124.

MASH 2016 requires test vehicles used in crash testing to be no more than six model years old. However, a 2009 model was used for the small car test because the vehicle geometry of newer models did not comply with recommended vehicle dimension ranges specified in Table 4.1 of MASH 2016. The use of older test vehicles due to recent small car vehicle properties falling outside of MASH 2016 recommendations was allowed by FHWA and AASHTO in MASH implementation guidance dated May 2018 [39].

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [40] was used to determine the vertical component of the c.g. for the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The vertical component of the c.g. for the 1100C vehicle was determined utilizing a procedure published by SAE [41]. The location of the final c.g. for the test vehicle used in test no. STBRT-1 is shown in Figures 121 and 125, and the location of the final c.g. for the test vehicle used in test no. STBRT-2 is shown in Figures 124 and 126. Data used to calculate the location of the c.g. and ballast information are shown in Appendix D.

Square, black- and white-checkered targets were placed on the vehicles for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figures 125 and 126. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicles.

The front wheels of the test vehicles were aligned to vehicle standards except the toe-in value was adjusted to zero such that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted under the vehicle’s left-side windshield wiper and was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed digital videos. A remote-controlled brake system was installed in the test vehicles so the vehicle could be brought safely to a stop after the test.


Figure 119. Test Vehicle, Test No. STBRT-1

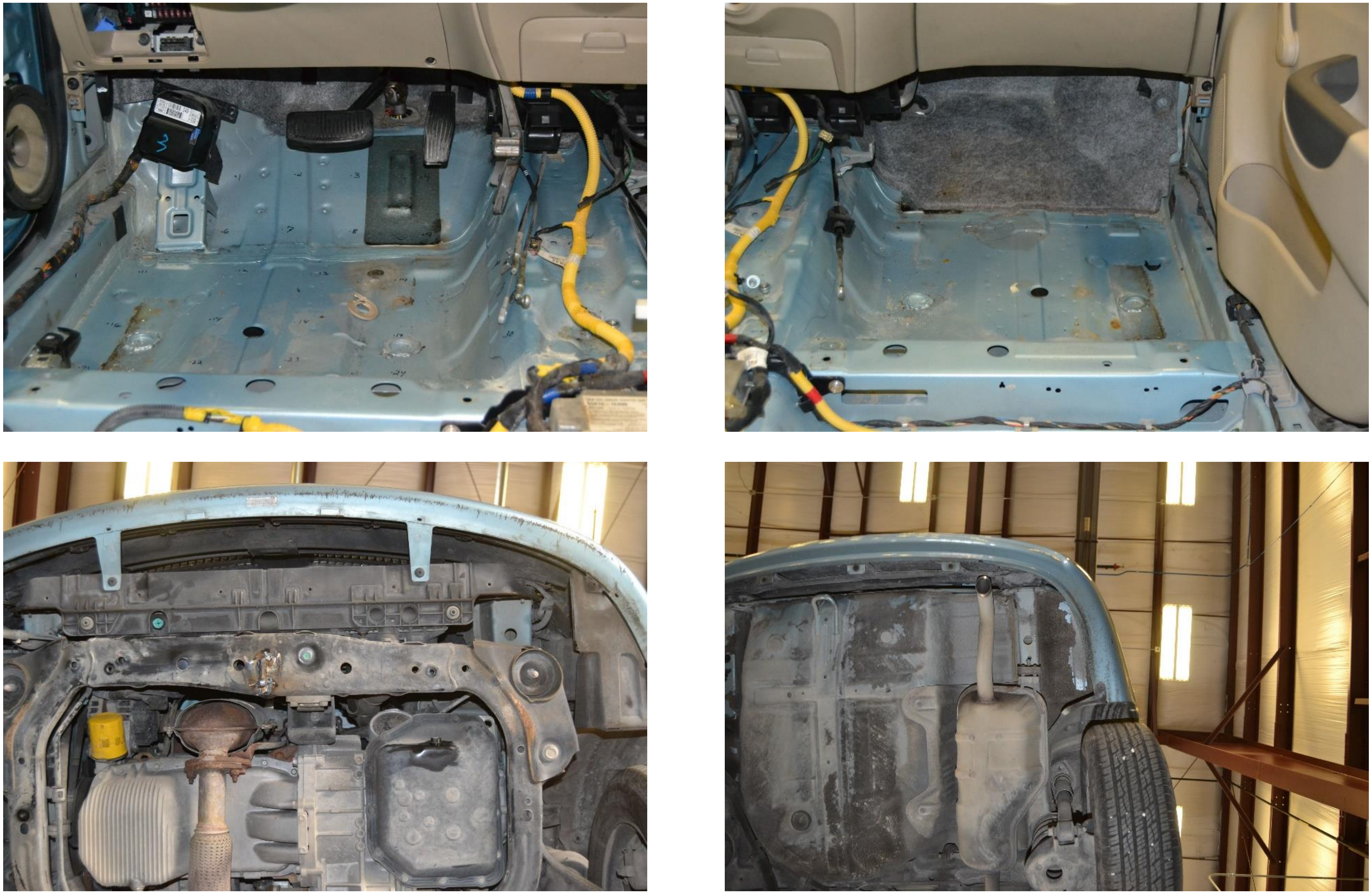
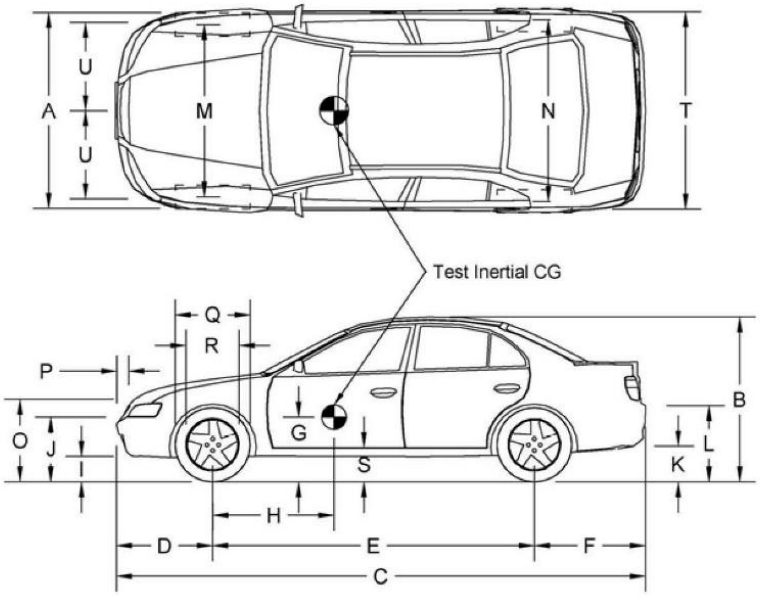


Figure 120. Test Vehicle's Interior Floorboards and Undercarriage, Test No. STBRT-1

| | | | | | |
|---|---|---|---|---|---|
| Date: | 8/24/2020 | Test Name: | STBRT-1 | VIN No: | kmhcn46c69u367008 |
| Model Year: | 2009 | Make: | Hyundai | Model: | Accent |
| Tire Size: | 185/65R14 | Tire Inflation Pressure: | 44 psi | Odometer: | 155708 |




**Vehicle Geometry - in. (mm)**
Target Ranges listed below

| | | | |
|---|---|---|---|
| A: | 66 (1676)<br>65±3 (1650±75) | B: | 57 3/4 (1467) |
| C: | 168 1/4 (4274)<br>169±8 (4300±200) | D: | 33 3/4 (857)<br>35±4 (900±100) |
| E: | 98 1/2 (2502)<br>98±5 (2500±125) | F: | 36 (914) |
| G: | 22 7/8 (581) | H: | 35 1/2 (902)<br>39±4 (990±100) |
| I: | 8 (203) | J: | 21 (533) |
| K: | 11 1/2 (292) | L: | 23 (584) |
| M: | 57 1/2 (1461)<br>56±2 (1425±50) | N: | 57 1/5 (1453)<br>56±2 (1425±50) |
| O: | 27 1/2 (699)<br>24±4 (600±100) | P: | 4 (102) |
| Q: | 23 (584) | R: | 15 1/4 (387) |
| S: | 12 (305) | T: | 65 1/2 (1664) |

| | |
|---|---|
| U (impact width): | 29 5/8 (752) |
| Top of radiator core support: | 28 3/4 (730) |
| Wheel Center Height (Front): | 10 5/8 (270) |
| Wheel Center Height (Rear): | 11 (279) |
| Wheel Well Clearance (Front): | 25 (635) |
| Wheel Well Clearance (Rear): | 25 (635) |
| Bottom Frame Height (Front): | 6 (152) |
| Bottom Frame Height (Rear): | 16 (406) |
| Engine Type: | 4 cyl. Gas |
| Engine Size: | 1.6L |
| Transmission Type: | Automatic |
| Drive Type: | FWD |

**Mass Distribution - lb (kg)**

| Gross Static | | | | |
|---|---|---|---|---|
| | LF | 830 (376) | RF | 797 (362) |
| | LR | 474 (215) | RR | 467 (212) |

| Weights lb (kg) | Curb | Test Inertial | Gross Static |
|---|---|---|---|
| W-front | 1550 (703) | 1538 (698) | 1627 (738) |
| W-rear | 897 (407) | 866 (393) | 941 (427) |
| W-total | 2447 (1110) | 2404 (1090)<br>2420±55 (1100±25) | 2568 (1165)<br>2585±55 (1175±50) |

| GVWR Ratings lb | | Surrogate Occupant Data | |
|---|---|---|---|
| Front | 1918 | Type: | Hybrid II |
| Rear | 1874 | Mass: | 164 lb |
| Total | 3638 | Seat Position: | Left/Drivers |

Note any damage prior to test: None

Figure 121. Vehicle Dimensions, Test No. STBRT-1


Figure 122. Test Vehicle, Test No. STBRT-2

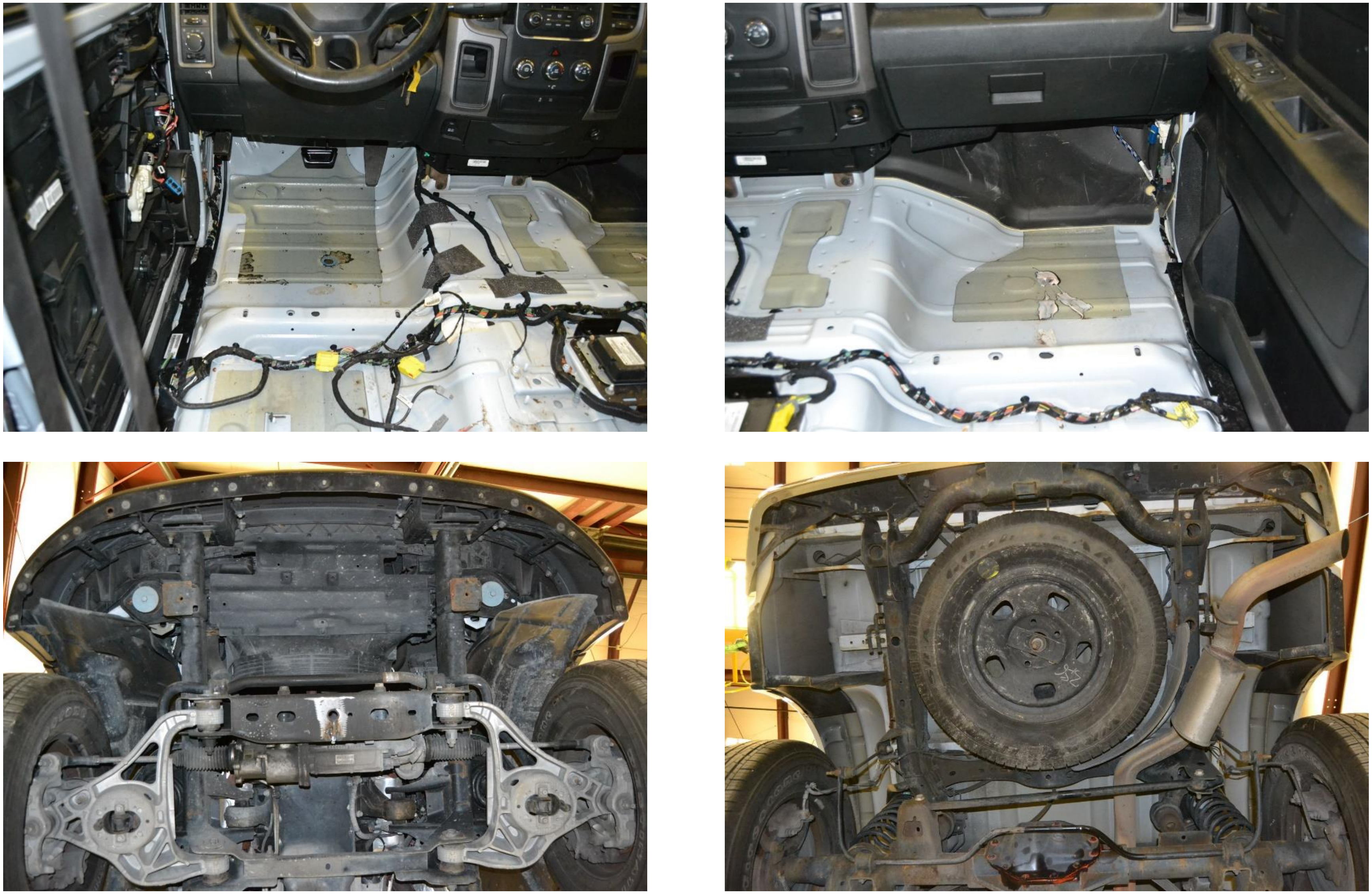
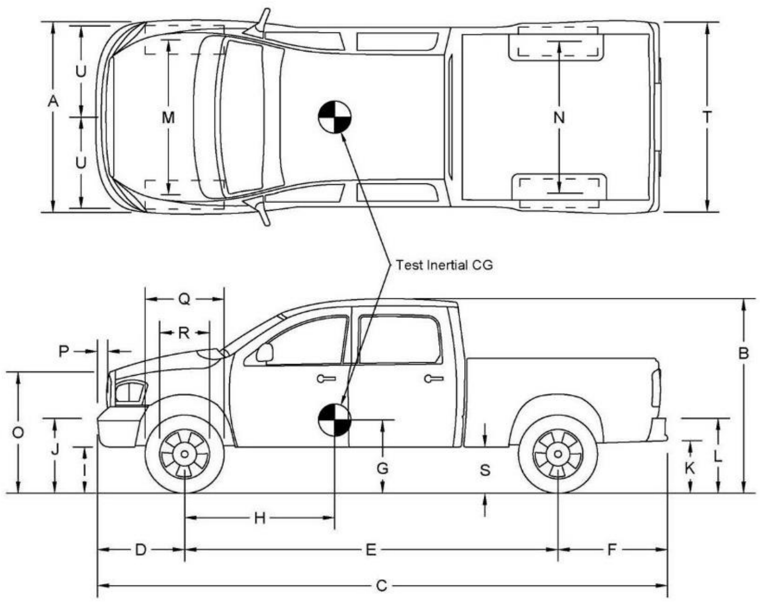


Figure 123. Test Vehicle’s Interior Floorboards and Undercarriage, Test No. STBRT-2

| | | | | | |
|---|---|---|---|---|---|
| Date: | 9/22/2020 | Test Name: | STBRT-2 | VIN No: | 1C6RR6FT9ES238613 |
| Model Year: | 2014 | Make: | Dodge | Model: | Ram 1500 Quad Cab |
| Tire Size: | 265/70R17 | Tire Inflation Pressure: | 40 psi | Odometer: | 54821 |




**Vehicle Geometry - in. (mm)**
Target Ranges listed below

| | | | |
|---|---|---|---|
| A: | 76 3/4 (1949)<br>78±2 (1950±50) | B: | 75 (1905) |
| C: | 229 1/4 (5823)<br>237±13 (6020±325) | D: | 40 3/8 (1026)<br>39±3 (1000±75) |
| E: | 140 1/2 (3569)<br>148±12 (3760±300) | F: | 48 3/8 (1229) |
| G: | 28 3/8 (721)<br>min: 28 (710) | H: | 61 (1549)<br>63±4 (1575±100) |
| I: | 12 5/8 (321) | J: | 25 (635) |
| K: | 21 (533) | L: | 29 (737) |
| M: | 68 (1729)<br>67±1.5 (1700±38) | N: | 67 7/8 (1724)<br>67±1.5 (1700±38) |
| O: | 44 1/2 (1130)<br>43±4 (1100±75) | P: | 4 1/2 (114) |
| Q: | 31 (787) | R: | 18 3/8 (467) |
| S: | 13 3/4 (349) | T: | 76 1/2 (1943) |

U (impact width): 36 1/2 (927)

**Mass Distribution - lb (kg)**

| | | | | |
|---|---|---|---|---|
| Gross Static | LF | 1485 (674) | RF | 1442 (654) |
| | LR | 1107 (502) | RR | 1126 (511) |

| Weights lb (kg) | Curb | Test Inertial | Gross Static |
|---|---|---|---|
| W-front | 2922 (1325) | 2834 (1285) | 2927 (1328) |
| W-rear | 2211 (1003) | 2173 (986) | 2233 (1013) |
| W-total | 5133 (2328) | 5007 (2271)<br>5000±110 (2270±50) | 5160 (2341)<br>5165±110 (2343±50) |

| | |
|---|---|
| Wheel Center Height (Front): | 15 (381) |
| Wheel Center Height (Rear): | 15 (381) |
| Wheel Well Clearance (Front): | 35 (889) |
| Wheel Well Clearance (Rear): | 38 (965) |
| Bottom Frame Height (Front): | 18 1/8 (460) |
| Bottom Frame Height (Rear): | 25 1/2 (648) |
| Engine Type: | Gasoline |
| Engine Size: | 5.7l v8 |
| Transmission Type: | Automatic |
| Drive Type: | RWD |
| Cab Style: | Quad cab |
| Bed Length: | 76" |

**GVWR Ratings - lb**

| | |
|---|---|
| Front | 3700 |
| Rear | 3900 |
| Total | 6800 |

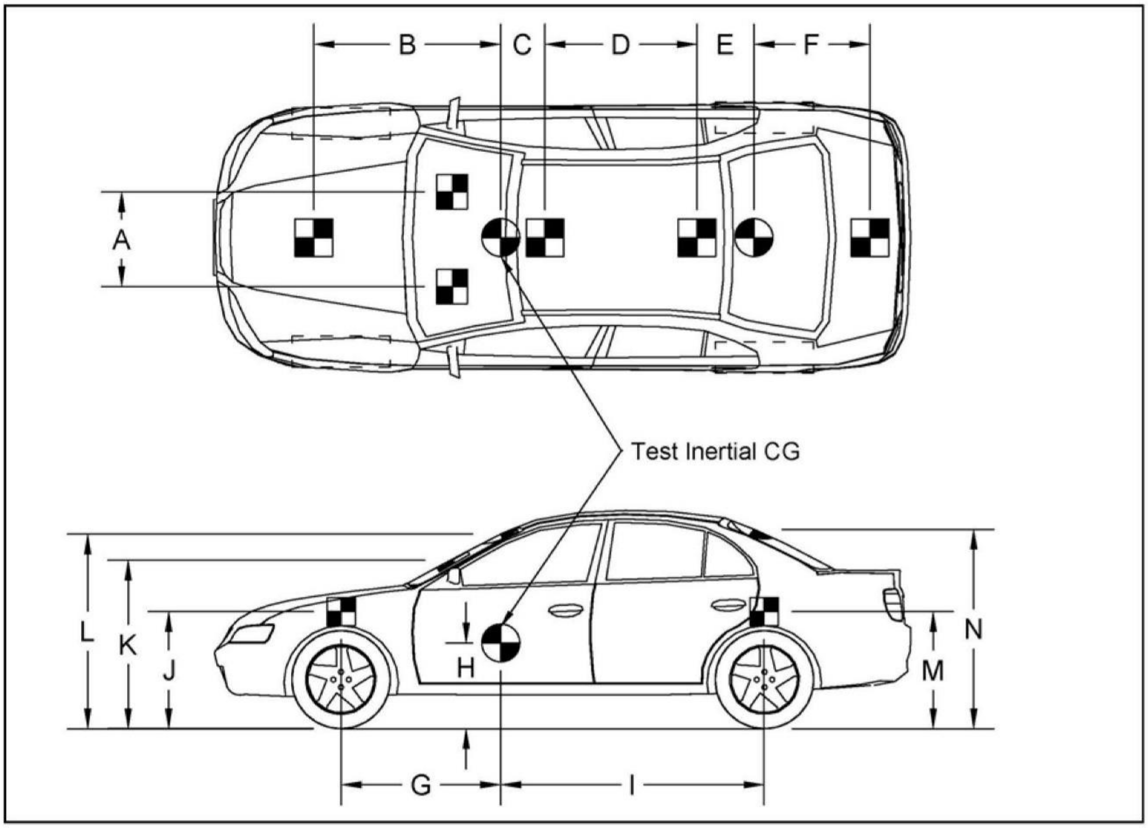
**Surrogate Occupant Data**

| | |
|---|---|
| Type: | Hybrid II |
| Mass: | 161 lb |
| Seat Position: | Driver/Left |

Note any damage prior to test: None

Figure 124. Vehicle Dimensions, Test No. STBRT-2

| | | | | | |
|---|---|---|---|---|---|
| Date: | 8/24/2020 | Test Name: | STBRT-1 | VIN: | kmhcn46c69u367008 |
| Model Year: | 2009 | Make: | Hyundai | Model: | Accent |

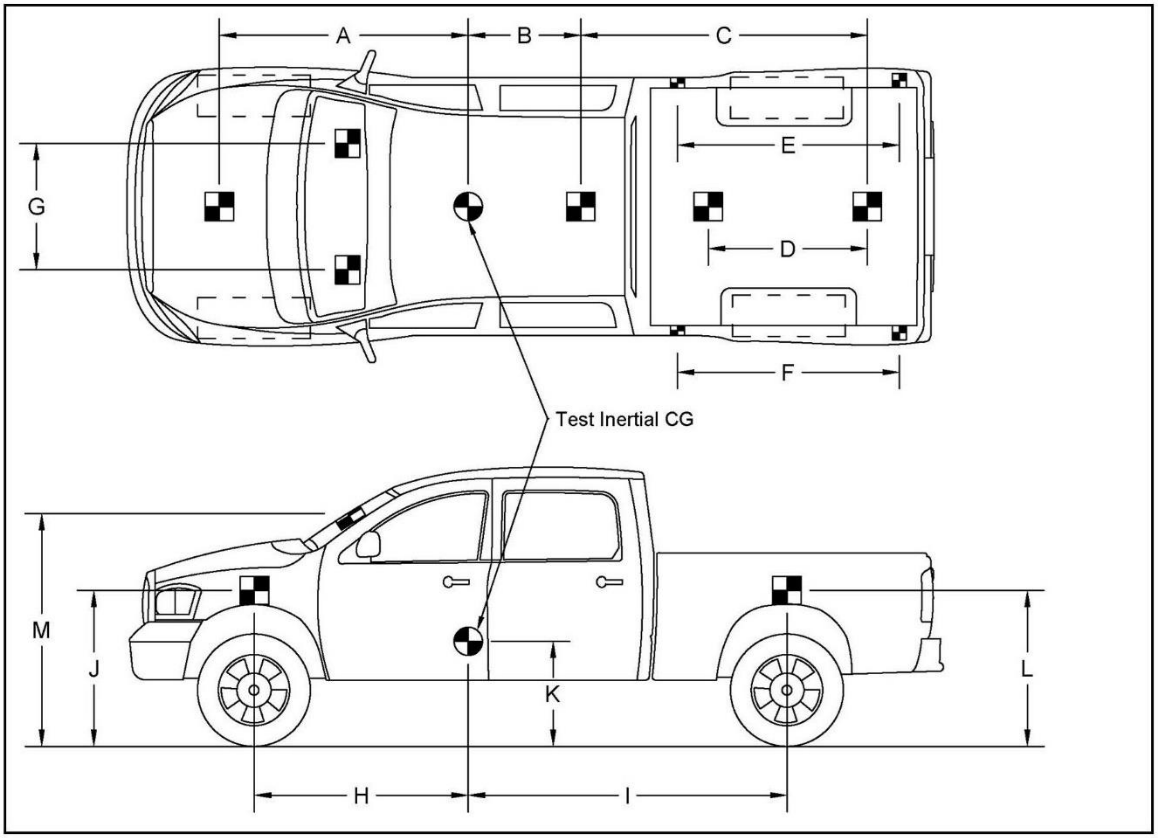



**TARGET GEOMETRY-- in. (mm)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| A: | 28 5/8 | (727) | F: | 25 | (635) | K: | 48 7/8<br>Windshield Target | (1241) |
| B: | 47 3/8 | (1203) | G: | 35 1/2 | (902) | L: | 52 3/8<br>Front round CG target | (1330) |
| C: | 8 1/2 | (216) | H: | 22 7/8 | (581) | M: | 29 | (737) |
| D: | 41 3/8 | (1051) | I: | 63 | (1600) | N: | 52 3/8<br>Rear Round target | (1330) |
| E: | 13 1/2 | (343) | J: | 28 3/4 | (730) | | | |

Figure 125. Target Geometry, Test No. STBRT-1

| | | | | | |
|---|---|---|---|---|---|
| Date: | 9/29/2020 | Test Name: | STBRT-2 | VIN: | 1C6RR6FT9ES238613 |
| Model Year: | 2014 | Make: | Dodge | Model: | Ram 1500 Quad Cab |




**TARGET GEOMETRY-- in. (mm)**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| A: | 74 7/16 | (1891) | E: | 63 5/8 | (1616) | J: | 39 | (991) |
| B: | 28 5/8 | (727) | F: | 63 5/8 | (1616) | K: | 28 1/2 | (724) |
| C: | 74 13/16 | (1900) | G: | 35 5/8 | (905) | L: | 42 | (1067) |
| D: | 442 1/2 | (11240) | H: | 61 | (1549) | M: | 63 | (1600) |
| | | | I: | 79 1/8 | (2010) | | | |

Figure 126. Target Geometry, Test No. STBRT-2

## 8.4 Simulated Occupant

For test nos. STBRT-1 and STBRT-2, a Hybrid II 50$^{th}$-Percentile, Adult Male Dummy equipped with footwear was placed in the left-front seat of the test vehicles with the seat belt fastened. The simulated occupant had a final weight of 164 lb in test no. STBRT-1 and 161 lb in test no. STBRT-2. As recommended by MASH 2016, the simulated occupant weight was not included in calculating the c.g. location.

## 8.5 Data Acquisition Systems

### 8.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both accelerometers systems were mounted near the c.g. of the test vehicles. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [42].

The SLICE-1 and SLICE-2 units were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The SLICE-1 unit was designated as the primary system for test no. STBRT-1, and the SLICE-2 unit was the primary system for test no. STBRT-2. The acceleration sensors were mounted inside the bodies of custom-built, SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessor. Both SLICE 6DX were configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

### 8.5.2 Rate Transducers

Two identical angular rate sensor systems mounted inside the bodies of the SLICE-1 and SLICE-2 event data recorders were used to measure the rates of rotation of the test vehicle. Each SLICE MICRO Triax ARS had a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) and recorded data at 10,000 Hz to the onboard microprocessors. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

### 8.5.3 Retroreflective Optic Speed Trap

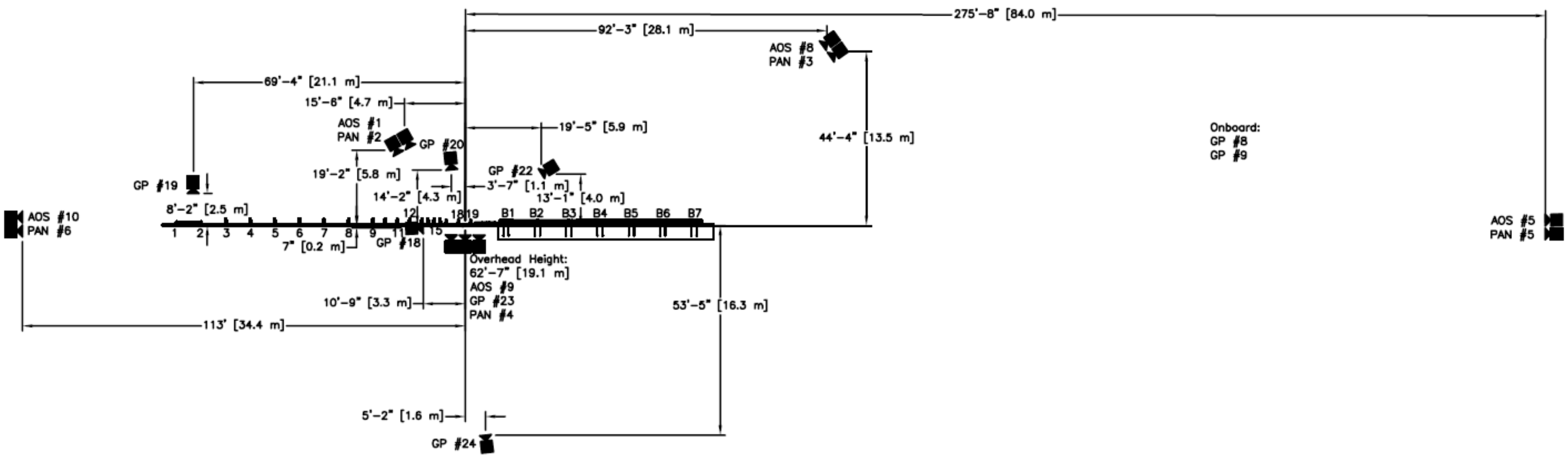
The retroreflective optic speed trap was used to determine the speed of the test vehicle before impact. Five retroreflective targets, spaced at approximately 18-in. intervals, were applied to the side of the vehicle. When the emitted beam of light was reflected by the targets and returned to the Emitter/Receiver, a signal was sent to the data acquisition computer, recording at 10,000 Hz, as well as the external LED box activating the LED flashes. The speed was then calculated using the spacing between the retroreflective targets and the time between the signals. LED lights and high-speed digital video analysis are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

### 8.5.4 Digital Photography

Five AOS high-speed digital video cameras, eight GoPro digital video cameras, and five Panasonic digital video cameras were utilized to film test no. STBRT-1. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 127.

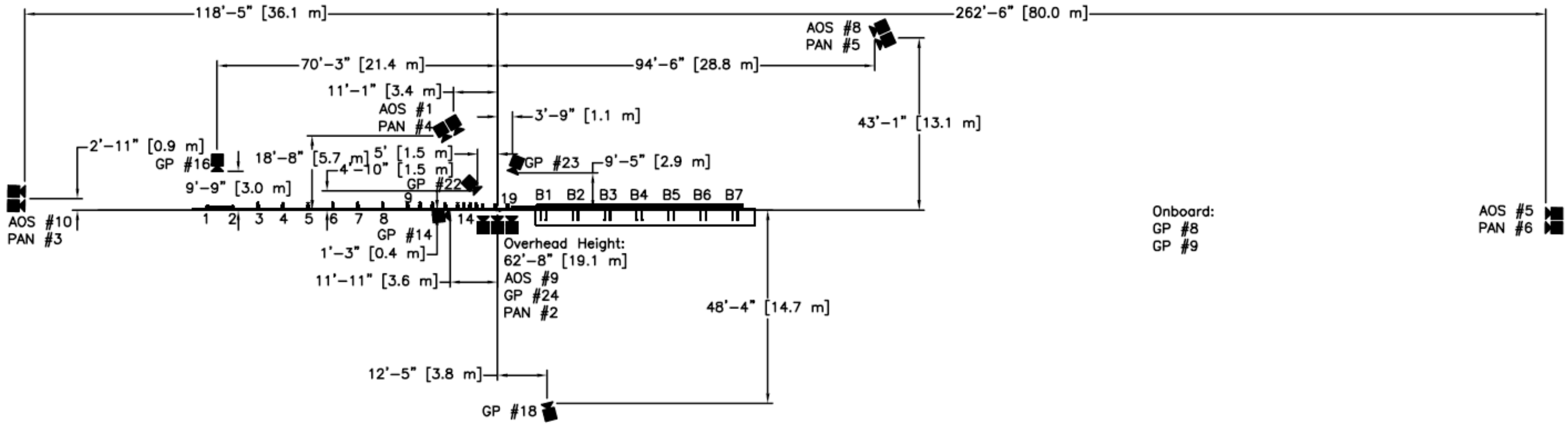
Five AOS high-speed digital video cameras, seven GoPro digital video cameras, and five Panasonic digital video cameras were utilized to film test no. STBRT-2. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 128.

The high-speed videos were analyzed using TEMA Motion and Redlake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos. A digital still camera was also used to document pre- and post-test conditions for all tests.




| No. | Type | Operating Speed (frames/sec) | Lens | Lens Setting |
|---|---|---|---|---|
| AOS-1 | AOS Vitcam | 500 | KOWA 16 mm | |
| AOS-5 | AOS X-PRI | 500 | 100 mm | |
| AOS-8 | AOS S-VIT 1531 | 500 | Fujinon 35 mm | |
| AOS-9 | AOS TRI-VIT 2236 | 1000 | KOWA 12 mm | |
| AOS-10 | AOS TRI-VIT | 500 | Fujinon 50 mm | |
| GP-8 | GoPro Hero 4 | 120 | | |
| GP-9 | GoPro Hero 4 | 120 | | |
| GP-18 | GoPro Hero 6 | 240 | | |
| GP-19 | GoPro Hero 6 | 240 | | |
| GP-20 | GoPro Hero 6 | 240 | | |
| GP-22 | GoPro Hero 7 | 240 | | |
| GP-23 | GoPro Hero 7 | 240 | | |
| GP-24 | GoPro Hero 7 | 240 | | |
| PAN-2 | Panisonic HC-V770 | 120 | | |
| PAN-3 | Panisonic HC-V770 | 120 | | |
| PAN-4 | Panisonic HC-V770 | 120 | | |
| PAN-5 | Panisonic HC-VX981 | 120 | | |
| PAN-6 | Panisonic HC-VX981 | 120 | | |

Figure 127. Camera Locations, Speeds, and Lens Settings, Test No. STBRT-1




| No. | Type | Operating Speed (frames/sec) | Lens | Lens Setting |
|---|---|---|---|---|
| AOS-1 | AOS Vitcam | 500 | KOWA 16 mm | |
| AOS-5 | AOS X-PRI | 500 | 100 mm | |
| AOS-8 | AOS S-VIT 1531 | 500 | Fujinon 75 mm | |
| AOS-9 | AOS TRI-VIT 2236 | 1000 | KOWA 12 mm | |
| AOS-10 | AOS TRI-VIT | 500 | Fujinon 50 mm | |
| GP-8 | GoPro Hero 4 | 120 | | |
| GP-9 | GoPro Hero 4 | 120 | | |
| GP-14 | GoPro Hero 4 | 120 | | |
| GP-16 | GoPro Hero 4 | 120 | | |
| GP-18 | GoPro Hero 6 | 240 | | |
| GP-22 | GoPro Hero 7 | 240 | | |
| GP-23 | GoPro Hero 7 | 240 | | |
| GP-24 | GoPro Hero 7 | 240 | | |
| PAN-2 | Panisonic HC-V770 | 120 | | |
| PAN-3 | Panisonic HC-V770 | 120 | | |
| PAN-4 | Panisonic HC-V770 | 120 | | |
| PAN-5 | Panisonic HC-VX981 | 120 | | |
| PAN-6 | Panisonic HC-VX981 | 120 | | |

Figure 128. Camera Locations, Speeds, and Lens Settings, Test No. STBRT-2

# 9 FULL-SCALE CRASH TEST NO. STBRT-1

## 9.1 Static Soil Test

Before full-scale crash test no. STBRT-1 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH 2016. The static test results, as shown in Appendix E, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

## 9.2 Weather Conditions

Test no. STBRT-1 was conducted on August 24, 2020 at approximately 2:45 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 13.

Table 13. Weather Conditions, Test No. STBRT-1

| | |
|---|---|
| Temperature | 94° F |
| Humidity | 33 % |
| Wind Speed | 14 mph |
| Wind Direction | 190° from True North |
| Sky Conditions | Sunny |
| Visibility | 9 Statute Miles |
| Pavement Surface | Dry |
| Previous 3-Day Precipitation | 0 in. |
| Previous 7-Day Precipitation | 0 in. |

## 9.3 Test Description

Initial vehicle impact was to occur 30 in. upstream from post no. 19, as shown in Figure 129, which was selected using an LS-DYNA analysis to maximize vehicle wedging and snag underneath the sloped lower bridge rail tube termination. The 2,404-lb small car impacted the bridge rail transition at a speed of 64.6 mph and at an angle of 25.2 degrees. The actual point of impact was 8.7 in. downstream from the target location. During the test, the 1100C small car was contained and smoothly redirected with only minor roll and pitch displacements. The AGT experienced minimal deflections with maximum dynamic and permanent set deflections of 8.6 in. and 2.7 in., respectively. Both deflections were measured at the upstream end of the middle transition tube rail. Vehicle components contacted the height transition of the lower transition tube rail and the first bridge post, but snag was minimal. The vehicle came to rest 193 ft – 11 in. downstream from the target point and 63 ft – 1 in. laterally in front of the traffic side of the system after the vehicle's brakes were applied.

A detailed description of the sequential impact events is contained in Table 14. Sequential photographs are shown in Figures 130 and 131. Documentary photographs of the crash test are shown in Figure 132. The vehicle trajectory and final position are shown in Figure 133.

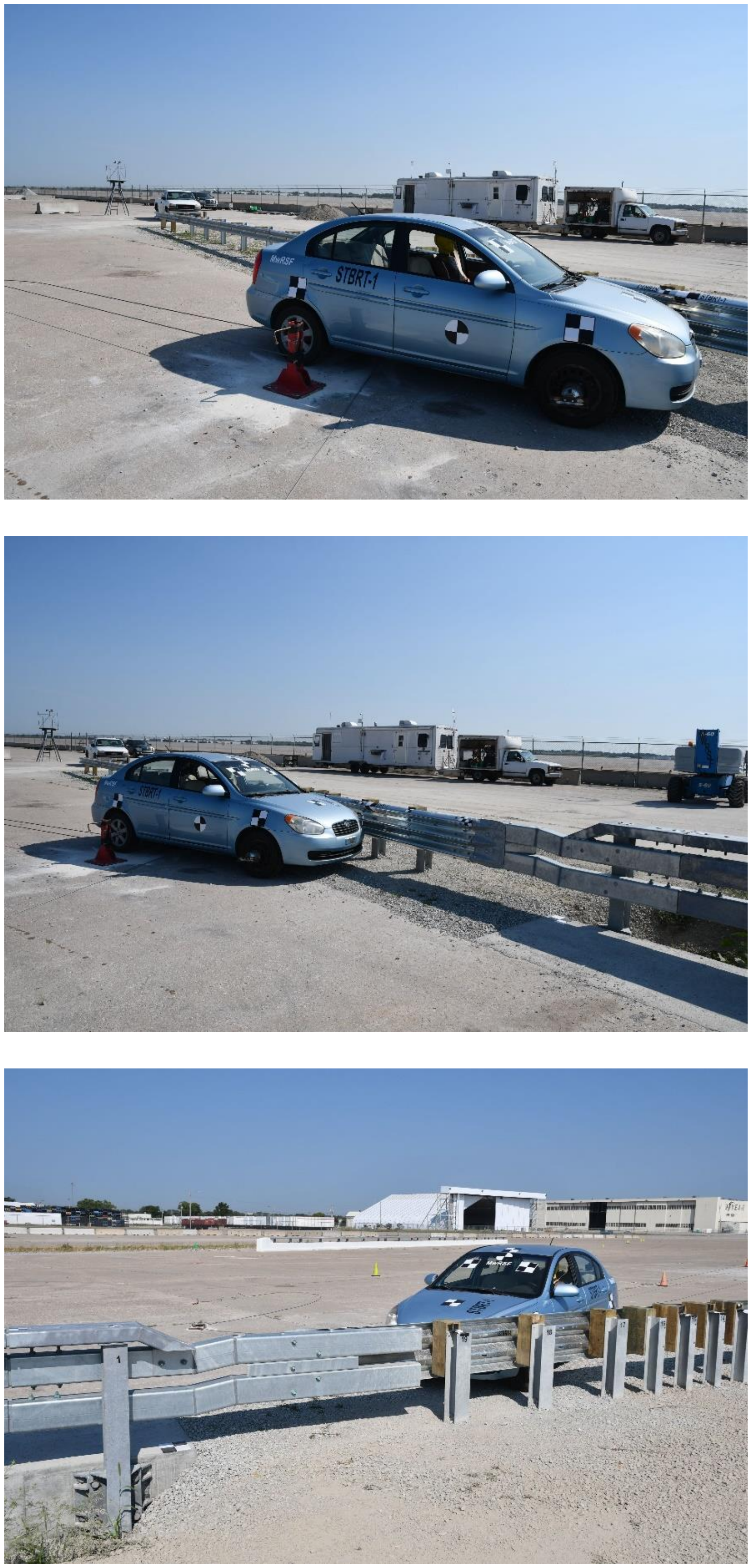



Figure 129. Impact Location, Test No. STBRT-1

Table 14. Sequential Description of Impact Events, Test No. STBRT-1

| TIME (sec) | EVENT |
|---|---|
| 0.000 | Vehicle's front bumper contacted system 21.3 in. upstream from post no. 19 (the farthest downstream transition post). |
| 0.008 | Vehicle's left fender contacted rail. |
| 0.010 | Vehicle's hood contacted the rail. |
| 0.016 | Post no. 19 deflected backward. |
| 0.020 | Post no. 19 rotated to face downstream. |
| 0.023 | Vehicle yawed away from system. |
| 0.024 | Post no. 18 deflected backward. |
| 0.028 | Post no. B1 (first bridge rail post) deflected backward. |
| 0.032 | Vehicle's left front door contacted rail, and vehicle rolled toward system. |
| 0.042 | Vehicle's roof deformed. |
| 0.054 | Vehicle pitched downward. |
| 0.060 | Post no. B2 deflected backward, and vehicle's left headlight shattered. |
| 0.074 | Post no. B1 bent backward. |
| 0.082 | Vehicle's left rear door contacted rail. |
| 0.096 | Top of left-front door deformed, resulting in top being opened. |
| 0.130 | Vehicle rolled toward system, and vehicle's right-rear tire became airborne. |
| 0.160 | Vehicle's left quarter panel contacted rail. |
| 0.165 | Vehicle was parallel to system traveling at 47.5 mph. |
| 0.174 | Vehicle's rear bumper contacted rail. |
| 0.188 | Vehicle pitched upward. |
| 0.234 | Vehicle yawed toward system. |
| 0.237 | Vehicle exited system at 46.2 mph and a -7.4-degree angle. |
| 0.328 | Vehicle rolled away from system. |
| 0.382 | System came to a rest. |
| 0.446 | Vehicle's right-rear tire regained contact with ground. |

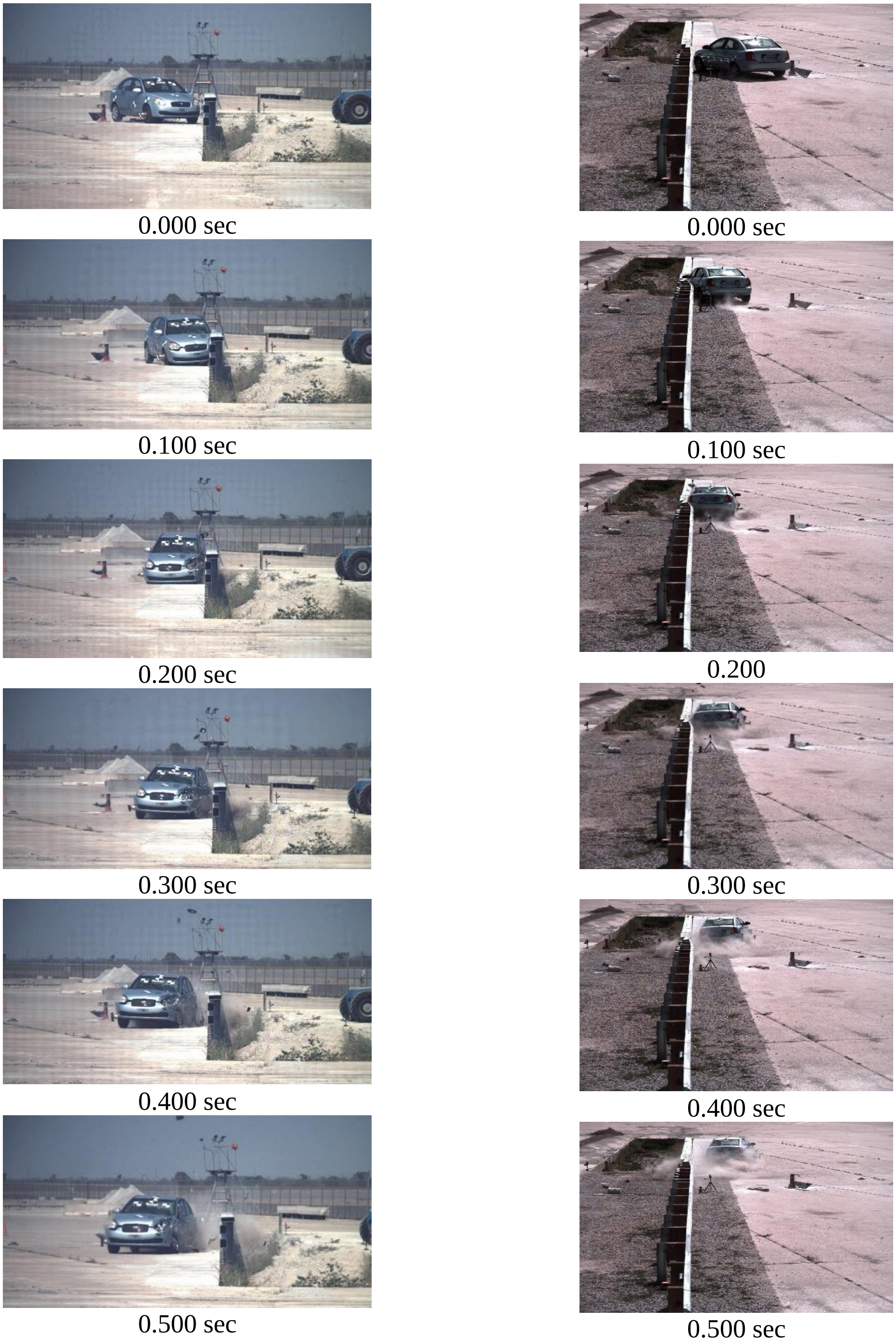



Figure 130. Sequential Photographs, Test No. STBRT-1

0.000 sec

0.100 sec

0.200 sec

0.300 sec

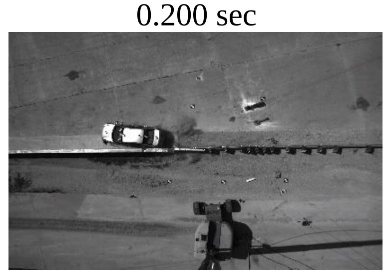
0.400 sec

0.500 sec

0.000 sec

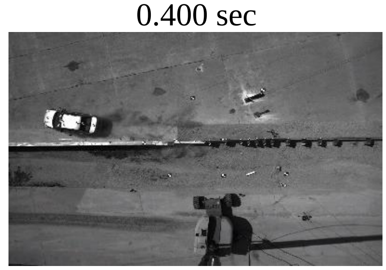
0.100 sec

0.200 sec



0.300 sec

0.400 sec



0.500 sec

Figure 131. Sequential Photographs, Test No. STBRT-1

Figure 132. Documentary Photographs, Test No. STBRT-1

Figure 133. Vehicle Final Position and Trajectory Marks, Test No. STBRT-1

### 9.4 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 134 through 136. Barrier damage consisted of contact marks and kinks on the thrie beam guardrail, contact marks on the HSS transition rails, and spalling of the concrete deck. The length of vehicle contact along the barrier was approximately 15 ft, which spanned from 6½ in. downstream from the centerline of post no. 18 to 4 ft downstream from the first bridge rail post.

Kinks on the thrie beam began 8½ in. upstream from the centerline of post no. 15 and continued downstream to the end of the thrie beam section. Multiple kinks were found on the top and bottom of the thrie beam between post nos. 15 and 19. The bottom corrugation was flattened beginning 1 ft – 8¼ in. upstream from the centerline of post no. 19 and continued 5 ft – 3 in. downstream to the thrie beam terminal connector. Post nos. 18 and 19 rotated backward.

Contact marks were found on the upstream end of the HSS transition rail sections and extended downstream past the first bridge rail post. The contact marks were mainly concentrated on the bottom transition tube rail. However, marks were found on the middle transition tube rail and on the face of the sloped portion of the upper transition tube rail. Tire marks were found on the face of the first bridge rail post below the lower rail.

Minor spalling occurred on the upstream corner of the concrete deck. The spalling began 1 ft – 4½ in. upstream from the centerline of the first bridge rail post and extended 2 ft downstream. Tire marks were observed on the concrete deck between the first and second bridge rail.

The maximum lateral permanent set of the barrier system was 2.7 in. at the upstream end of the middle transition tube rail, as measured in the field. The maximum lateral dynamic barrier deflection was 8.6 in. at the upstream end of the middle transition tube, as determined from high-speed digital video analysis. The working width of the system was found to be 21.4 in., also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 137.


Figure 134. System Damage, Test No. STBRT-1

Figure 135. Thrie Beam and Transition Rail Damage, Test No. STBRT-1

Figure 136. Deck Damage, Test No. STBRT-1

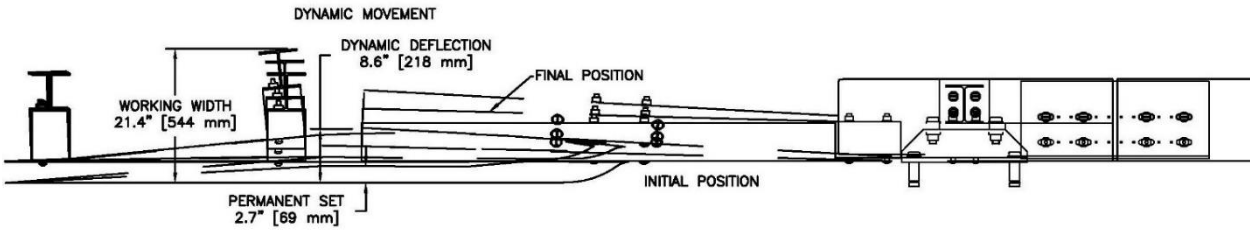



Figure 137. Permanent Set, Dynamic Deflection, and Working Width, Test No. STBRT-1

### 9.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 138 through 141. The maximum occupant compartment intrusions are listed in Table 15, along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix F. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. There were no penetrations into the occupant compartment, and none of the established MASH 2016 deformation limits were violated. Outward deformations, which are denoted as negative numbers in Appendix F, are not considered crush toward the occupant, and are not evaluated by MASH 2016 criteria.

Majority of the damage was concentrated on the left-front corner and left side of the vehicle where impact had occurred. The front bumper had scrapes along its left side, and the left headlight was disengaged from the vehicle. The hood was crushed downward and inward at the headlight opening. The left-front fender remained intact but was crushed inward along its entire length. The left-front door was dented inward, and the left-rear door was crushed and dented. The windshield was cracked along the left side of the vehicle, but the system had no direct contact with the windshield.

Undercarriage damage was minimal. The left-side strut assembly remained intact but was bent, causing the tire and wheel to lean inward. The engine cradle was bent upward and inward at the left-front corner. The right-side frame horn kinked 16 in. behind the leading edge and was bent to the right. The left-side frame horn was bent to the right and inward.


Figure 138. Vehicle Damage, Test No. STBRT-1


Figure 139. Vehicle Damage, Test No. STBRT-1

Figure 140. Occupant Compartment Damage, Test No. STBRT-1

Figure 141. Undercarriage Damage, Test No. STBRT-1

Table 15. Maximum Occupant Compartment Intrusion by Location, Test No. STBRT-1

| LOCATION | MAXIMUM INTRUSION (in.) | MASH 2016 ALLOWABLE INTRUSION (in.) |
|---|---|---|
| Wheel Well & Toe Pan | 0.4 | ≤ 9 |
| Floor Pan & Transmission Tunnel | 0.5 | ≤ 12 |
| A-Pillar | 0.7 | ≤ 5 |
| A-Pillar (Lateral) | 0.6 | ≤ 3 |
| B-Pillar | 0.2 | ≤ 5 |
| B-Pillar (Lateral) | 0.2 | ≤ 3 |
| Side Front Panel (in Front of A-Pillar) | 0.8 | ≤ 12 |
| Side Door (Above Seat) | 0.0 | ≤ 9 |
| Side Door (Below Seat) | 0.0 | ≤ 12 |
| Roof | 0.1 | ≤ 4 |
| Windshield | 2.1 | ≤ 3 |
| Side Window | Intact | No shattering resulting from contact with structural member of test article |
| Dash | 0.6 | N/A |

N/A – No MASH 2016 criteria exist for this location

## 9.6 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 16. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 16. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix G.

Table 16. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. STBRT-1

| Evaluation Criteria | | Transducer | | MASH 2016 Limits |
|---|---|---|---|---|
| | | SLICE-1 (primary) | SLICE-2 | |
| OIV (ft/s) | Longitudinal | -18.83 | -17.79 | ±40 |
| | Lateral | 28.98 | 27.52 | ±40 |
| ORA (g's) | Longitudinal | -9.44 | -9.22 | ±20.49 |
| | Lateral | 11.40 | 11.30 | ±20.49 |
| Maximum Angular Displacement (deg.) | Roll | -6.1 | -3.3 | ±75 |
| | Pitch | -3.9 | -4.5 | ±75 |
| | Yaw | 36.3 | 36.0 | not required |
| THIV (ft/s) | | 29.06 | 28.22 | not required |
| PHD (g's) | | 11.53 | 11.35 | not required |
| ASI | | 1.91 | 1.80 | not required |

## 9.7 Discussion

The analysis of the test results for test no. STBRT-1 showed that the system adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 142. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix G, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of -7.4 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. STBRT-1 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-20.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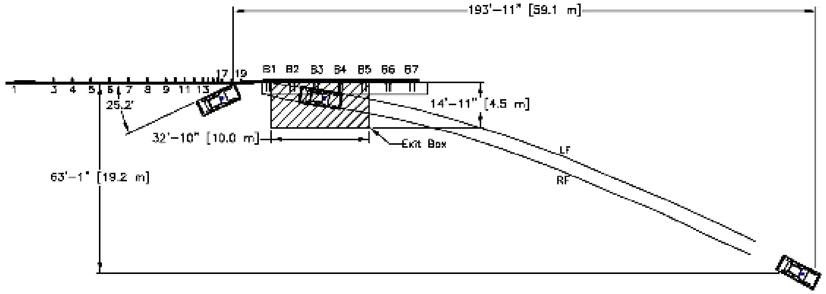


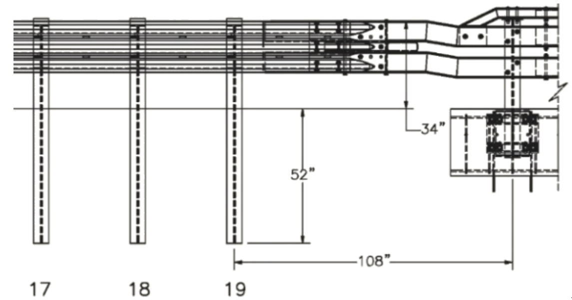


- Test Agency ........ MwRSF
- Test Number ........ STBRT-1
- Date ........ August 24, 2020
- MASH 2016 Test Designation No. ........ 3-20
- Test Article ........ OH-IL Steel-Tube Bridge Rail Transition
- Total Length ........ 137 ft – 9 in.
- Key Component –Rails
  - Middle and Lower Tube Rails ........ HSS8x6x¼
  - Top Rail ........ HSS12x4x¼
  - AGT Rail ........ Nested 12-gauge Thrie Beam
  - Thrie Beam Connector ........ 10-gauge Terminal Connector
- Key Component –Posts
  - Bridge Rail ........ W6x15 at 8 ft on-center
  - AGT ........ W6x15 at 37.5 in. on-center
  - Spacing between Adjacent AGT and Bridge Post ........ 9 ft
- Vehicle Make /Model ........ 2009 Hyundai Accent
  - Curb ........ 2,447 lb
  - Test Inertial ........ 2,404 lb
  - Gross Static ........ 2,568 lb
- Impact Conditions
  - Speed ........ 64.6 mph
  - Angle ........ 25.2 deg.
  - Impact Location ........ 21.3 in. U.S. from post no. 19
- Impact Severity ........ 60.9 kip-ft > 51.1 kip-ft limit from MASH 2016
- Exit Conditions
  - Speed ........ 46.2 mph
  - Angle ........ -7.4 deg.
- Exit Box Criterion ........ Pass
- Vehicle Stability ........ Satisfactory
- Vehicle Stopping Distance ........ 193 ft – 11 in. downstream
- Vehicle Damage ........ Moderate
  - VDS [43] ........ 11-LFQ-5
  - CDC [44] ........ 11-LFEW-2
  - Maximum Interior Deformation ........ 2.1 in.
- Test Article Damage ........ Minimal
- Maximum Test Article Deflections
  - Permanent Set ........ 2.7 in.
  - Dynamic ........ 8.6 in.
  - Working Width ........ 21.4 in.
- Transducer Data

| Evaluation Criteria | | Transducer | | MASH 2016 Limits |
|---|---|---|---|---|
| | | SLICE-1 (primary) | SLICE-2 | |
| OIV (ft/s ) | Longitudinal | -18.83 | -17.79 | ±40 |
| | Lateral | 28.98 | 27.52 | ±40 |
| ORA (g's) | Longitudinal | -9.44 | -9.22 | ±20.49 |
| | Lateral | 11.40 | 11.30 | ±20.49 |
| Maximum Angular Displacement (deg.) | Roll | -6.1 | -3.3 | ±75 |
| | Pitch | -3.9 | -4.5 | ±75 |
| | Yaw | 36.3 | 36.0 | not required |
| THIV (ft/s) | | 29.06 | 28.22 | not required |
| PHD (g's) | | 11.53 | 11.35 | not required |
| ASI | | 1.91 | 1.8 | not required |

Figure 142. Summary of Test Results and Sequential Photographs, Test No. STBRT-1

# 10 FULL-SCALE CRASH TEST NO. STBRT-2

## 10.1 Static Soil Test

Before full-scale crash test no. STBRT-2 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH 2016. The static test results, as shown in Appendix E, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

## 10.2 Weather Conditions

Test no. STBRT-2 was conducted on September 22, 2020 at approximately 2:00 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 17.

Table 17. Weather Conditions, Test No. STBRT-2

| | |
|---|---|
| Temperature | 83° F |
| Humidity | 37 % |
| Wind Speed | 14 mph |
| Wind Direction | 180° from True North |
| Sky Conditions | Sunny |
| Visibility | 8 Statute Miles |
| Pavement Surface | Dry |
| Previous 3-Day Precipitation | 0 in. |
| Previous 7-Day Precipitation | 0 in. |

## 10.3 Test Description

Initial vehicle impact was to occur 17 in. upstream from post no. 19, as shown in Figure 143, which was selected from LS-DYNA analysis to maximize vehicle snag on the AGT connection hardware. The 5,007-lb quad cab pickup truck impacted the bridge rail transition at a speed of 62.7 mph and at an angle of 24.9 degrees. The actual point of impact was 1.1 in. downstream from the target location. During the test, the 2270P pickup was contained and smoothly redirected with only minor roll and pitch displacements. The AGT experienced maximum dynamic and permanent set deflections of 18.6 in. and 8.4 in., respectively. Both deflections were measured at the upstream end of the middle transition tube rail. Vehicle components contacted the height transition of the lower transition tube rail and the first bridge post, but snag was minimal. The vehicle came to rest 183 ft – 10 in. downstream from the target point and 2 ft – 4 in. laterally behind the traffic side of the system after the vehicle’s brakes were applied.

A detailed description of the sequential impact events is contained in Table 18. Sequential photographs are shown in Figures 144 and 145. Documentary photographs of the crash test are shown in Figure 146. The vehicle trajectory and final position are shown in Figure 147.


Figure 143. Impact Location, Test No. STBRT-2

Table 18. Sequential Description of Impact Events, Test No. STBRT-2

| TIME (sec) | EVENT |
|---|---|
| 0.0 | Vehicle's front bumper contacted system 28.9 in. upstream from post no. 19 (the farthest downstream transition post). |
| 0.002 | Vehicle's front bumper deformed, and vehicle's left-front tire contacted rail. |
| 0.008 | Vehicle's hood deformed, and vehicle's left fender contacted rail. |
| 0.016 | Post no. 19 deflected backward, and vehicle's grille deformed. |
| 0.022 | Post no. 18 deflected backward. |
| 0.026 | Post no. B1 (first bridge rail post) deflected backward, and vehicle's left-front door deformed. |
| 0.032 | Post no. 17 deflected backward, and vehicle yawed away from system. |
| 0.038 | Vehicle rolled toward system. |
| 0.054 | Vehicle's left-rear door deformed, and vehicle's left-front door contacted rail. |
| 0.058 | Post no. 16 deflected backward. |
| 0.062 | Vehicle pitched downward. |
| 0.070 | Post no. B2 deflected backward. |
| 0.084 | Post no. B1 bent backward. |
| 0.126 | Vehicle's left-rear door contacted rail. |
| 0.136 | Vehicle's right-front tire became airborne. |
| 0.146 | Vehicle's right-rear tire became airborne. |
| 0.160 | Occupant’s head contacted left-front window. |
| 0.174 | Vehicle's rear bumper contacted rail. |
| 0.178 | Post no. B3 deflected backward. |
| 0.179 | Vehicle was parallel to system travelling at 51.2 mph. |
| 0.184 | Vehicle's tailgate contacted the rail. |
| 0.250 | Vehicle's left-front tire became airborne. |
| 0.318 | Vehicle's left-front tire regained contact with ground. |
| 0.360 | Vehicle exited system at 49.6 mph and a -11.4-degree angle. |
| 0.442 | System came to rest. |
| 0.508 | Vehicle rolled away from system. |
| 0.554 | Vehicle's right-front tire regained contact with ground. |
| 0.578 | Vehicle pitched upward. |
| 0.760 | Vehicle's right-rear tire regained contact with ground. |

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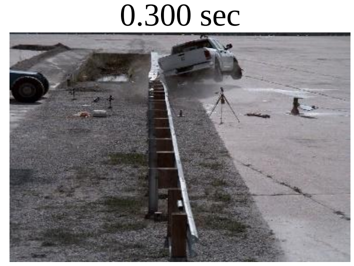

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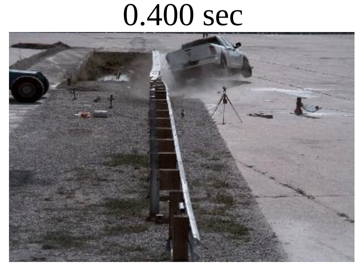

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Figure 144. Sequential Photographs, Test No. STBRT-2


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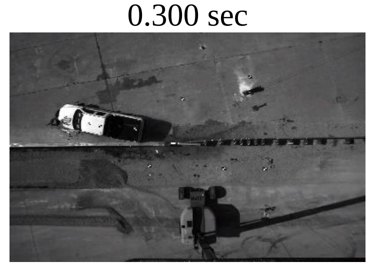
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Figure 145. Sequential Photographs, Test No. STBRT-2

Figure 146. Documentary Photographs, Test No. STBRT-2


Figure 147. Vehicle Final Position and Trajectory Marks, Test No. STBRT-2

## 10.4 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 148 and 149. Barrier damage consisted of contact marks and kinks on the thrie beam section and contact marks on the HSS transition tube rails. The length of vehicle contact along the barrier was approximately 14 ft and spanned from post no. 18 to downstream from the first bridge rail post.

Contact marks on the thrie beam began at post no. 18 and continued downstream to the end of the thrie beam terminal connector. The top corrugation sustained various kinks and bends beginning 8½ in. upstream from the centerline of post no. 15 and continued to 5 in. downstream from the centerline of post no. 19. The bottom corrugation was kinked and folded upward beginning 2 in. downstream from the centerline of post no. 19 and continuing to the terminal connector.

Contact marks were found on the front faces of all three HSS transition rails and extended approximately 2 ft past the first bridge rail post. Contact marks were also found covering most of the top surface of the top rail's sloped upstream end. The upstream ends of the middle and lower transition tube rails were displaced backward, but no sharp bends in the rails were visible. The first bridge rail post was bent backward as a plastic hinge formed in the post just above the welded attachment plate. Flange buckling was also observed on the first bridge rail post adjacent to the transition tube rails.

The maximum lateral permanent set of the barrier system was 8.4 in. at the upstream end of the middle transition tube, as measured in the field. The maximum lateral dynamic barrier deflection was 18.6 in. at the upstream end of the middle transition tube, as determined from high-speed digital video analysis. The working width of the system was found to be 27.8 in., also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 150.


Figure 148. System Damage, Test No. STBRT-2

Figure 149. Thrie Beam and Transition Rail Damage, Test No. STBRT-2

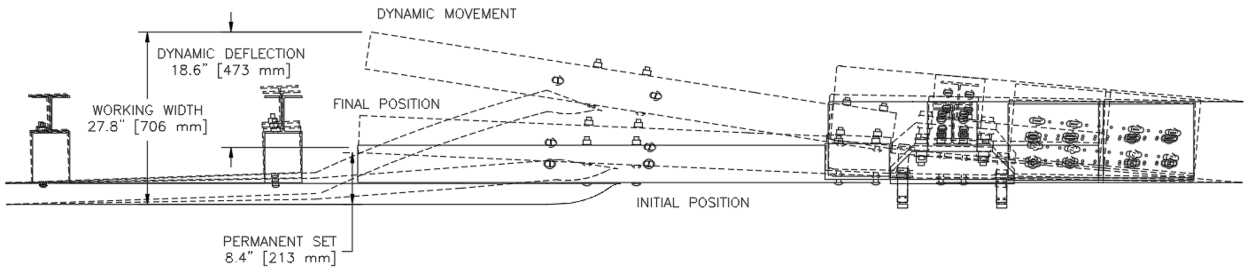


Figure 150. Permanent Set, Dynamic Deflection, and Working Width, Test No. STBRT-2

## 10.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 151 through 154. The maximum occupant compartment intrusions are listed in Table 19, along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix F. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. There were no penetrations into the occupant compartment, and none of the established MASH 2016 deformation limits were violated. Outward deformations, which are denoted as negative numbers in Appendix F, are not considered crush toward the occupant, and are not evaluated by MASH 2016 criteria.

Majority of the damage was concentrated on the left-front corner and left side of the vehicle where the impact had occurred. The front bumper was crushed inward on the left side, and the grille disengaged from the vehicle. The left fender was crushed and scraped, and the left-front tire was deflated. The left-front door remained intact was scraped and dented. The left-rear door had some minor scrapes and dents. The left-rear taillight was disengaged from the vehicle, and the back bumper was pushed inward toward the center of the vehicle.

Undercarriage damage was minimal. The front sway bar moved slightly to the right, and the left end link was bent backward. The left upper control arm was bent and torn at the rear mount, and the left lower control arm was fractured at both mounting locations. The left outer tie rod was also slightly bent. The left frame horn was bent inward approximately 2 in. at the leading edge.

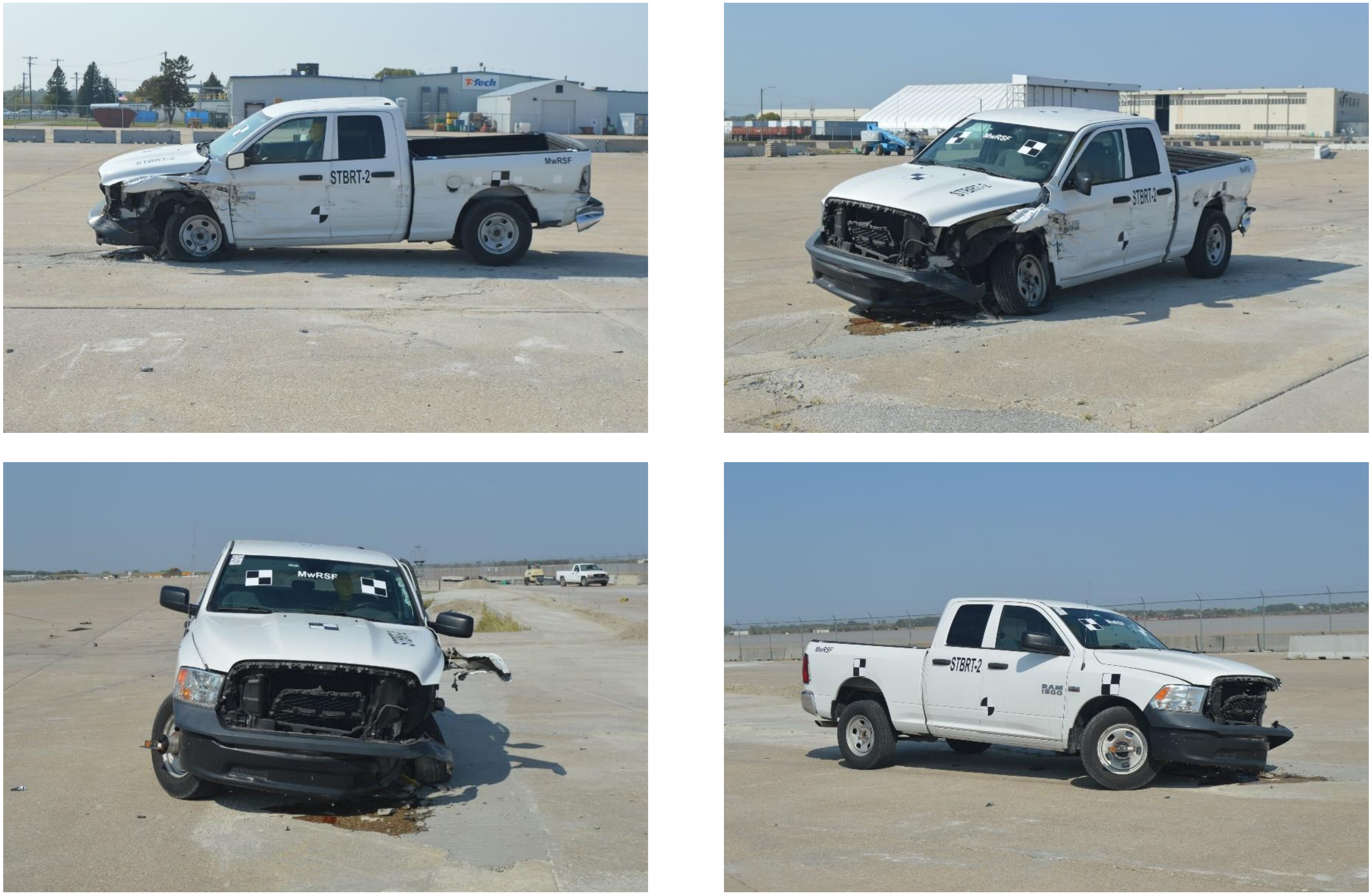


Figure 151. Vehicle Damage, Test No. STBRT-2


Figure 152. Vehicle Damage, Test No. STBRT-2

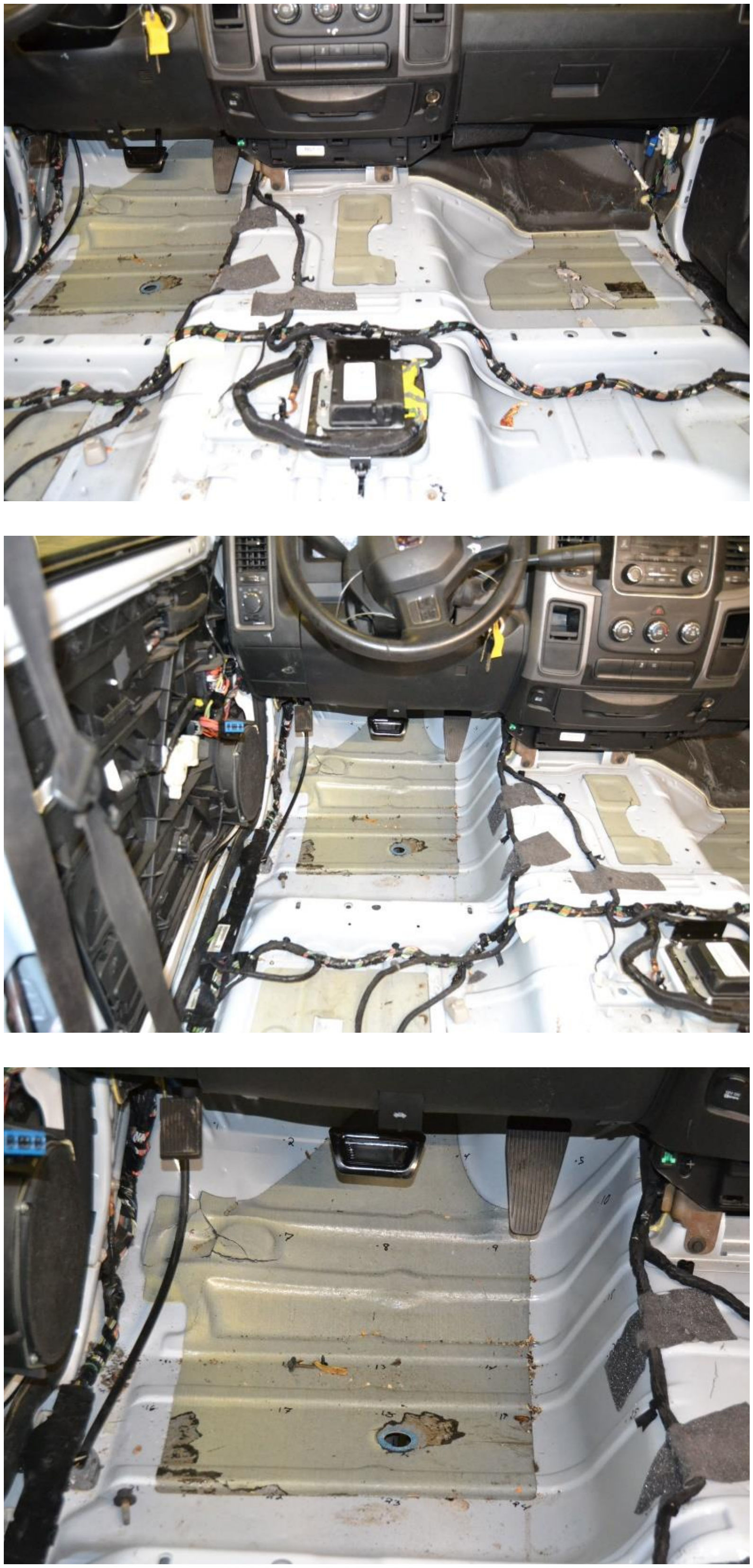

Figure 153. Occupant Compartment Damage, Test No. STBRT-2

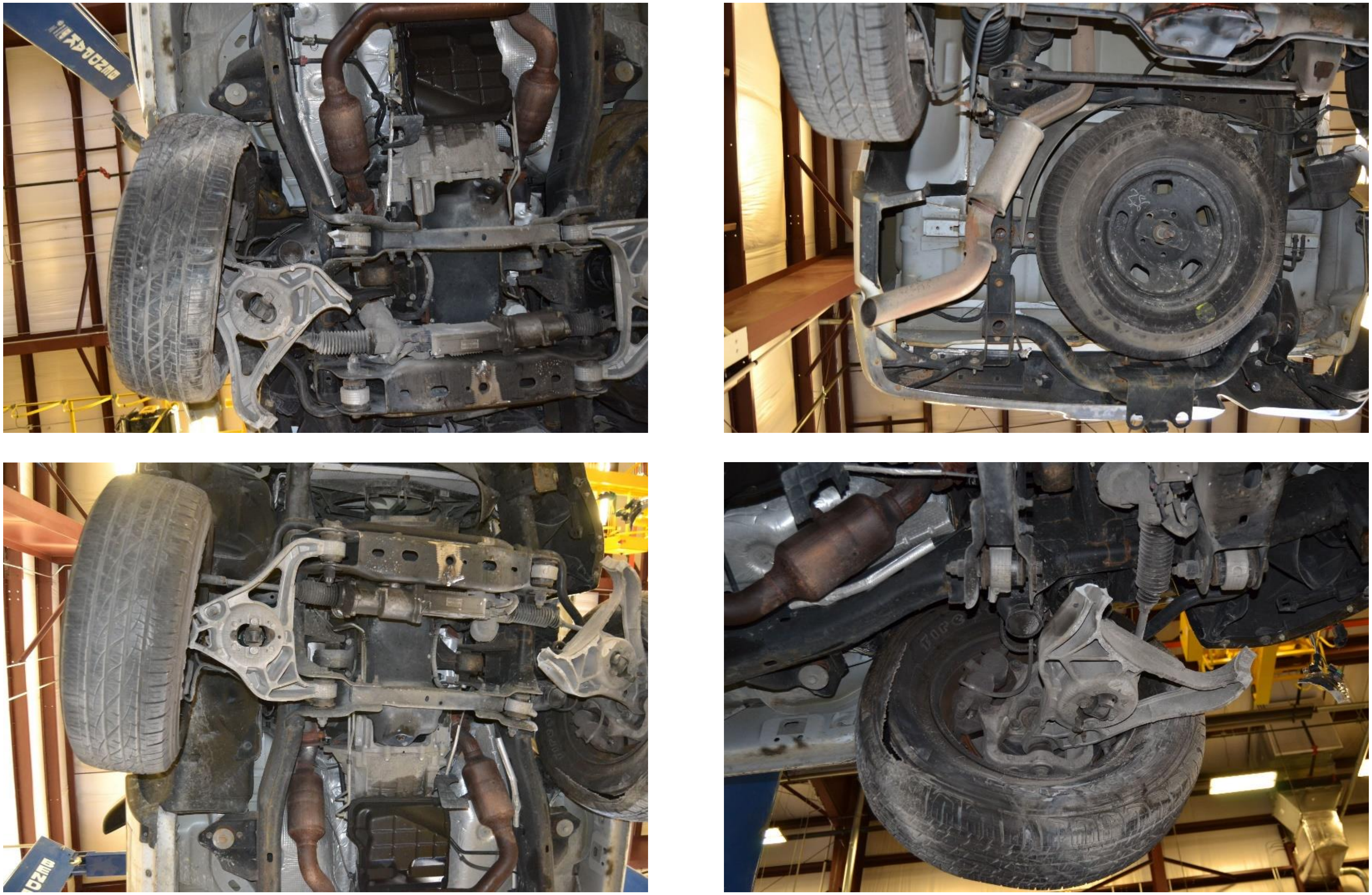

Figure 154. Undercarriage Damage, Test No. STBRT-2

Table 19. Maximum Occupant Compartment Intrusion by Location, Test No. STBRT-2

| LOCATION | MAXIMUM INTRUSION (in.) | MASH 2016 ALLOWABLE INTRUSION (in.) |
|---|---|---|
| Wheel Well & Toe Pan | 0.7 | ≤ 9 |
| Floor Pan & Transmission Tunnel | 0.0 | ≤ 12 |
| A-Pillar | 0.2 | ≤ 5 |
| A-Pillar (Lateral) | 0.2 | ≤ 3 |
| B-Pillar | 0.1 | ≤ 5 |
| B-Pillar (Lateral) | 0.2 | ≤ 3 |
| Side Front Panel (in Front of A-Pillar) | 1.8 | ≤ 12 |
| Side Door (Above Seat) | 0.6 | ≤ 9 |
| Side Door (Below Seat) | 0.2 | ≤ 12 |
| Roof | 0.0 | ≤ 4 |
| Windshield | 0.0 | ≤ 3 |
| Side Window | Intact | No shattering resulting from contact with structural member of test article |
| Dash | 0.6 | N/A |

N/A – No MASH 2016 criteria exist for this location

## 10.6 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 20. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 20. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix H.

Table 20. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. STBRT-2

| Evaluation Criteria | | Transducer SLICE-1 | Transducer SLICE-2 (primary) | MASH 2016 Limits |
|---|---|---|---|---|
| **OIV (ft/s)** | Longitudinal | -18.04 | -16.27 | ±40 |
| | Lateral | 20.41 | 21.60 | ±40 |
| **ORA (g's)** | Longitudinal | -11.28 | -11.86 | ±20.49 |
| | Lateral | 13.62 | 15.81 | ±20.49 |
| **Maximum Angular Displacement (deg.)** | Roll | -21.5 | -17.7 | ±75 |
| | Pitch | 3.6 | -5.5 | ±75 |
| | Yaw | 46.9 | 46.2 | not required |
| **THIV (ft/s)** | | 25.56 | 25.80 | not required |
| **PHD (g's)** | | 17.26 | 19.24 | not required |
| **ASI** | | 1.14 | 1.25 | not required |

## 10.7 Discussion

The analysis of the test results for test no. STBRT-2 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 155. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix H, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of -11.4 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. STBRT-2 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-21.


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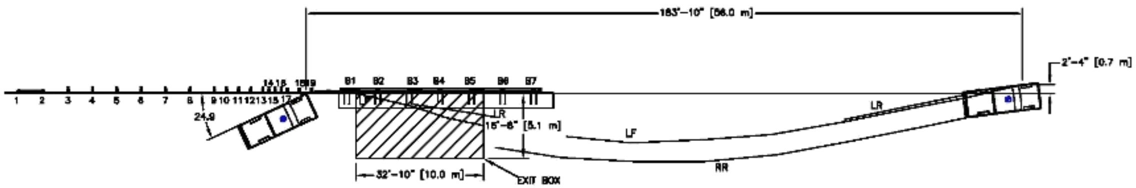
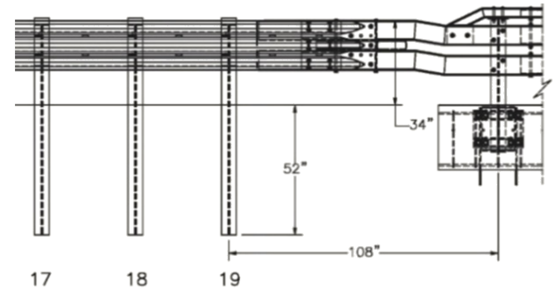



- Test Agency ........ MwRSF
- Test Number ........ STBRT-2
- Date ........ 9/22/2020
- MASH 2016 Test Designation No. ........ 3-21
- Test Article ........ OH-IL Steel Tube Bridge Rail Transition
- Total Length ........ 137 ft – 9 in.
- Key Component –Rails
  - Middle and Lower Tube Rails ........ HSS8x6x¼
  - Top Rail ........ HSS12x4x¼
  - AGT Rail ........ Nested 12-Gauge Thrie Beam
  - Thrie Beam Terminal Connector ........ 10-Gauge Terminal Connector
- Key Component –Posts
  - Bridge Rail ........ W6x15 at 8 ft on-center
  - AGT ........ W6x15 at 37.5 in. on-center
  - Spacing between Adjacent AGT and Bridge Post ........ 9 ft
- Vehicle Make /Model ........ 2014 Dodge Ram 1500
  - Curb ........ 5,133 lb
  - Test Inertial ........ 5,007 lb
  - Gross Static ........ 5,160 lb
- Impact Conditions
  - Speed ........ 62.7 mph
  - Angle ........ 24.9 deg.
  - Impact Location ........ 15.9 in. upstream from post no. 19
- Impact Severity ........ 116 kip-ft > 106 kip-ft limit from MASH 2016
- Exit Conditions
  - Speed ........ 49.6 mph
  - Angle ........ -11.4 deg.
- Exit Box Criterion ........ Pass
- Vehicle Stability ........ Satisfactory
- Vehicle Stopping Distance ........ 183 ft – 10 in. downstream
- Vehicle Damage ........ Moderate
  - VDS [43] ........ 11-LFQ-5
  - CDC [44] ........ 11-LFEW-3
  - Maximum Interior Deformation ........ 1.8 in.
- Test Article Damage ........ Minimal
- Maximum Test Article Deflections
  - Permanent Set ........ 8.4 in.
  - Dynamic ........ 18.6 in.
  - Working Width ........ 27.8 in.
- Transducer Data

| Evaluation Criteria | | Transducer | | MASH 2016 Limits |
|---|---|---|---|---|
| | | SLICE-1 | SLICE-2 (primary) | |
| OIV (ft/s) | Longitudinal | -18.04 | -16.27 | ±40 |
| | Lateral | 20.41 | 21.60 | ±40 |
| ORA (g's) | Longitudinal | -11.28 | -11.86 | ±20.49 |
| | Lateral | 13.62 | 15.81 | ±20.49 |
| Maximum Angular Displacement (deg.) | Roll | -21.5 | -17.7 | ±75 |
| | Pitch | 3.6 | -5.5 | ±75 |
| | Yaw | 46.9 | 46.2 | not required |
| THIV (ft/s) | | 25.56 | 25.80 | not required |
| PHD (g's) | | 17.26 | 19.24 | not required |
| ASI | | 1.14 | 1.25 | not required |

Figure 155. Summary of Test Results and Sequential Photographs, Test No. STBRT-2

# 11 SUMMARY AND CONCLUSIONS

The objective of this project was to develop a MASH TL-3 approach guardrail transition to the TL-4 steel-tube bridge rail, which was recently developed for the Ohio and Illinois DOTs. The AGT was required to safely connect the new steel-tube bridge rail to the Midwest Guardrail System (MGS) located on the adjacent roadway. Although the bridge rail was MASH TL-4 compliant, the AGT was only required to satisfy MASH TL-3 criteria, similar to the test level of the adjacent MGS. The AGT needed to prevent snag on the bridge rail during both conventional- and reverse-direction (traveling from bridge to roadway) impacts. Additionally, it was desired to maximize the distance between the last AGT post and the first bridge rail post to avoid post installation obstacles, such as bridge abutments and wing walls. Finally, the AGT was to remain crashworthy both before and after roadway overlays up to 3 in. thick. Note that the new bridge rail was designed with the same overlay criteria.

After a review of previously developed, MASH crashworthy AGTs, the Nebraska DOT 34-in. tall AGT was selected as the basis for the new AGT to steel-tube bridge rail. This nested thrie beam AGT was installed with a top mounting height of 34 in. to account for future overlays up to 3 in. thick. After an overlay, the symmetric W-to-thrie transition segment would be swapped out with an asymmetric W-to-thrie transition segment, and the W-beam in the upstream MGS region would be raised 3 in. on the guardrail posts. Thus, the effective nominal height for the entire system would become the standard 31 in. after a 3-in. thick overlay and these minor adjustments. Note that the posts would not have to be replaced or reset as part of these minor adjustments. Additionally, the Nebraska DOT 34-in. tall AGT utilized W6x15 posts spaced at 37.5 in. on-center. This post configuration was thought to be more conducive to maximizing the span length between the last transition post and the first bridge rail post as compared to the other AGTs with smaller W6x9 posts spaced at 18.75 in. on-center.

To attach the thrie-beam AGT to the steel-tube bridge rail, two connection design concepts were explored. The first concept involved a reinforced plate assembly that bridged the gap between the two systems. The thrie-beam terminal connector was bolted to the front face of the plate connector assembly, while the downstream end of the assembly would slide into the open ends of the HSS tube rails. The back side of the plate connector assembly contained both horizontal and vertical gussets to reinforce the assembly and provide adequate bending strength.

The second concept involved specialized transition tube rails that angled upward at a 6:1 slope and raised the height of the lower and middle HSS tube rails to match the height of the thrie beam. Thus, the thrie-beam terminal connector could be directly bolted to the transition tube rails. To prevent vehicle snag on the top tube rail, it was angled downward at a 2:1 slope and attached to the middle tube rail. Finally, an HSS6x4x¼ section was sandwiched between the lower two tube rails, and the downstream end was tapered back laterally at a 3:1 slope to prevent vehicle snag on the thrie-beam terminal connector during reverse-direction impacts.

LS-DYNA computer simulations of MASH TL-3 impacts were conducted on both concepts to finalize component design and evaluate design feasibility. Although design concept #1 showed promise as a crashworthy connection between the AGT and the bridge rail, high stresses and plastic deformations were observed in the plate connector assembly during the simulations. Additionally, both the Illinois and Ohio DOTs expressed concern with the complexity and potential cost required to construct the plate connector assembly. Simulations on Concept #2 showed only minor vehicle snag on the system components during both conventional- and reverse-direction impacts. Additionally, the simulations also showed a potential for safely using a 9-ft span length between the last transition post and first bridge post, which was more than double the post distances of other MASH AGTs. Thus, concept #2 with the specialized transition tube rails was ultimately selected as the desired configuration

LS-DYNA computer simulations were also used to identify critical impact points (CIPs) for both full-scale crash tests required by MASH TL-3 evaluation criteria. Multiple impacts were simulated on the AGT with both vehicles to identify the impact point that would maximize vehicle snag and thereby maximize the potential for excessive decelerations, occupant compartment crush, and/or vehicle instabilities. The CIP for test designation no. 3-21 was determined to be 17 in. upstream from the last W6x15 AGT post to maximize occupant risk values and the potential for snagging on the sloped end of the upper transition tube and the first bridge rail post. The CIP for test designation no. 3-20 was determined to be 30 in. upstream from the last AGT post to maximize wedging of the small car tire underneath the sloped transition tube rails and the potential for snagging on the posts.

LS-DYNA computer simulations of reverse-direction impacts showed no indication of significant pocketing or snag. Additionally, these simulated reverse-direction impacts on the AGT showed similar vehicle behavior, accelerations, and system deflections as observed during the actual full-scale crash tests conducted on the interior sections of the bridge railing, test nos. STBR-2 and STBR-3. Since MASH testing on the bridge rail was successful, any reverse direction crash tests on the transition from the bridge rail to the thrie-beam AGT should also be successful. Thus, reverse-direction testing was deemed non-critical and only conventional direction impacts were conducted in the full-scale testing and evaluation of the new AGT connection.

A full-scale test installation of the AGT to steel-tube bridge rail was constructed, and test nos. STBRT-1 and STBRT-2 were conducted on the test article in accordance with MASH 2016 test designation nos. 3-20 and 3-21, respectively. A summary of the test evaluation is shown in Table 21. In test no. STBRT-1, the 2,404-lb small car impacted the steel-tube bridge rail system 21.3 in. upstream from post no. 19 at a speed of 64.6 mph and an angle of 25.2 degrees, resulting in an impact severity of 60.9 kip-ft. The vehicle was successfully contained and smoothly redirected with moderate damage to both the bridge rail system and the vehicle. After impacting the barrier system, the vehicle exited the system at a speed of 46.2 mph and an angle of -7.4 degrees. All vehicle decelerations, ORAs, and OIVs fell within the recommended safety limits established in MASH 2016. Therefore, test no. STBRT-1 satisfied the safety criteria of MASH 2016 test designation no. 3-20.

In test no. STBRT-2, the 5,007-lb pickup truck impacted the steel-tube bridge rail system 15.9 in. upstream from post no. 19 at a speed of 62.7 mph and an angle of 24.9 degrees, resulting in an impact severity of 116 kip-ft. The vehicle was successfully contained and smoothly redirected with moderate damage to both the bridge rail system and the vehicle. After impacting the barrier, the vehicle exited the system at a speed of 49.6 mph and an angle of -11.4 degrees. All vehicle decelerations, ORAs, and OIVs fell within the recommended safety limits established in MASH 2016. Therefore, test no. STBRT-2 was successful according to the safety criteria of MASH 2016 test designation no. 3-21.

Recall, the upstream end of the AGT incorporated the MGS stiffness transition, which had previously been successfully crash tested to MASH TL-3 criteria [32-33]. Further, LS-DYNA simulations of reverse-direction impacts on the AGT showed negligible vehicle snag and resulted in behavior similar to the full-scale tests on the steel-tube bridge railing, which also previously passed MASH safety criteria [6-7]. Therefore, with the successful crash tests documented herein, the new AGT to the Ohio/Illinois steel-tube bridge railing was determined to be crashworthy to MASH 2016 TL-3 safety performance criteria.

The research presented within this research report pertains only to the development and MASH 2016 evaluation of the new AGT to steel-tube bridge rail. Recommendations and implementation guidance for both the bridge rail and the AGT were documented in a separate summary report [10].

Table 21. Summary of Safety Performance Evaluation

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. STBRT-1</th><th>Test No. STBRT-2</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">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.</td><td>S</td><td>S</td></tr>
<tr><td rowspan="8">Occupant Risk</td><td rowspan="2">D.</td><td colspan="3">1. 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.</td><td>S</td><td>S</td></tr>
<tr><td colspan="3">2. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td><td>S</td><td>S</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td><td>S</td></tr>
<tr><td rowspan="2">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td><td>S</td><td>S</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits<br>Component | Preferred | Maximum<br>Longitudinal and Lateral | 30 ft/s | 40 ft/s</td><td>S</td><td>S</td></tr>
<tr><td rowspan="2">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td><td>S</td><td>S</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits<br>Component | Preferred | Maximum<br>Longitudinal and Lateral | 15.0 g’s | 20.49 g’s</td><td>S</td><td>S</td></tr>
<tr><td colspan="5">MASH 2016 Test Designation No.</td><td>3-20</td><td>3-21</td></tr>
<tr><td colspan="5">Final Evaluation (Pass or Fail)</td><td>Pass</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

# 12 MASH EVALUATION

The MASH TL-3 approach guardrail transition developed and evaluated herein was specifically designed for use with the MASH TL-4 steel-tube bridge railing that was developed for the Ohio and Illinois Departments of Transportation. Since the AGT was intended for use on roadways that may receive future overlays up to 3 in. thick, the AGT was based on Nebraska DOT’s 34-in. tall thrie-beam AGT. The nested thrie-beam rail at the downstream end of the AGT was supported by W6x15 posts spaced at 37.5 in., while the upstream end rail elements were supported by W6x8.5 posts at various spacings corresponding to the MGS stiffness transition. A symmetric W-to-thrie transition segment was utilized to attach the 34-in. tall thrie beam to 31-in. tall MGS upstream from the AGT. At the downstream end of the AGT, a 9-ft span length was used between the last transition post and the first bridge rail post to avoid post installation conflicts with bridge elements, such as wing walls, abutments, or bents.

To attach the thrie-beam AGT to the steel-tube bridge rail, specialized transition tube rails were extended from the upstream end of the bridge rail. The transition tube rails angled upward at a 6:1 slope and raised the height of the lower and middle HSS tube rails to match the height of the thrie beam. Thus, the thrie-beam terminal connector could be directly bolted to the transition tube rails. To prevent vehicle snag on the top tube rail, it was angled downward at a 2:1 slope and attached to the middle tube rail. Finally, an HSS6x4x¼ was sandwiched between the lower two tube rails, and the downstream end was tapered back laterally at a 3:1 slope to prevent vehicle snag on the thrie beam terminal connector during reverse-direction impacts.

The upstream region of the AGT was specifically designed to replicate the MASH-crashworthy MGS stiffness transition. Upon initial installation, the only difference between the two systems was that the 34-in. tall AGT utilized a symmetric W-to-thrie transition rail instead of an asymmetric transition rail. Since the W-beam upstream from the transition rail was mounted at its nominal 31-in. height, vehicles impacting this region of the barrier should not extend over the rail and roll excessively. Additionally, the bottom of the symmetric transition rail had a shallower slope than the asymmetric segment and would likely produce less snag as a small vehicle tried to wedge underneath the rail. Thus, there were no concerns about vehicle stability and/or snag on the upstream region of the new AGT prior to a roadway overlay.

After the roadway overlay, the symmetric rail segment would be replaced by an asymmetric segment, and the W-beam of the adjacent MGS would be raised 3 in. on the posts to maintain its nominal 31-in. mounting height. Previous studies have concluded that guardrail can be raised up to 4 in. on the support posts and the system will remain crashworthy. Thus, after an overlay, the upstream stiffness transition is essentially identical to the MASH-tested MGS stiffness transition. Since the MGS stiffness transition was previously subjected to and successfully passed MASH TL-3 criteria, the upstream stiffness transition within the new AGT to a steel-tube bridge rail would be MASH TL-3 crashworthy as well. Therefore, all crash testing of the upstream stiffness transition, both before and after an overlay, was deemed non-critical.

At the downstream end of the AGT, there were concerns for rail pocketing within the 9-ft unsupported span length adjacent to the stiff bridge rail as well as vehicle snag on the transition tube rails and bridge posts. Rail pocketing issues would be the same regardless of the presence of an overlay as an overlay would not affect the strength of the system. However, an overlay would reduce the gap below the rail, thereby reducing the likelihood that vehicle bumpers and wheels would extend under the rail and snag on system components. Accordingly, the system configuration without an overlay would present the worst-case scenario for vehicle snag. Thus, only two full-scale tests were recommended to evaluate the crashworthiness of the 34-in. tall AGT to MASH 2016 TL-3 criteria.

Test nos. STBRT-1 and STBRT-2 were conducted in accordance with MASH test designation nos. 3-20 and 3-21, respectively, on the downstream end of the AGT without an overlay. Test no. STBRT-1 was performed with the 1100C small car impacting 21.3 in. upstream from the last transition post to maximize vehicle snag on the vertically sloped portion of the lower transition tube rail, while test no. STBRT-2 was performed with the 2270P pickup impacting 15.9 in. upstream from the last transition post to maximize loading to the connection hardware and snag on the sloped end of the top transition tube rail. Both vehicles were contained and smoothly redirected with minor roll and pitch angular displacements. Vehicle contact did occur on the targeted snag points on the AGT, but the tapered designs limited the snag severity. None of the MASH 2016 occupant compartment deformation limits were violated, and all ORA and OIV values were within MASH 2016 safety limits. Therefore, test nos. STBRT-1 and STBRT-2 were determined to be acceptable according to test designation nos. 3-20 and 3-21, respectively, of MASH 2016.

Due to the two successful full-scale crash tests, the incorporation of the upstream MGS stiffness transition, and modification to the AGT and adjacent MGS after an overlay as described herein, the new 34-in. AGT to steel-tube bridge rail was determined to be crashworthy to MASH 2016 TL-3 standards both before and after a 3-in. roadway overlay.

# 13 REFERENCES

1. *Twin Steel Tube Bridge Railing*, State of Ohio Department of Transportation, Office of Structural Engineering, Bridge Rail Drawing No. TST-1-99, Columbus, Ohio, July 2016.

2. *Type Side-Mounted Steel Bridge Rail*, State of Illinois Department of Transportation, Bureau of Bridges and Structures, Bridge Rail Drawing No. R-34HMAWS, Springfield, Illinois, November 2016.

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

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

5. *Manual for Assessing Safety Hardware (MASH), Second Edition*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2016.

6. Peña, O., Faller, R.K., Rasmussen, J.D., Steelman, J.S., Rosenbaugh, S.K., Bielenberg, R.W., Mauricio, P., and Duren, J.T., *Development of a MASH Test Level 4 Steel, Side-Mounted, Beam-and-Post, Bridge Rail*, Research Report No. TRP-03-410-20, Midwest Roadside Safety Facility, University of Nebraska – Lincoln, Lincoln, Nebraska, July 20, 2020.

7. Peña, O., *Development of a MASH Test Level 4 Steel, Side-Mounted, Beam-and-Post, Bridge Rail*, Thesis, University of Nebraska – Lincoln, April 2019.

8. Mauricio, P., Rasmussen J.D., Faller, R.K., Rosenbaugh, S.K., Bielenberg, R.W., Pena, O., Steelman, J.S., and Stolle, C.S., *Development of a Post-to-Deck Connections for a TL-4 Steel-Tube Bridge Rail*, Research Report No. 03-409-20, Midwest Roadside Safety Facility, University of Nebraska – Lincoln, May 27, 2020.

9. Mauricio, P., *An Evaluation of Post-to-Deck Connections for Use in a MASH TL-4 Steel-Tube Bridge Rail*, Thesis, University of Nebraska – Lincoln, April 2019.

10. Rosenbaugh, S.K., Rasmussen, J.D., Faller, R.K., Bielenberg, R.W., and Steelman, J.S., *Steel Railing, Type IL-OH: MASH Evaluation and Implementation Guidance*, DRAFT Research Report No. TRP-03-438-20, Midwest Roadside Safety Facility, University of Nebraska – Lincoln, Lincoln, Nebraska, 2020.

11. *MGS Bridge Terminal Assembly, Type 1*, State of Ohio Department of Transportation, Office of Structural Engineering, Transition Drawing No. MGS-3.1, Columbus, Ohio, January 2018.

12. *Guide Specifications for Bridge Railings*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 1989.

13. *Traffic Barrier Terminal, Type 6A,* State of Illinois Department of Transportation, Bureau of Bridges and Structures, Transition Drawing No. 631032-09, Springfield, Illinois, January 2003.

14. Buth, C.E., Hirsch, T.J., Menges, W.L., *Testing of New Bridge Rail and Transition Designs Illinois Side Mount Bridge Railing.* Report No. FHWA-RD-93-066, Texas Transportation Institute, College Station, Texas, September 1993.

15. Williams, W.F., Bligh, R.P., Menges, W.L., *MASH TL-3 Testing and Evaluation of the TxDOT T131RC Bridge Rail and Transition.* Report No. FHWA-TX-13-9-1002-12-4, Texas Transportation Institute, College Station, Texas, March 2013.

16. Williams, W.F., Bligh, R.P., Menges, W.L., *MASH Test 3-11 on the T131RC Bridge Rail.* Report No. FHWA-TX-12-9-1002-12-1, Texas Transportation Institute, College Station, Texas, October 2012.

17. *Oregon Two-Tube Side Mount Rail Transition,* State of Oregon Department of Transportation, Roadway Engineering Unit, Transition Drawing No. BR230, Salem, Oregon, January 2016.

18. *Oregon Two-Tube Side Mount Rail,* State of Oregon Department of Transportation, Roadway Engineering Unit, Bridge Rail Drawing No. BR226, Salem, Oregon, January 2017.

19. Buth, C.E., Menges, W.L., Williams, W.F., Schoeneman, S.K., *NCHRP Report 350 Test 4-21 of the Alaska Multi-State Bridge Rail Thrie-Beam Transition.* Report No. 404311-5, Texas Transportation Institute, College Station, Texas, July 1999.

20. Buth, C.E., Menges, W.L., Williams, W.F., Schoeneman, S.K., *NCHRP Report 350 Test 4-12 of the Alaska Multi-State Bridge Rail.* Report No. 404311-3, Texas Transportation Institute, College Station, Texas, February 1999.

21. Jewell, J., Glauz, D., Stoughton, R.L., Crozier, W., Folsom, J.J., *Vehicle Crash Tests of Type 115 Barrier Rail Systems for Use on Secondary Highways.* Paper No. 1419, Transportation Research Board, Washington, D.C., March 1993.

22. Alberson, D.C., Buth, E.C., Menges, W.L., Haug, R.R., *NCHRP Report 350 Testing and Evaluation of NETC Bridge Rail Transitions.* Report No. NETCR 53, New England Transportation Consortium, Storrs, Connecticut, January 2006.

23. Alberson, D.C., Menges, W.L., Bligh, R.P., Abu-Odeh, A.Y., Buth, E.C., Haug, R.R., *Thrie Beam Transition Crash Tests.* Report No. FHWA-RD-04-115, Texas Transportation Institute, College Station, Texas, January 2005.

24. Polivka, K.A. Faller, R.K., Ritter, M.A., Rosson, B.T., Fowler, M.D., and Keller, E.A., *Two Test Level 4 Bridge Railing and Transition Systems for Transverse Glue-Laminated Timber Decks*, Report No. TRP-03-71-01, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, January 30, 2002.

25. Eller, C.M., Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Reid, J.D., Bielenberg, R.W., and Allison, E.M., *Development of the Midwest Guardrail System (MGS) W-beam to Thrie Beam Transition Element*, Report No. TRP-03-167-07, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE, November 2007.

26. Rosenbaugh, S.K., Fallet, W.G., Faller, R.K., Bielenberg, R.W., and Schmidt, J.D., *34-in. Tall Thrie Beam Transition to Concrete Buttress*, Report No. TRP-03-367-19-R1, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, July 2, 2019.

27. Halquist, L.O., *LS-DYNA Keyword User's Manual*, Version 970, Livermore Software Technology Corporation, Livermore, California, 2003.

28. Bickhaus, R.F., Rasmussen, J.D., and Reid, J.D., *Development and Validation of a Thrie-Beam AGT LS-DYNA Model*, Draft Report to the Midwest Pooled Fund Program, Report No. TRP-03-441-20, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, 2020.

29. Rosenbaugh, S.K., Faller, R.K., Asselin, N., and Hartwell, J.A., *Development of a Standardized Buttress for Approach Guardrail Transitions*, Report No. TRP-03-369-20, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, November 10, 2020.

30. Dhafer, M., *Update on New MASH Pickup Truck Model,* Center for Collision Safety and Analysis, TRB 98$^{th}$ Annual Meeting (2019) Roadside Safety Design Computational Mechanics Subcommittee, AFB20(1), Washington, D.C., January 14, 2019, Obtained on February 12, 2019.

31. National Crash Analysis Center, *2010 Toyota Yaris FE Model*, Retrieved from http://www.ncac.gwu.edu/vml/archive/ncac/vehicle/yaris-vlm.pdf, Accessed June 1, 2013.

32. Rosenbaugh, S.K., Lechtenberg, K.A., Faller, R.K., Sicking, D.L., Bielenberg, R.W., Reid, J.D., *Development of the MGS Approach Guardrail Transition Using Standardized Steel Posts*, Report No. TRP-03-210-10, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, December 21, 2010.

33. Lechtenberg, K.A., Mongiardini, M., Rosenbaugh, S.K., Faller, R.K., Bielenberg, R.W., and Albuquerque, F.D.B., Development and Implementation of the Simplified MGS Stiffness Transition, *Transportation Research Record: Journal of the Transportation Research Board,* 2012. Volume 2309, pp. 1-11.

34. Mongiardini, M., Faller, R.K., Reid, J.D., Sicking, D.L., Stolle, C.S., and Lechtenberg, K.A., *Downstream Anchoring Requirements for the Midwest Guardrail System*, Report No. TRP-03-279-13, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, October 28, 2013.

35. Mongiardini, M., Faller, R.K., Reid, J.D., and Sicking, D.L., *Dynamic Evaluation and Implementation Guidelines for a Non-Proprietary W-Beam Guardrail Trailing-End Terminal*, Paper No. 13-5277, Transportation Research Record No. 2377, Journal of the Transportation Research Board, TRB AFB20 Committee on Roadside Safety Design, Transportation Research Board, Washington D.C., January 2013, pages 61-73.

36. Stolle, C.S., Reid, J.D., Faller, R.K., and Mongiardini, M., *Dynamic Strength of a Modified W-Beam BCT Trailing-End Termination*, Paper No. IJCR 886R1, Manuscript ID 1009308, International Journal of Crashworthiness, Taylor & Francis, Vol. 20, Issue 3, Published online February 23, 2015, pages 301-315.

37. Griffith, M.S., Federal Highway Administration (FHWA), *Eligibility Letter HSST/B-256 for: Trailing-End Anchorage for 31" Tall Guardrail*, December 18, 2015.

38. Hinch, J., Yang, T.L., and Owings, R., *Guidance Systems for Vehicle Testing*, ENSCO, Inc., Springfield, Virginia, 1986.

39. *Clarifications on Implementing the AASHTO Manual for Assessing Safety Hardware*, 2016, FHWA and AASHTO, https://design.transportation.org/wp-content/uploads/sites/21/2019/11/Clarifications-on-Implementing-MASH-2016-aka-MASH-QA-Updated-Nov-19-2019.pdf, November 2019.

40. *Center of Gravity Test Code - SAE J874 March 1981*, SAE Handbook Vol. 4, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1986.

41. MacInnis, D., Cliff, W., and Ising, K., *A Comparison of the Moment of Inerita Estimation Techniques for Vehicle Dynamics Simulation*, SAE Technical Paper Series – 970951, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1997.

42. Society of Automotive Engineers (SAE), *Instrumentation for Impact Test – Part 1 – Electronic Instrumentation*, SAE J211/1 MAR95, New York City, New York, July, 2007.

43. *Vehicle Damage Scale for Traffic Investigators*, Second Edition, Technical Bulletin No. 1, Traffic Accident Data (TAD) Project, National Safety Council, Chicago, Illinois, 1971.

44. *Collision Deformation Classification – Recommended Practice J224 March 1980*, Handbook Volume 4, Society of Automotive Engineers (SAE), Warrendale, Pennsylvania, 1985.

# 14 APPENDICES

# Appendix A. DOT Standard Drawings for AGTs and Bridge Rail

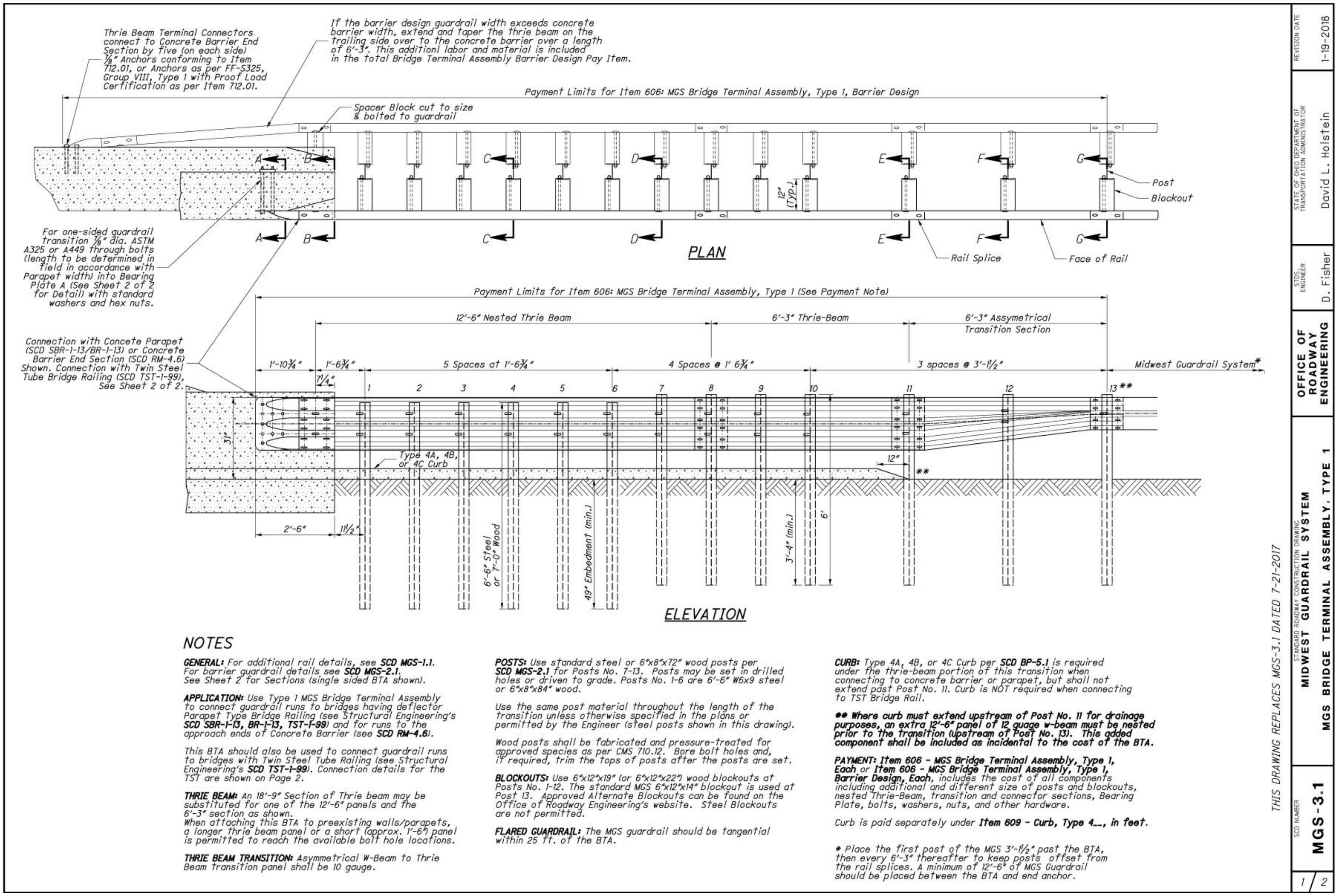



Figure A-1. Ohio MGS Bridge Terminal Assembly, Type 1, Sheet 1 of 2

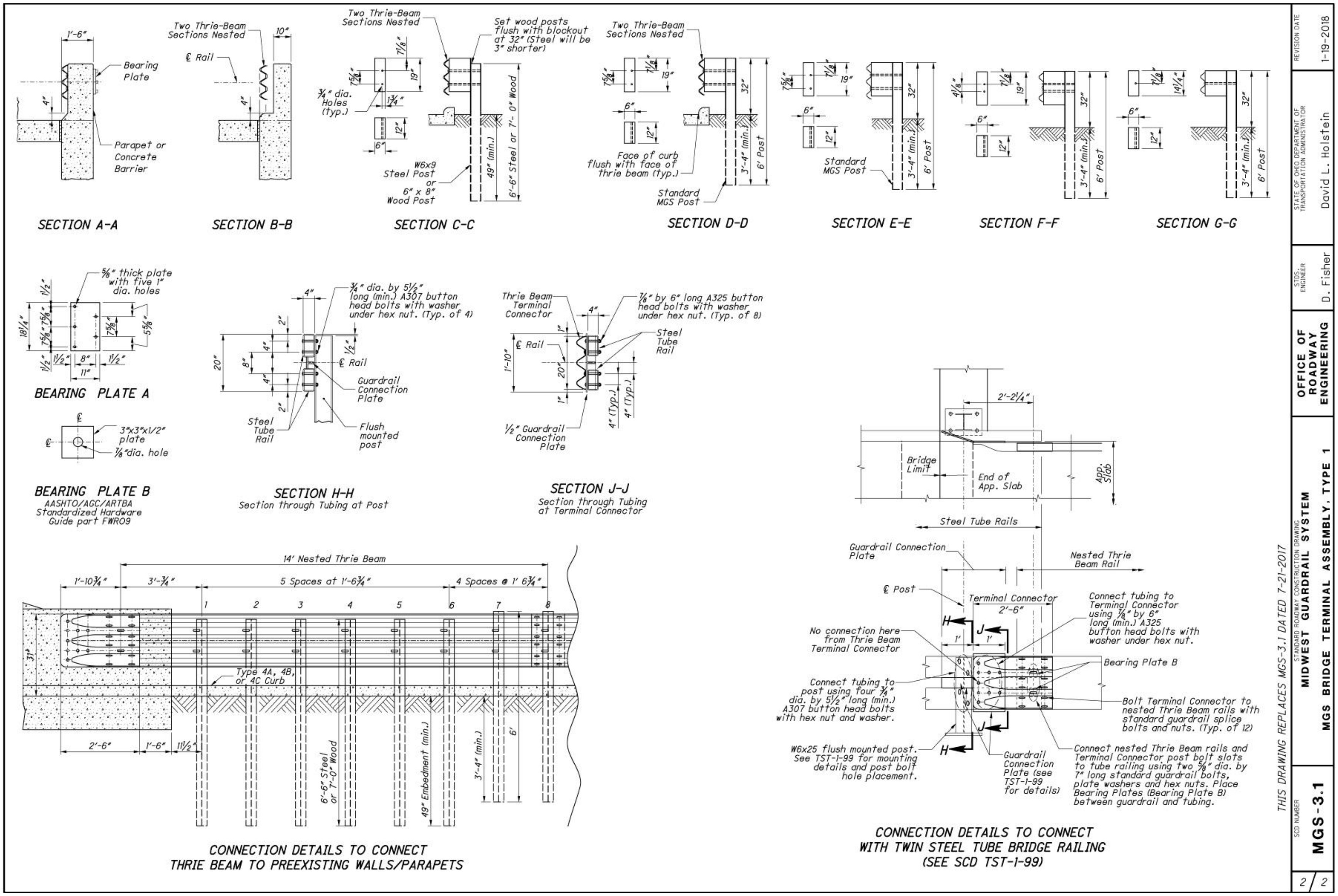



Figure A-2. Ohio MGS Bridge Terminal Assembly, Type 1, Sheet 2 of 2

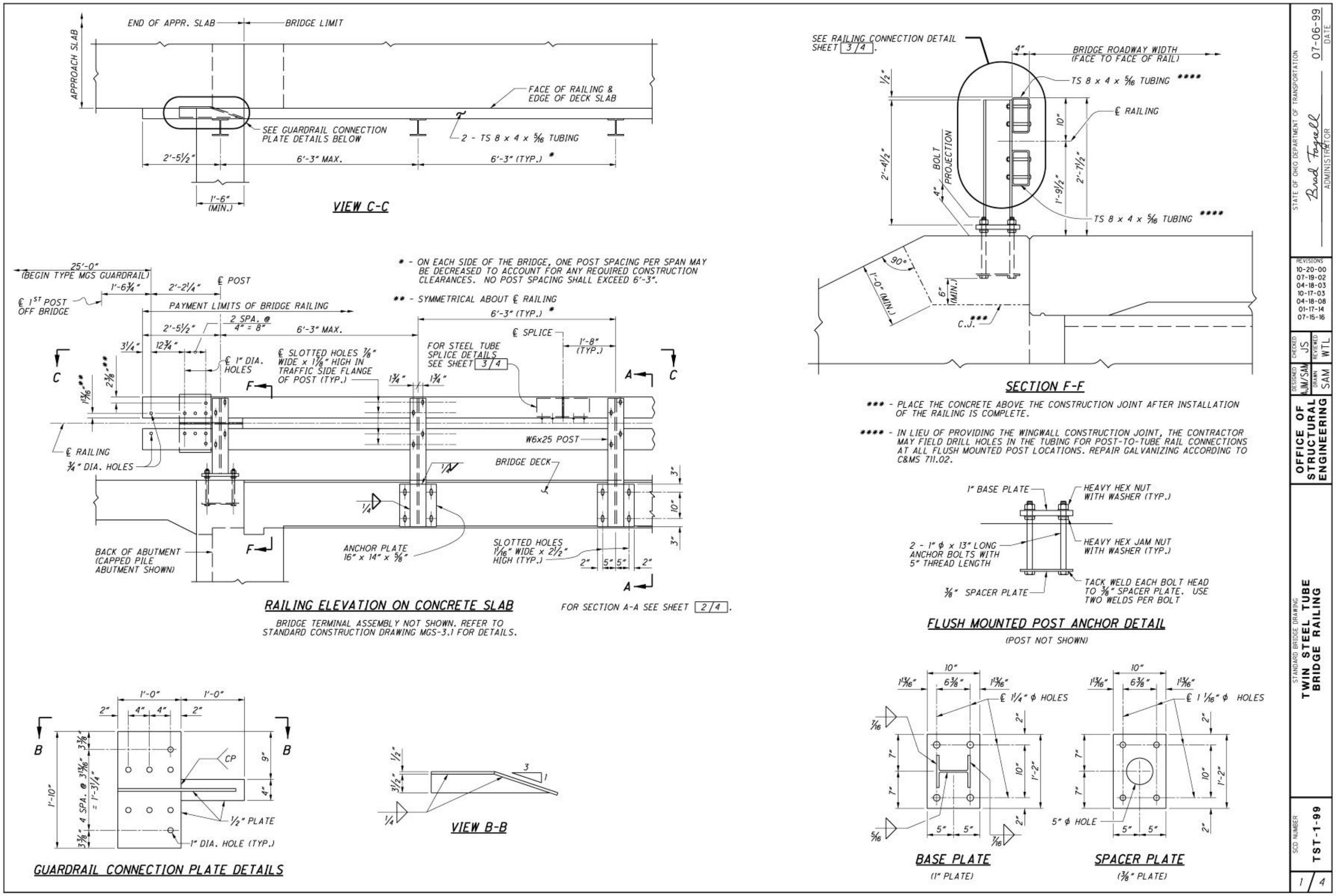



Figure A-3. Ohio Twin Steel Tube Bridge Railing, Sheet 1 of 4

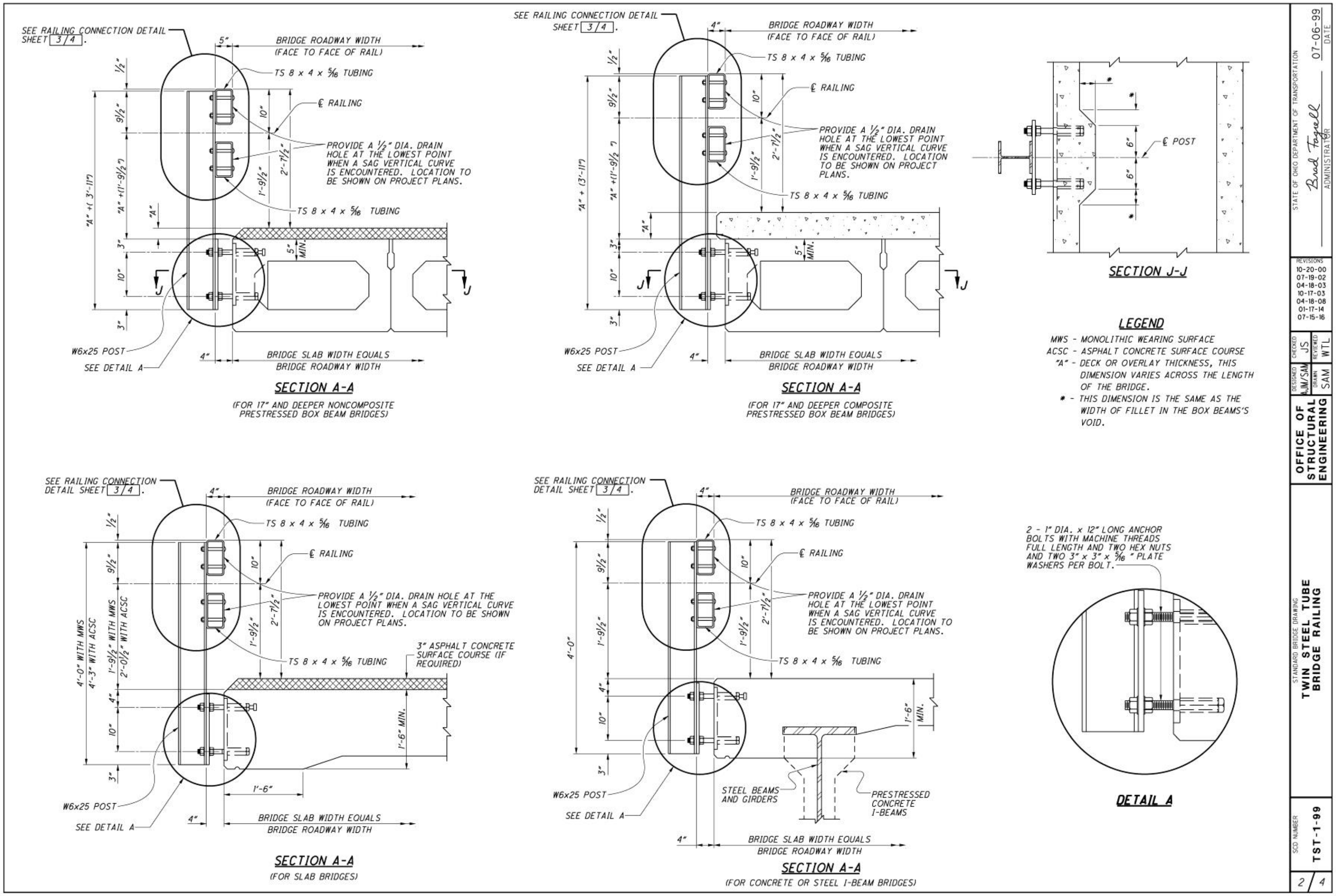



Figure A-4. Ohio Twin Steel Tube Bridge Railing, Sheet 2 of 4

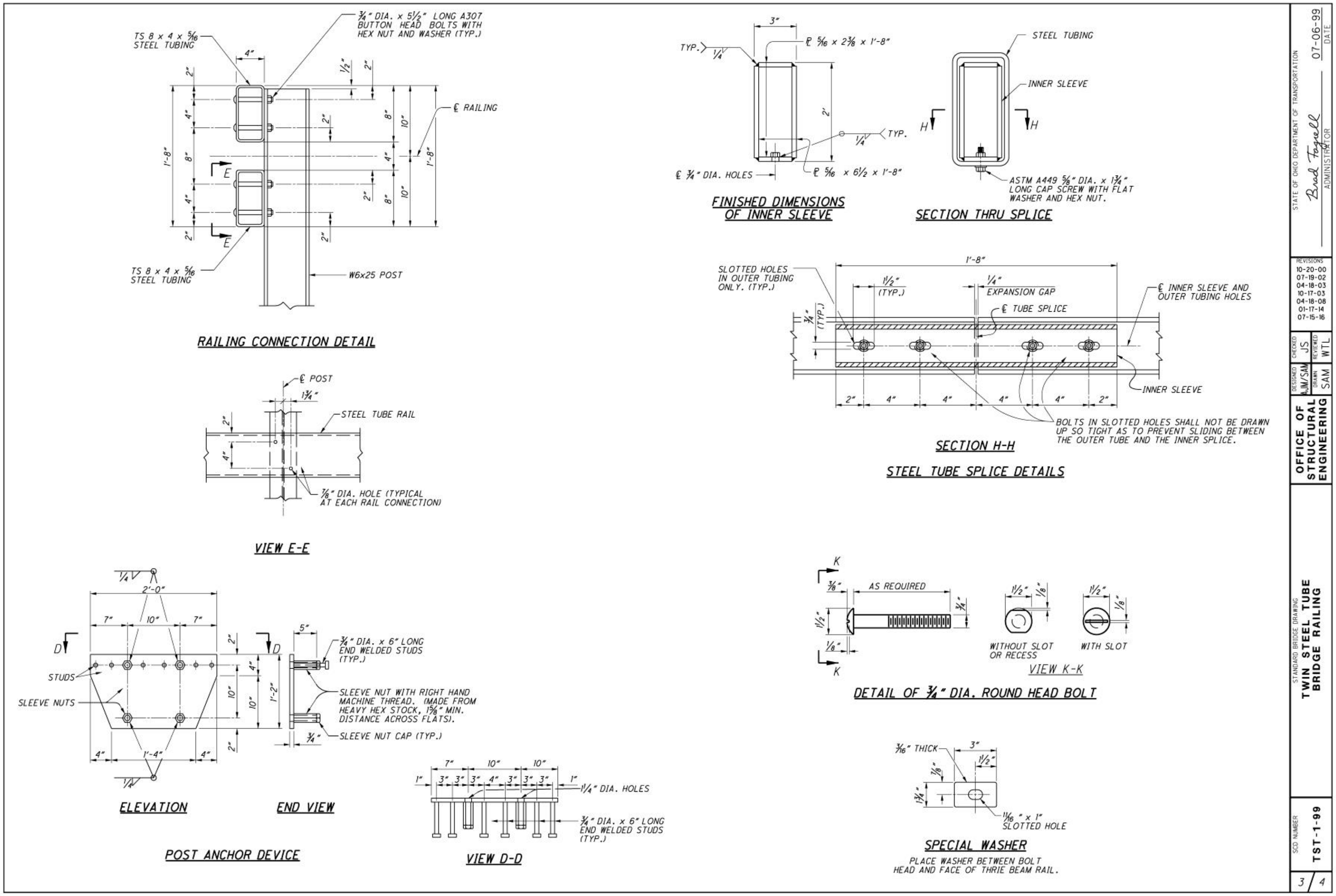



Figure A-5. Ohio Twin Steel Tube Bridge Railing, Sheet 3 of 4

## TST-1-99 GENERAL NOTES:

**GENERAL:** THIS DRAWING PROVIDES DESIGN AND CONSTRUCTION DETAILS. THE PROJECT PLANS FOR EACH STRUCTURE SHALL PROVIDE NECESSARY ADDITIONAL RAILING DIMENSIONS INCLUDING RAILING LENGTHS, POST SPACINGS, POST LENGTHS AND ANY OTHER PERTINENT INFORMATION INCLUDING SPECIAL NOTES AND DETAILS. FOR ADDITIONAL GUARDRAIL DETAILS, SEE STD. CONSTR. DWGS. MGS-1.1, MGS-2.1 AND OTHER DRAWINGS PERTAINING TO DESIGN OF SPECIFIC GUARDRAIL TYPES.

**APPLICATION:** THIS RAILING SYSTEM HAS BEEN ACCEPTED TO THE TL-4 CRITERIA OF NCHRP REPORT 350. THE TWIN STEEL TUBE RAILING SHALL BE USED ON STRUCTURES DESIGNED TO DRAIN SURFACE WATER OVER THE SIDES OF THE STRUCTURE. THIS RAILING IS NOT APPLICABLE TO COMPOSITE BOX BEAM BRIDGES WITH DESIGN OVERHANGS GREATER THAN 2" OR TOP FLANGE THICKNESSES LESS THAN 5".

CONNECT THE APPROACH AND TRAILING ENDS OF THE TWIN STEEL TUBE RAILING TO THE BRIDGE TERMINAL ASSEMBLY DETAILED IN STANDARD CONSTRUCTION DRAWING MGS-3.1. THE FIRST POST AT THE APPROACH END AND THE LAST POST AT THE TRAILING END OF THE BRIDGE RAILING SHALL BE FLUSH MOUNTED AS SHOWN ON SHEET 1 OF 4.

**DESIGN DATA:**
REINFORCING STEEL - MINIMUM YIELD STRENGTH = 60,000 PSI
STEEL TUBING - MINIMUM YIELD STRENGTH = 46,000 PSI
ALL OTHER STEEL - MINIMUM YIELD STRENGTH = 50,000 PSI

**MATERIALS:** FURNISH SHAPED STRUCTURAL TUBING ACCORDING TO 707.10 (ASTM A500, GRADE B). IN LIEU OF THE "DROP WEIGHT TEAR TEST" (ASTM E436), THE MANUFACTURER MAY CHOOSE TO SUPPLY TUBING THAT MEETS IMPACT TOUGHNESS ACCORDING TO AASHTO T266, "NOTCHED BAR IMPACT TESTING OF METALLIC MATERIALS (CVN)". THE CVN IMPACT REQUIREMENTS SHALL BE 15 FT-LBS AT 0°F. FOR EACH HEAT SUPPLIED, THE MANUFACTURER SHALL FURNISH ONE 2" x 18" SPECIMEN, MARKED WITH ITS HEAT NUMBER, FOR IMPACT TESTING.

FURNISH STRUCTURAL STEEL SHAPES, PLATES AND PLATE WASHERS ACCORDING TO 711.01.

**GALVANIZING:** GALVANIZE ALL SHAPED STRUCTURAL TUBES, POSTS, PLATES, HARDWARE AND ACCESSORIES IN ACCORDANCE WITH 711.02. PRIOR TO GALVANIZING, ROUND ALL STRUCTURAL TUBING ENDS AND REMOVE BURRS FROM ALL STEEL TUBING, SHAPES AND PLATES.

**HORIZONTAL CURVATURE:** THIS STANDARD IS APPLICABLE TO STRUCTURES HAVING A RAILING CURVATURE RADIUS OF 20 FEET OR MORE. FOR A RADIUS OF LESS THAN 20 FEET, THE DESIGN SHALL BE SPECIAL. FOR ALL CURVED STRUCTURES, HEAT CURVE THE HORIZONTAL RAIL ELEMENTS ACCORDING TO THE AASHTO LRFD BRIDGE CONSTRUCTION SPECIFICATIONS.

**TUBE SPLICES:** LOCATE SPLICES SO THAT EACH TUBE SEGMENT IS CONNECTED TO NOT LESS THAN TWO POSTS. STAGGER SPLICES IN THE TOP AND BOTTOM TUBES TO AVOID OCCURRENCES IN THE SAME PANEL.

**FASTENERS:** FURNISH MATERIAL CONFORMING TO THE FOLLOWING:

ALL ANCHOR BOLTS, SLEEVE NUTS, NUTS AND WASHERS SHALL CONFORM TO ASTM A 449.

END WELDED STUDS SHALL CONFORM TO ASTM A108.

THE TUBE RAIL TO POST CONNECTION BOLTS AND HEX NUTS SHALL CONFORM TO 711.10 (ASTM A307). REFER TO STANDARD CONSTRUCTION DRAWING MGS-3.1 FOR THE BRIDGE TERMINAL ASSEMBLY CONNECTION HARDWARE.

THE HEX CAP SCREWS (BOLTS), HEX NUTS AND WASHERS SHALL CONFORM TO ASTM A 449.

**BOX BEAMS:** THE DISTANCE FROM THE CENTERLINE OF A GUARDRAIL POST TO THE ABUTMENT END OF THE BEAM OR TO THE CENTERLINE OF A TIE ROD SHALL NOT BE LESS THAN 1'-8". THE DISTANCE FROM THE CENTERLINE OF A GUARDRAIL POST TO THE PIER END OF THE BEAM SHALL NOT BE LESS THAN 2'-10". THE LOCATION OF THE HORIZONTAL TIE RODS MAY NEED TO BE ADJUSTED IN ORDER TO ACCOMMODATE EACH POST ANCHOR DEVICE.

**METHOD OF MEASUREMENT:** THE DEPARTMENT WILL MEASURE TWIN STEEL TUBE BRIDGE RAILING BY THE NUMBER OF FEET. THE DEPARTMENT WILL MEASURE THE LENGTH OF RAILING AS THE DISTANCE BETWEEN THE CENTERS OF THE FLUSH MOUNTED POSTS AT THE APPROACH AND TRAILING ENDS PLUS 4'-11".

**BASIS OF PAYMENT:** THE DEPARTMENT WILL CONSIDER THE COSTS ASSOCIATED WITH FURNISHING AND INSTALLING STEEL TUBING, STEEL POSTS, POST ANCHOR DEVICES, ANCHOR PLATES, TUBE SPLICE PLATES, STEEL SHIM PLATES, GUARDRAIL CONNECTION PLATES, ANCHOR BOLTS, ¾" ROUND HEAD BOLTS, SLEEVE NUTS, NUTS, CAP SCREWS, WASHERS AND OTHER HARDWARE TO BE INCLUDED WITH THE TWIN STEEL TUBE RAILING. THE DEPARTMENT WILL PAY FOR ACCEPTED QUANTITIES AT THE CONTRACT PRICE FOR ITEM 517, RAILING (TWIN STEEL TUBE).

THE DEPARTMENT WILL PAY FOR BRIDGE TERMINAL ASSEMBLY HARDWARE SEPARATELY.

STATE OF OHIO DEPARTMENT OF TRANSPORTATION
Brad Fagrell
ADMINISTRATOR
07-06-99
DATE

REVISIONS
10-20-00
07-19-02
04-18-03
10-17-03
04-18-08
01-17-14
07-15-16

DESIGNED AJM/SAM
CHECKED JS
DRAWN SAM
REVIEWED WTL

OFFICE OF STRUCTURAL ENGINEERING

STANDARD BRIDGE DRAWING
TWIN STEEL TUBE BRIDGE RAILING

SCD NUMBER
TST-1-99

4/4

Figure A-6. Ohio Twin Steel Tube Bridge Railing, Sheet 4 of 4

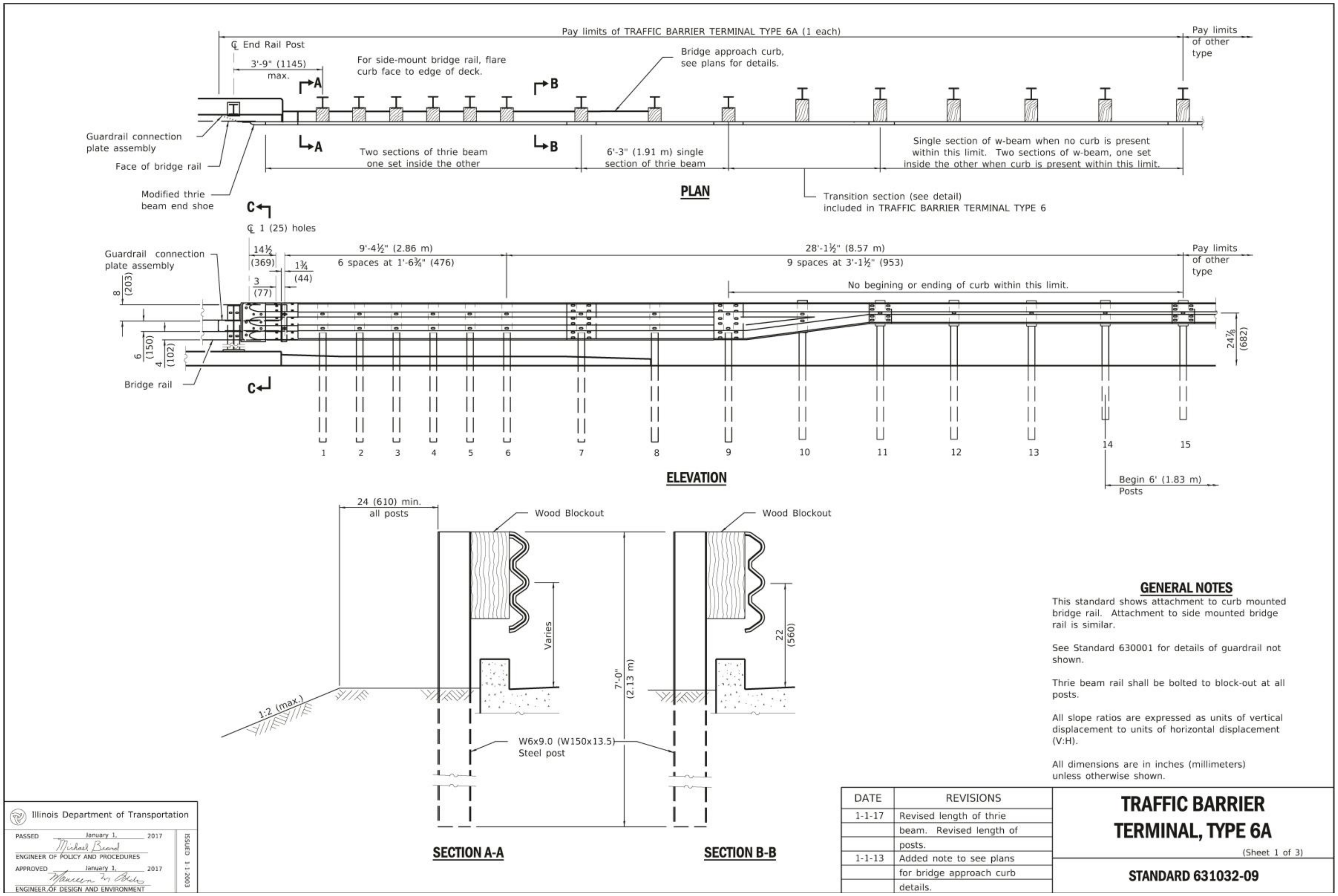


Figure A-7. Illinois Traffic Barrier Terminal, Type 6A, Sheet 1 of 3

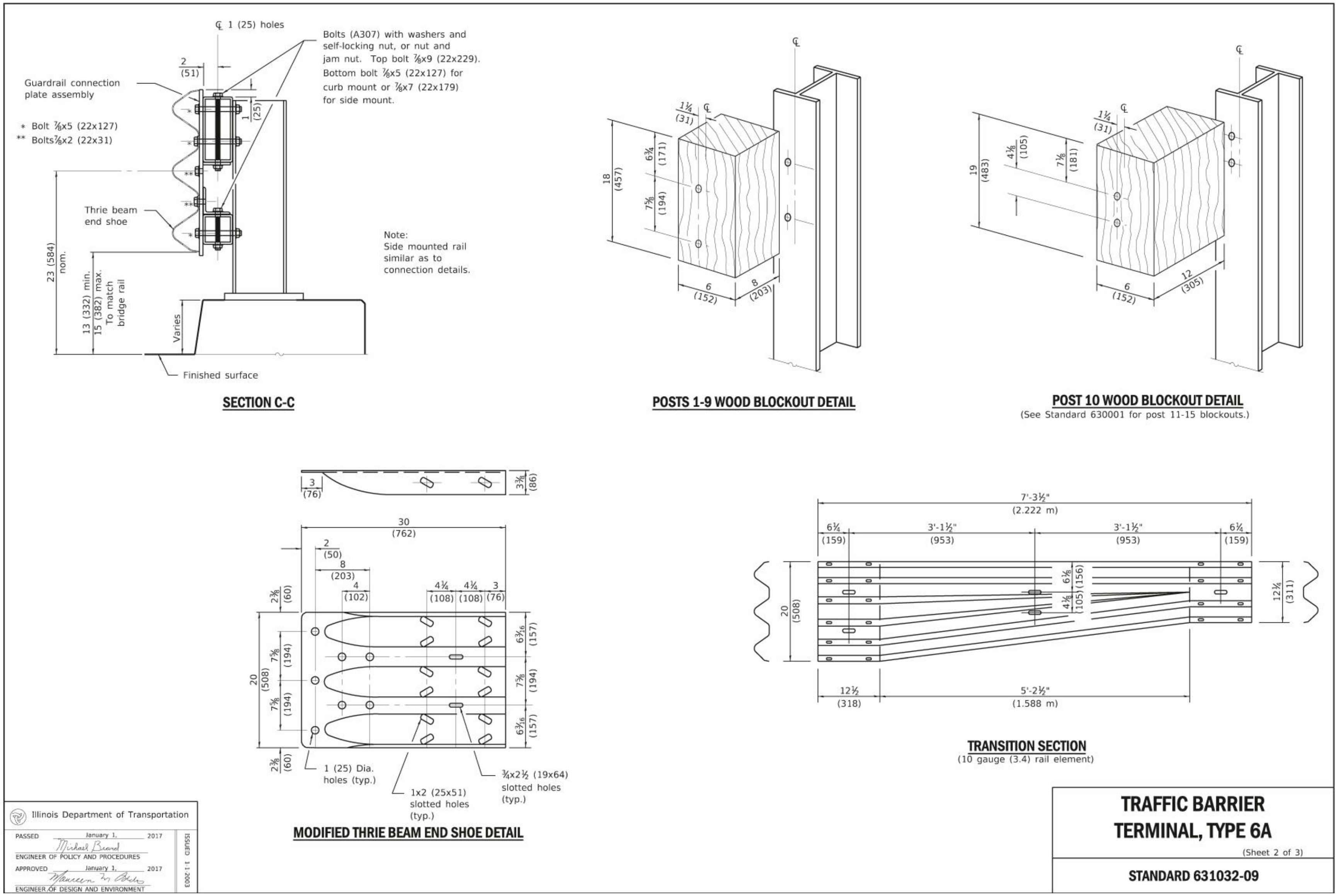



Figure A-8. Illinois Traffic Barrier Terminal, Type 6A, Sheet 2 of 3

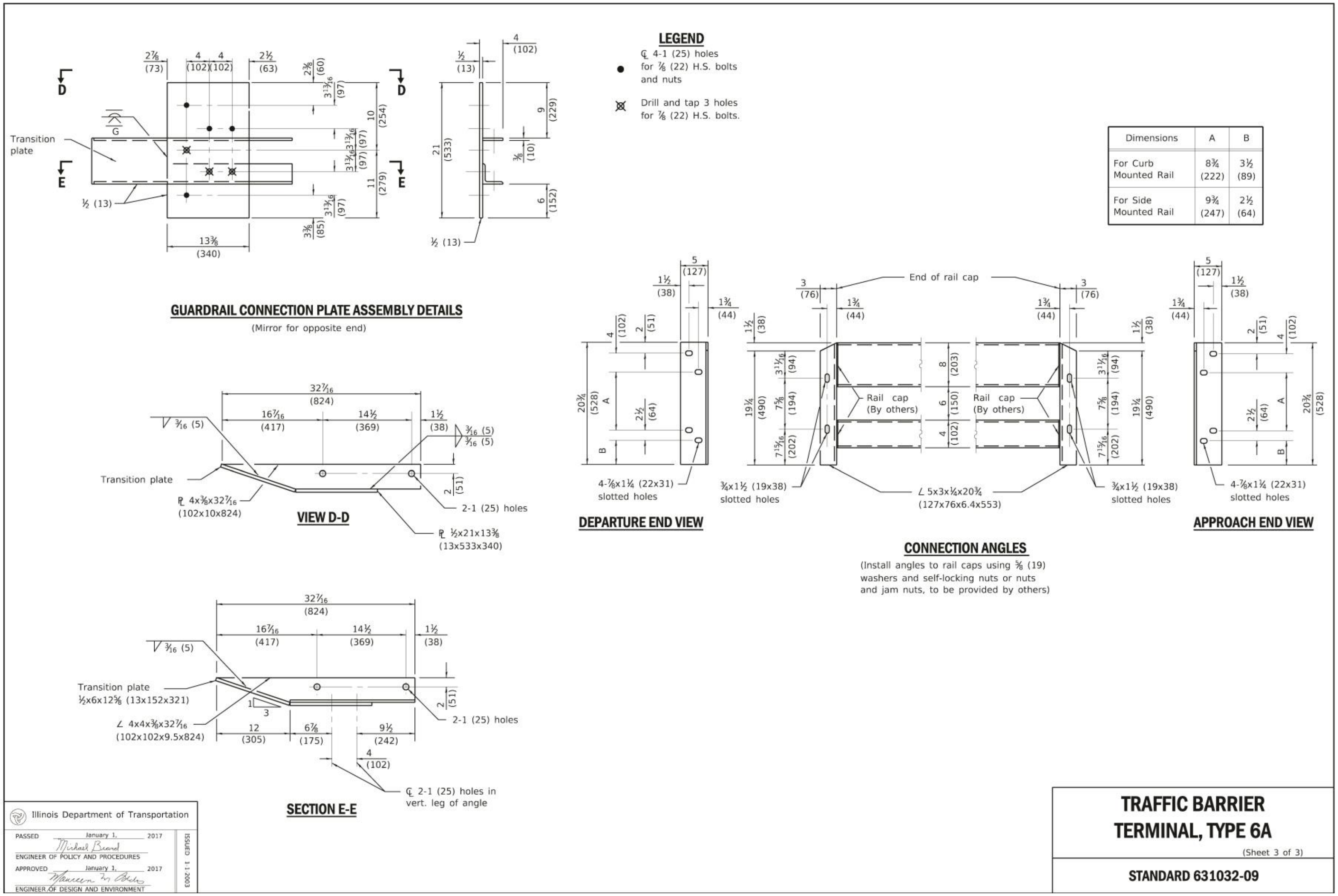



Figure A-9. Illinois Traffic Barrier Terminal, Type 6A, Sheet 3 of 3

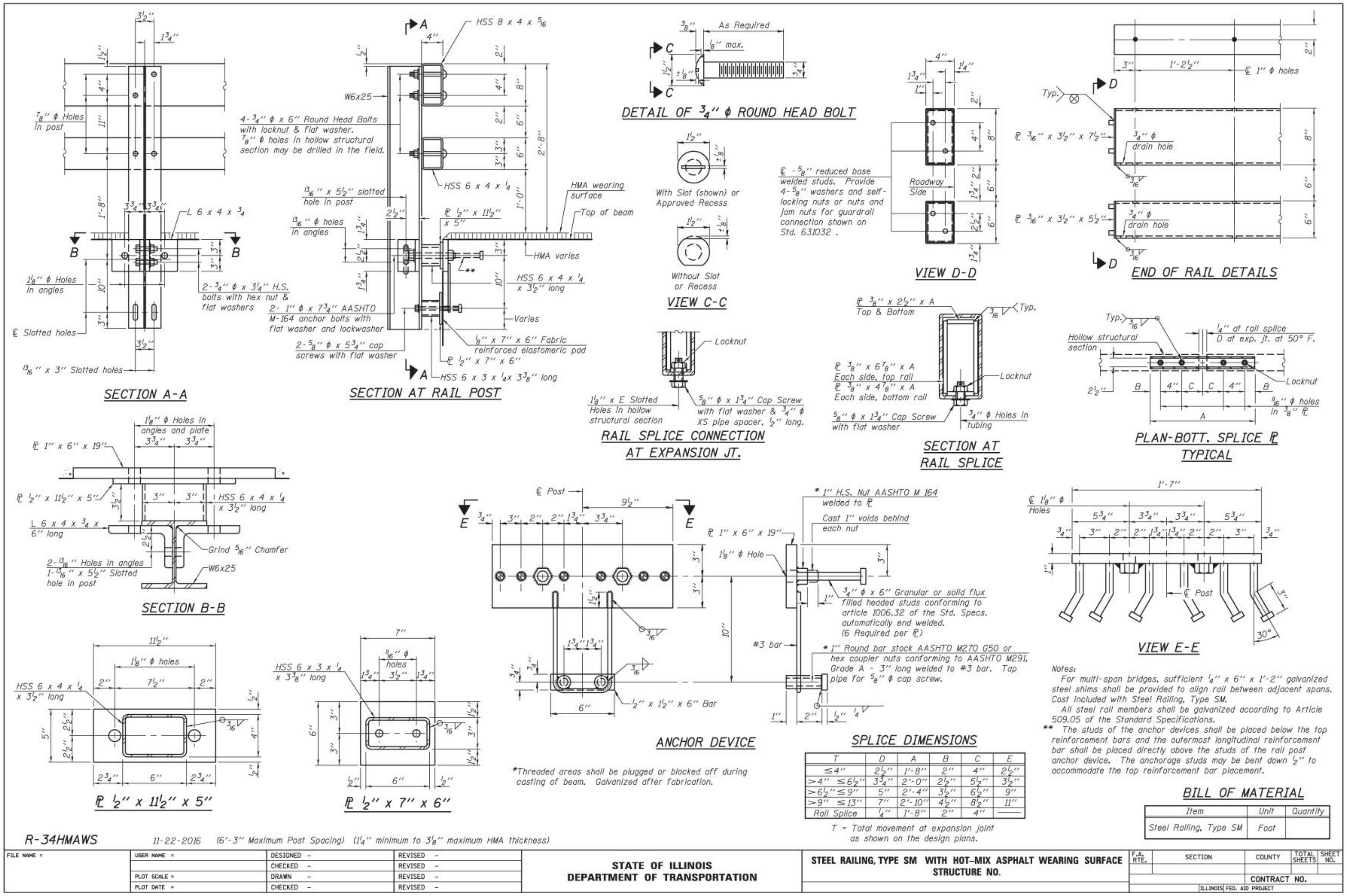



Figure A-10. Illinois Type SM Side Mount Bridge Rail

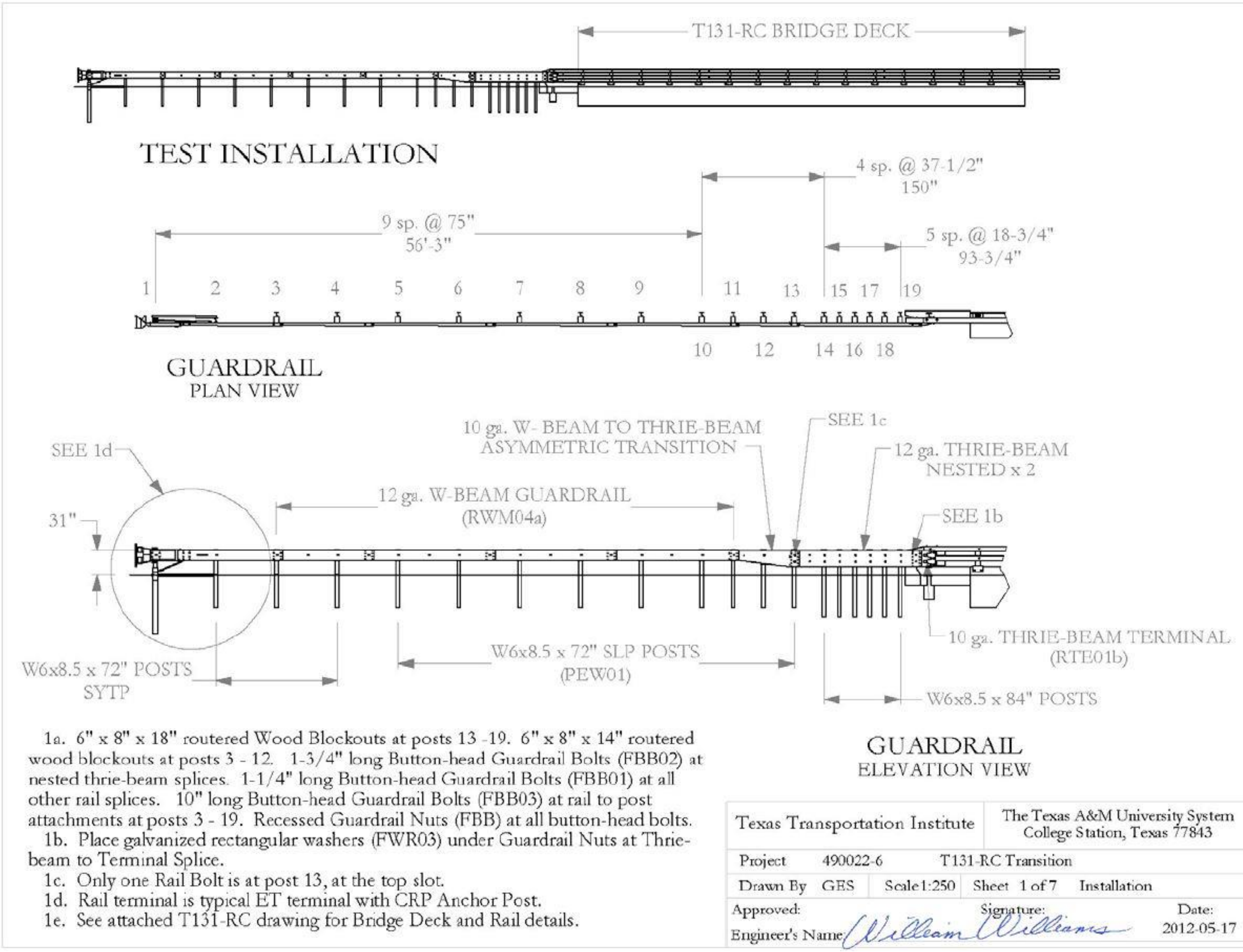
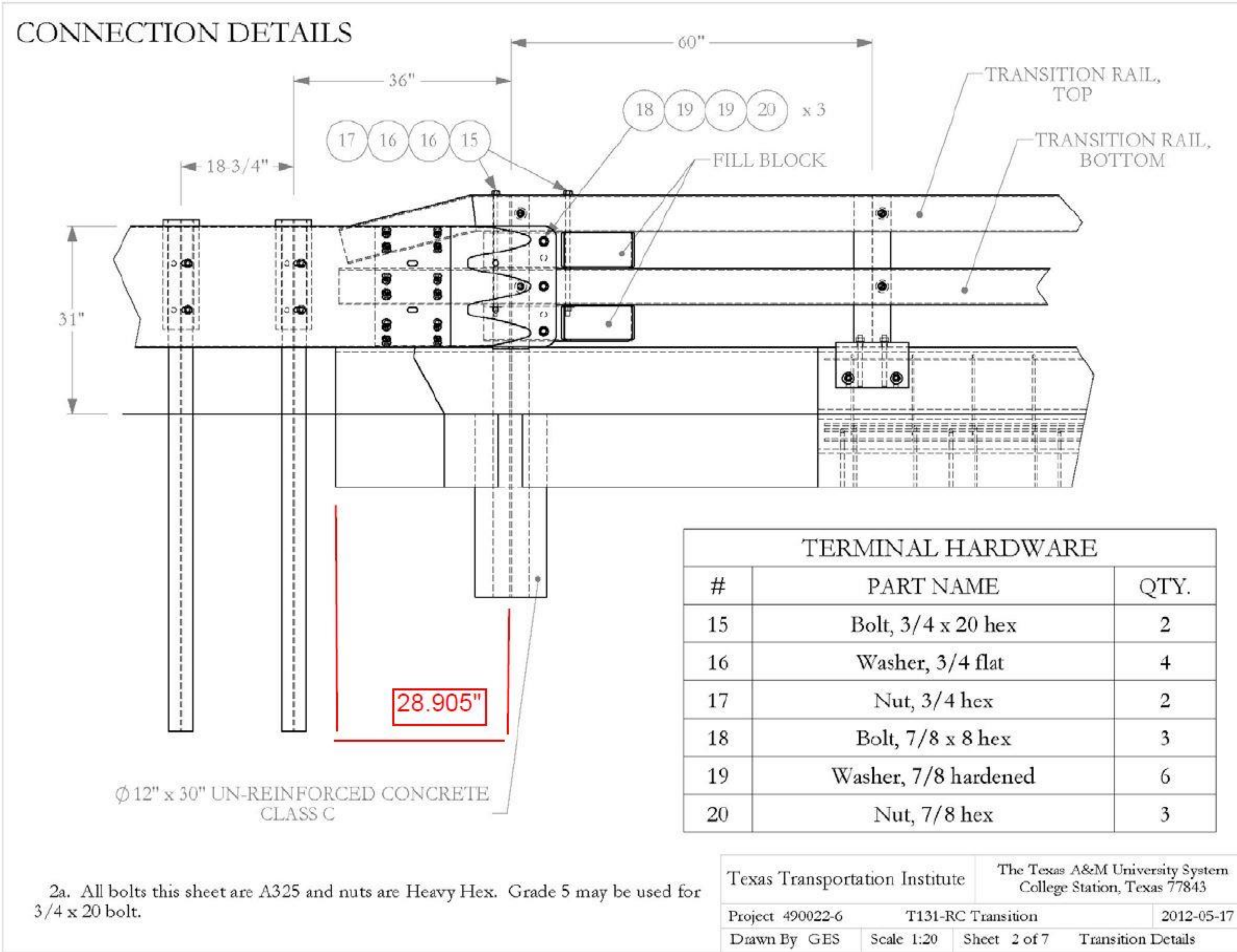



Figure A-11. Texas T131RC Bridge Rail Transition, Sheet 1 of 7




TERMINAL HARDWARE

| # | PART NAME | QTY. |
|---|---|---|
| 15 | Bolt, 3/4 x 20 hex | 2 |
| 16 | Washer, 3/4 flat | 4 |
| 17 | Nut, 3/4 hex | 2 |
| 18 | Bolt, 7/8 x 8 hex | 3 |
| 19 | Washer, 7/8 hardened | 6 |
| 20 | Nut, 7/8 hex | 3 |

Figure A-12. Texas T131RC Bridge Rail Transition, Sheet 2 of 7

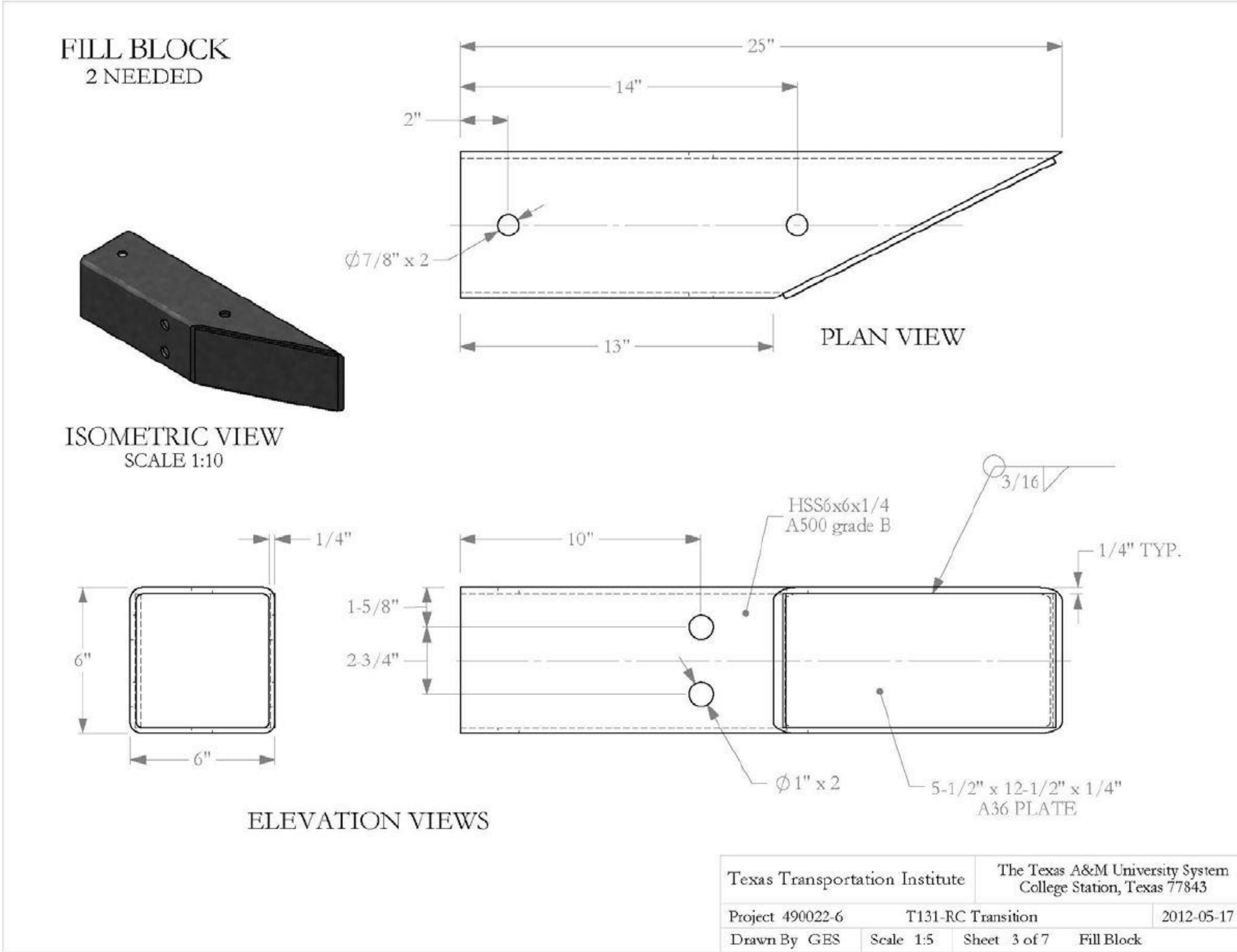



Figure A-13. Texas T131RC Bridge Rail Transition, Sheet 3 of 7

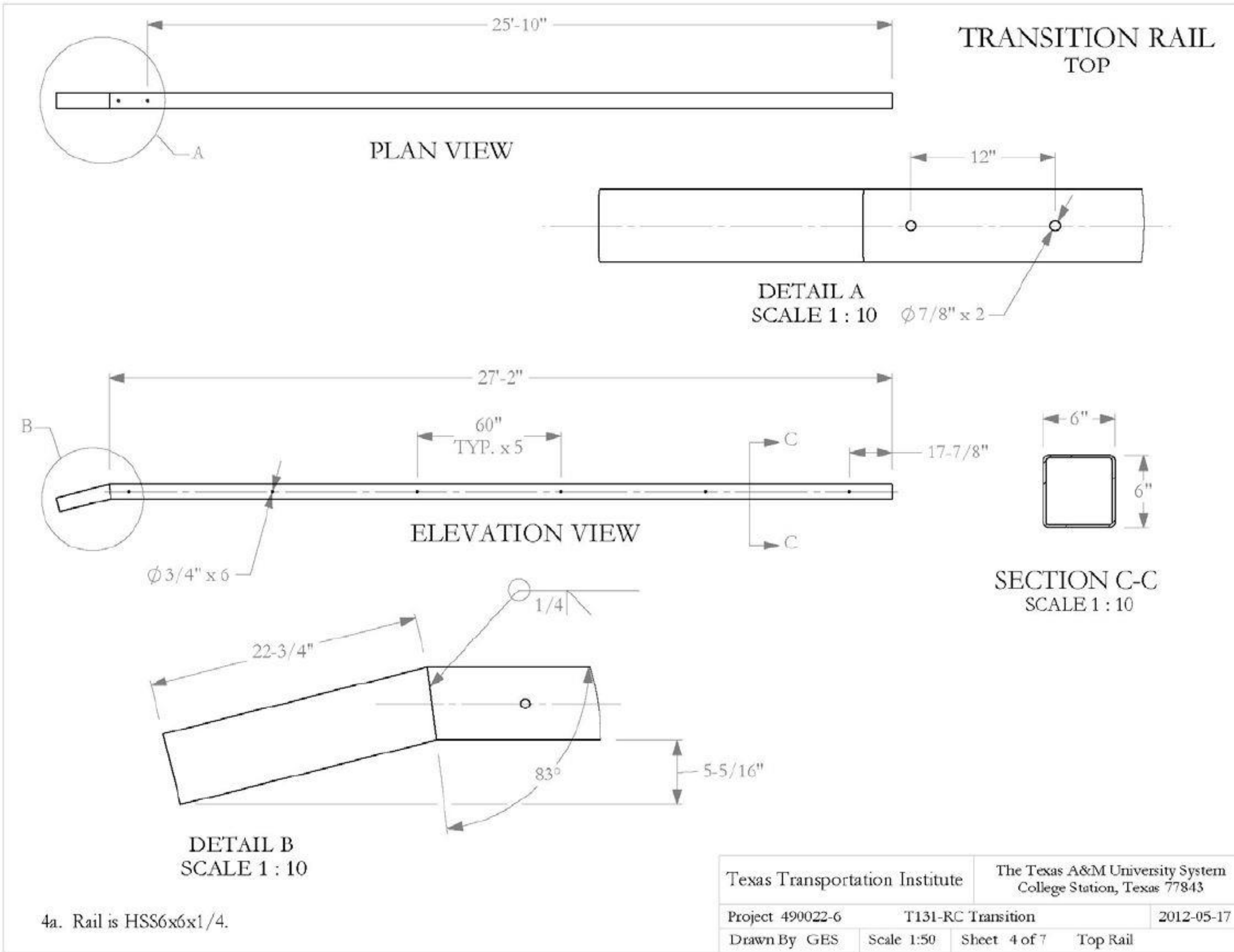



Figure A-14. Texas T131RC Bridge Rail Transition, Sheet 4 of 7

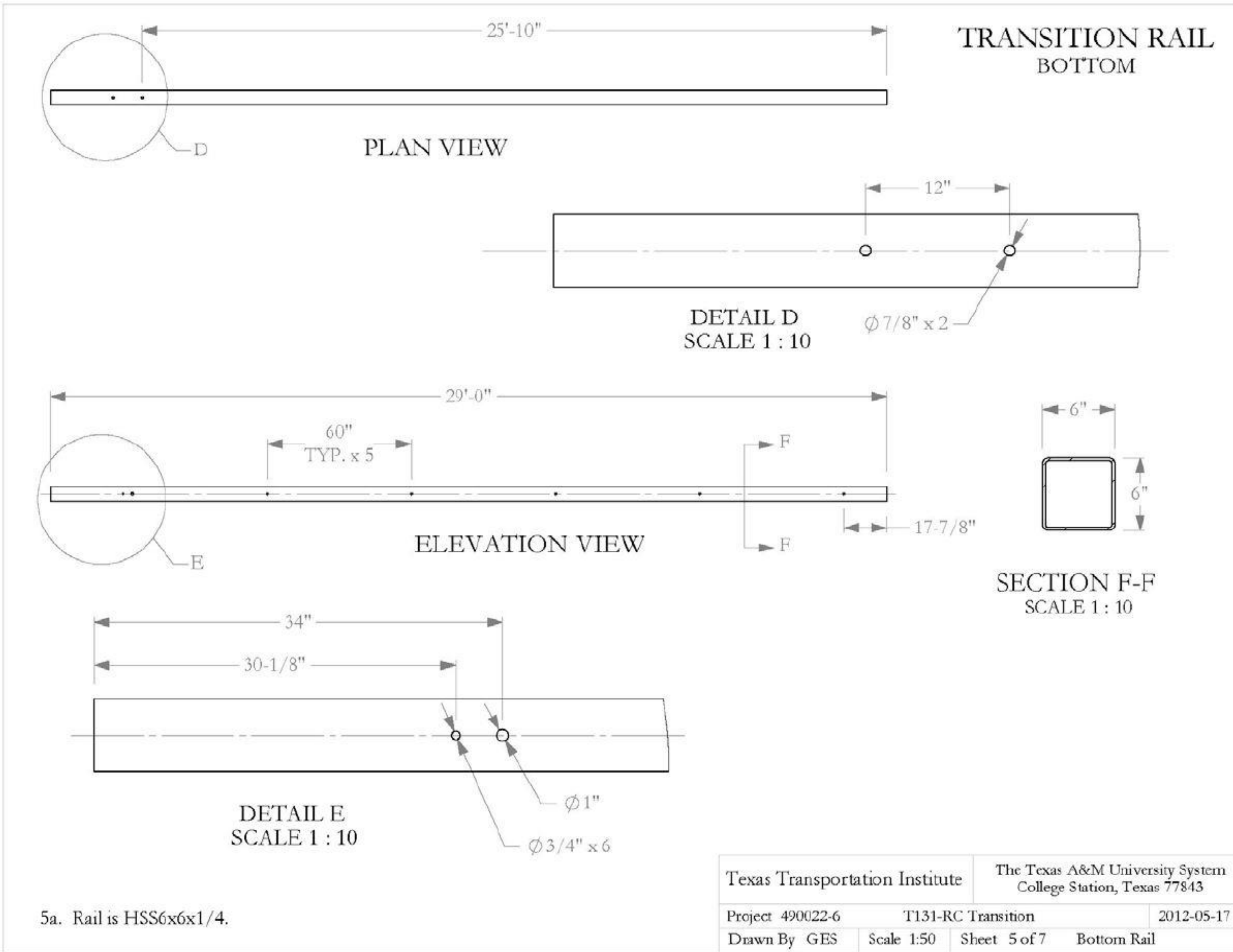
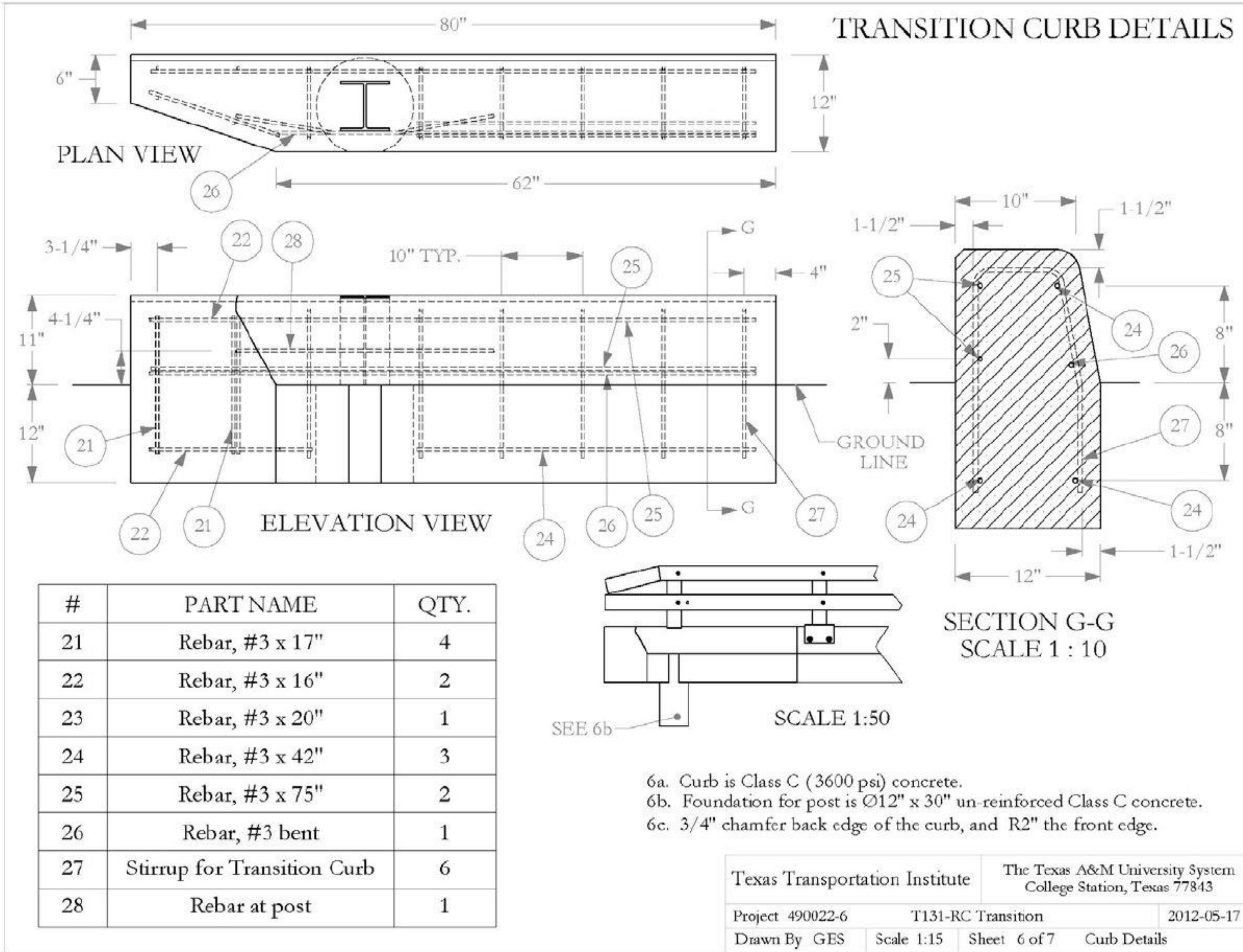



Figure A-15. Texas T131RC Bridge Rail Transition, Sheet 5 of 7




| # | PART NAME | QTY. |
|---|---|---|
| 21 | Rebar, #3 x 17" | 4 |
| 22 | Rebar, #3 x 16" | 2 |
| 23 | Rebar, #3 x 20" | 1 |
| 24 | Rebar, #3 x 42" | 3 |
| 25 | Rebar, #3 x 75" | 2 |
| 26 | Rebar, #3 bent | 1 |
| 27 | Stirrup for Transition Curb | 6 |
| 28 | Rebar at post | 1 |

Figure A-16. Texas T131RC Bridge Rail Transition, Sheet 6 of 7

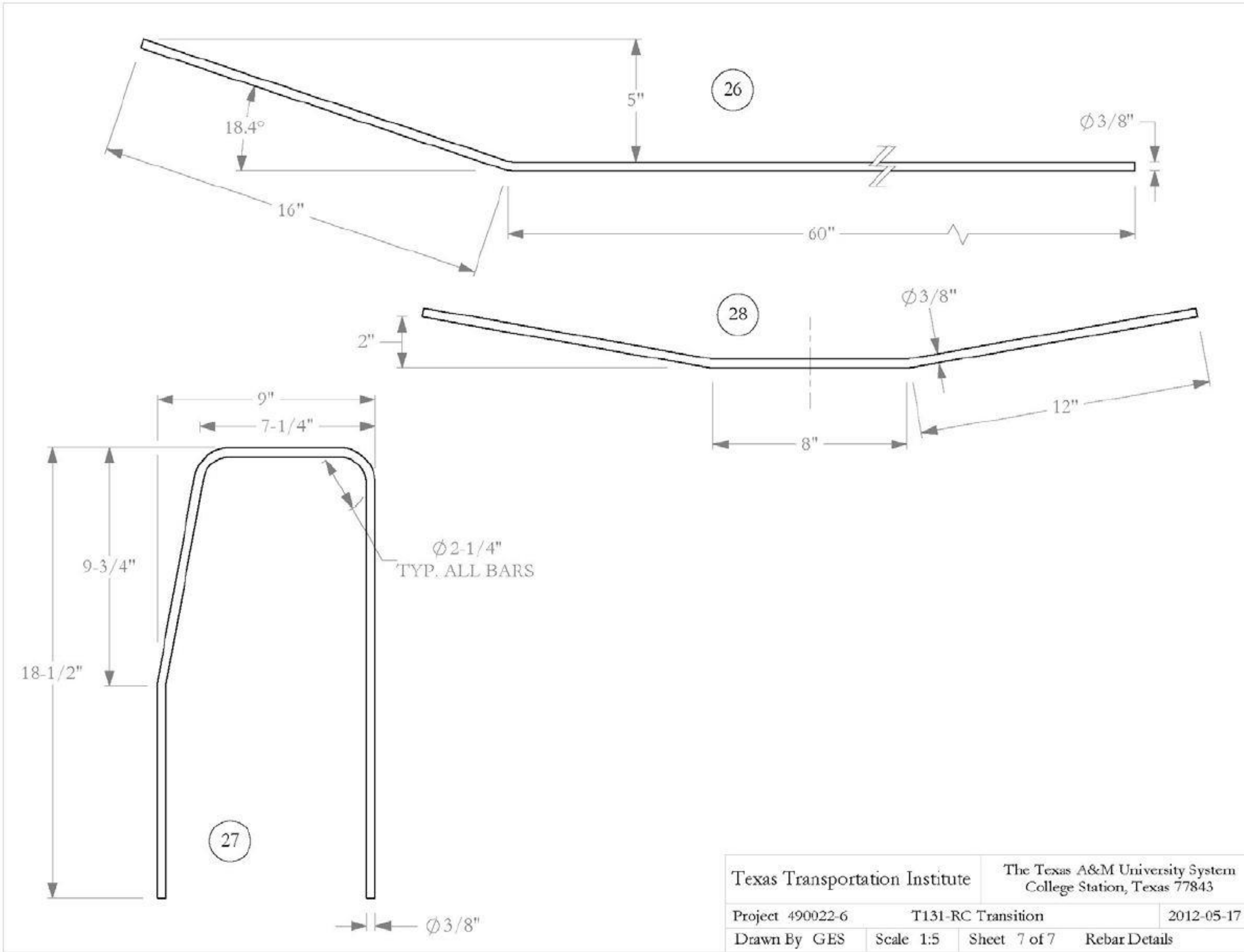



Figure A-17. Texas T131RC Bridge Rail Transition, Sheet 7 of 7

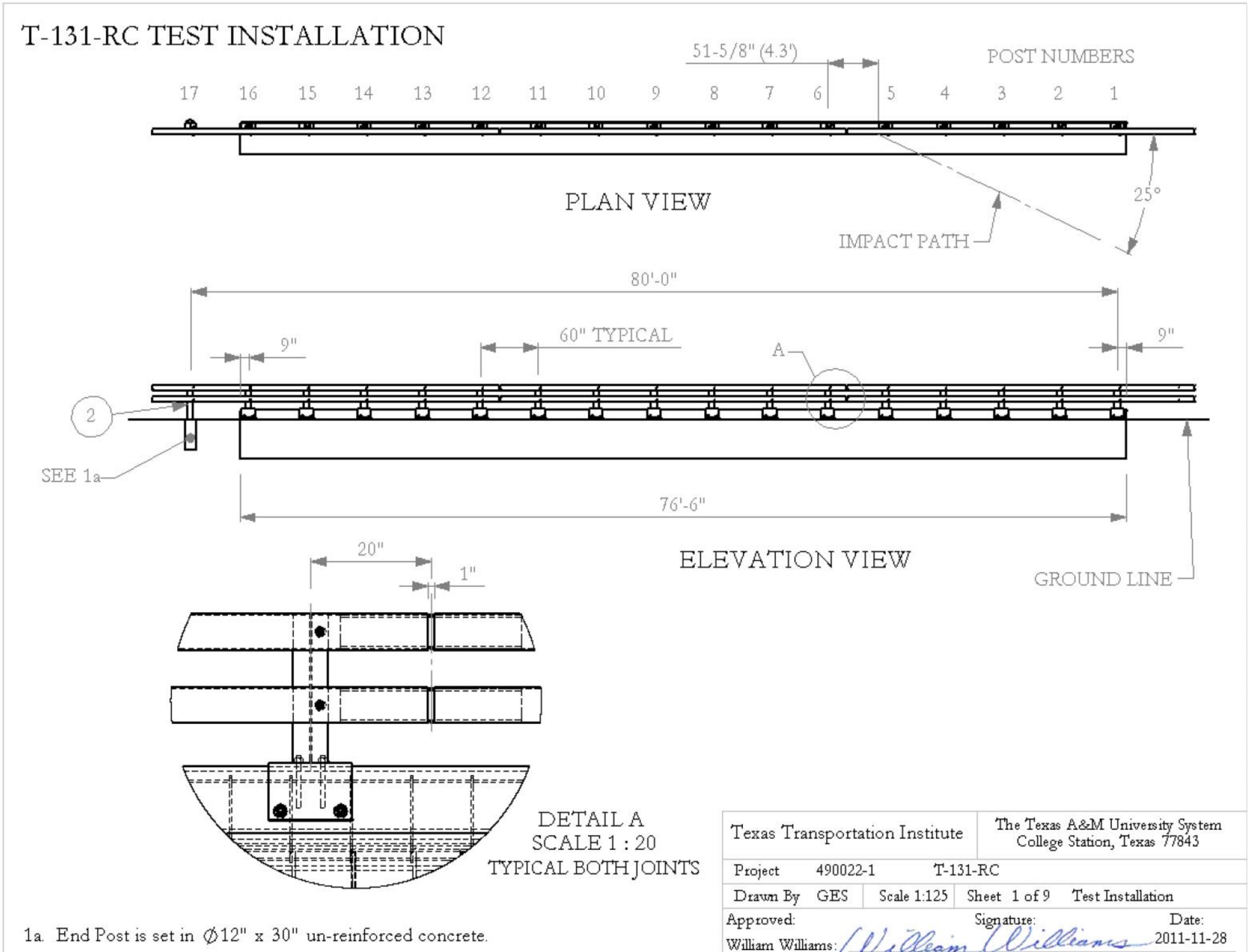
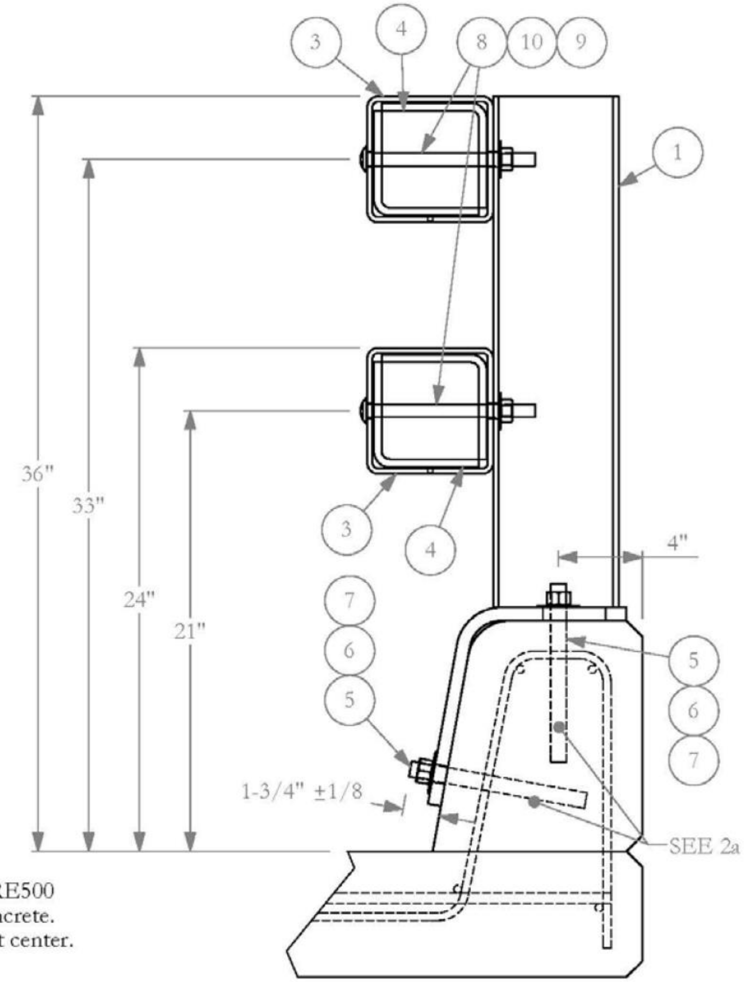



Figure A-18. Texas T131RC Bridge Rail, Sheet 1 of 9

| # | PART NAME | QTY. | SHEET |
|---|---|---|---|
| 1 | Post, T131RC | 16 | 3 |
| 2 | Post, end T131RC | 1 | 4 |
| 3 | Rail, TS6x6x1/4 | 6 | 5 |
| 4 | Splice Sleeve for 6x6 Rail | 4 | 5 |
| 5 | Hilti Anchor (see 1a) | 64 | |
| 6 | Nut, 3/4 hex | see 2e | |
| 7 | Washer, 3/4 flat | see 2e | |
| 8 | Bolt, 5/8 x 8 round-head slotted | 34 | 6 |
| 9 | Nut, 5/8 hex | 34 | |
| 10 | Washer, 5/8 flat | 34 | |




2a. Hilti Super HAS-E Ø3/4 (cut off to 8-1/2" long), installed with Hilti RE500 epoxy according to label directions, with 1-3/4" ±1/8" protruding above concrete. Place anchors in curb top at 4" from back of curb. Do not place them in slot center. This is to allow removal of the posts.

2b. All bolts, nuts, and washers (except Hilti products) are grade A307.

2c. Threads not shown on bolts for clarity, and End Post and its foundation are also not shown here.

2d. Connection details typical for Bridge Posts and End Post.

2e. Ø3/4" nuts and washers are provided with Hilti Anchors and do not need to be supplied separately.

| Texas Transportation Institute | | The Texas A&M University System College Station, Texas 77843 | |
|---|---|---|---|
| Project 490022-1 | T-131-RC | | 2011-11-28 |
| Drawn By GES | Scale 1:7 | Sheet 2 of 9 | Posts and Rail |

Figure A-19. Texas T131RC Bridge Rail, Sheet 2 of 9

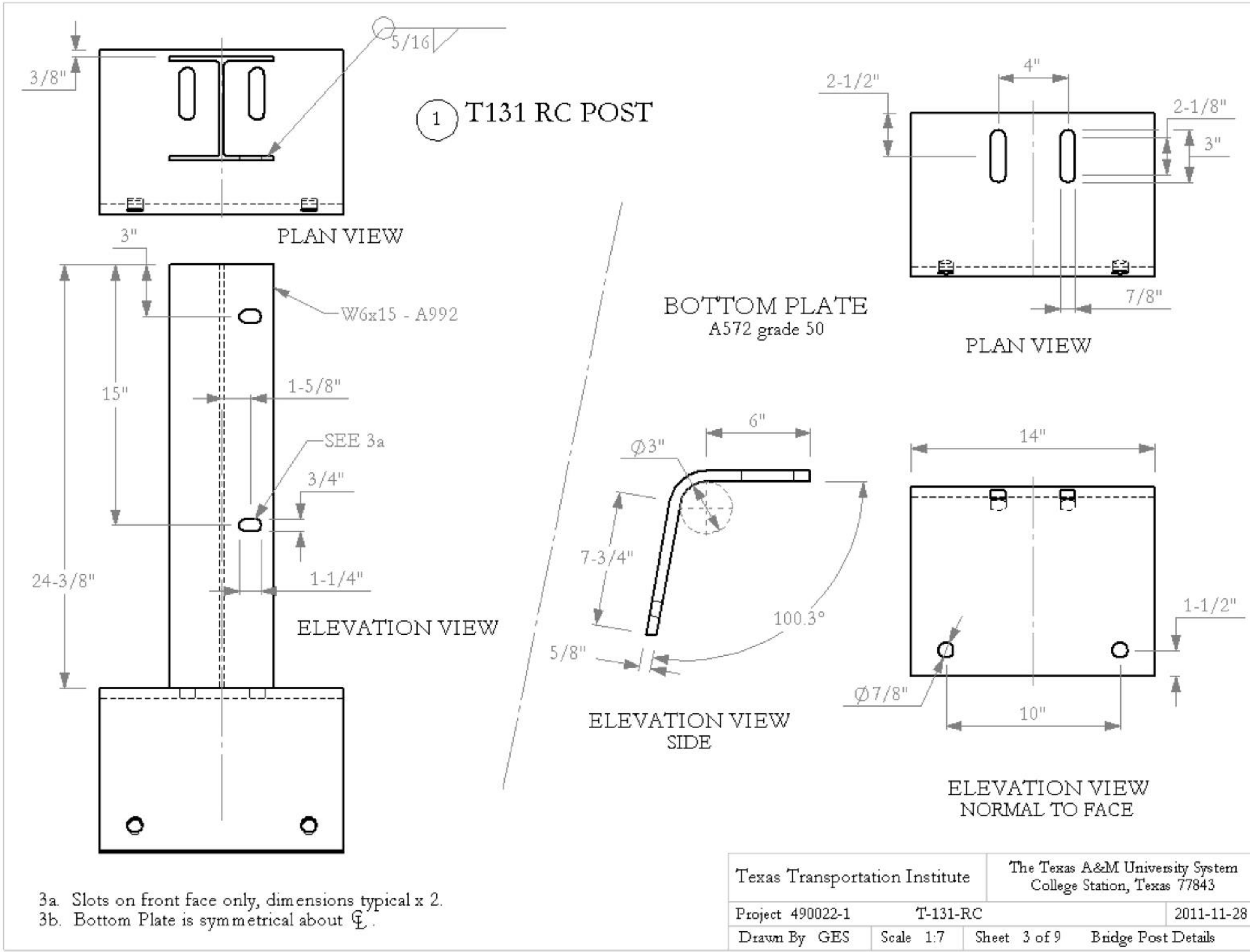



Figure A-20. Texas T131RC Bridge Rail, Sheet 3 of 9

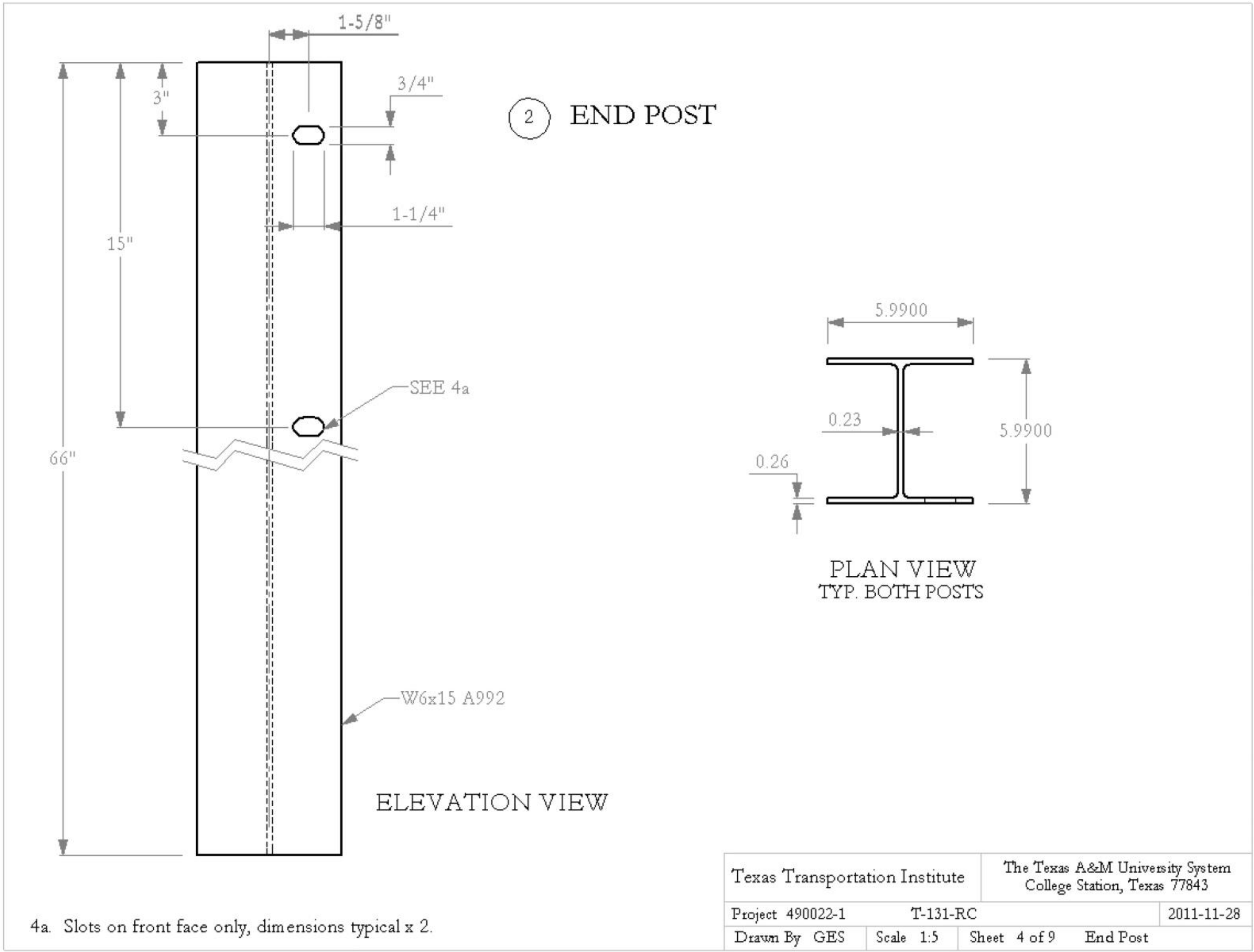



Figure A-21. Texas T131RC Bridge Rail, Sheet 4 of 9

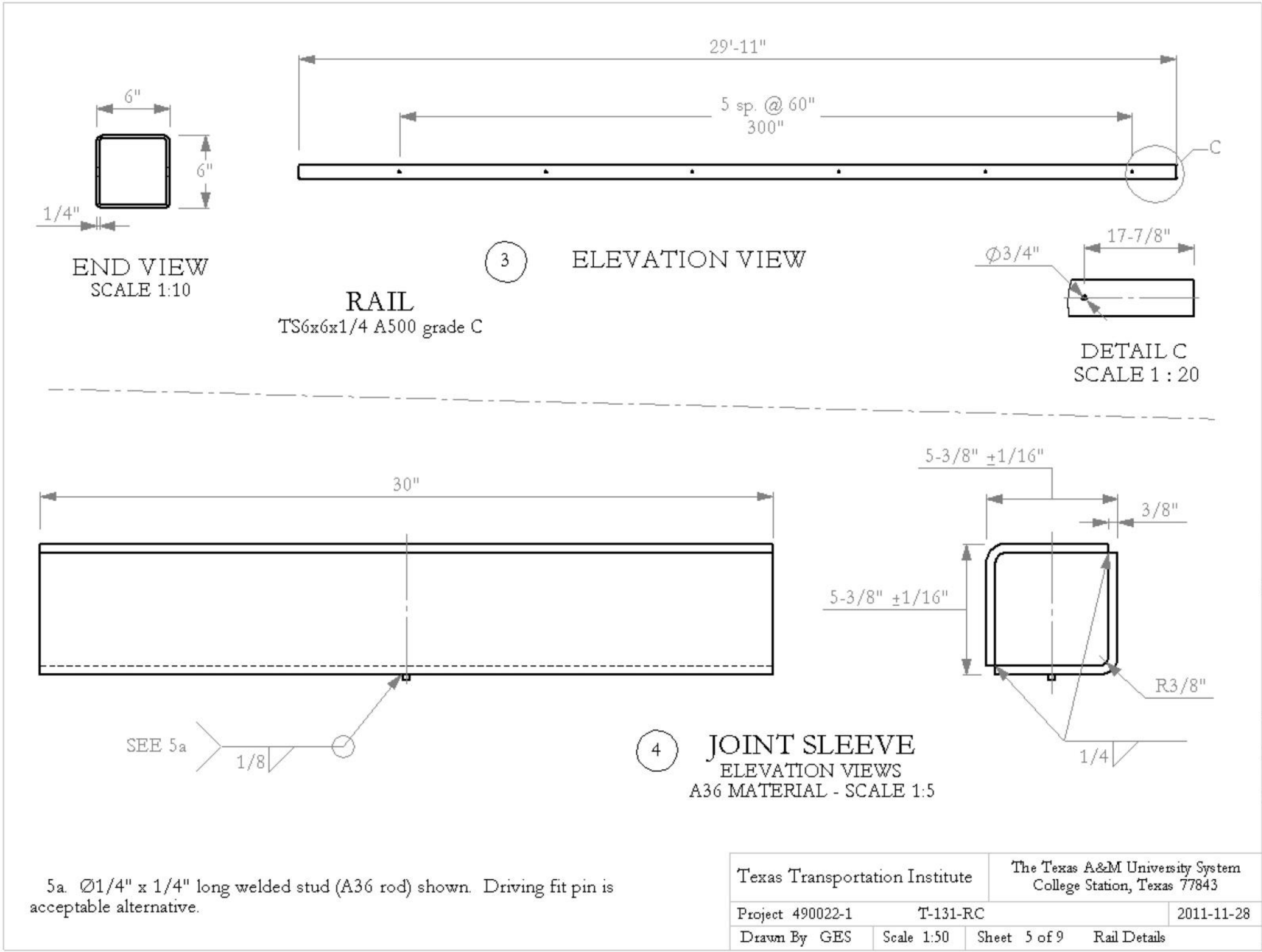



Figure A-22. Texas T131RC Bridge Rail, Sheet 5 of 9

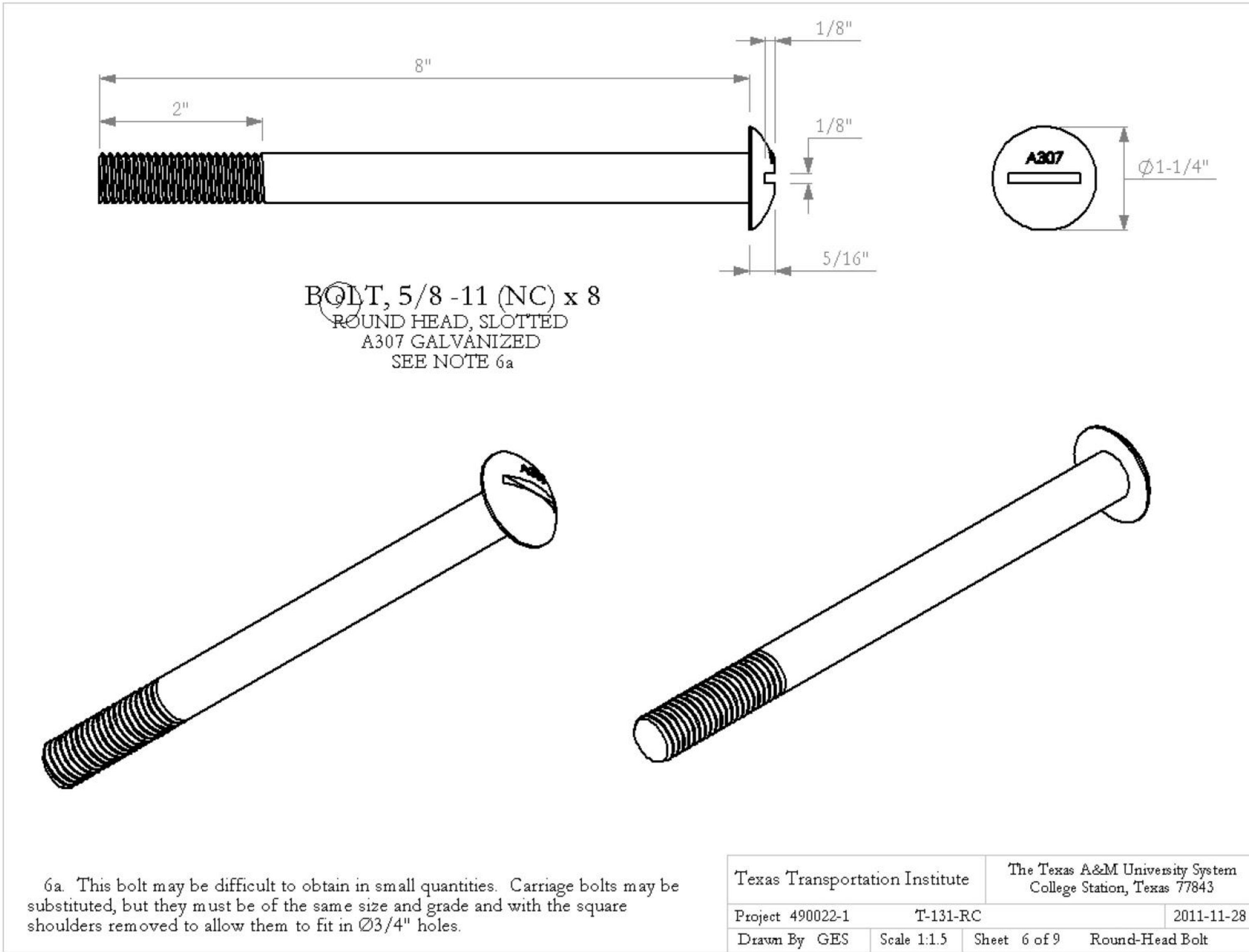



Figure A-23. Texas T131RC Bridge Rail, Sheet 6 of 9

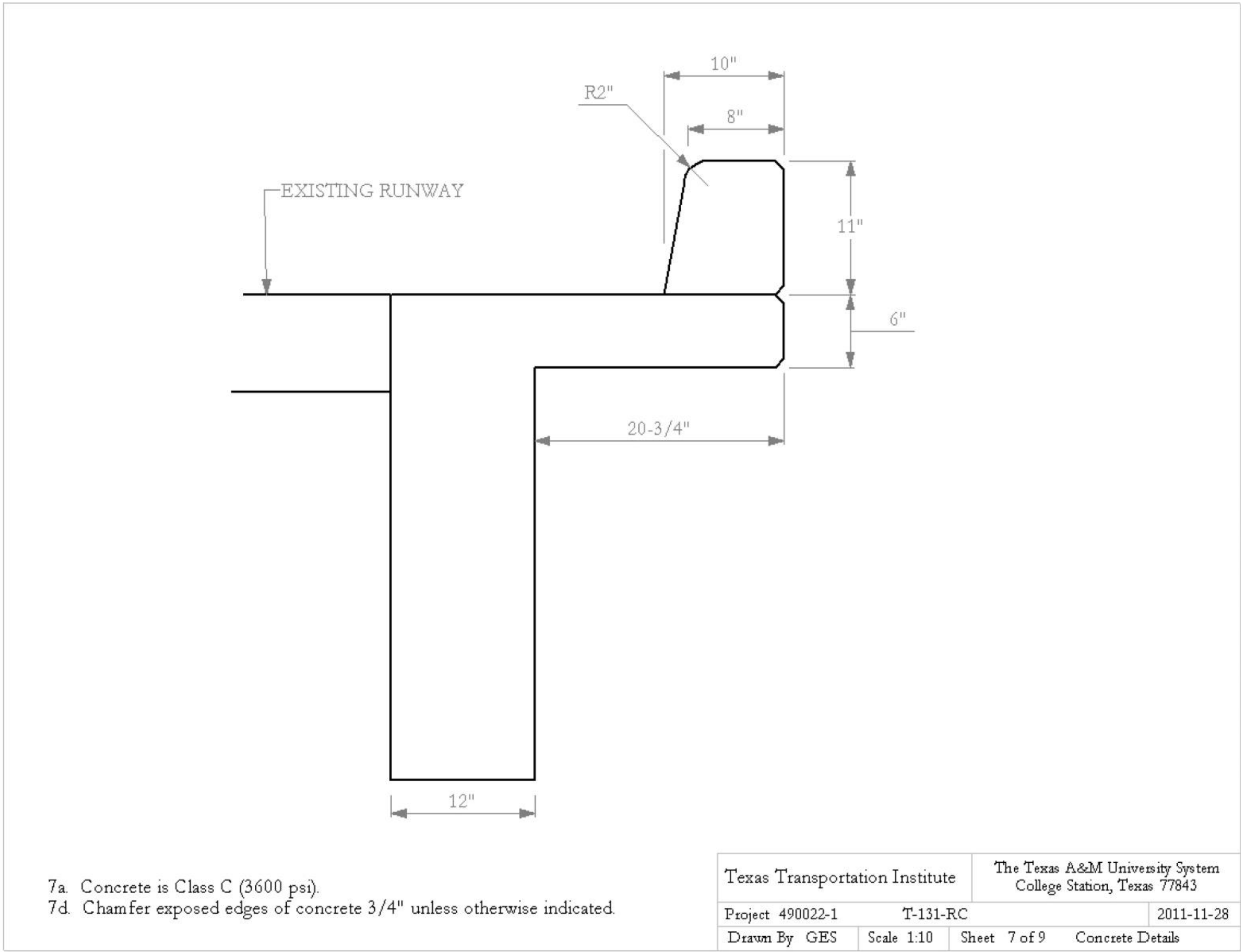
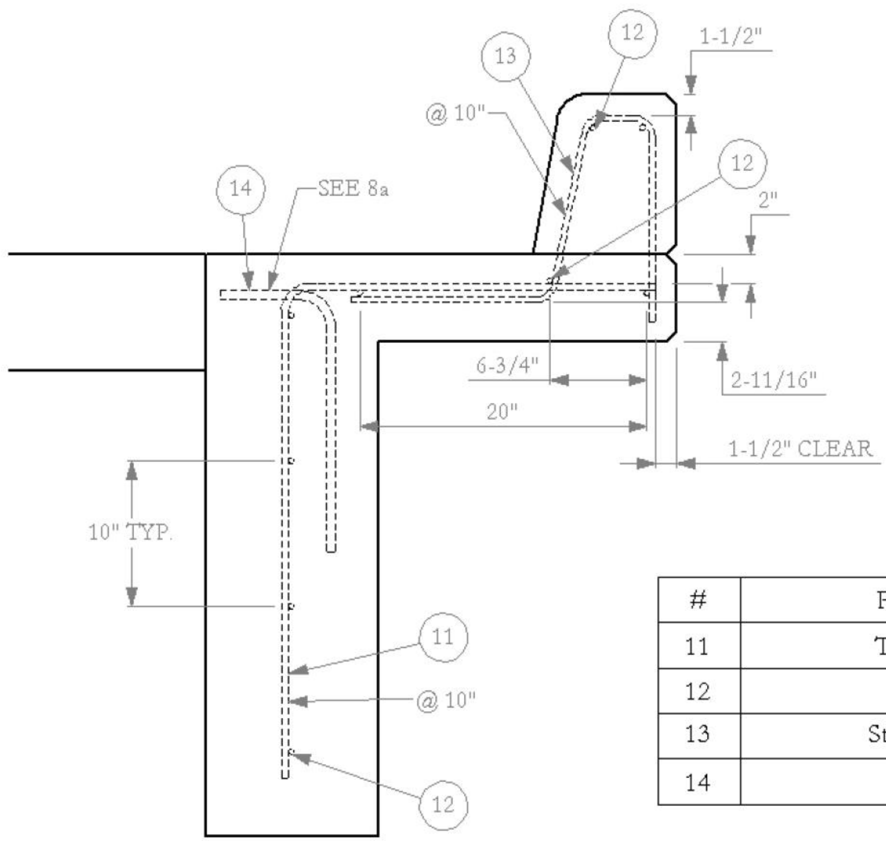



Figure A-24. Texas T131RC Bridge Rail, Sheet 7 of 9




| # | PART NAME | QTY. |
|---|---|---|
| 11 | Transverse Bar | 92 |
| 12 | Rebar, #3 | * |
| 13 | Stirrup for Curb | 92 |
| 14 | L Bar | 51 |

8a. L-bars spaced @ 18" and welded to existing rebar (not shown) protruding from runway.
8b. All rebar is grade 60.
8c. Longitudinal rebar lap distance is 16" for #3 bars.
8f. All rebar clearance is 1-1/2" unless otherwise noted.

| | | | |
|---|---|---|---|
| Texas Transportation Institute | | The Texas A&M University System College Station, Texas 77843 | |
| Project 490022-1 | T-131-RC | | 2011-11-28 |
| Drawn By GES | Scale 1:10 | Sheet 8 of 9 | Rebar Layout |

Figure A-25. Texas T131RC Bridge Rail, Sheet 8 of 9

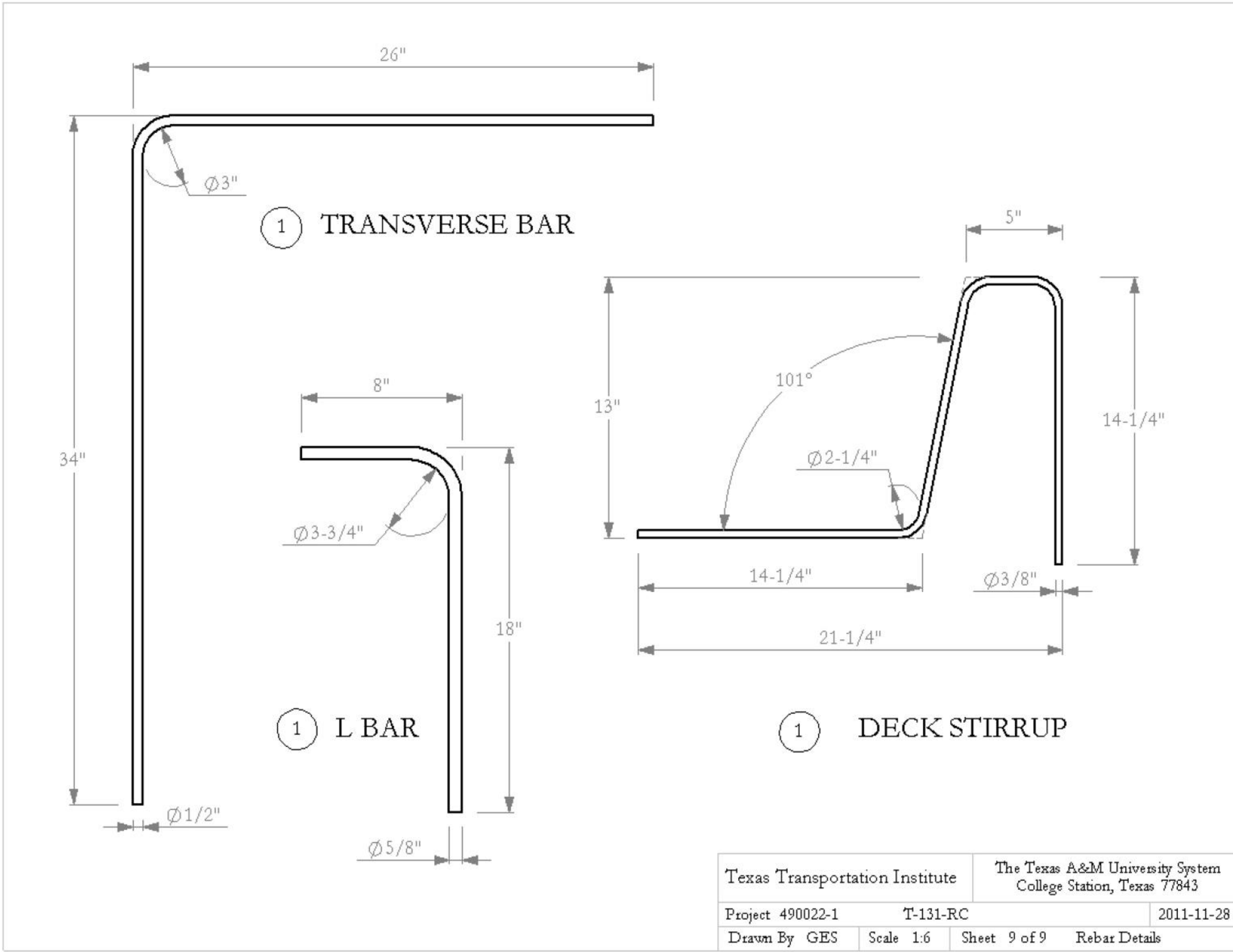



Figure A-26. Texas T131RC Bridge Rail, Sheet 9 of 9

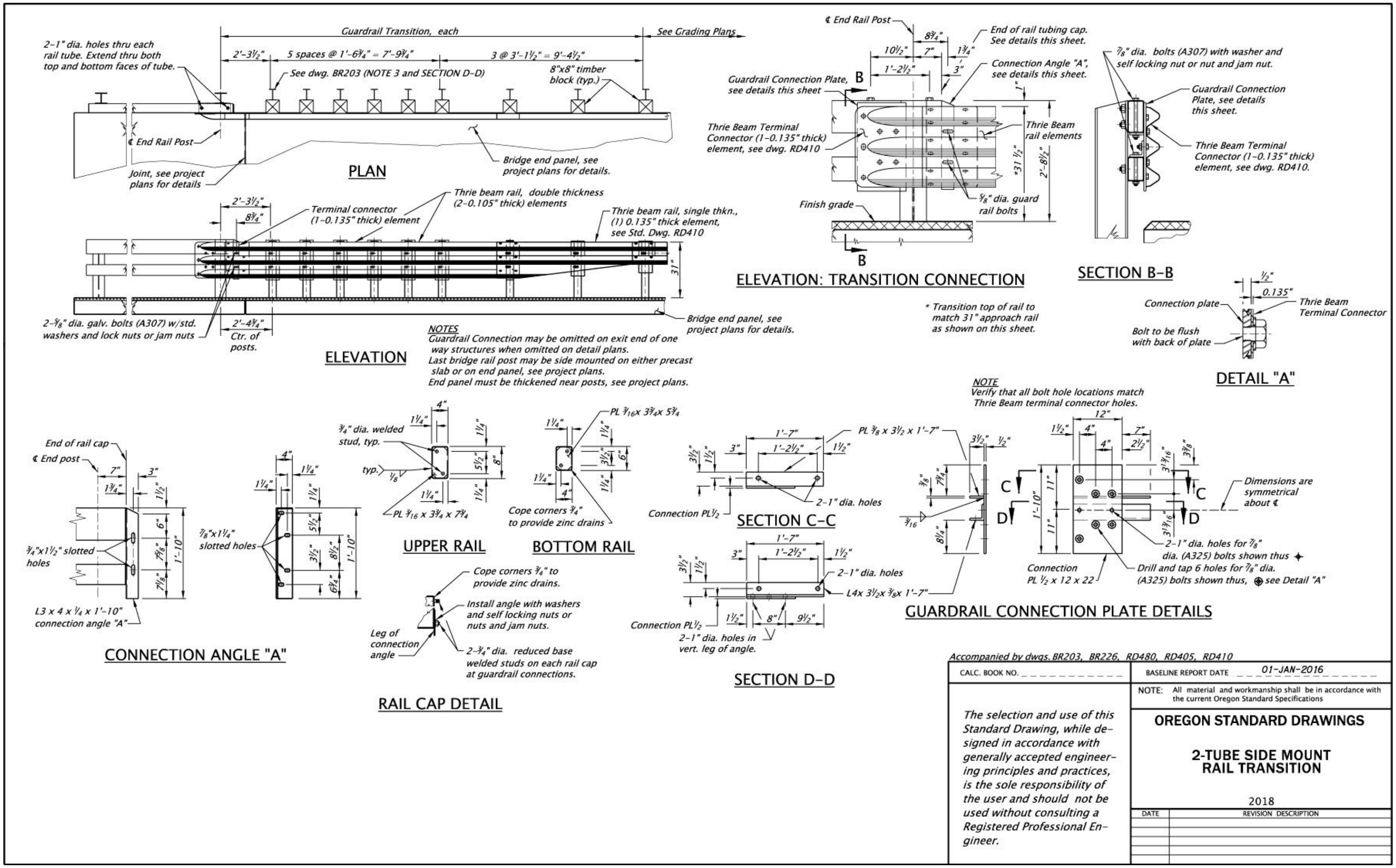



Figure A-27. Oregon Two-Tube Side Mount Rail Transition

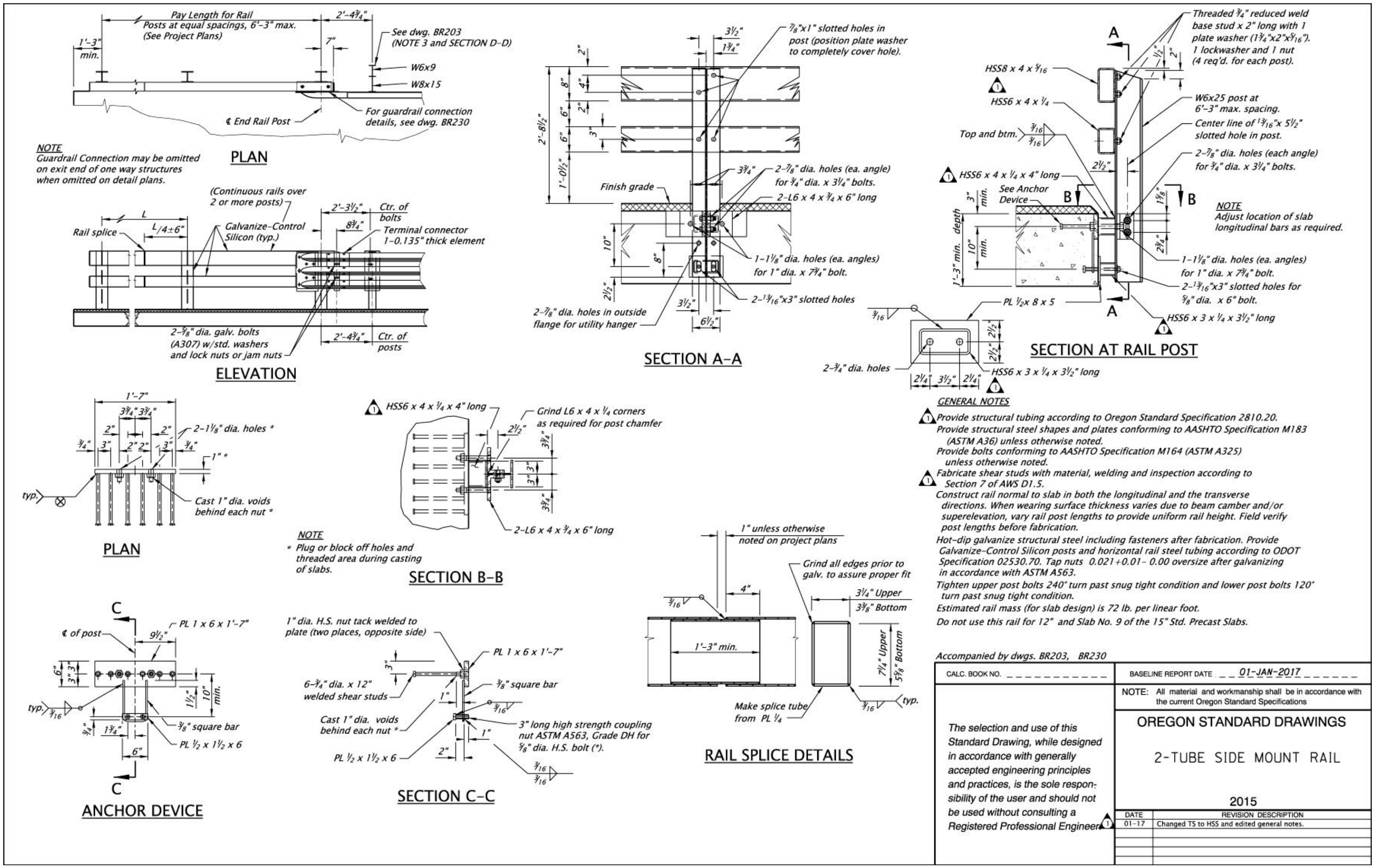



Figure A-28. Oregon Two-Tube Side Mount Rail

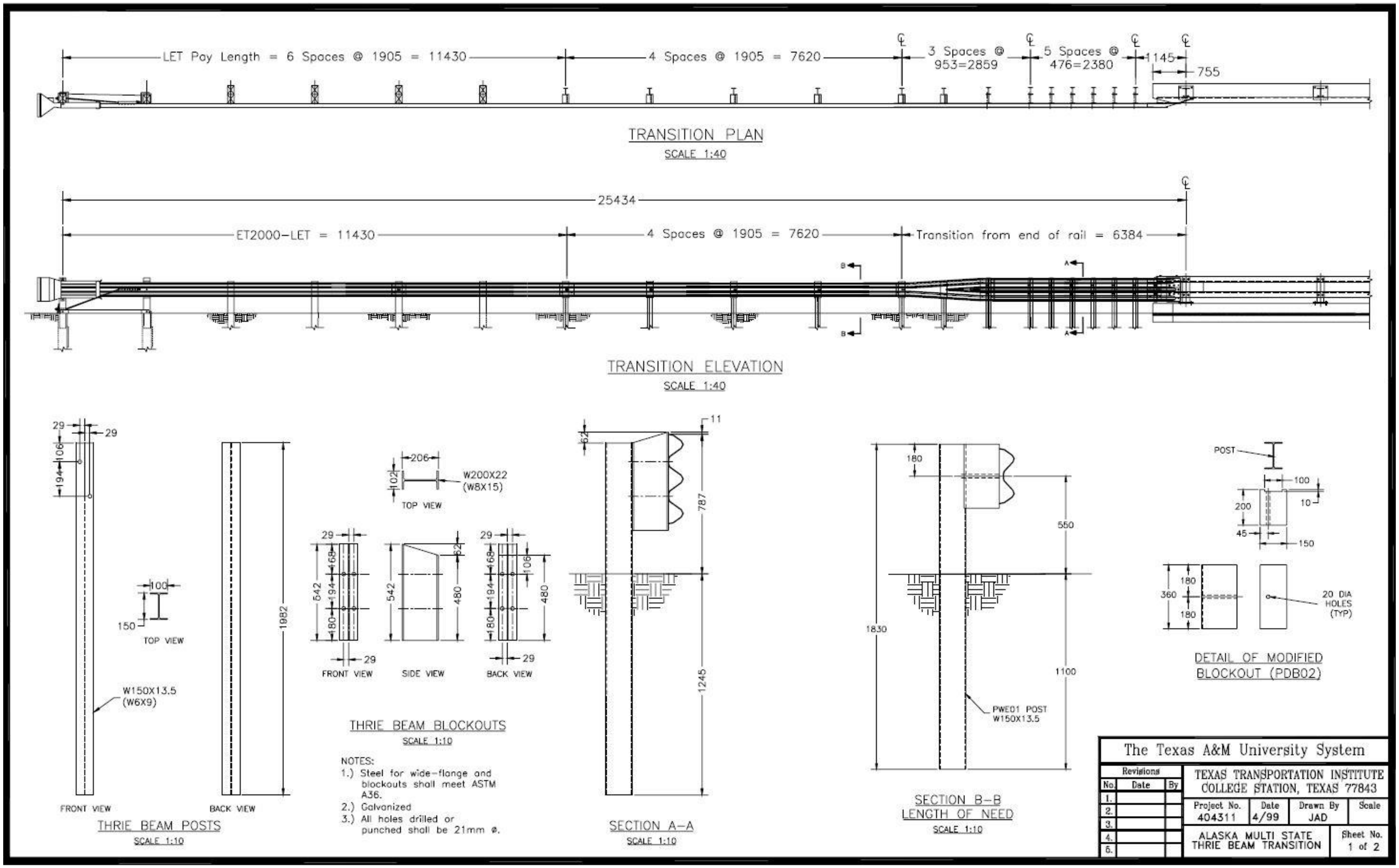



Figure A-29. Alaska Multi-State Thrie-Beam Transition, Sheet 1 of 2

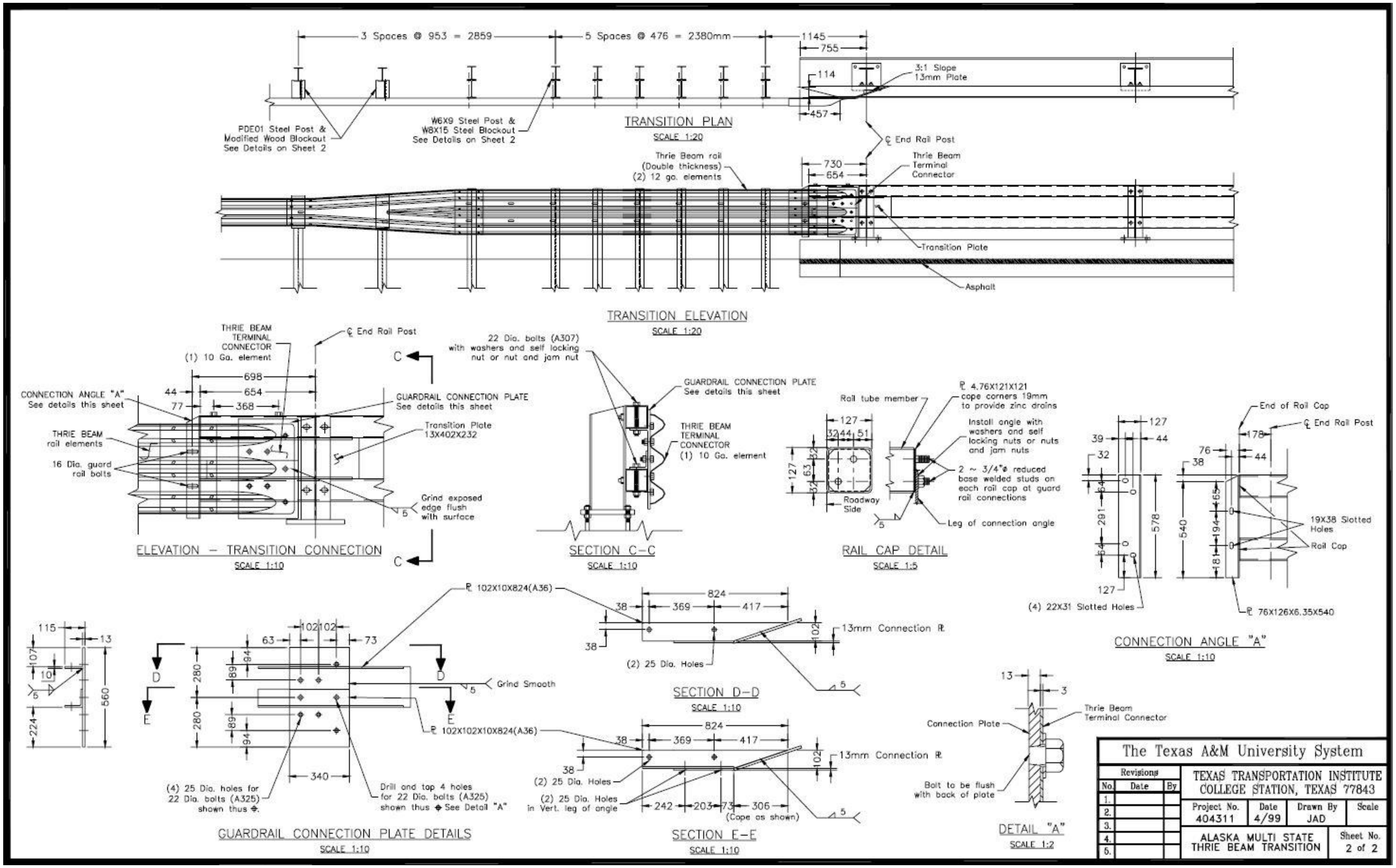



Figure A-30. Alaska Multi-State Thrie-Beam Transition, Sheet 2 of 2

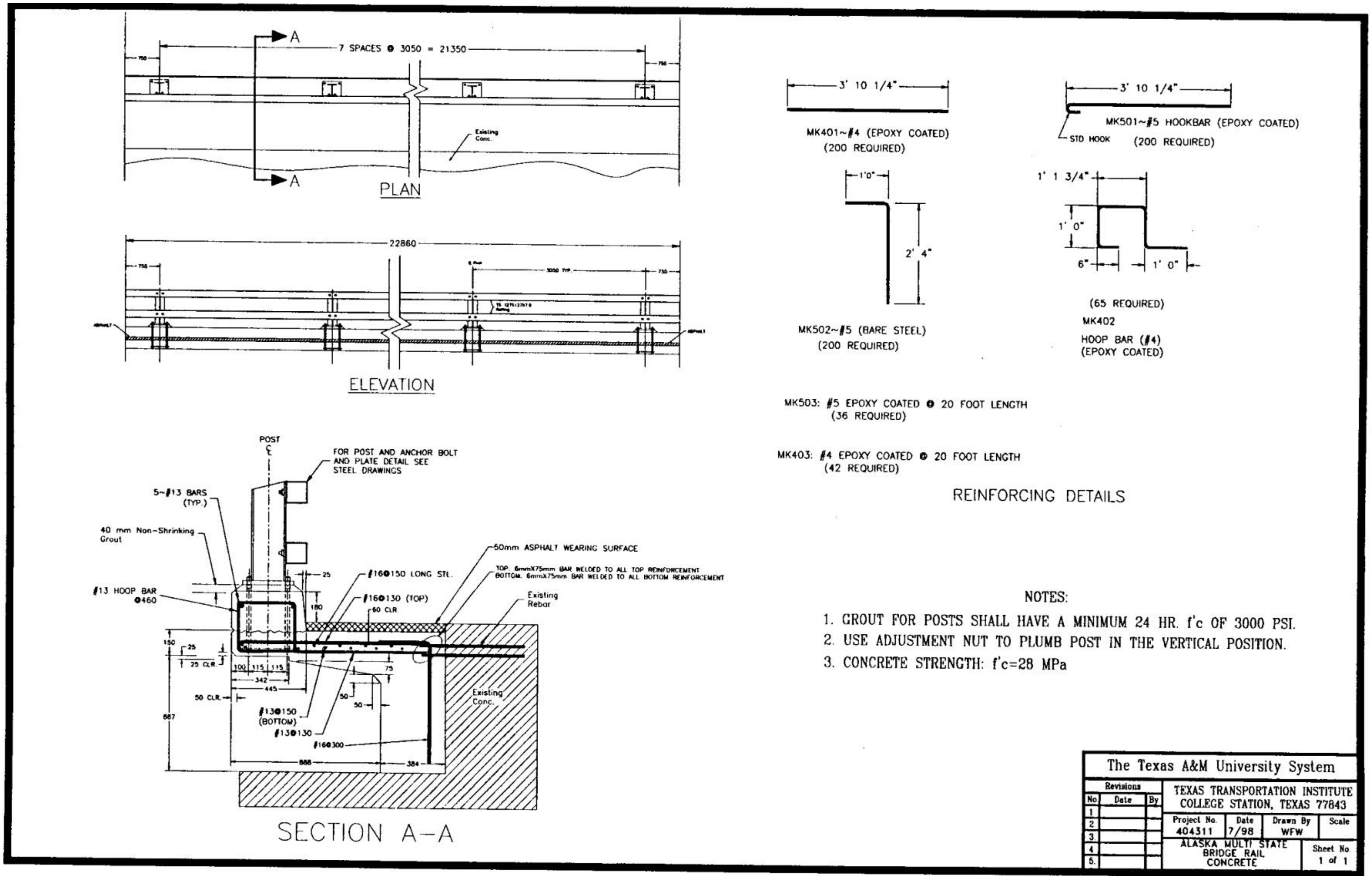



Figure A-31. Alaska Multi-State Bridge Rail, Sheet 1 of 3

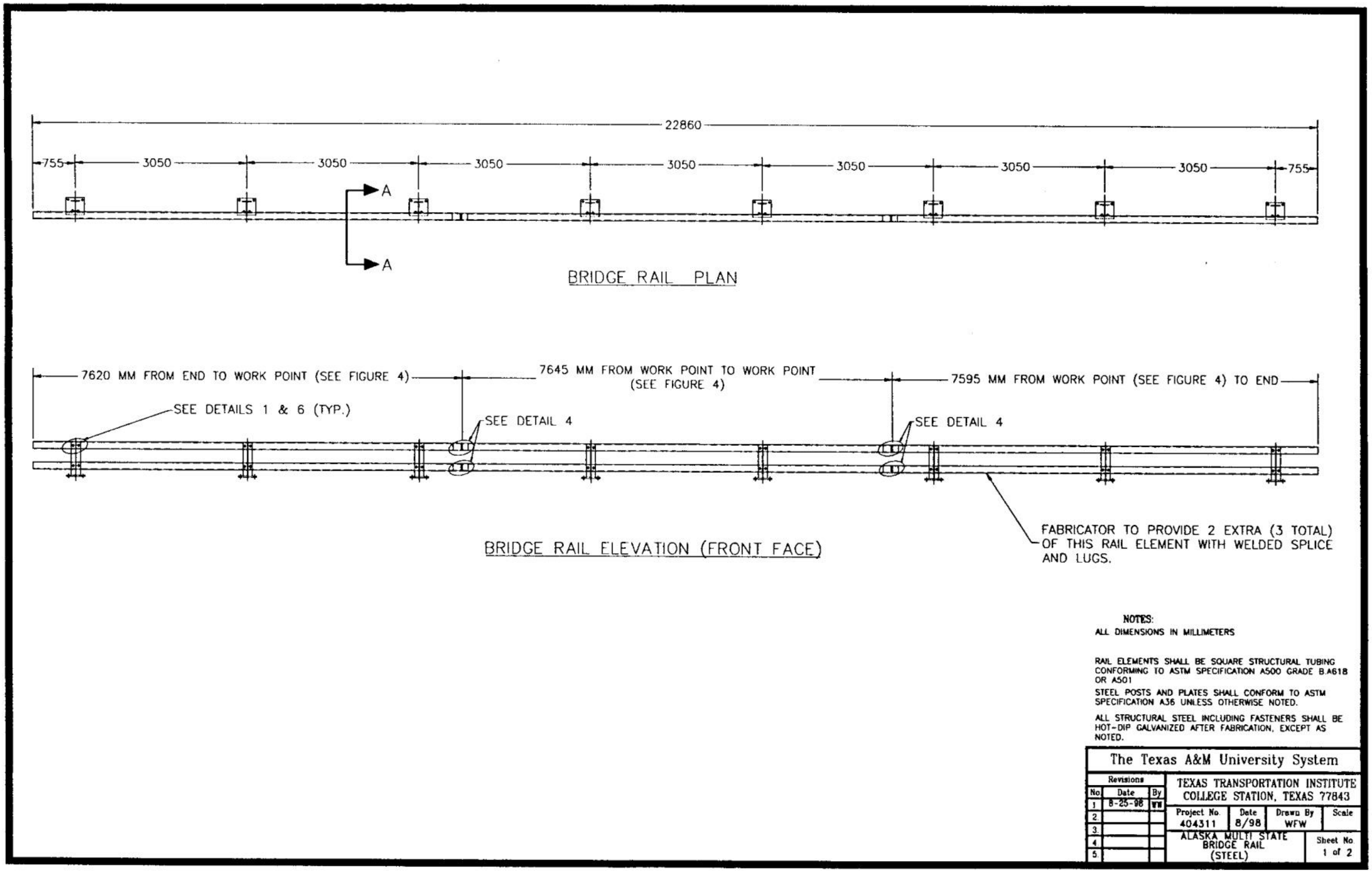



Figure A-32. Alaska Multi-State Bridge Rail, Sheet 2 of 3

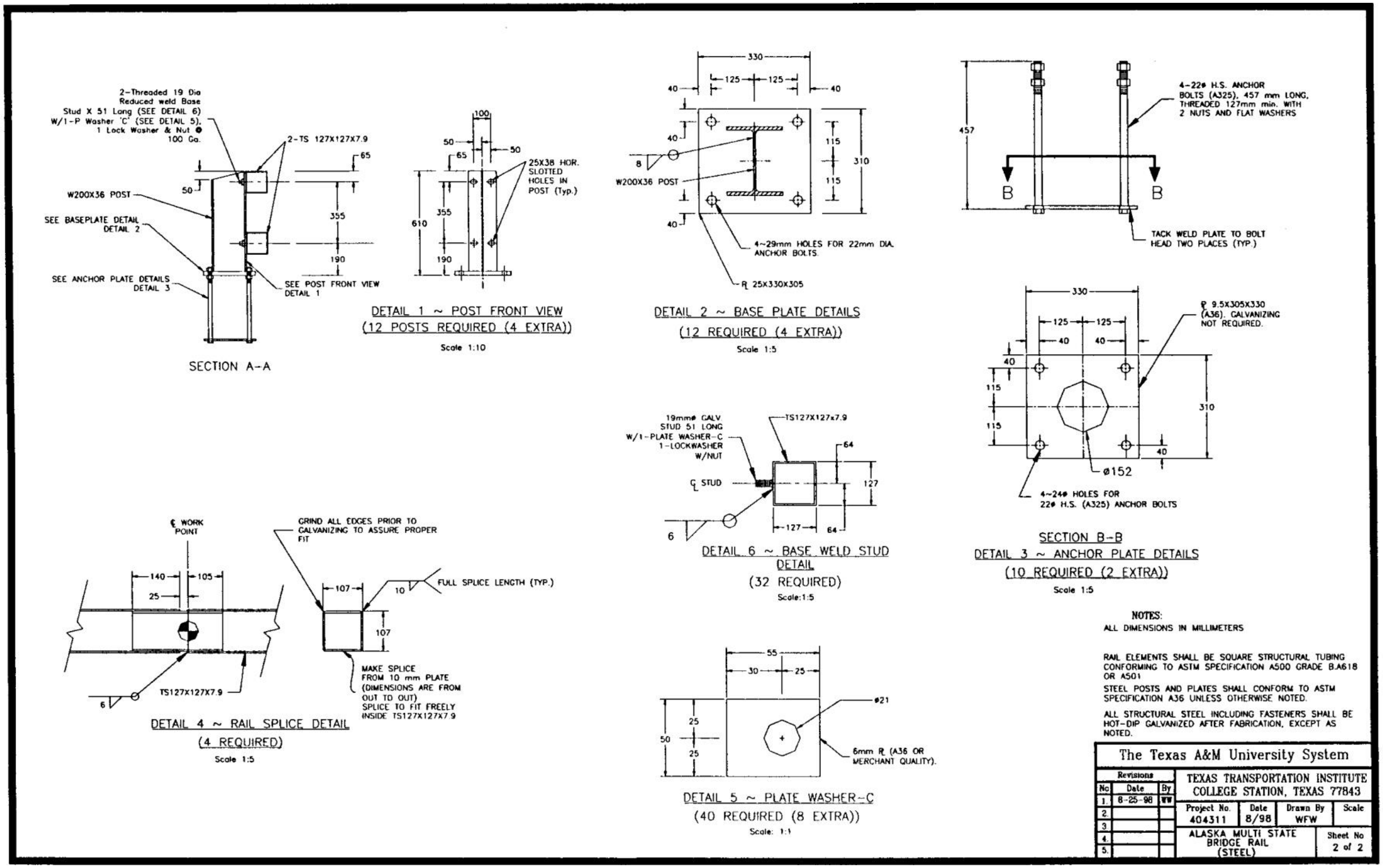



Figure A-33. Alaska Multi-State Bridge Rail, Sheet 3 of 3

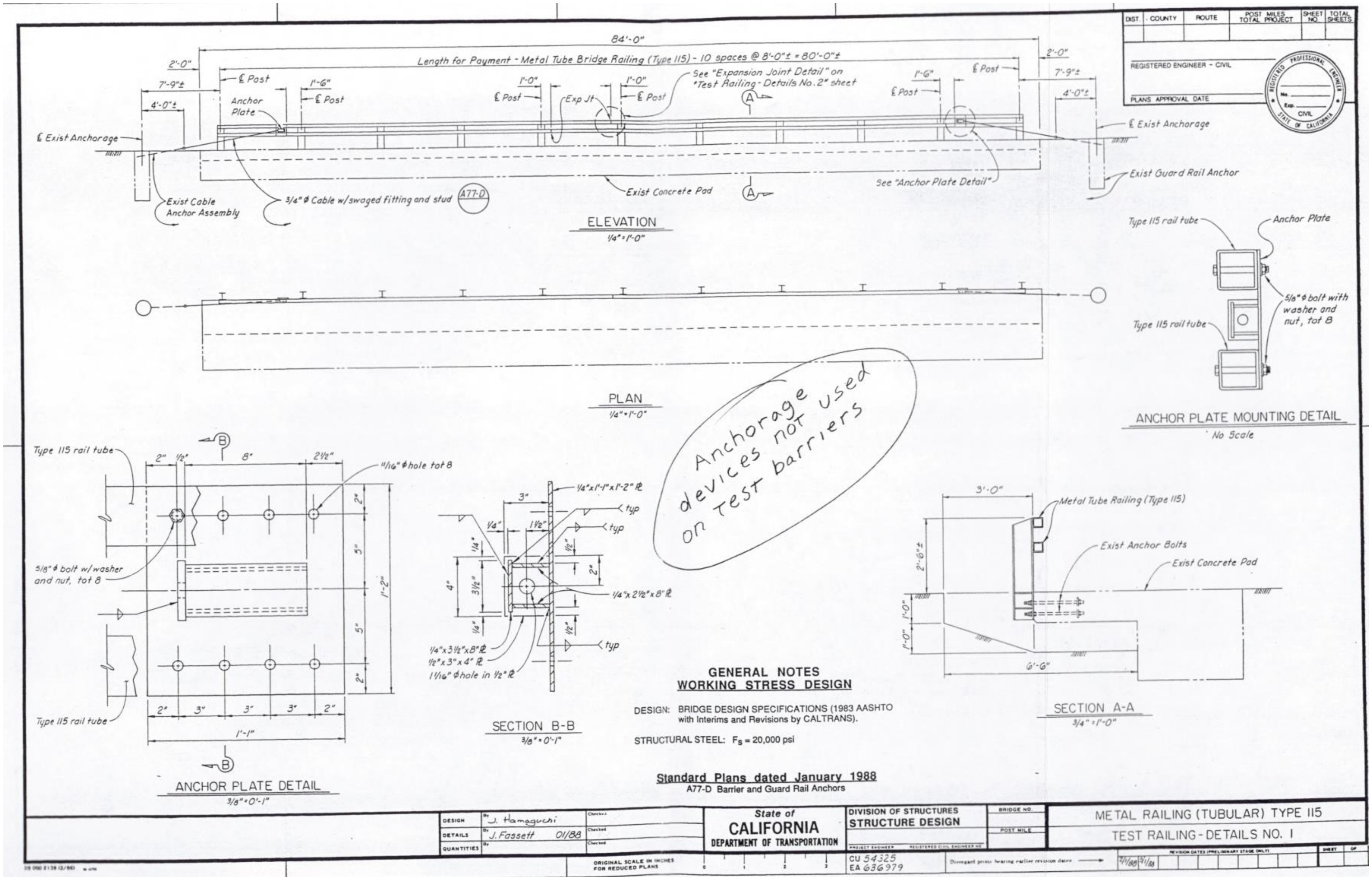



Figure A-34. California Type 115 Bridge Rail, Sheet 1 of 3

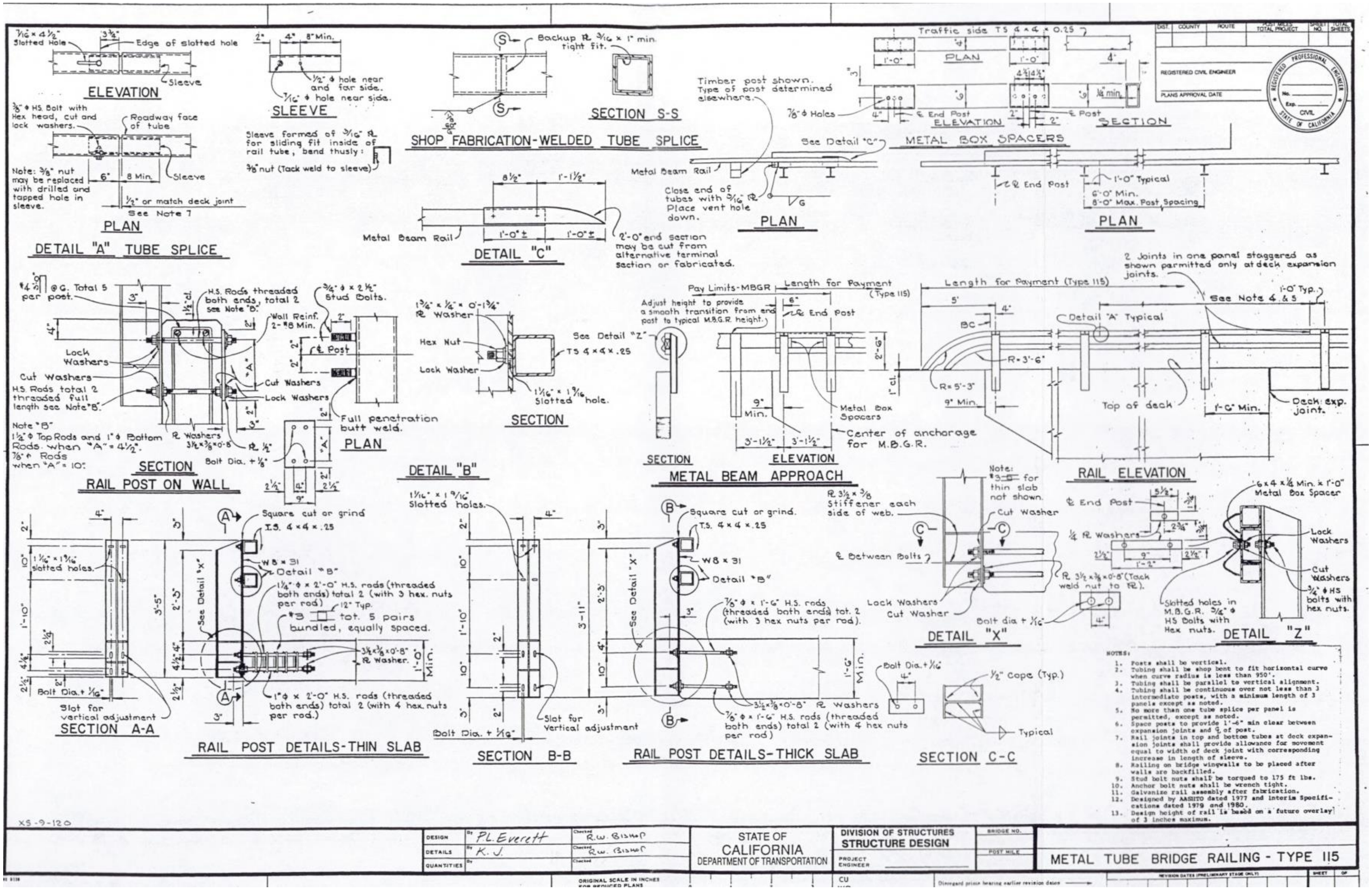


Figure A-35. California Type 115 Bridge Rail, Sheet 2 of 3

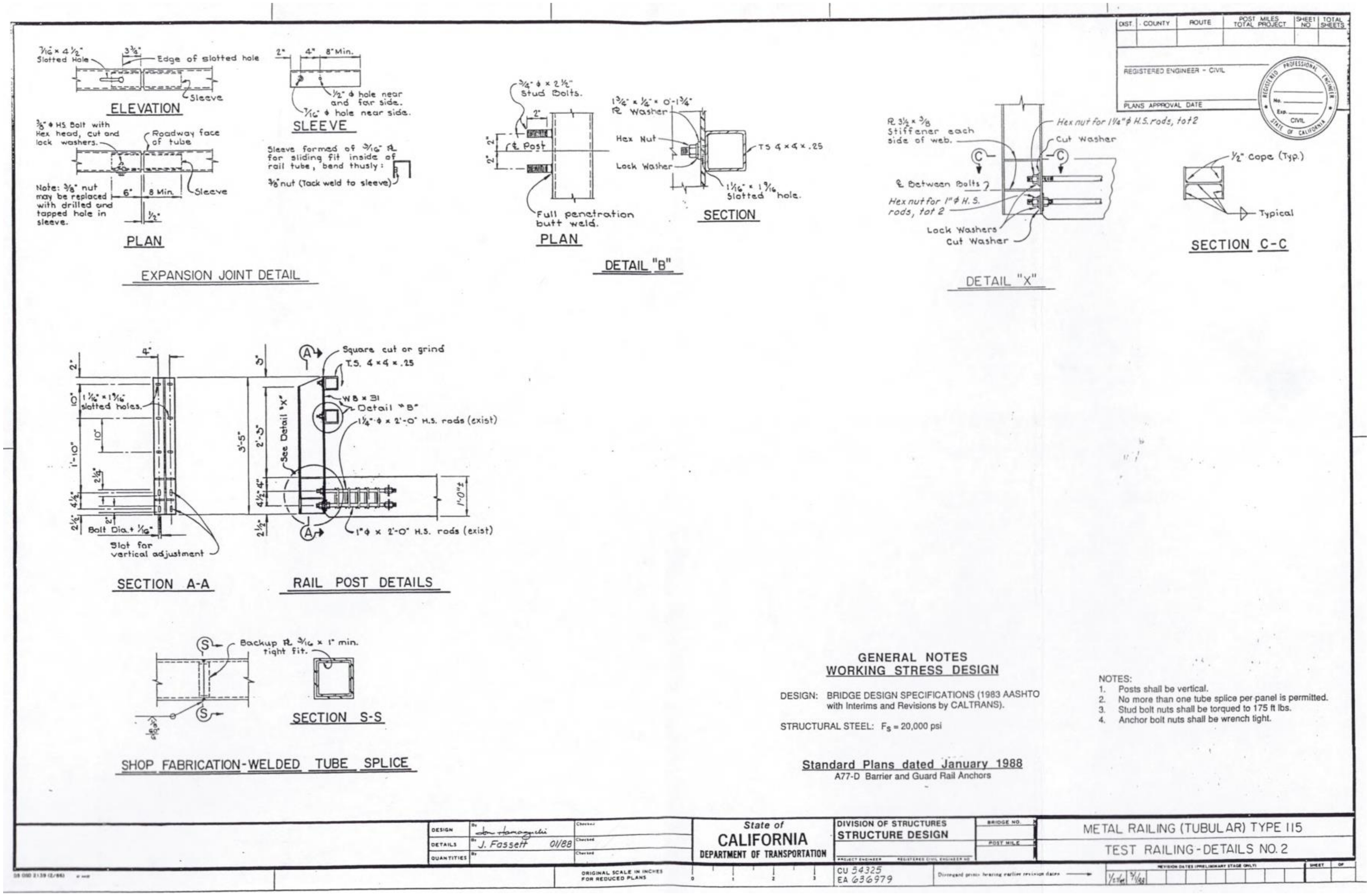



Figure A-36. California Type 115 Bridge Rail, Sheet 3 of 3

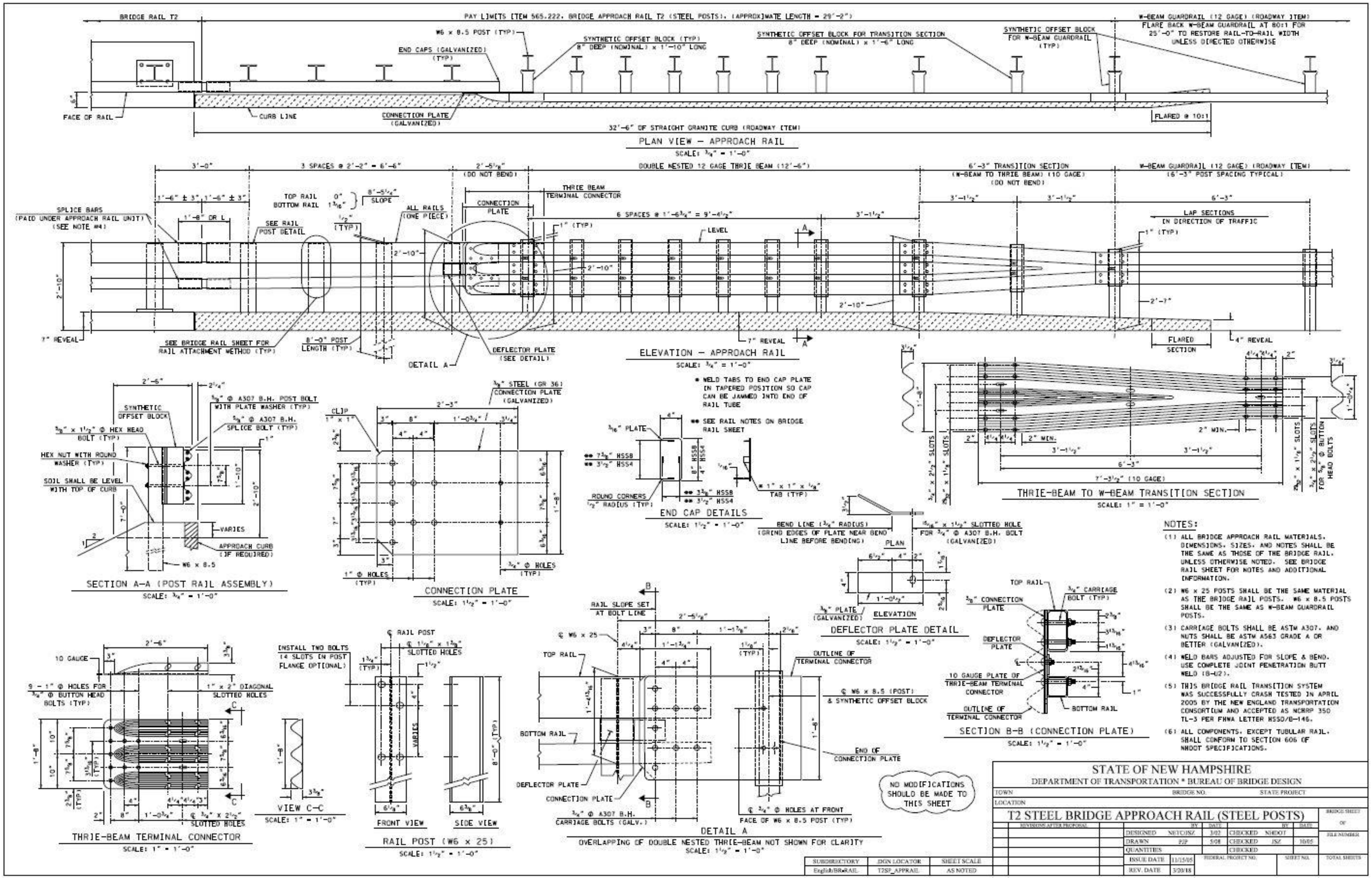



Figure A-37. New Hampshire T2 Steel Bridge Rail Transition

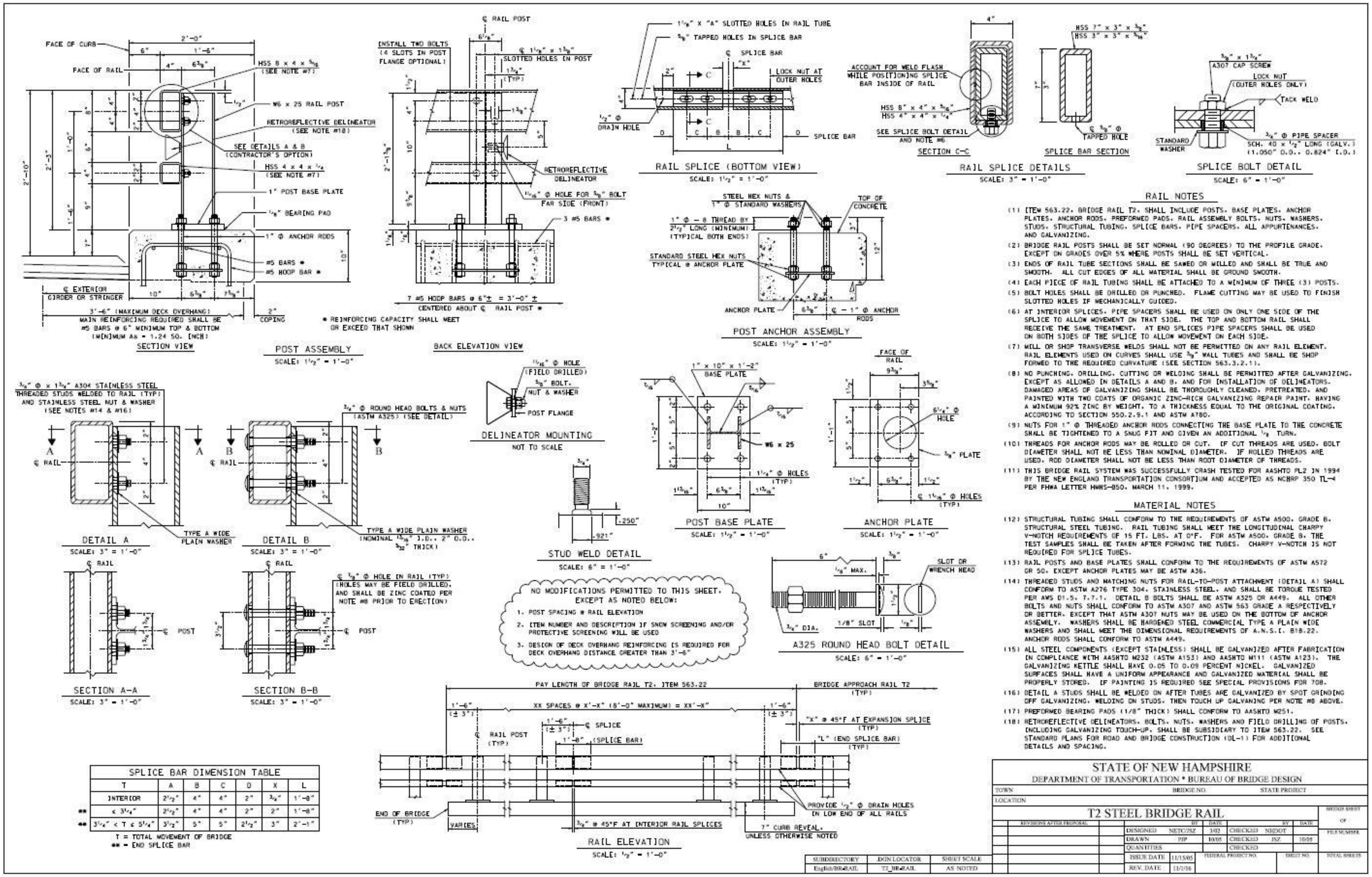



Figure A-38. New Hampshire T2 Steel Bridge Rail

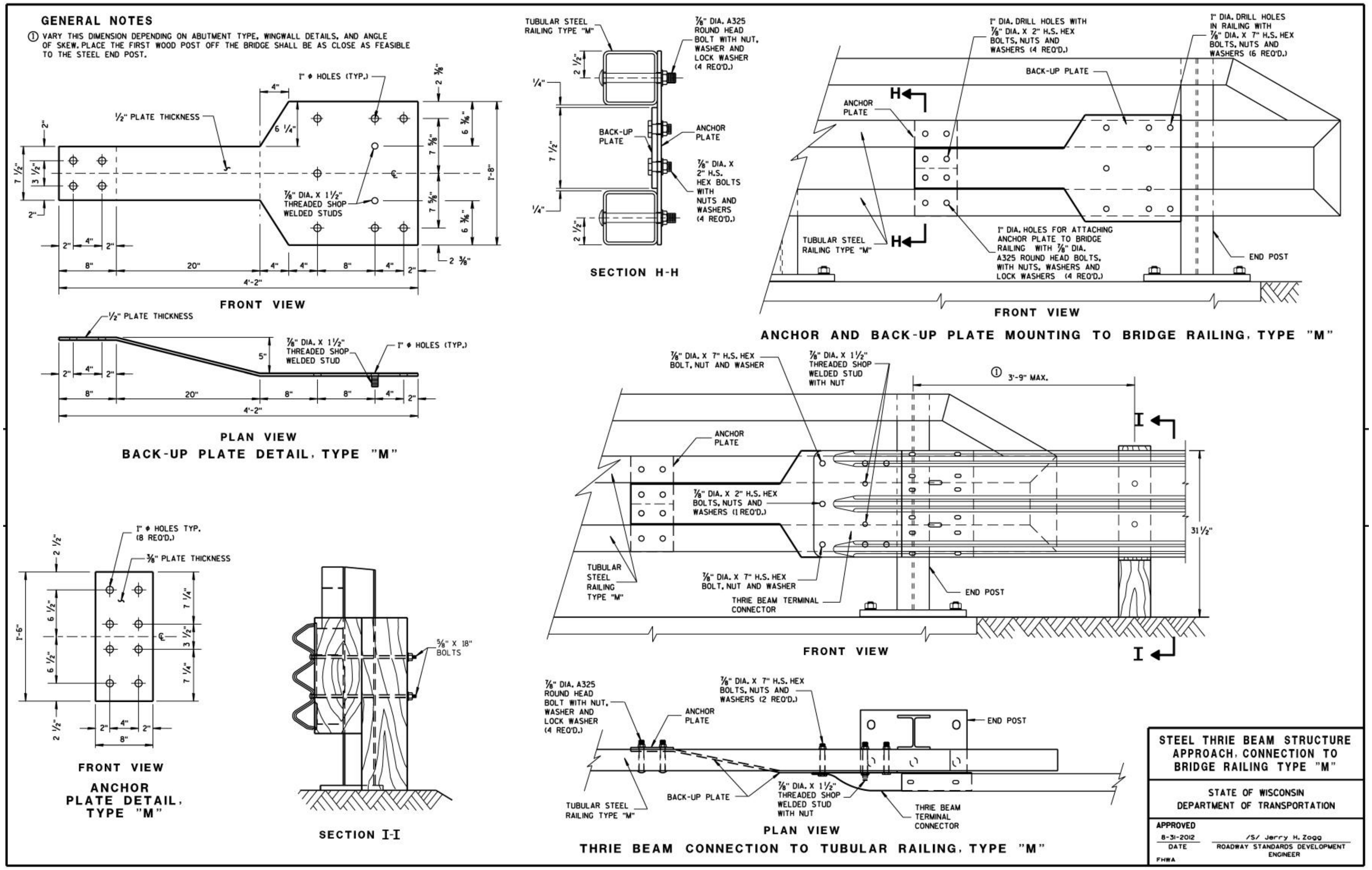



Figure A-39. Wisconsin Thrie-Beam Transition Connection

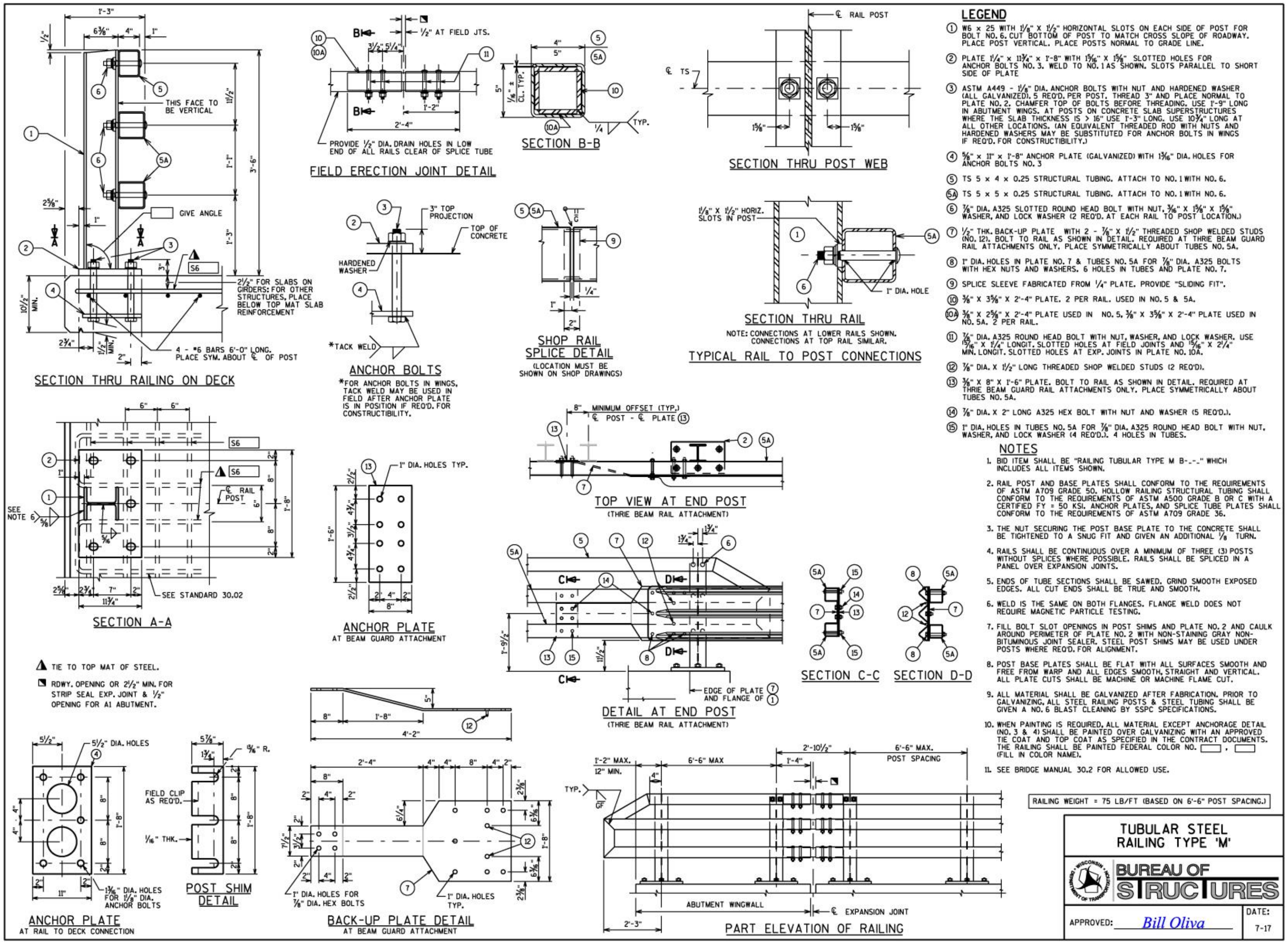



Figure A-40. Wisconsin Tubular Steel Railing Type "M"

# Appendix B. Material Specifications

Table B-1. Bill of Materials, Test Nos. STBRT-1 and STBRT-2

| Item No. | Description | Material Specification | Reference |
|---|---|---|---|
| a1 | 12'-6" 12-gauge Thrie Beam | AASHTO M180 | H#L31920 |
| a2 | 6'-3" 12-gauge Thrie Beam | AASHTO M180 | H#L34919 |
| a3 | 10-gauge Symmetrical W-beam to Thrie Beam Transition | AASHTO M180 | H#C89858 |
| a4 | 12'-6" 12-gauge W-Beam | AASHTO M180 | H#C85187 |
| a5 | 12'-6" 12-gauge W-Beam End | AASHTO M180 | H#C85187 |
| a6 | 10-gauge Thrie Beam Terminal Connector | AASHTO M180<br>Min yield strength = 50 ksi<br>Min. ultimate strength = 70 ksi | H#A81568 |
| a7 | 6'-3" 12-gauge W-Beam MGS | AASHTO M180 | H#31631800 |
| b1 | 30"x10⅝"x$^{5}/_{16}$" Plate | ASTM A572 Gr. 50 | H#18170241 |
| b2 | 30"x2⅝"x⅜" Plate | ASTM A572 Gr. 50 | H#E8H296 |
| b3 | 8"x8"x⅜" Plate | ASTM A572 Gr. 50 | H#E8H296 |
| b4 | 17¾"x13"x1" Post Plate | ASTM A572 Gr. 50 | H#W8J820 |
| b5 | 6 1/8"x5$^{11}/_{16}$"x¼" Gusset | ASTM A572 Gr. 50 | H#E8I347 |
| b6 | HSS5x4x½, 20" Long | ASTM A500 Gr. C | H#17111221 |
| b7 | 30"x6⅝"x⅜" Plate | ASTM A572 Gr. 50 | H#E8H296 |
| b8 | 30"x4⅝"x$^{5}/_{16}$" Plate | ASTM A572 Gr. 50 | H#18170241 |
| b9 | HSS8x6x¼, 191¼" Long | ASTM A500 Gr. C | H#835188 |
| b10 | HSS12x4x¼, 191¼" Long | ASTM A500 Gr. C | H#NH4681 "B" and H#TH4011 |
| b11 | 20"x15"x$^{3}/_{16}$" Steel Plate | ASTM A572 Gr. 50 | H#B8E871 |
| c1 | BCT Timber Post - MGS Height | SYP Grade No. 1 or better (No knots +/- 9" from weakening hole) | Ch#1488 and Ch#652 |
| c2 | 72" Long Foundation Tube | ASTM A500 Gr. B | H#821T08220 |
| c3 | Ground Strut Assembly | ASTM A36 | C.A. 3/22/17 |
| c4 | BCT Cable Anchor Assembly | - | C.o.C. 9/24/2018 |
| c5 | 8"x8"x⅝" Anchor Plate | ASTM A36 | H#4181496 |
| c6 | Anchor Bracket Assembly | ASTM A36 | H#JK16101488 |
| c7 | 2⅜" O.D. x 6" BCT Post Sleeve | ASTM A53 Gr. B Schedule 40 | H#712810 |
| c8 | Bent 16D Double Head Nail | - | C.o.C.8/2/2018 |

Table B-1. Bill of Materials, Test Nos. STBRT-1 and STBRT-2, Cont.

| Item No. | Description | Material Specification | Reference |
|---|---|---|---|
| d1 | W6x9 or W6x8.5, 72" Long Post | ASTM A992 | H#55066998/03 and H#59091883/02 |
| d2 | W6x9 or W6x8.5, 72" Long Post | ASTM A992 | H#55066998/03 and H#59091883/02 |
| d3 | W6x9 or W6x8.5, 72" Long Post | ASTM A992 | H#55066998/03 |
| d4 | W6x15, 84" Long Steel Post | ASTM A992 | H#59091494/02 |
| d5 | W6x15, 53½" Long Post | ASTM A992 | H#59082360/02 |
| d6 | 6"x8"x19" Timber Blockout | SYP Grade No.1 or better | Ch#1695 |
| d7 | 6"x12"x19" Timber Blockout | SYP Grade No.1 or better | CH#1597 |
| d8 | 6"x12"x19" Timber Blockout | SYP Grade No.1 or better | Ch#25698 |
| d9 | 6"x12"x14¼" Timber Blockout | SYP Grade No.1 or better | Ch#1672 |
| e1 | ⅝" Dia. UNC, 14" Long Bolt | ASTM A307 Gr. A | H#DL17100590 |
| e2 | ⅝" Dia. UNC, 10" Long Bolt | ASTM A307 Gr. A | H#1721198 |
| e3 | ⅝" Dia. UNC, 2" Long Bolt | ASTM A307 Gr. A | H#10626360 |
| e4 | ⅝" Dia. UNC, 1¼" Long Bolt | ASTM A307 Gr. A | H#10641050 |
| e5 | ⅝" Dia. UNC, 10" Hex Bolt | ASTM A307 Gr. A | H#JK18104124 |
| e6 | ⅝" Dia. UNC, 1½" Hex Bolt | ASTM A307 Gr. A | H#5-01570 |
| e7 | ¾"-11 UNC, 21" Round Bolt | ASTM A449 | H#3090536 |
| e8 | ¾"-10 UNC, 9½" Heavy Hex Bolt | ASTM F3125 Gr. A325 Type 1 | H#3078659 |
| e9 | ¾"-10 UNC, 7½" Round Bolt | ASTM A449 | H#3078659 H#3090536 |
| e10 | ¾"-10 UNC, 6" Round Head Bolt | ASTM A449 | H#3078659 |
| e11 | ⅞" Dia. UNC, 8" Hex Bolt | ASTM A307 Gr. A | H#489517 |
| e12 | 1"-8 UNC, 3½" Heavy Hex Bolt | ASTM F3125 Gr. A325 Type 1 | H#10552460 |
| e13 | 1"-8 UNC, 2¼" Heavy Hex Bolt | ASTM F3125 Gr. A325 Type 1 | H#10415990 |
| f1 | ⅝" Dia. SAE Plain Round Washer | ASTM F844 | L#M-SWE0412454-8 |
| f2 | ⅞" Dia. USS Plain Round Washer | ASTM F844 | L#1844804 |
| f3 | 1" Dia. USS Plain Round Washer | ASTM F844 | Certified 10/22/2018 |

Table B-1. Bill of Materials, Test Nos. STBRT-1 and STBRT-2, Cont.

| Item No. | Description | Material Specification | Reference |
|---|---|---|---|
| f4 | ¾" Dia. SAE Hardened Flat Washer | ASTM F436 | H#1P791 |
| f5 | 2¼"x2¼"x¼" Square Washer | ASTM A36 | H#17126641 |
| g1 | ¾"-10 UNC Heavy Hex Nut | ASTM A563DH | H#100798971 |
| g2 | ⅝" Dia. Guardrail Nut | ASTM A563A | H#10624590 |
| g3 | ⅝" Dia. Hex Nut | ASTM A563A | H#331608011 |
| g4 | ⅞" Dia. Hex Nut | ASTM A563A | L#1N18BC001<br>L#1N1880113 |
| g5 | 1"-8 UNC Heavy Hex Nut | ASTM A563DH | C.o.C. 11/29/2018 |
| g6 | 1" Dia. Hex Nut | ASTM A563DH | C.o.C. 4/17/2019 |
| h1 | HSS6x4x¼, 36" Long Tapered Tube | ASTM A500 Gr. C | H#90992C |
| h2 | 13"x3 ¾"x¼" Plate | ASTM A572 Gr. 50 | H#B9L648 |
| h3 | 13"x10⅜"x¼" Bent Plate | ASTM A572 Gr. 50 | H#B9L648 |
| h4 | 12"x4"x¼", 15" Long Sloped Transition Rail | ASTM A500 Gr. C | H#NJ8018 Inv#56648 |
| h5 | 12"x4"x¼", 30 1/8" Long Transition Rail | ASTM A500 Gr. C | H#NJ8018 Inv#56648 |
| h6 | HSS8x6x¼, 62 $^{15}/_{16}$" Long Middle Transition Rail | ASTM A500 Gr. C | H#19197161<br>H#87705C |
| h7 | HSS8x6x¼, 45⅜" Long Middle Transition Rail | ASTM A500 Gr. C | H#19197161<br>H#87705C |
| h8 | HSS8"x6x¼, 12 $^{13}/_{16}$" Long Transition Rail | ASTM A500 Gr. C | H#19197161<br>H#87705C |
| h9 | HSS8x6x¼, 62 $^{15}/_{16}$" Long Bottom Transition Rail | ASTM A500 Gr. C | H#19197161<br>H#87705C |
| h10 | HSS8x6x¼, 45⅜" Long Bottom Transition Rail | ASTM A500 Gr. C | H#19197161<br>H#87705C |

# Certified Analysis

Trinity Highway Products LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH & SUPPLY CO
P. O. BOX 703

MILFORD, NE 68405
Project: STOCK

Order Number: 1324622 Prod Ln Grp: 0-OE2.0
Customer PO: 3954
BOL Number: 112739 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 6/30/20

| Qty | Part # | Description | Spec | CL | TY | Heat Code/ Heat | Yield | TS | Elg | C | Mn | P | S | Si | Cu | Cb | Cr | Vn | ACW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 12173G | T12/6'3/4@1'6.75"/S | | | 2 | L34919 | | | | | | | | | | | | | |
| | | | M-180 | A | 2 | 245021 | 64,480 | 83,940 | 22.2 | 0.190 | 0.700 | 0.013 | 0.004 | 0.020 | 0.060 | 0.000 | 0.060 | 0.001 | 4 |
| | | | M-180 | A | 2 | 245984 | 62,860 | 80,840 | 26.2 | 0.190 | 0.720 | 0.008 | 0.003 | 0.010 | 0.080 | 0.000 | 0.050 | 0.000 | 4 |
| 50 | 12365G | T12/12'6/8@1'6.75/S | | | 2 | L32420 | | | | | | | | | | | | | |
| | | | M-180 | A | 2 | 251386 | 62,920 | 81,060 | 24.4 | 0.200 | 0.720 | 0.010 | 0.002 | 0.020 | 0.100 | 0.000 | 0.070 | 0.002 | 4 |
| | | | M-180 | B | 2 | 248862 | 64,080 | 82,460 | 25.1 | 0.180 | 0.730 | 0.011 | 0.001 | 0.020 | 0.100 | 0.000 | 0.060 | 0.001 | 4 |
| | | | M-180 | B | 2 | 249478 | 61,020 | 80,630 | 27.0 | 0.190 | 0.720 | 0.010 | 0.001 | 0.020 | 0.090 | 0.000 | 0.060 | 0.000 | 4 |
| | 12365G | | | | 2 | L31920 | | | | | | | | | | | | | |
| | | | M-180 | A | 2 | 249480 | 63,400 | 81,930 | 25.1 | 0.190 | 0.740 | 0.010 | 0.003 | 0.010 | 0.060 | 0.000 | 0.060 | 0.000 | 4 |
| | | | M-180 | B | 2 | 248862 | 64,080 | 82,460 | 25.1 | 0.180 | 0.730 | 0.011 | 0.001 | 0.020 | 0.100 | 0.000 | 0.060 | 0.001 | 4 |
| 180 | 54043G | 7'0 PST/6X15/DB:3HI | A-572 | | | 59091538 | 62,786 | 81,568 | 20.0 | 0.090 | 1.330 | 0.015 | 0.029 | 0.240 | 0.340 | 0.000 | 0.200 | 0.049 | 4 |

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy QMS-LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.
ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED

2 of 3

Figure B-1. 12-gauge Thrie Beam Sections, Test Nos. STBRT-1 and STBRT-2

NUCOR STEEL GALLATIN LLC

Nucor Steel Gallatin
4831 U.S. Highway 42 West
Ghent, KY 41045-9704
Phone: 1(800)581-3853 Fax: (859)567-3165

## METALLURGICAL CERTIFICATION

**Invoice To:** Metals USA-Flat Rolled-Jeffersonville
702 Port Rd
Jeffersonville, IN 47130

**Ship To:** Metals USA-Flat Rolled-Jeffersonville
Metals USA -Flat Rolled-Jeffersonville
702 Port Road
Jeffersonville, IN 47130

**Date:** 2/18/2019
**Customer No:** 27599
**Customer P.O.:** C44974

**Mill Order No:** 224055-1 **Customer Reference No:** NA **Load No:** 779675

**This product was melted and manufactured in the USA to meet the requirements of:** ASTM A1011-18a SS Gr 50 modified w/ 70 ksi min ten, C 0.26 max, P 0.02max, S 0.05 max, Si 0.04 max
HR Sheet Steel Bands

**Ordered Size:** Min 0.125 (In.) X 51.50 (In.) X Coil
Min 3.175 (mm) X 1308 (mm) X Coil

**Coil Number(s):** 1538093

**CHEMICAL ANALYSIS (Weight %)**

| Heat No | C | Mn | P | S | Si | Cu | Ni | Cr | Mo |
|---|---|---|---|---|---|---|---|---|---|
| C89858 | 0.20 | 0.49 | 0.014 | 0.002 | 0.03 | 0.09 | 0.03 | 0.06 | 0.01 |
| | Al | Ca | Nb | V | B | Ti | N | Sn | |
| | 0.025 | 0.0018 | 0.001 | 0.001 | 0.0001 | 0.001 | 0.0084 | 0.006 | |

**MECHANICAL PROPERTIES**

| Coil Tested | 1538091 | 1538097 | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Yield Strength(ksi) | 58.4 | 59.3 | | | | | | |
| Yield Strength(mpa) | 403 | 409 | | | | | | |
| Tensile Strength(ksi) | 82.9 | 81.6 | | | | | | |
| Tensile Strength(mpa) | 572 | 563 | | | | | | |
| % Elongation | 23.3 | 24.2 | | | | | | |
| N-Value | 0.14 | 0.14 | | | | | | |
| N-Value Range | 5-15% | 5-15% | | | | | | |
| Hardness(HRBW) | 88.5 | 85.4 | | | | | | |
| Test Section | Mill | Mill | | | | | | |
| Orientation | Long | Long | | | | | | |
| Test Method | ASTM | ASTM | | | | | | |

**BEND TEST RESULTS**

| Coil ID # | Orientation | Diameter/radius of mandrel | No. of cracks | Size of cracks | Pass/Fail |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

Hot rolled coils manufactured through Nucor Steel Gallatin do not contain welds or weld repairs at the time of shipment (fca mill)
Mercury was not added during production of this material. The material was produced using a fully killed fine grain practice with a grain size of 6 or finer according to ASTM E112.

This product is in compliance with DFARS 252.225, the Buy American Act.

Above tests performed in accordance to ASTM standards E8 (yield strength determined using 0.2% offset method and elongation determined using at fracture method) or JIS Z2241, E18, E415, and E1019 and are correct as contained in the records of the company.

The elongation original gauge length is 2 inches for ASTM test method and 1.97 inches for JIS test method
Above test results were performed in accordance to EN 10204 3.1

Bend tests were conducted in accordance with ISO 7438, ASTM E290, or JIS Z2248 using the press, guided, two support and a mandrel bend method at a 180 degree bend. Bend test specimen is longer than 6" and wider than 0.8"

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* This mechanical property has been tested at a subcontractor's laboratory.

Neil Miller
Neil Miller
Lab Supervisor
neil.miller@nucor.com

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Figure B-2. 10-ga. W-to-Thrie Transition Segment, Test Nos. STBRT-1 and STBRT-2

**Nucor Steel Gallatin**
4831 U.S. Highway 42 West
Ghent, KY 41045-9704
Phone: 1(800)581-3853 Fax: (859)567-3165

NUCOR
NUCOR STEEL GALLATIN

## METALLURGICAL TEST REPORT

**Invoice To:** Gregory Industries
4100 13th Street SW
Canton, OH 44710

**Ship To:** Gregory Industries
4100 13th Street SW
Canton, OH 44710

**Date:** 1/21/2018
**Customer No:** 10019
**Customer P.O.:** 39620

**Mill Order No:** 214078-1 **Customer Reference No:** 39620 **Load No:** 736148

**This product was melted and manufactured in the USA to meet the requirements of:** 1020 steel for SS 50 grade for Guard Rails - 50 ksi min yield, 70 ksi min tensile, 0.10% max Si, and 0.06% Cr max
HR Sheet Steel Bands

**Ordered Size:** Min 0.095 (In.) X 56.88 (In.) X Coil
Min 2.413 (mm) X 1445 (mm) X Coil

**Coil Number(s):** 1465177

**CHEMICAL ANALYSIS (Weight %)**

| Heat No | C | Mn | P | S | Si | Cu | Ni | Cr | Mo |
|---|---|---|---|---|---|---|---|---|---|
| C85187 | 0.20 | 0.48 | 0.008 | 0.003 | 0.03 | 0.06 | 0.02 | 0.05 | 0.01 |
| | Al | Ca | Nb | V | B | Ti | N | Sn | |
| | 0.029 | 0.0017 | 0.000 | 0.001 | 0.0001 | 0.001 | 0.0080 | 0.003 | |

**MECHANICAL PROPERTIES**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Coil Tested | | | | | | | | |
| Yield Strength(ksi) | | | | | | | | |
| Yield Strength(mpa) | | | | | | | | |
| Tensile Strength(ksi) | | | | | | | | |
| Tensile Strength(mpa) | | | | | | | | |
| % Elongation | | | | | | | | |
| N-Value | | | | | | | | |
| N-Value Range | | | | | | | | |
| Hardness(HRBW) | | | | | | | | |
| Test Section | | | | | | | | |
| Orientation | | | | | | | | |
| Test Method | | | | | | | | |

**BEND TEST RESULTS**

| Coil ID # | Orientation | Diameter/radius of mandrel | No. of cracks | Size of cracks | Pass/Fail |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

Ht code
1207

Hot rolled coils manufactured through Nucor Steel Gallatin do not contain welds or weld repairs at the time of shipment (fca mill).
Mercury was not added during production of this material. The material was produced using a fully killed fine grain practice with a grain size of 6 or finer according to ASTM E112.

This product is in compliance with DFARS 252.225, the Buy American Act.

Above tests performed in accordance to ASTM standards E8 (yield strength determined using 0.2% offset method and elongation determined using at fracture method) or JIS Z2241, E18, E415, and E1019 and are correct as contained in the records of the company.

The elongation original gauge length is 2 inches for ASTM test method and 1.97 inches for JIS test method.
Above test results were performed in accordance to EN 10204 3.1

Bend tests were conducted in accordance with ISO 7438, ASTM E290, or JIS Z2248 using the press, guided, two support and a mandrel bend method at a 180 degree bend. Bend test specimen is longer than 6" and wider than 0.8"

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* This mechanical property has been tested at a subcontractor's laboratory.

Stephen S. Sipple
Stephen S. Sipple
Chemical Laboratory
Mechanical Laboratory
steve.sipple@nucor.com

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**Page 1 of 1**

Figure B-3. 12-gauge W-Beam Sections, Test Nos. STBRT-1 and STBRT-2

NUCOR
NUCOR STEEL GALLATIN

**Nucor Steel Gallatin**
4831 U.S. Highway 42 West
Ghent, KY 41045-9704
Phone: 1(800)581-3853 Fax: (859)567-3165

## METALLURGICAL CERTIFICATION

**Invoice To:** Metals USA-Flat Rolled-Jeffersonville
702 Port Rd
Jeffersonville, IN 47130

**Ship To:** Metals USA-Flat Rolled-Jeffersonville
Pick Up
702 Port Road
Jeffersonville, IN 47130

**Date:** 9/29/2016
**Customer No:** 27599
**Customer P.O.:** C42117

**Mill Order No:** 201815-1 **Customer Reference No:** NA **Load No:** 680178

**This product was melted and manufactured in the USA to meet the requirements of:** ASTM A1011-15 SS Gr 50 modified w/ 70 ksi min ten, C 0.26 max, P 0.02max, S 0.05 max, Si 0.04 max
HR Sheet Steel Bands

**Ordered Size:** Min 0.126 (In.) X 62.25 (In.) X Coil
Min 3.2 (mm) X 1581 (mm) X Coil

**Coil Number(s):** 1376986

**CHEMICAL ANALYSIS (Weight %)**

| Heat No | C | Mn | P | S | Si | Cu | Ni | Cr | Mo |
|---|---|---|---|---|---|---|---|---|---|
| A81568 | 0.20 | 0.70 | 0.010 | 0.002 | 0.03 | 0.11 | 0.03 | 0.04 | 0.02 |
| | Al | Ca | Nb | V | B | Ti | N | Sn | |
| | 0.025 | 0.0014 | 0.000 | 0.001 | 0.0001 | 0.001 | 0.0065 | 0.005 | |

**MECHANICAL PROPERTIES**

| Coil Tested | 1376985 | 1376986 | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Yield Strength(ksi) | 56.1 | 57.6 | | | | | | |
| Yield Strength(mpa) | 387 | 397 | | | | | | |
| Tensile Strength(ksi) | 78.8 | 81.5 | | | | | | |
| Tensile Strength(mpa) | 543 | 562 | | | | | | |
| % Elongation | 26.8 | 23.0 | | | | | | |
| N-Value | 0.16 | 0.15 | | | | | | |
| N-Value Range | 5-15% | 5-15% | | | | | | |
| Hardness(HRBW) | 88.8 | 85.4 | | | | | | |
| Test Section | Mill | Mill | | | | | | |
| Orientation | Long | Long | | | | | | |
| Test Method | ASTM | ASTM | | | | | | |

**BEND TEST RESULTS**

| Coil ID # | Orientation | Diameter/radius of mandrel | No. of cracks | Size of cracks | Pass/ Fail |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

Hot rolled coils manufactured through Nucor Steel Gallatin do not contain welds or weld repairs at the time of shipment (fca mill). Mercury was not added during production of this material. The material was produced using a fully killed fine grain practice.

This product is in compliance with DFARS 252.225, the Buy American Act

Above tests performed in accordance to ASTM standards E8 (yield strength determined using 0.2% offset method and elongation determined using after fracture method) or JIS Z2241, E18, E415, and E1019 and are correct as contained in the records of the company.

The elongation original gauge length is 2 inches for ASTM test method and 1.97 inches for JIS test method.
Above test results were performed in accordance to EN 10204 3.1

Bend tests were conducted in accordance with ISO 7438, ASTM E290, or JIS Z2248 using the press, guided, two support and a mandrel bend method at a 180 degree bend. Bend test specimen is longer than 6" and wider than 0.8"

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* This mechanical property has been tested at a subcontractor's laboratory.

Stephen S. Sipple
Stephen S. Sipple
Chemical Laboratory
Mechanical Laboratory
steve.sipple@nucor.com

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Page 1 of 1

Figure B-4. 10-gauge Thrie Beam Terminal Connector, Test Nos. STBRT-1 and STBRT-2

**GREGORY HIGHWAY PRODUCTS, INC.**
**4100 13th St. SW**
**Canton, Ohio 44710**

Customer: GUARDRAIL SYSTEMS
8000 SERUM AVE.
RALSTON,NE,68127-4213

Test Report
Ship Date; 10/12/2016
Customer P O EMAIL 6-21-2016
Shipped to: GUARDRAIL SYSTEMS
Project: STOCK
GHP Order No.: 9386AJ

| HT # code | Heat # | C. | MN. | P. | S. | Si. | Tensile | Yield | Elong. | Quanity | Class | Type | Description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9760 | 31631800 | 0.2 | 0.85 | 0.01 | 0.001 | 0.04 | 79600 | 62100 | 25 | 6 | A | 1 | 12GA 15FT7.5IN WB T13FT1.5IN |
| 9761 | 4152233 | 0.22 | 0.74 | 0.011 | 0.006 | 0.01 | 79057 | 59958 | 25.33 | 6 | A | 1 | 12 GA 12FT6IN WB T1 FLEAT-SKT COMBO PAN |
| 9760 | 31631800 | 0.2 | 0.85 | 0.01 | 0.001 | 0.04 | 79600 | 62100 | 25 | 5 | A | 1 | 12GA 25FT0IN 3FT1 1/2IN WB T1 |
| 9692 | 31629790 | 0.2 | 0.82 | 0.012 | 0.002 | 0.04 | 81442 | 58556 | 17.56 | 1 | A | 1 | 12GA 25FT0IN 3FT1 1/2IN WB T1 |
| 9760 | 31631800 | 0.2 | 0.85 | 0.01 | 0.001 | 0.04 | 79600 | 62100 | 25 | 40 | A | 1 | 12GA 6FT 3IN WB T1 HS@ 3FT 1.5IN |

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
All other galvanized material conforms with ASTM-123 & ASTM-653
All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska & Iowa Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4

By ___
Andrew Artar, VP of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by Andrew Artar this 13 day of October, 2016

Notary Public, State of Ohio

Figure B-5. 6 ft – 3 in., 12-gauge W-Beam, Test Nos. STBRT-1 and STBRT-2

**STEEL AND PIPE SUPPLY**
**SPS Coil Processing Tulsa**
**5275 Bird Creek Ave.**
**Port of Catoosa, OK 74015**

**METALLURGICAL TEST REPORT**

PAGE 1 of 1
DATE 12/12/2018
TIME 05:49:02

SOLD TO: 66031-1127

SHIP TO: 13716
Kansas City Warehouse
401 New Century Parkway
NEW CENTURY KS

| Order | Material No. | Description | Quantity | Weight | Customer Part | Customer PO | Ship Date |
|---|---|---|---|---|---|---|---|
| 40321447-0010 | 701072120A2 | 5/16 72 X 120 A572GR50 STP MIL PLT | 1 | 765.600 | | | 12/11/2018 |

**Chemical Analysis**

Heat No. 18170241 Vendor BIG RIVER STEEL LLC DOMESTIC Mill BIG RIVER STEEL LLC **Melted and Manufactured in the USA**
**Produced from Coil**

| Carbon | Manganese | Phosphorus | Sulphur | Silicon | Nickel | Chromium | Molybdenum | Boron | Copper | Aluminum | Titanium | Vanadium | Columbium | Nitrogen | Tin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0500 | 0.8600 | 0.0100 | 0.0030 | 0.0300 | 0.0300 | 0.0600 | 0.0100 | 0.0001 | 0.0900 | 0.0280 | 0.0010 | 0.0040 | 0.0160 | 0.0064 | 0.0047 |

**Mechanical / Physical Properties**

Mill Coil No. 18170241-08

| Tensile | Yield | Elong | Rckwl | Grain | Charpy | Charpy Dr | Charpy Sz | Temperature | Olsen |
|---|---|---|---|---|---|---|---|---|---|
| 73700.000 | 65900.000 | 29.60 | | | 187 | Longitudinal | 6.7 | -20 F | |
| 72800.000 | 62900.000 | 33.20 | | | 182 | Longitudinal | 6.7 | -20 F | |
| | | | | | 183 | Longitudinal | 6.7 | -20 F | |

Batch 0005584036 1 EA 765.600 LB

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.
The material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1
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Figure B-6. $^{5}/_{16}$-in. Plates, Test Nos. STBRT-1 and STBRT-2

**STEEL AND PIPE SUPPLY**
**SPS Coil Processing Tulsa**
**5275 Bird Creek Ave.**
**Port of Catoosa, OK 74015**

**METALLURGICAL TEST REPORT**

PAGE 1 of 1
DATE 11/01/2018
TIME 05:59:17

SOLD TO: 66031-1127

SHIP TO: 13716
Kansas City Warehouse
401 New Century Parkway
NEW CENTURY KS

| Order | Material No. | Description | Quantity | Weight | Customer Part | Customer PO | Ship Date |
|---|---|---|---|---|---|---|---|
| 40317778-0010 | 721296120A2 | 3/8 96 X 120 A572GR50 MILL PLATE | 3 | 3,676.800 | | | 10/31/2018 |

**Chemical Analysis**

Heat No. E8H296 Vendor SSAB - MONTPELIER WORKS DOMESTIC Mill SSAB - MONTPELIER WORKS **Melted and Manufactured in the USA**
**Produced from Coil**

| Carbon | Manganese | Phosphorus | Sulphur | Silicon | Nickel | Chromium | Molybdenum | Boron | Copper | Aluminum | Titanium | Vanadium | Columbium | Nitrogen | Tin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1800 | 1.0300 | 0.0100 | 0.0020 | 0.0400 | 0.1500 | 0.0900 | 0.0300 | 0.0000 | 0.3000 | 0.0410 | 0.0010 | 0.0240 | 0.0010 | 0.0000 | 0.0000 |

**Mechanical / Physical Properties**

Mill Coil No. E8H2960947

| Tensile | Yield | Elong | Rckwl | Grain | Charpy | Charpy Dr | Charpy Sz | Temperature | Olsen |
|---|---|---|---|---|---|---|---|---|---|
| 80100.000 | 57500.000 | 27.50 | | | 0 | NA | | | |
| 82100.000 | 61500.000 | 30.30 | | | 0 | NA | | | |
| 84500.000 | 65900.000 | 28.00 | | | 0 | NA | | | |
| 79600.000 | 58500.000 | 27.00 | | | 0 | NA | | | |

Batch 0005536674 3 EA 3,676.800 LB

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.
The material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1
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Figure B-7. ⅜-in. Plates, Test Nos. STBRT-1 and STBRT-2

**SSAB**
12400 Highway 43 North, Axis, Alabama 36505, US

**Test Certificate**

Form TC1: Revision 3: Date 7 Feb 2018

**Customer:**
STEEL & PIPE SUPPLY
P.O. BOX 1688

MANHATTAN
KS 66502

**Customer P.O.No.:** 4500317235
**Mill Order No.** 41-553979-03
**Shipping Manifest:** AT276683
**Product Description:** ASTM A572-50/M345(18)/A709-50/M345(17)
**Ship Date:** 05 Nov 18
**Cert Date:** 05 Nov18
**Cert No:** 081692938 (Page 1 of 1)
**Size:** 1.000 X 96.00 X 240.0 (IN)

| Tested Pieces: | | | | Tensiles: | | | | | | | Charpy Impact Tests | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Heat Id | Piece Id | Piece Dimensions | Tst Loc | YS (KSI) | UTS (KSI) | %RA | Elong % 2in | Elong % 8in | Tst Dir | Hardness | Abs. Energy(FTLB) 1 | 2 | 3 | Avg | % Shear 1 | 2 | 3 | Avg | Tst Tmp | Tst Dir | Tst Siz (mm) | BDWTT Tmp %Shr |
| W8J820 | D19 | 0.999 (DISCRT) | L | 58 | 79 | | | 24 | T | | | | | | | | | | | | | |

**Chemical Analysis**

| Heat Id | C | Mn | P | S | Si | Tot Al | Cu | Ni | Cr | Mo | Cb | V | Ti | ORGN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W8J820 | .18 | 1.17 | .008 | <.001 | .25 | .031 | .24 | .12 | .11 | .03 | .000 | .052 | .008 | USA |

KILLED STEEL
MERCURY IS NOT A METALLURGICAL COMPONENT OF THE STEEL AND NO MERCURY WAS INTENTIONALLY ADDED DURING THE MANUFACTURE OF THIS PRODUCT.
MTR EN 10204:2004 INSPECTION CERTIFICATE 3.1 COMPLIANT
100% MELTED AND MANUFACTURED IN THE USA.
PRODUCTS SHIPPED:
W8J820 D19 PCES: 3, LBS: 19602

(P) Cust Part #: 7210096240A2

WE HEREBY CERTIFY THAT THIS MATERIAL WAS TESTED IN ACCORDANCE WITH, AND MEETS THE REQUIREMENTS OF, THE APPROPRIATE SPECIFICATION

Justin Ward
SENIOR METALLURGIST - PRODUCT

Figure B-8. 17¾-in. x 13-in. x 1-in. Post Plate, Test Nos. STBRT-1 and STBRT-2

**STEEL AND PIPE SUPPLY**
**SPS Coil Processing Tulsa**
**5275 Bird Creek Ave.**
**Port of Catoosa, OK 74015**

# METALLURGICAL TEST REPORT

**PAGE** 1 of 1
**DATE** 11/30/2018
**TIME** 05:54:18

SOLD TO
66031-1127

SHIP TO
13716
Kansas City Warehouse
401 New Century Parkway
NEW CENTURY KS

| Order | Material No. | Description | Quantity | Weight | Customer Part | Customer PO | Ship Date |
|---|---|---|---|---|---|---|---|
| 40320870-0010 | 72896240A2 | 1/4 96 X 240 A572GR50 MILL PLATE | 2 | 3,267.200 | | | 11/29/2018 |

**Chemical Analysis**

Heat No. E8I347 Vendor SSAB - MONTPELIER WORKS DOMESTIC Mill SSAB - MONTPELIER WORKS **Melted and Manufactured in the USA**
**Produced from Coil**

| Carbon | Manganese | Phosphorus | Sulphur | Silicon | Nickel | Chromium | Molybdenum | Boron | Copper | Aluminum | Titanium | Vanadium | Columbium | Nitrogen | Tin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1600 | 1.0100 | 0.0070 | 0.0040 | 0.0300 | 0.1200 | 0.0700 | 0.0400 | 0.0000 | 0.2100 | 0.0370 | 0.0010 | 0.0210 | 0.0000 | 0.0000 | 0.0000 |

**Mechanical / Physical Properties**

Mill Coil No. E8I3470512

| Tensile | Yield | Elong | Rckwl | Grain | Charpy | Charpy Dr | Charpy Sz | Temperature | Olsen |
|---|---|---|---|---|---|---|---|---|---|
| 78500.000 | 59700.000 | 27.40 | | | 56 | Longitudinal | 5.0 | -20 F | |
| 75600.000 | 56900.000 | 32.40 | | | 50 | Longitudinal | 5.0 | -20 F | |
| 77700.000 | 59600.000 | 29.60 | | | 43 | Longitudinal | 5.0 | -20 F | |
| 78500.000 | 60400.000 | 25.00 | | | 0 | NA | | | |

Batch 0005571830 2 EA 3,267.200 LB

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.
The material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1


Figure B-9. ¼-in. Gusset Plate, Test Nos. STBRT-1 and STBRT-2

Atlas Tube Corporation
1855 East 122nd Street
Chicago, Illinois, USA
60633
Tel: 773-646-4500
Fax: 773-646-6128

**Atlas Tube**
A DIVISION OF ZEKELMAN INDUSTRIES

**Ref.B/L:** 80795210
**Date:** 11.30.2017
**Customer:** 193

## MATERIAL TEST REPORT

**Sold to**

Tubular Steel
1031 Executive Parkway
ST. LOUIS MO 63141
USA

**Shipped to**

Tubular Steel
7220 Polson Lane
HAZELWOOD MO 63042
USA

**Material:** 20.0x8.0x500x43'0"0(1x2)NMH **Material No:** 200080500 **Made in:** USA **Melted in:** USA

**Sales order:** 1216180 **Purchase Order:** PO-064074 **Cust Material #:** 013969

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E44934 | 0.200 | 0.800 | 0.010 | 0.008 | 0.010 | 0.046 | 0.020 | 0.004 | 0.006 | 0.010 | 0.030 | 0.001 | 0.001 | 0.000 | 0.006 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE: 0.34 |
|---|---|---|---|---|---|---|
| M900960662 | 2 | 058209 Psi | 075041 Psi | 36 % | ASTM A500-13 GRADE B&C | |

**Material Note:**
**Sales Or.Note:**

**Material:** 4.0x4.0x500x40'0"0(4x2). **Material No:** 400405004000 **Made in:** USA **Melted in:** USA

**Sales order:** 1236805 **Purchase Order:** PO-065525 **Cust Material #:** 012007

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17117241 | 0.200 | 0.740 | 0.006 | 0.002 | 0.030 | 0.029 | 0.110 | 0.001 | 0.010 | 0.040 | 0.030 | 0.003 | 0.000 | 0.000 | 0.008 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE: 0.35 |
|---|---|---|---|---|---|---|
| M800744469 | 8 | 073296 Psi | 084387 Psi | 31 % | ASTM A500-13 GRADE B&C | |

**Material Note:**
**Sales Or.Note:**

**Material:** 5.0x4.0x500x40'0"0(3x3). **Material No:** 500405004000 **Made in:** USA **Melted in:** USA

**Sales order:** 1236805 **Purchase Order:** PO-065525 **Cust Material #:** 012321

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17111221 | 0.210 | 0.740 | 0.005 | 0.002 | 0.030 | 0.031 | 0.060 | 0.001 | 0.017 | 0.030 | 0.030 | 0.003 | 0.001 | 0.000 | 0.006 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE: 0.35 |
|---|---|---|---|---|---|---|
| M800743105 | 9 | 066916 Psi | 077416 Psi | 36 % | ASTM A500-13 GRADE B&C | |

**Material Note:**
**Sales Or.Note:**

**Authorized by Quality Assurance:**
**The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.**
**CE calculated using the AWS D1.1 method.**

Steel Tube Institute OF NORTH AMERICA

Page : 2 Of 3

Metals Service Center Institute

Figure B-10. 20-in. Long HSS5x4x½, Test Nos. STBRT-1 and STBRT-2

Atlas Tube Canada
200 Clark St.
Harrow Ontario Canada
NOR 1G0
Tel: 519-738-3541
Fax: 519-738-3537

Atlas Tube
A DIVISION OF ZEKELMAN INDUSTRIES

REF.B/L: 80852636
Date: 11/13/2018
Customer: 179

## MATERIAL TEST REPORT

Sold To
Steel & Pipe Supply Company
PO Box 1688
MANHATTAN KS 66505
USA

Shipped To
Steel & Pipe Supply Company
1020 West Fort Gibson
CATOOSA OK 74015
USA

Material: 16.0x4.0x375x40'0"0(1x2). Material No: 160040375 Made in: Canada
Melted in: Canada
Sales Order: 1340914 Purchase Order: 4500318744 Cust Material#: 66160040037540

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N | Ca |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 835845 | 0.200 | 0.810 | 0.013 | 0.008 | 0.017 | 0.042 | 0.036 | 0.005 | 0.003 | 0.011 | 0.047 | 0.002 | 0.002 | 0.0002 | 0.0040 | 0.0002 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | |
|---|---|---|---|---|---|---|
| M201325206 | 2 | 060925 Psi | 073628 Psi | 37.8 % | ASTM A500-18 GRADE B&C | CE: 0.35 |

Material Note:
Sales Or. Note:

Material: 8.0x6.0x250x40'0"0(3x2). Material No: 800602504000 Made in: Canada
Melted in: Canada
Sales Order: 1337754 Purchase Order: C450007477 Cust Material#: 6680060025040

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N | Ca |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 835188 | 0.190 | 0.800 | 0.008 | 0.011 | 0.022 | 0.046 | 0.066 | 0.005 | 0.005 | 0.021 | 0.035 | 0.002 | 0.002 | 0.0002 | 0.0050 | 0.0000 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | |
|---|---|---|---|---|---|---|
| M101826832 | 6 | 058363 Psi | 065756 Psi | 33.9 % | ASTM A500-18 GRADE B&C | CE: 0.34 |

Material Note:
Sales Or. Note:

ALL 40 PIECES THIS HEAT#

Authorized by Quality Assurance: Jason Richard

The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
CE calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Metals Service Center Institute

Page: 2 of 2

Figure B-11. HSS8x6x¼, Test Nos. STBRT-1 and STBRT-2

12Sep18 13:39 TEST CERTIFICATE No: DCR 865273

INDEPENDENCE TUBE CORPORATION
6226 W. 74TH STREET
CHICAGO, IL 60638
Tel: 708-496-0380 Fax: 708-563-1950

P/O No 4500315602
Rel
S/O No DCR 107708-005
B/L No DCR 73528-004 Shp 12Sep18
Inv No Inv

Sold To: ( 5018)
STEEL & PIPE SUPPLY
4750 W. MARSHALL AVENUE
LONGVIEW, TX 75604

Ship To: ( 1)
STEEL & PIPE SUPPLY
4750 W. MARSHALL AVENUE
LONGVIEW, TX 75604

Tel: 785-587-5100 Fax: 785 587-5339

CERTIFICATE of ANALYSIS and TESTS Cert. No: DCR 865273
06Sep18

| Part No | | Pcs | Wgt |
|---|---|---|---|
| TUBING A500 GRADE B(C) 12" X 4" X 1/4" X 40' | | 6 | 6,197 |
| Heat Number | Tag No | Pcs | Wgt |
| NH4681 | 28422 | 6 | 6,197 |

YLD=61100/TEN=70900/ELG=33

8-PIECES MARKED "B" THIS HEAT #

Heat Number *** Chemical Analysis ***
NH4681 C=0.0600 Mn=0.5800 P=0.0050 S=0.0010 Si=0.2520 Al=0.0310
Cu=0.0700 Cr=0.0300 Mo=0.0100 V=0.0020 Ni=0.0200 Nb=0.0090
Cb=0.0090 Sn=0.0020 N=0.0048 B=0.0001 Ti=0.0010 Ca=0.0010
MELTED AND MANUFACTURED IN THE USA

WE PROUDLY MANUFACTURE ALL OUR PRODUCT IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED,
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.
MATERIAL IDENTIFIED AS A500 GRADE B(C) MEETS BOTH
ASTM A500 GRADE B AND A500 GRADE C SPECIFICATIONS.

CURRENT STANDARDS:
A252-10
A500/A500M-18
A513/A513M-15
ASTM A53/A53M-12 | ASME SA-53/SA-53M-13
A847/A847M-14
A1085/A1085M-15

22Aug18 22:57 TEST CERTIFICATE No: DCR 852468

INDEPENDENCE TUBE CORPORATION
6226 W. 74TH STREET
CHICAGO, IL 60638
Tel: 708-496-0380 Fax: 708-563-1950

P/O No 4500314328
Rel
S/O No DCR 107030-001
B/L No DCR 73089-002 Shp 22Aug18
Inv No Inv

Sold To: ( 5018)
STEEL & PIPE SUPPLY
4750 W. MARSHALL AVENUE
LONGVIEW, TX 75604

Ship To: ( 1)
STEEL & PIPE SUPPLY
4750 W. MARSHALL AVENUE
LONGVIEW, TX 75604

Tel: 785-587-5100 Fax: 785 587-5339

CERTIFICATE of ANALYSIS and TESTS Cert. No: DCR 852468
17Aug18

| Part No | | Pcs | Wgt |
|---|---|---|---|
| TUBING A500 GRADE B(C) 12" X 4" X 1/4" X 40' | | 6 | 6,197 |
| Heat Number | Tag No | Pcs | Wgt |
| TH4011 | 21552 | 6 | 6,197 |

YLD=66200/TEN=78000/ELG=25

12-PIECES NOT MARKED THIS HEAT #

Heat Number *** Chemical Analysis ***
TH4011 C=0.0600 Mn=0.6200 P=0.0080 S=0.0010 Si=0.2530 Al=0.0350
Cu=0.1200 Cr=0.0500 Mo=0.0200 V=0.0030 Ni=0.0400 Nb=0.0090
Cb=0.0090 Sn=0.0070 N=0.0087 B=0.0002 Ti=0.0010 Ca=0.0016
MELTED AND MANUFACTURED IN THE USA

WE PROUDLY MANUFACTURE ALL OUR PRODUCT IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED,
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.
MATERIAL IDENTIFIED AS A500 GRADE B(C) MEETS BOTH
ASTM A500 GRADE B AND A500 GRADE C SPECIFICATIONS.

CURRENT STANDARDS:
A252-10
A500/A500M-18
A513/A513M-15
ASTM A53/A53M-12 | ASME SA-53/SA-53M-13
A847/A847M-14
A1085/A1085M-15

Figure B-12. HSS12x4x¼, Test Nos. STBRT-1 and STBRT-2

**STEEL AND PIPE SUPPLY**
SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

**METALLURGICAL TEST REPORT**

PAGE 1 of 1
DATE 10/09/2018
TIME 08:56:11
USER WF-BATCH

SOLD TO
66031-1127

SHIP TO
13716
Kansas City Warehouse
401 New Century Parkway
NEW CENTURY KS

| Order | Material No. | Description | Quantity | Weight | Customer Part | Customer PO | Ship Date |
|---|---|---|---|---|---|---|---|
| 40316995-0010 | 72696240A2 | 3/16 96 X 240 A572GR50 MILL PLATE | 3 | 3,676.800 | | | 10/08/2018 |

**Chemical Analysis**

Heat No. B8E871 Vendor SSAB - MONTPELIER WORKS DOMESTIC Mill SSAB - MONTPELIER WORKS Melted and Manufactured in the USA
Produced from Coil

| Carbon | Manganese | Phosphorus | Sulphur | Silicon | Nickel | Chromium | Molybdenum | Boron | Copper | Aluminum | Titanium | Vanadium | Columbium | Nitrogen | Tin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1500 | 0.8400 | 0.0080 | 0.0020 | 0.0400 | 0.0900 | 0.0800 | 0.0300 | 0.0000 | 0.2800 | 0.0310 | 0.0080 | 0.0200 | 0.0010 | 0.0000 | 0.0000 |

**Mechanical / Physical Properties**

Mill Coil No. B8E8710925

| Tensile | Yield | Elong | Rckwl | Grain | Charpy | Charpy Dr | Charpy Sz | Temperature | Olsen |
|---|---|---|---|---|---|---|---|---|---|
| 72900.000 | 53000.000 | 27.60 | | | 33 | Longitudinal | 3.3 | -20 F | |
| 73800.000 | 56300.000 | 25.60 | | | 34 | Longitudinal | 3.3 | -20 F | |
| 75500.000 | 60200.000 | 27.10 | | | 33 | Longitudinal | 3.3 | -20 F | |
| 73900.000 | 56100.000 | 30.00 | | | 0 | NA | | | |

Batch 0005505764 3 EA 3,676.800 LB Batch 0005505757 8 EA 9,804.800 LB Batch 0005505763 8 EA 9,804.800 LB

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.
The material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1
This test report shall not be reproduced, except in full, without the written approval of Steel & Pipe Supply Company, Inc.

Figure B-13. 20-in. x 15-in. x $^{3}/_{16}$-in. Steel Plate, Test Nos. STBRT-1 and STBRT-2

Charge 1488
Plant: (02) Central Nebraska
Sutton, NE EPA Reg. No. 3008-36

Treatment: TRINITY GUARDRAIL
Date: 2/19/2020 7:27 AM
Preservative: CCA
Retention Target: 0.6
Cylinder: 1 Void (9000)
Tank: 2
Operator: Bob

Total Time: 01:45
Change Out (min): 36.5
Change Out Reason:
Board Ft: 5,157
Cubic Ft: 430
DVIn / DVOut: 393 / 388
Treat By: Tally
Date Off DripPad: 2/19/20 9:12 PM

| Step | Time Min | Time Max | Time Act | Pressure Min | Pressure Max | Pressure Act | Injection Min | Injection Max | Injection Act | Retention Min | Retention Max | Retention Act | Flow Rate Min | Flow Rate Max | Flow Rate Act | Temp | Ramp | Time Start | Time End |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial Vacuum | | 7.0 | 7.0 | | -22 | -22 | | | 0.00 | | | 0.000 | | | 0.0000 | | | 07:27:54 | 07:34:57 |
| Fill | | 6.0 | 5.1 | | -22 | -3 | | | 0.64 | | | 0.103 | | | 2.5866 | | | 07:34:58 | 07:40:05 |
| Raise Press | | 7.0 | 0.7 | | 75 | 77 | | | 1.23 | | | 0.197 | | | 0.0000 | | | 07:40:05 | 07:40:50 |
| Pressure | 20 | 25.0 | 25.0 | | 140 | 140 | | 3.40 | 3.48 | | | 0.559 | | 0.0300 | 0.0140 | | | 07:40:50 | 08:05:52 |
| Press Relief | | 4.0 | 3.9 | 15 | 25 | 9 | | | 3.35 | | | 0.538 | | | 0.0000 | | 4 | 08:05:52 | 08:09:43 |
| Empty | | 7.0 | 5.8 | | | -1 | | | 2.76 | | | 0.463 | | | 0.0000 | | | 08:09:44 | 08:15:29 |
| Final Vacuum | 50 | 50.0 | 50.0 | | -23 | -23 | | 2.10 | 2.94 | | | 0.492 | | | 0.0000 | | | 08:15:30 | 09:05:31 |
| Final Empty | | 7.0 | 6.1 | | | -1 | | | 1.69 | | | 0.291 | | | 0.0000 | | | 09:05:32 | 09:11:38 |
| Finish | | 0.5 | 0.5 | | | -1 | | | 1.69 | | | 0.291 | | | 0.0000 | | | 09:11:38 | 09:12:09 |

Automatic Mix Information

| Chemical | Current | Target | As Mixed | Unit | Required | Actual | Difference |
|---|---|---|---|---|---|---|---|
| Water | 7,015 | 7,860 | 7,873 | Gals. | 825.0 | 837.0 | 12.0 |
| CCA | 1.8200 % | 1.9000 % | 1.8982 % | Gals. | 20.0 | 20.1 | 0.1 |

Chemical Usage

| Type | Chemical | Solution Start | Solution Finish | Unit | Lbs / Gal Start | Lbs / Gal Finish | Lbs Used Gauge | Lbs Used Adjusted | Retention Gauge | Retention Adjusted |
|---|---|---|---|---|---|---|---|---|---|---|
| Active | CCA | 1.9000 % | 1.8857 % | Lbs (Active) | 0.1606 | 0.1594 | 116.42 | 125.16 | 0.2709 | 0.2912 |

| Comp |
|---|
| Copper |
| Totals |

Material Information

| | ItemCode | Description | Pieces | Packs/Size | BF | CF | Std | Mill | Retreat | Customer |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | t105175b | Trinity Guardrail | 42 | 1 @ 42 | 553 | 46 | | | | |
| 2 | t004063b | Trinity Guardrail | 70 | 1 @ 70 | 1,680 | 140 | | | | |
| 3 | t006115b | Trinity Guardrail | 84 | 1 @ 84 | 1,107 | 92 | | | | |
| 4 | t004050b | Trinity Guardrail | 84 | 1 @ 84 | 1,023 | 85 | | | | |
| 5 | t004125b | Trinity Guardrail | 84 | 1 @ 84 | 529 | 44 | | | | |
| 6 | 6x8x43.5s4s | Trinity Guardrail | 42 | 1 @ 42 | 265 | 22 | | | | |

OXFORD LAB X CCA
WOOD ANALYSIS
19/2/2020 13:22
Calibration title: SAWDUST-pcf

SAMPLE ID: 1488
************************************
DENSITY = 32.0 pcf
************************************

| | %WT OXIDES | %BALANCE |
|---|---|---|
| CRO3 = | 0.941 % | 49.7 |
| CUO = | 0.334 % | 17.6 |
| AS2O5 = | 0.621 % | 32.7 |
| TOTAL = | 1.896 %WT | 100.0 |

************************************
RETENTION
CRO3 = 0.301 pcf
CUO = 0.107 pcf
AS2O5 = 0.199 pcf
TOTAL= 0.607 pcf
************************************

0
0
0
0
0

Printed On: 2/19/2020 9:12:11 AM Charge Number: 1488 Page 1 of 1

Figure B-14. BCT Timber Post, Test Nos. STBRT-1 and STBRT-2

# Charge 652

Plant: (02) Central Nebraska

Sutton, NE EPA Reg. No. 3008-36

Treatment: TRINITY GUARDRAIL
Date: 8/5/2019 11:41 AM
Preservative: CCA
Retention Target: 0.6
Cylinder: 1 Void (9000)
Tank: 2
Operator: Bob

Total Time: 01:41
Change Out (min): 29.5
Change Out Reason:
Board Ft: 4,672
Cubic Ft: 331
DVIn / DVOut: 368 / 351
Treat By: Tally
Date Off DripPad: 8/6/19 1:22 AM

| Step | Time Min | Time Max | Time Act | Pressure Min | Pressure Max | Pressure Act | Injection Min | Injection Max | Injection Act | Retention Min | Retention Max | Retention Act | Flow Rate Min | Flow Rate Max | Flow Rate Act | Temp | Ramp | Time Start | Time End |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial Vacuum | | 7.0 | 7.0 | | -22 | -22 | | | 0.00 | | | 0.000 | | | 0.0000 | | | 11:41:48 | 11:48:5[illegible] |
| Fill | | 6.0 | 5.2 | | -22 | -3 | | | 0.00 | | | 0.000 | | | 3.3395 | | | 11:48:50 | 11:54:0[illegible] |
| Raise Press | | 7.0 | 0.5 | | 75 | 78 | | | 0.00 | | | 0.000 | | | 0.0000 | | | 11:54:05 | 11:54:3[illegible] |
| Pressure | 20 | 25.0 | 25.0 | | 140 | 140 | | 3.40 | 2.01 | | | 0.323 | | 0.0300 | 0.0159 | | | 11:54:34 | 12:19:3[illegible] |
| Press Relief | | 4.0 | 3.8 | 15 | 25 | 4 | | | 1.88 | | | 0.302 | | | 0.0000 | | 4 | 12:19:37 | 12:23:2[illegible] |
| Empty | | 7.0 | 7.6 | | | -1 | | | 2.45 | | | 0.414 | | | 0.0000 | | | 12:23:24 | 12:31:0[illegible] |
| Final Vacuum | 45 | 45.0 | 45.0 | | -24 | -24 | | 2.10 | 2.48 | | | 0.418 | | | 0.0000 | | | 12:31:03 | 13:16:0[illegible] |
| Final Empty | | 7.0 | 6.2 | | | -1 | | | 1.26 | | | 0.222 | | | 0.0000 | | | 13:16:05 | 13:22:1[illegible] |
| Finish | | 0.5 | 0.5 | | | -1 | | | 1.25 | | | 0.221 | | | 0.0000 | | | 13:22:20 | 13:22:5[illegible] |

**Automatic Mix Information**

| Chemical | Current | Target | As Mixed | Unit | Required | Actual | Difference |
|---|---|---|---|---|---|---|---|
| Water | 6,662 | 7,860 | 7,858 | Gals. | 1,173.9 | 1,170.0 | -3.9 |
| CCA | 1.8500 % | 1.9000 % | 1.9027 % | Gals. | 24.1 | 24.2 | 0.1 |

**Chemical Usage**

| Type | Chemical | Solution Start | Solution Finish | Unit | Lbs / Gal Start | Lbs / Gal Finish | Lbs Used Gauge | Lbs Used Adjusted | Retention Gauge | Retention Adjusted |
|---|---|---|---|---|---|---|---|---|---|---|
| Active | CCA | 1.9000 % | 1.8894 % | Lbs (Active) | 0.1606 | 0.1597 | 66.64 | 73.40 | 0.2011 | 0.2216 |

| Com[illegible] |
|---|
| Copper |
| Totals |

**Material Information**

| | ItemCode | Description | Pieces | Packs/Size | BF | CF | Std | Mill | Retreat | Custo[illegible] |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6x8x45s4s | Guardrail | 42 | 1 @ 42 | 541 | 45 | | | | |
| 2 | 6x8x23s4s | Rough Timber | 84 | 1 @ 84 | 482 | 45 | | | | |
| 3 | 6x6x20 | Timber | 48 | 1 @ 48 | 2,880 | 202 | | | | |
| 4 | 5/8x48x8 | Plywood | 24 | 1 @ 24 | 768 | 40 | | | | |

OXFORD LAB-X CCA
WOOD ANALYSIS
5/8/2019 15:24
Calibration title: SAWDUST-pcf

SAMPLE ID: 652
**************************************
DENSITY = 32.0 pcf
**************************************

| | %WT OXIDES | %BALANCE |
|---|---|---|
| CRO3 = | 0.915 % | 48.1 |
| CUO = | 0.344 % | 18.1 |
| AS205 = | 0.643 % | 33.8 |
| TOTAL = | 1.902 %WT | 100.0 |

**************************************
RETENTION
CRO3 = 0.293 pcf
CUO = 0.1[illegible]0 pcf
AS205 = 0.20[illegible] pcf
TOTAL= 0.608 pcf
**************************************

0
0

Printed On: 8/5/2019 1:22:53 PM Charge Number: 652 Page 1 of 1

Figure B-15. BCT Timber Post, Test Nos. STBRT-1 and STBRT-2

30460H1D6

Atlas Tube Corp (Chicago)
1855 East 122nd Street
Chicago, Illinois, USA
60633
Tel: 773-646-4500
Fax: 773-646-6128

Atlas Tube
A DIVISION OF ZEKELMAN INDUSTRIES

Ref.B/L: 80728203
Date: 08.17.2016
Customer: 2908

## MATERIAL TEST REPORT

**Sold to**

Gregory Industries Inc.
4100 13th Street SW.
CANTON OH 44710
USA

**Shipped to**

Tru-Form Steel & Wire
1204 Gilkey Ave
HARTFORD CITY IN 47348
USA

Material: 8.0x6.0x188x27'0"0(2x2)SILDOMUS | Material No: 80060188 | Made in: USA | Melted in: USA

Sales order: 1105121 | Purchase Order: 35569 | Cust Material #: TRB3/16-8-6-27

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 616137 | 0.210 | 0.930 | 0.011 | 0.003 | 0.020 | 0.041 | 0.020 | 0.008 | 0.020 | 0.020 | 0.030 | 0.008 | 0.001 | 0.000 | 0.003 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE |
|---|---|---|---|---|---|---|
| M800650076 | 4 | 058210 Psi | 073148 Psi | 32 % | ASTM A500-13 GRADE B&C | 0.38 |

Material Note:
Sales Or.Note:

Material: 8.0x6.0x188x30'0"0(2x3)SILDOMUS | Material No: 80060188 | Made in: USA | Melted in: USA

Sales order: 1105121 | Purchase Order: 35569 | Cust Material #: TRB3/16-8-6-30

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 821T08220 | 0.220 | 0.810 | 0.013 | 0.006 | 0.006 | 0.041 | 0.160 | 0.002 | 0.005 | 0.010 | 0.020 | 0.002 | 0.002 | 0.000 | 0.007 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE |
|---|---|---|---|---|---|---|
| M800650038 | 6 | 057275 Psi | 070934 Psi | 32 % | ASTM A500-13 GRADE B&C | 0.37 |

Material Note:
Sales Or.Note:

Material: 8.0x6.0x188x30'0"0(2x3)SILDOMUS | Material No: 80060188 | Made in: USA | Melted in: USA

Sales order: 1105121 | Purchase Order: 35569 | Cust Material #: TRB3/16-8-6-30

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 821T08220 | 0.220 | 0.810 | 0.013 | 0.006 | 0.006 | 0.041 | 0.160 | 0.002 | 0.005 | 0.010 | 0.020 | 0.002 | 0.002 | 0.000 | 0.007 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE |
|---|---|---|---|---|---|---|
| M800650039 | 6 | 057275 Psi | 070934 Psi | 32 % | ASTM A500-13 GRADE B&C | 0.37 |

Material Note:
Sales Or.Note:

Jason Richard

Authorized by Quality Assurance:
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
CE calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Page : 1 Of 6

Metals Service Center Institute

Figure B-16. 72-in. Long Foundation Tube, Test Nos. STBRT-1 and STBRT-2

# Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1275017 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3400
BOL Number: 99202 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 3/22/17

| Qty | Part # | Description | Spec | CL | TY | Heat Code/ Heat | Yield | TS | Elg | C | Mn | P | S | Si | Cu | Cb | Cr | Vn | ACW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 400 | 3380G | 5/8"X1.5" HEX BOLT A307 | HW | | | 0052429-113200 | | | | | | | | | | | | | |
| 600 | 3400G | 5/8"X2" GR BOLT | HW | | | 29221 | | | | | | | | | | | | | |
| 500 | 3480G | 5/8"X8" GR BOLT A307 | HW | | | 29369 | | | | | | | | | | | | | |
| 450 | 3500G | 5/8"X10" GR BOLT A307 | HW | | | 29550-B | | | | | | | | | | | | | |
| 700 | 3540G | 5/8"X14" GR BOLT A307 | HW | | | 29567 | | | | | | | | | | | | | |
| 300 | 3580G | 5/8"X18" GR BOLT A307 | HW | | | 29338 | | | | | | | | | | | | | |
| 600 | 4235G | 3/16"X1.75"X3" WSHR | HW | | | C7001 | | | | | | | | | | | | | |
| 10 | 9852A | STRUT & YOKE ASSY | A-36 | | | 195070 | 52,940 | 69,970 | 31.1 | 0.190 | 0.520 | 0.014 | 0.004 | 0.020 | 0.110 | 0.000 | 0.050 | 0.000 | 4 |
| | 9852A | | A-36 | | | A82292 | 54,000 | 73,300 | 31.0 | 0.200 | 0.460 | 0.010 | 0.003 | 0.020 | 0.150 | 0.000 | 0.060 | 0.001 | 4 |
| | 9852A | | A-36 | | | 645887 | 39,900 | 62,500 | 32.0 | 0.190 | 0.400 | 0.009 | 0.015 | 0.009 | 0.054 | 0.001 | 0.038 | 0.001 | 4 |
| | 9852A | | A-36 | | | 645887 | 39,900 | 62,500 | 32.0 | 0.190 | 0.400 | 0.009 | 0.015 | 0.009 | 0.054 | 0.001 | 0.038 | 0.001 | 4 |
| | 9852A | | HW | | | 15056184 | | | | | | | | | | | | | |
| 20 | 12173G | T12/6'3/4@1'6.75"/S | | | 2 | L35216 | | | | | | | | | | | | | |
| | | | M-180 | A | 2 | 209331 | 62,090 | 81,500 | 28.1 | 0.190 | 0.720 | 0.013 | 0.002 | 0.020 | 0.110 | 0.000 | 0.070 | 0.002 | 4 |
| | | | M-180 | A | 2 | 209332 | 61,400 | 81,290 | 25.3 | 0.190 | 0.730 | 0.014 | 0.003 | 0.020 | 0.120 | 0.000 | 0.060 | 0.001 | 4 |
| | | | M-180 | A | 2 | 209333 | 61,200 | 80,050 | 25.8 | 0.200 | 0.740 | 0.016 | 0.005 | 0.010 | 0.120 | 0.000 | 0.070 | 0.002 | 4 |

2 of 4

Figure B-17. Ground Strut Assembly, Test Nos. STBRT-1 and STBRT-2

ASSEMBLY
SPECIALTY PRODUCTS INC

PH 216.676.5600
FX 216.676.6761
www.assemblyspecialty.com

ISO 9001:2008

14700 Brookpark Rd
Cleveland, OH 44135-5166
customerservice@assemblyspecialty.com

## Certificate of Conformance

**Date:** September 24, 2018

**To:** Gregory Industries, Inc.
Gregory Galv. & Metal Processing
4100 13th St. SW
Canton, OH 44710

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 #:** 40299
**DATE SHIPPED:** 09/24/18
**ASPI SALES ORDER #:** 122160
**MANUFACTURER:** ASSEMBLY SPECIALTY PRODUCTS, INC.

| QTY | CUST P/N | ASPI P/N | ASPI LOT# | DESCRIPTION |
|---|---|---|---|---|
| 250 | 3012G | C-2028 | 89315 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89316 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89318 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89864 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89865 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89866 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89929 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89930 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89931 | 6' 6" BCT Cable Assembly |
| 250 | 3012G | C-2028 | 89932 | 6' 6" BCT Cable Assembly |

**REMARKS:** NOMINAL 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.

STEEL USED TO MANUFACTURE THESE ITEMS WAS MELTED AND MANUFACTURED IN THE U.S.A
ALL MANUFACTURING PROCESSES SUPPLIED OR PERFORMED BY ASSEMBLY SPECIALTY PRODUCTS, INC. TOOK PLACE IN THE U.S.A.

Signature: [signature]
Certification and Compliance Manager

Figure B-18. BCT Cable Anchor Assembly, Test Nos. STBRT-1 and STBRT-2

**GREGORY HIGHWAY PRODUCTS, INC.**
**4100 13th St. SW**
**Canton, Ohio 44710**

MIDWEST MACHINERY & SUPPLY CO.
P. O. BOX 703

MILFORD,NE,68405

Test Report
Ship Date: 11/17/2017
Customer P.O.: 3515
Shipped to: MIDWEST MACHINERY & SUPPLY CO.
Project:
GHP Order No: 128AA

| HT # code | LOT# | C. | Mn. | P. | S. | Si. | Tensile | Yield | Elong. | Quantity | Class | Type | Description |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A74070 | | 0.21 | 0.46 | 0.012 | 0.002 | 0.03 | 76100 | 58800 | 25.2 | 4 | A | 2 | 12GA TB TRANS. |
| 4181496 | | 0.24 | 0.84 | 0.014 | 0.01 | 0.01 | 72400 | 44800 | 34 | 4 | | 2 | 5/8IN X 8IN X 8IN BRG. PL. |
| 4181489 | | 0.09 | 0.45 | 0.012 | 0.004 | 0.01 | 58000 | 43100 | 27 | 4 | | 2 | 350 STRUT & YOKE |
| 196828BM | | 0.04 | 0.84 | 0.014 | 0.003 | | 76000 | 74000 | 25 | | | 2 | 350 STRUT & YOKE |
| E22985 | | 0.17 | 0.51 | 0.013 | 0.008 | 0.008 | 72510 | 64310 | 29.5 | 4 | | 2 | 2IN X 5 1/2IN PIPE SLEEVE |
| 811T08220 | | 0.22 | 0.81 | 0.013 | 0.006 | 0.005 | 71412 | 56323 | 35 | 8 | | 2 | 3/16IN X 6IN X 8IN X 6FT0IN TUBE SLEEVE |

All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By:

James P. Dehnke
Notary Public, State of Ohio
My Commission Expires 10-19-2019

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by
Andrew Artar this 21 day of November, 2017

Notary Public, State of Ohio

Figure B-19. 8-in. x 8-in. x ⅝-in. Plate, Test Nos. STBRT-1 and STBRT-2

# Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1269489 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3346
BOL Number: 97457 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 11/7/16

| Qty | Part # | Description | Spec | CL | TY | Heat Code/ Heat | Yield | TS | Elg | C | Mn | P | S | Si | Cu | Cb | Cr | Vn | ACW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 701A | Anchor Box | A-36 | | | JK16101488 | 56,172 | 75,460 | 25.0 | 0.160 | 0.780 | 0.017 | 0.028 | 0.200 | 0.280 | 0.001 | 0.140 | 0.028 | 4 |
| | 701A | | A-36 | | | 535133 | 43,300 | 68,500 | 33.0 | 0.019 | 0.460 | 0.013 | 0.016 | 0.013 | 0.090 | 0.001 | 0.090 | 0.002 | 4 |
| 4 | 729G | TS 8X6X3/16X8'-0" SLEEVE | A-500 | | | A49248 | 64,818 | 78,412 | 32.0 | 0.200 | 0.810 | 0.014 | 0.002 | 0.040 | 0.020 | 0.000 | 0.040 | 0.001 | 4 |
| 20 | 738A | 5'TUBE SL.188X6X8 1/4 /PL | A-36 | | 2 | 4182184 | 45,000 | 67,900 | 31.0 | 0.210 | 0.760 | 0.012 | 0.008 | 0.010 | 0.050 | 0.001 | 0.030 | 0.002 | 4 |
| | 738A | | A-500 | | | A49248 | 64,818 | 78,412 | 32.0 | 0.200 | 0.810 | 0.014 | 0.002 | 0.040 | 0.020 | 0.000 | 0.040 | 0.001 | 4 |
| 6 | 749G | TS 8X6X3/16X6'-0" SLEEVE | A-500 | | | A49248 | 64,818 | 78,412 | 32.0 | 0.200 | 0.810 | 0.014 | 0.002 | 0.040 | 0.020 | 0.000 | 0.040 | 0.001 | 4 |
| 6 | 782G | 5/8"X8"X8" BEAR PL/OF | A-36 | | | DL15103543 | 58,000 | 74,000 | 25.0 | 0.150 | 0.750 | 0.013 | 0.025 | 0.200 | 0.360 | 0.003 | 0.090 | 0.000 | 4 |
| 20 | 783A | 5/8X8X8 BEAR PL 3/16 STP | A-36 | | | PL14107973 | 48,167 | 69,811 | 25.0 | 0.160 | 0.740 | 0.012 | 0.041 | 0.190 | 0.370 | 0.000 | 0.220 | 0.002 | 4 |
| | 783A | | A-36 | | | DL15103543 | 58,000 | 74,000 | 25.0 | 0.150 | 0.750 | 0.013 | 0.025 | 0.200 | 0.360 | 0.003 | 0.090 | 0.000 | 4 |
| 45 | 3000G | CBL 3/4X6'6/DBL | HW | | | 119048 | | | | | | | | | | | | | |
| 7,000 | 3340G | 5/8" GR HEX NUT | HW | | | 0055551-116146 | | | | | | | | | | | | | |
| 4,000 | 3360G | 5/8"X1.25" GR BOLT | HW | | | 0053777-115516 | | | | | | | | | | | | | |
| 450 | 3500G | 5/8"X10" GR BOLT A307 | HW | | | 28971-B | | | | | | | | | | | | | |
| 1,225 | 3540G | 5/8"X14" GR BOLT A307 | HW | | | 29053-B | | | | | | | | | | | | | |

Figure B-20. Anchor Bracket Assembly, Test Nos. STBRT-1 and STBRT-2

Atlas Tube (Alabama), Inc.
171 Cleage Dr
Birmingham, Alabama, USA
35217
Tel:
Fax:

**Atlas Tube**
A DIVISION OF ZEKELMAN INDUSTRIES

Ref.B/L: 80791452
Date: 11.10.2017
Customer: 179

## MATERIAL TEST REPORT

**Sold to**

Steel & Pipe Supply Compan
PO Box 1688
MANHATTAN KS 66505
USA

**Shipped to**

Steel & Pipe Supply Compan
401 New Century Parkway
NEW CENTURY KS 66031
USA

Material: 3.0x2.0x188x40'0"0(5x4). Material No: 0300201884000-B Made in: USA
Melted in: USA
Sales order: 1226976 Purchase Order: 4500296656 Cust Material #: 6630020018840

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B704212 | 0.200 | 0.450 | 0.010 | 0.004 | 0.020 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE: 0.28 |
|---|---|---|---|---|---|---|
| 40867002 | 20 | 064649 Psi | 087652 Psi | 24 % | ASTM A500-13 GRADE B&C | |

Material Note:
Sales Or.Note:

Material: 2.375x154x42'0"0(34x1). Material No: R023751544200 Made in: USA
Melted in: USA
Sales order: 1226976 Purchase Order: 4500296656 Cust Material #: 642004042

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B712810 | 0.210 | 0.460 | 0.012 | 0.002 | 0.020 | 0.024 | 0.100 | 0.002 | 0.020 | 0.030 | 0.060 | 0.004 | 0.002 | 0.000 | 0.008 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Rb | Certification | CE: 0.32 |
|---|---|---|---|---|---|---|---|
| MC00006947 | 34 | 063688 Psi | 083220 Psi | 25 % | 91 | ASTM A500-13 GRADE B&C | |

Material Note:
Sales Or.Note:

Material: 2.375x154x42'0"0(34x1). Material No: R023751544200 Made in: USA
Melted in: USA
Sales order: 1226976 Purchase Order: 4500296656 Cust Material #: 642004042

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17037261 | 0.210 | 0.810 | 0.005 | 0.004 | 0.020 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE: 0.35 |
|---|---|---|---|---|---|---|
| 41532001 | 34 | 066144 Psi | 082159 Psi | 27 % | ASTM A500-13 GRADE B&C | |

Material Note:
Sales Or.Note:

Authorized by Quality Assurance:
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
C... AWS D1.1 method.

Steel Tube Institute

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Metals Service Center Institute

Figure B-21. 2⅜-in. O.D. x 6-in. Post Sleeve, Test Nos. STBRT-1 and STBRT-2

**McMASTER-CARR.**

## Certificate of Compliance

600 N County Line Rd
Elmhurst IL 60126-2081
630-600-3600
chi.sales@mcmaster.com

University of Nebraska
Midwest Roadside Safety Facility
M W R S F
4630 Nw 36TH St
Lincoln NE 68524-1802
Attention: Shaun M Tighe
Midwest Roadside Safety Facility

Purchase Order
**E000548963**

Order Placed By
**Shaun M Tighe**

McMaster-Carr Number
**7204107-01**

Page 1 of 1

08/02/2018

| Line | Product | Ordered | Shipped |
|---|---|---|---|
| 1 | **97812A109** Raised-Head Removable Nails, 16D Penny Size, 3" Long, Packs of 5 | **5 Packs** | **5** |

Certificate of compliance

This is to certify that the above items were supplied in accordance with the description and as illustrated in the catalog. Your order is subject only to our terms and conditions, available at www.mcmaster.com or from our Sales Department.

Sarah Weinberg
Compliance Manager

Figure B-22. Bent 16D Double Head Nail, Test Nos. STBRT-1 and STBRT-2

**CERTIFIED MATERIAL TEST REPORT**

Page 1 / 1

GERDAU

US-ML-CARTERSVILLE
384 OLD GRASSDALE ROAD NE
CARTERSVILLE, GA 30121
USA

| CUSTOMER SHIP TO | CUSTOMER BILL TO | GRADE | SHAPE / SIZE | DOCUMENT ID: |
|---|---|---|---|---|
| STEEL AND PIPE SUPPLY CO INC<br>4750 W MARSHALL AVE<br>LONGVIEW,TX 75604-4817<br>USA | STEEL AND PIPE SUPPLY CO INC<br><br>MANHATTAN,KS 66505-1688<br>USA | A992/A572-50 | Wide Flange Beam / 6 X 9# / 150 X 13.5 | 0000329181 |

| LENGTH | PCS | WEIGHT | HEAT / BATCH |
|---|---|---|---|
| 20'00" | 81 | 14,580 LB | **55066998/03** |

| SALES ORDER | CUSTOMER MATERIAL Nº |
|---|---|
| 8904486/000010 | 000000000037690020 |

| CUSTOMER PURCHASE ORDER NUMBER | BILL OF LADING | DATE |
|---|---|---|
| 4500348119 | 1323-0000159221 | 06/15/2020 |

SPECIFICATION / DATE or REVISION
ASTM A6-17
ASTM A709-17
ASTM A992-11 (2015), A572-15
CSA G40.21-13 345WM

CHEMICAL COMPOSITION

| C % | Mn % | P % | S % | Si % | Cu % | Ni % | Cr % | Mo % | Sn % | V % | Nb % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.13 | 0.83 | 0.016 | 0.032 | 0.19 | 0.33 | 0.20 | 0.12 | 0.038 | 0.010 | 0.000 | 0.009 |

MECHANICAL PROPERTIES

| YS 0.2% PSI | UTS PSI | YS MPa | UTS MPa | Y/T rati % | G/L Inch |
|---|---|---|---|---|---|
| 57500 | 76200 | 396 | 525 | 0.760 | 8.000 |
| 58200 | 76700 | 401 | 529 | 0.760 | 8.000 |

MECHANICAL PROPERTIES

| Elong. % |
|---|
| 23.10 |
| 25.20 |

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. Weld repair has not been performed on this material. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR
Phone: (409) 267-1071 Email: Bhaskar.Yalamanchili@gerdau.com

YAN WANG
QUALITY ASSURANCE MGR
Phone: (770) 387.5718 Email: yan.wang@gerdau.com

Figure B-23. W6x9 or W6x8.5, 72-in. Long Steel Post, Test Nos. STBRT-1 and STBRT-2

**CERTIFIED MATERIAL TEST REPORT**

Page 1 / 1

GERDAU

US-ML-MIDLOTHIAN
300 WARD ROAD
MIDLOTHIAN, TX 76065
USA

| CUSTOMER SHIP TO | CUSTOMER BILL TO | GRADE | SHAPE / SIZE | DOCUMENT ID: |
|---|---|---|---|---|
| STEEL AND PIPE SUPPLY CO INC<br>1003 FORT GIBSON RD<br>CATOOSA,OK 74015-3033<br>USA | STEEL AND PIPE SUPPLY CO INC<br><br>MANHATTAN,KS 66505-1688<br>USA | A992/A572-50 | Wide Flange Beam / 6 X 9# / 150 X 13.5 | 0000467681 |

| LENGTH | PCS | WEIGHT | HEAT / BATCH |
|---|---|---|---|
| 50'00" | 24 | 10,800 LB | **59091883/02** |

| SALES ORDER | CUSTOMER MATERIAL Nº |
|---|---|
| 8992383/000010 | 000000000037690050 |

| CUSTOMER PURCHASE ORDER NUMBER | BILL OF LADING | DATE |
|---|---|---|
| 4500349334 | 1327-0000373778 | 06/19/2020 |

SPECIFICATION / DATE or REVISION
ASTM A6-17
ASTM A709-17
ASTM A992-11 (2015), A572-15
CSA G40.21-13 345WM

CHEMICAL COMPOSITION

| C (%) | Mn (%) | P (%) | S (%) | Si (%) | Cu (%) | Ni (%) | Cr (%) | Mo(%) | Sn (%) | V (%) | Nb (%) | Al (%) | CEqvA6 (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.09 | 0.91 | 0.015 | 0.037 | 0.23 | 0.32 | 0.11 | 0.20 | 0.024 | 0.005 | 0.001 | 0.012 | 0.003 | 0.32 |

MECHANICAL PROPERTIES

| YS 0.2% (PSI) | UTS (PSI) | YS (MPa) | UTS (MPa) | Y/T rati (%) | G/L (Inches) | G/L (mm) | Elong. (%) |
|---|---|---|---|---|---|---|---|
| 59778 | 73289 | 412 | 505 | 0.820 | 8.000 | 200.0 | 24.10 |
| 58424 | 70802 | 403 | 488 | 0.820 | 8.000 | 200.0 | 24.00 |

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. Weld repair has not been performed on this material. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR
Phone: (409) 267-1071 Email: Bhaskar.Yalamanchili@gerdau.com

WADE LUMPKINS
QUALITY ASSURANCE MGR
Phone: 972-779-3118 Email: Wade.Lumpkins@gerdau.com

Figure B-24. W6x9 or W6x8.5, 72-in. Long Steel Post, Test Nos. STBRT-1 and STBRT-2

GERDAU

US-ML-MIDLOTHIAN
300 WARD ROAD
MIDLOTHIAN, TX 76065
USA

**CERTIFIED MATERIAL TEST REPORT** Page 1 / 1

| CUSTOMER SHIP TO | CUSTOMER BILL TO | GRADE | SHAPE / SIZE | DOCUMENT ID: |
|---|---|---|---|---|
| NORFOLK IRON & METAL CO INC 3001 N VICTORY ROAD NORFOLK,NE 68701-0833 USA | NORFOLK IRON & METAL CO INC NORFOLK,NE 68702-1129 USA | A992/A572-50 | Wide Flange Beam / 6 X 15# / 150 X 22.5 | 0000453355 |

| LENGTH | PCS | WEIGHT | HEAT / BATCH |
|---|---|---|---|
| 50'00" | 12 | 9,000 LB | 59091494/02 |

| SALES ORDER | CUSTOMER MATERIAL N° |
|---|---|
| 8396750/000020 | 25855 |

SPECIFICATION / DATE or REVISION
ASTM A6-17
ASTM A709-17
ASTM A992-11 (2015), A572-15
CSA G40.21-13 345WM

| CUSTOMER PURCHASE ORDER NUMBER | BILL OF LADING | DATE |
|---|---|---|
| 01030121 | 1327-0000369454 | 05/15/2020 |

CHEMICAL COMPOSITION

| C % | Mn % | P % | S % | Si % | Cu % | Ni % | Cr % | Mo % | Sn % | V % | Nb % | Al % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.09 | 0.86 | 0.013 | 0.021 | 0.21 | 0.37 | 0.09 | 0.15 | 0.023 | 0.011 | 0.001 | 0.016 | 0.003 |

CHEMICAL COMPOSITION

| CEqyA6 % |
|---|
| 0.30 |

MECHANICAL PROPERTIES

| YS 0.2% PSI | UTS PSI | YS MPa | UTS MPa | Y/T rati % | G/L Inch |
|---|---|---|---|---|---|
| 56168 | 74857 | 387 | 516 | 0.750 | 8.000 |
| 55381 | 74091 | 382 | 511 | 0.750 | 8.000 |

MECHANICAL PROPERTIES

| G/L mm | Elong. % |
|---|---|
| 200.0 | 23.90 |
| 200.0 | 23.80 |

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. Weld repair has not been performed on this material. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR
Phone: (409) 267-1071 Email: Bhaskar.Yalamanchili@gerdau.com

WADE LUMPKINS
QUALITY ASSURANCE MGR.
Phone: 972-779-3118 Email: Wade.Lumpkins@gerdau.com

Figure B-25. W6x15, 84-in. Long Steel Post, Test Nos. STBRT-1 and STBRT-2

GERDAU

US-ML-MIDLOTHIAN
300 WARD ROAD
MIDLOTHIAN, TX 76065
USA

**CERTIFIED MATERIAL TEST REPORT** Page 1/1

| CUSTOMER SHIP TO | CUSTOMER BILL TO | GRADE | SHAPE / SIZE | DOCUMENT ID: |
|---|---|---|---|---|
| STEEL AND PIPE SUPPLY CO INC JONESBURG INDUSTRIAL PARK JONESBURG,MO 63351 USA | STEEL AND PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA | A992/A572-50 | Wide Flange Beam / 6 X 15# / 150 X 22.5 | 0000000000 |

| LENGTH | PCS | WEIGHT | HEAT / BATCH |
|---|---|---|---|
| 60'00" | 0 | 10,800 LB | 59082360/02 |

| SALES ORDER | CUSTOMER MATERIAL N° |
|---|---|
| 7177340/000010 | 000000000376150060 |

SPECIFICATION / DATE or REVISION
ASTM A6-17
ASTM A709-17
ASTM A992-11 (2015), A572-15
CSA G40.21-13 345WM

| CUSTOMER PURCHASE ORDER NUMBER | BILL OF LADING | DATE |
|---|---|---|
| 4500319529 | 1327-0000300764 | 11/12/2018 |

CHEMICAL COMPOSITION

| C % | Mn % | P % | S % | Si % | Cu % | Ni % | Cr % | Mo % | Sn % | V % | Nb % | Al % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.09 | 0.81 | 0.015 | 0.036 | 0.20 | 0.37 | 0.12 | 0.14 | 0.024 | 0.011 | 0.002 | 0.016 | 0.003 |

CHEMICAL COMPOSITION

| CEqyA6 % |
|---|
| 0.29 |

MECHANICAL PROPERTIES

| YS 0.2% PSI | UTS PSI | YS MPa | UTS MPa | Y/T rati % | G/L Inch |
|---|---|---|---|---|---|
| 52633 | 74340 | 363 | 513 | 0.710 | 8.000 |
| 53070 | 74956 | 366 | 517 | 0.710 | 8.000 |

MECHANICAL PROPERTIES

| G/L mm | Elong. % |
|---|---|
| 200.0 | 24.20 |
| 200.0 | 23.60 |

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
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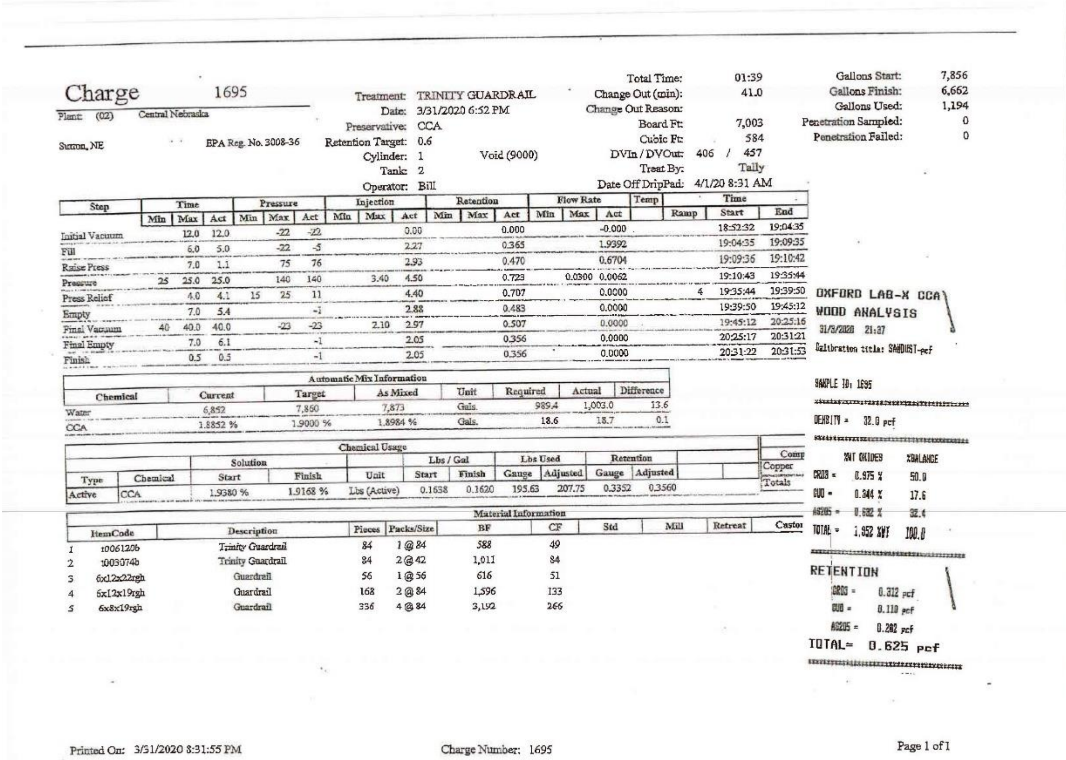
WADE LUMPKINS
QUALITY ASSURANCE MGR.
Phone: 972-779-3118 Email: Wade.Lumpkins@gerdau.com

Figure B-26. W6x15, 53½-in. Long Steel Post, Test Nos. STBRT-1 and STBRT-2



Charge 1695

Plant: (02) Central Nebraska

Sutton, NE EPA Reg. No. 3008-36

Treatment: TRINITY GUARDRAIL
Date: 3/31/2020 6:52 PM
Preservative: CCA
Retention Target: 0.6
Cylinder: 1 Void (9000)
Tank: 2
Operator: Bill

Total Time: 01:39
Change Out (min): 41.0
Change Out Reason:
Board Ft: 7,003
Cubic Ft: 584
DVIn / DVOut: 406 / 457
Treat By: Tally
Date Off DripPad: 4/1/20 8:31 AM

Gallons Start: 7,856
Gallons Finish: 6,662
Gallons Used: 1,194
Penetration Sampled: 0
Penetration Failed: 0

| Step | Time | | | Pressure | | | Injection | | | Retention | | | Flow Rate | | | Temp | Time | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | Act | Min | Max | Act | Min | Max | Act | Min | Max | Act | Min | Max | Act | | Ramp | Start | End |
| Initial Vacuum | | 12.0 | 12.0 | | -22 | -22 | | | 0.00 | | | 0.000 | | | -0.000 | | | 18:52:32 | 19:04:35 |
| Fill | | 6.0 | 5.0 | | -22 | -5 | | | 2.27 | | | 0.365 | | | 1.9392 | | | 19:04:35 | 19:09:35 |
| Raise Press | | 7.0 | 1.1 | | 75 | 76 | | | 2.93 | | | 0.470 | | | 0.6704 | | | 19:09:36 | 19:10:42 |
| Pressure | 25 | 25.0 | 25.0 | | 140 | 140 | | 3.40 | 4.50 | | | 0.723 | | 0.0300 | 0.0062 | | | 19:10:43 | 19:35:44 |
| Press Relief | | 4.0 | 4.1 | 15 | 25 | 11 | | | 4.40 | | | 0.707 | | | 0.0000 | | 4 | 19:35:44 | 19:39:50 |
| Empty | | 7.0 | 5.4 | | | -1 | | | 2.88 | | | 0.483 | | | 0.0000 | | | 19:39:50 | 19:45:12 |
| Final Vacuum | 40 | 40.0 | 40.0 | | -23 | -23 | | 2.10 | 2.97 | | | 0.507 | | | 0.0000 | | | 19:45:12 | 20:25:16 |
| Final Empty | | 7.0 | 6.1 | | | -1 | | | 2.05 | | | 0.356 | | | 0.0000 | | | 20:25:17 | 20:31:21 |
| Finish | | 0.5 | 0.5 | | | -1 | | | 2.05 | | | 0.356 | | | 0.0000 | | | 20:31:22 | 20:31:53 |

Automatic Mix Information

| Chemical | Current | Target | As Mixed | Unit | Required | Actual | Difference |
|---|---|---|---|---|---|---|---|
| Water | 6,852 | 7,860 | 7,873 | Gals. | 989.4 | 1,003.0 | 13.6 |
| CCA | 1.8852 % | 1.9000 % | 1.8984 % | Gals. | 18.6 | 18.7 | 0.1 |

Chemical Usage

| | | Solution | | | Lbs / Gal | | Lbs Used | | Retention | | Comp |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Type | Chemical | Start | Finish | Unit | Start | Finish | Gauge | Adjusted | Gauge | Adjusted | Copper |
| Active | CCA | 1.9380 % | 1.9168 % | Lbs (Active) | 0.1638 | 0.1620 | 195.63 | 207.75 | 0.3352 | 0.3560 | Totals |

Material Information

| | ItemCode | Description | Pieces | Packs/Size | BF | CF | Std | Mill | Retreat | Custor |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | t006120b | Trinity Guardrail | 84 | 1 @ 84 | 588 | 49 | | | | |
| 2 | t003074b | Trinity Guardrail | 84 | 2 @ 42 | 1,011 | 84 | | | | |
| 3 | 6x12x22rgh | Guardrail | 56 | 1 @ 56 | 616 | 51 | | | | |
| 4 | 6x12x19rgh | Guardrail | 168 | 2 @ 84 | 1,596 | 133 | | | | |
| 5 | 6x8x19rgh | Guardrail | 336 | 4 @ 84 | 3,192 | 266 | | | | |

OXFORD LAB-X CCA
WOOD ANALYSIS
31/3/2020 21:37
Calibration title: SAWDUST-pcf

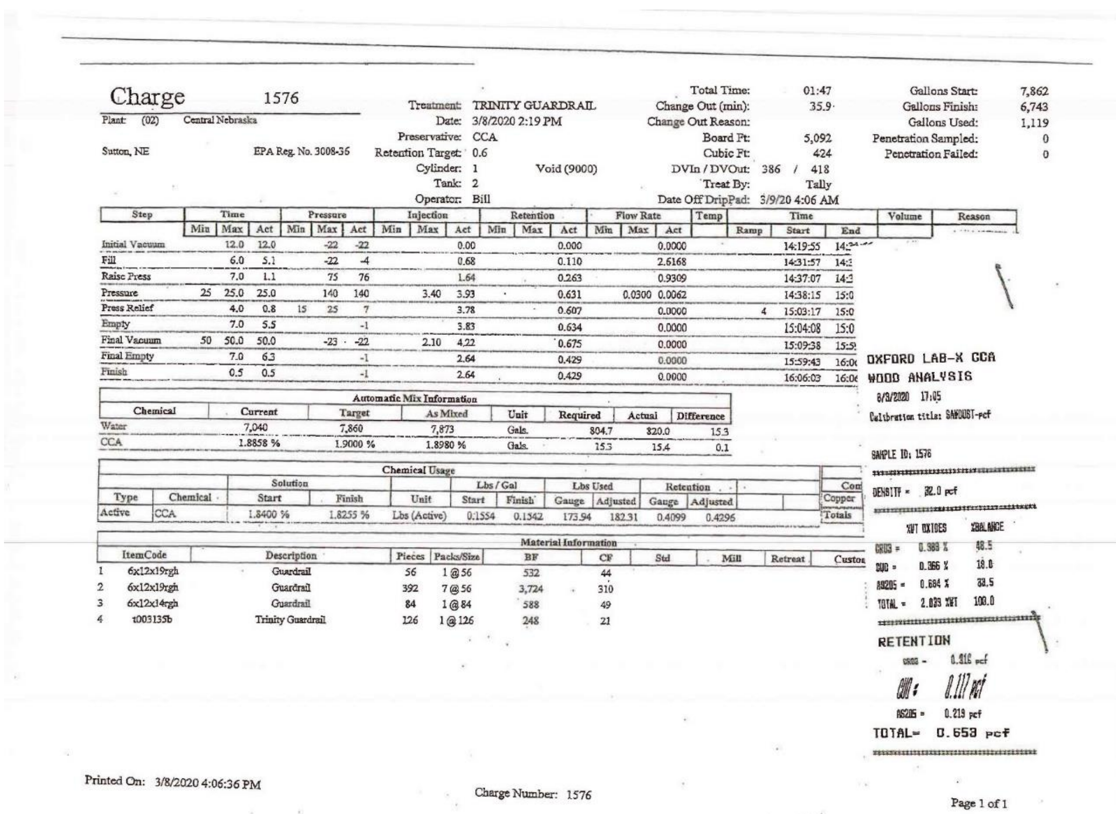
SAMPLE ID: 1695
DENSITY = 32.0 pcf

| | %WT OXIDES | %BALANCE |
|---|---|---|
| CRO3 = | 0.975 % | 50.0 |
| CUO = | 0.344 % | 17.6 |
| AS205 = | 0.632 % | 32.4 |
| TOTAL = | 1.952 %WT | 100.0 |

RETENTION
CRO3 = 0.312 pcf
CUO = 0.110 pcf
AS205 = 0.202 pcf
TOTAL= 0.625 pcf

Printed On: 3/31/2020 8:31:55 PM Charge Number: 1695 Page 1 of 1

Figure B-27. 6-in. x 8-in. x 19-in. Timber Blockout, Test Nos. STBRT-1 and STBRT-2



Charge 1576

Plant: (02) Central Nebraska

Sutton, NE EPA Reg. No. 3008-36

Treatment: TRINITY GUARDRAIL
Date: 3/8/2020 2:19 PM
Preservative: CCA
Retention Target: 0.6
Cylinder: 1 Void (9000)
Tank: 2
Operator: Bill

Total Time: 01:47
Change Out (min): 35.9
Change Out Reason:
Board Ft: 5,092
Cubic Ft: 424
DVIn / DVOut: 386 / 418
Treat By: Tally
Date Off DripPad: 3/9/20 4:06 AM

Gallons Start: 7,862
Gallons Finish: 6,743
Gallons Used: 1,119
Penetration Sampled: 0
Penetration Failed: 0

| Step | Time | | | Pressure | | | Injection | | | Retention | | | Flow Rate | | | Temp | Time | | | Volume | Reason |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | Act | Min | Max | Act | Min | Max | Act | Min | Max | Act | Min | Max | Act | | Ramp | Start | End | | |
| Initial Vacuum | | 12.0 | 12.0 | | -22 | -22 | | | 0.00 | | | 0.000 | | | 0.0000 | | | 14:19:55 | 14:2 | | |
| Fill | | 6.0 | 5.1 | | -22 | -4 | | | 0.68 | | | 0.110 | | | 2.6168 | | | 14:31:57 | 14:3 | | |
| Raise Press | | 7.0 | 1.1 | | 75 | 76 | | | 1.64 | | | 0.263 | | | 0.9309 | | | 14:37:07 | 14:3 | | |
| Pressure | 25 | 25.0 | 25.0 | | 140 | 140 | | 3.40 | 3.93 | | | 0.631 | | 0.0300 | 0.0062 | | | 14:38:15 | 15:0 | | |
| Press Relief | | 4.0 | 0.8 | 15 | 25 | 7 | | | 3.78 | | | 0.607 | | | 0.0000 | | 4 | 15:03:17 | 15:0 | | |
| Empty | | 7.0 | 5.5 | | | -1 | | | 3.83 | | | 0.634 | | | 0.0000 | | | 15:04:08 | 15:0 | | |
| Final Vacuum | 50 | 50.0 | 50.0 | | -23 | -22 | | 2.10 | 4.22 | | | 0.675 | | | 0.0000 | | | 15:09:38 | 15:5 | | |
| Final Empty | | 7.0 | 6.3 | | | -1 | | | 2.64 | | | 0.429 | | | 0.0000 | | | 15:59:43 | 16:0 | | |
| Finish | | 0.5 | 0.5 | | | -1 | | | 2.64 | | | 0.429 | | | 0.0000 | | | 16:06:03 | 16:0 | | |

Automatic Mix Information

| Chemical | Current | Target | As Mixed | Unit | Required | Actual | Difference |
|---|---|---|---|---|---|---|---|
| Water | 7,040 | 7,860 | 7,873 | Gals. | 804.7 | 820.0 | 15.3 |
| CCA | 1.8858 % | 1.9000 % | 1.8980 % | Gals. | 15.3 | 15.4 | 0.1 |

Chemical Usage

| | | Solution | | | Lbs / Gal | | Lbs Used | | Retention | | Com |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Type | Chemical | Start | Finish | Unit | Start | Finish | Gauge | Adjusted | Gauge | Adjusted | Copper |
| Active | CCA | 1.8400 % | 1.8255 % | Lbs (Active) | 0.1554 | 0.1542 | 173.94 | 182.31 | 0.4099 | 0.4296 | Totals |

Material Information

| | ItemCode | Description | Pieces | Packs/Size | BF | CF | Std | Mill | Retreat | Custor |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6x12x19rgh | Guardrail | 56 | 1 @ 56 | 532 | 44 | | | | |
| 2 | 6x12x19rgh | Guardrail | 392 | 7 @ 56 | 3,724 | 310 | | | | |
| 3 | 6x12x14rgh | Guardrail | 84 | 1 @ 84 | 588 | 49 | | | | |
| 4 | t003135b | Trinity Guardrail | 126 | 1 @ 126 | 248 | 21 | | | | |

OXFORD LAB-X CCA
WOOD ANALYSIS
8/3/2020 17:05
Calibration title: SAWDUST-pcf

SAMPLE ID: 1576
DENSITY = 32.0 pcf

| | %WT OXIDES | %BALANCE |
|---|---|---|
| CRO3 = | 0.989 % | 48.5 |
| CUO = | 0.366 % | 18.0 |
| AS205 = | 0.684 % | 33.5 |
| TOTAL = | 2.039 %WT | 100.0 |

RETENTION
CRO3 = 0.316 pcf
CUO = 0.117 pcf
AS205 = 0.219 pcf
TOTAL= 0.653 pcf

Printed On: 3/8/2020 4:06:36 PM Charge Number: 1576 Page 1 of 1

Figure B-28. 6-in. x 12-in. x 19-in. Timber Blockout, Test Nos. STBRT-1 and STBRT-2

# CCA Charge Report

Central Nebras
105 N. Owen
Sutton, NE 68979
Tel: (402) 773-4319

| | | | | | |
|---|---|---|---|---|---|
| Charge | C1-25698/U0 | Recipe | Default | Start Time | 7/23/18 11:1 |
| Tally | 25698/U26795 | Preset | GuardRail | End Time | 7/23/18 12:5 |
| Cylinder | CYL_1 | Operator | Bob | Duration | |

| | | | | FLW | INJ | MNT | MXT | PRS | VAC |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Initial Vacuum | Time | SP<br>ACT | | | | 7.00<br>11.75 | | 2:<br>2: |
| 2 | Vacuum Fill | Cylinder Full | SP<br>ACT | | | | 4.80 | | 22<br>20 |
| 3 | Atm Absorption | Time | SP<br>ACT | | | | 1.00<br>1.00 | | |
| 4 | Pressure | Time | SP<br>ACT | 0.00 | 4.10<br>15.39 | 25.00<br>25.00 | 25.00<br>25.00 | 140.00<br>149.33 | |
| 5 | Release Pressure | Pressure | SP<br>ACT | | | | 6.00<br>6.60 | 10.00<br>9.99 | |
| 6 | Emptying | Cylinder Empty | SP<br>ACT | | | | 5.92 | | |
| 7 | Final Vacuum | Operator Stepped | SP<br>ACT | | | 40.00<br>30.02 | 40.00<br>30.02 | | 24.<br>24. |
| 8 | Drain Cylinder | Cylinder Empty | SP<br>ACT | | | | 5.47 | | |

OXFORD LAB-X CCA
WOOD ANALYSIS
23/7/2018 13:49
Calibration title: SAWDUST-pcf

SAMPLE ID: 25698
**************************************
DENSITY = 32.0 pcf
**************************************

| | %WT.OXIDES | %BALANCE |
|---|---|---|
| CRO3 = | 1.067 % | 49.8 |
| CUO = | 0.376 % | 17.5 |
| AS2O5 = | 0.702 % | 32.7 |
| TOTAL = | 2.145 %WT | 100.0 |

**************************************

RETENTION
CRO3 = 0.342 pcf
CUO = 0.120 pcf
AS2O5 = 0.225 pcf
TOTAL= 0.686 pcf
**************************************

**Tank Information for T02 CCA**

| Phase | FT | GAL | LBS |
|---|---|---|---|
| Initial Vacuum | 9.3 | 7880 | 66715 |
| Vacuum Fill | 2.2 | 1836 | 15543 |
| Pressure | 0.4 | 349 | 2952 |
| End of Charge | 7.8 | 6570 | 55629 |

**Charge Data**

| | | | |
|---|---|---|---|
| Solution Concentration | 1.90% | Volume Basis | Tally |
| Calculated Chemical Use (Lbs) | 210.48 | Disp. Volume (CuFT) | 424.16 |
| Net Injection (Gal/CuFt) | 3.24 | Target Assay Retention | 0.60 |
| Estimated Heartwood (%) | | Assay (Lbs/CuFT) / NC | / |
| Calculated Retention | 0.52 | | |
| Total Gallons Used (Gal) | 1,308.46 | | |

**Tally** BF/SF 4,836.00 Total Volume 404.24 CuFt

| Designation | Description | Qty | Specie | Grade | Lot | MC % | Dressing | CuFt | BdFt |
|---|---|---|---|---|---|---|---|---|---|
| Stock | 6x8x7Rgh | 50 | SYP | 1 | | | | 116.67 | 1,400.00 |
| Stock | 6x12x19\"Rgh | 168 | SYP | 1 | | | | 133.00 | 1,596.00 |
| Stock | T006298B | 16 | SYP | 1 | | | | 154.58 | 1,840.00 |

Generated by Treat Right® on 7/23/2018.

Figure B-29. 6-in. x 12-in. x 19-in. Timber Blockout, Test Nos. STBRT-1 and STBRT-2

# Charge 1672

Plant: (02) Central Nebraska

Sutton, NE

EPA Reg. No. 3008-36

Treatment: TRINITY GUARDRAIL
Date: 3/26/2020 7:20 AM
Preservative: CCA
Retention Target: 0.6
Cylinder: 1 Void (9000)
Tank: 2
Operator: Bob

Total Time: 01:49
Change Out (min): 35:1
Change Out Reason:
Board Ft: 5,394
Cubic Ft: 450
DVIn / DVOut: 415 / 435
Treat By: Tally
Date Off DripPad: 3/26/20 9:09 PM

| Step | Time | | | Pressure | | | Injection | | | Retention | | | Flow Rate | | | Temp | Time | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | Act | Min | Max | Act | Min | Max | Act | Min | Max | Act | Min | Max | Act | | Ramp | Start | End |
| Initial Vacuum | | 12.0 | 12.0 | | -22 | -22 | | | 0.00 | | | 0.000 | | | 0.0000 | | | 07:20:51 | 07:32:53 |
| Fill | | 6.0 | 4.9 | | -22 | -3 | | | 0.58 | | | 0.092 | | | 2.5462 | | | 07:32:53 | 07:37:50 |
| Raise Press | | 7.0 | 0.7 | | 75 | 77 | | | 1.04 | | | 0.167 | | | 0.0000 | | | 07:37:50 | 07:38:31 |
| Pressure | 25 | 25.0 | 25.0 | | 140 | 140 | | 3.40 | 3.60 | | | 0.579 | | 0.0300 | 0.0128 | | | 07:38:31 | 08:03:32 |
| Press Relief | | 4.0 | 4.0 | 15 | 25 | 8 | | | 3.52 | | | 0.565 | | | 0.0000 | | 4 | 08:03:32 | 08:07:32 |
| Empty | | 7.0 | 5.4 | | | -1 | | | 3.36 | | | 0.560 | | | 0.0000 | | | 08:07:32 | 08:12:58 |
| Final Vacuum | 50 | 50.0 | 50.0 | | -23 | -23 | | 2.10 | 3.49 | | | 0.581 | | | 0.0000 | | | 08:12:59 | 09:03:01 |
| Final Empty | | 7.0 | 6.1 | | | -1 | | | 2.38 | | | 0.402 | | | 0.0000 | | | 09:03:02 | 09:09:06 |
| Finish | | 0.5 | 0.5 | | | -1 | | | 2.38 | | | 0.402 | | | 0.0000 | | | 09:09:07 | 09:09:38 |

**Automatic Mix Information**

| Chemical | Current | Target | As Mixed | Unit | Required | Actual | Difference |
|---|---|---|---|---|---|---|---|
| Water | 6,780 | 7,860 | 7,873 | Gals. | 1,062.4 | 1,076.0 | 13.6 |
| CCA | 1.9200 % | 1.9000 % | 1.8978 % | Gals. | 17.6 | 17.7 | 0.1 |

**Chemical Usage**

| | | Solution | | | Lbs / Gal | | Lbs Used | | Retention | |
|---|---|---|---|---|---|---|---|---|---|---|
| Type | Chemical | Start | Finish | Unit | Start | Finish | Gauge | Adjusted | Gauge | Adjusted |
| Active | CCA | 1.9000 % | 1.8843 % | Lbs (Active) | 0.1606 | 0.1592 | 171.83 | 180.96 | 0.3822 | 0.4025 |

| Comp |
|---|
| Copper |
| Totals |

**Material Information**

| | ItemCode | Description | Pieces | Packs/Size | BF | CF | Std | Mill | Retreat | Custom |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | t004063b | Trinity Guardrail | 175 | 1 @ 175 | 4,200 | 350 | | | | |
| 2 | t004660b | Trinity Guardrail | 84 | 1 @ 84 | 606 | 51 | | | | |
| 3 | 6x12x14rgh | Guardrail | 84 | 1 @ 84 | 588 | 49 | | | | |

OXFORD LAB-X CCA
WOOD ANALYSIS
26/3/2020 12:01
Calibration title: SAWDUST-pcf

SAMPLE ID: 1672
****************************************
DENSITY = 32.0 pcf
****************************************

| | %WT OXIDES | %BALANCE |
|---|---|---|
| CRO3 = | 1.101 % | 50.9 |
| CUO = | 0.383 % | 17.7 |
| AS2O5 = | 0.680 % | 31.4 |
| TOTAL = | 2.164 %WT | 100.0 |

****************************************
RETENTION
CRO3 = 0.352 pcf
CUO = 0.123 pcf
AS2O5 = 0.218 pcf
TOTAL= 0.692 pcf
****************************************

0
0
0

Printed On: 3/26/2020 9:09:40 AM    Charge Number: 1672    Page 1 of 1

Figure B-30. 6-in. x 12-in. x 14¼-in. Timber Blockout, Test Nos. STBRT-1 and STBRT-2

**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:** 187087

**SHIPPER #:** 061972
**DATE SHIPPED:** 11/06/2017

**LOT#:** 30361-P

**SPECIFICATION:** ASTM A307, GRADE A MILD CARBON STEEL BOLTS

| | | | | |
|---|---|---|---|---|
| **TENSILE:** | SPEC: | 60,000 psi*min | RESULTS: | 66,566<br>66,832 |
| **HARDNESS:** | | 100 max | | 82.60<br>82.70 |

*Pounds Per Square Inch.

**COATING:** ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE
**ROGERS GALVANIZE:** 30361-P

**CHEMICAL COMPOSITION**

| MILL | GRADE | HEAT# | C | Mn | P | S | Si |
|---|---|---|---|---|---|---|---|
| NUCOR | 1010 | DL17100590 | .10 | .41 | .005 | .005 | .05 |

**QUANTITY AND DESCRIPTION:**

**4,825** PCS 5/8" X 14" GUARD RAIL BOLT
P/N 3540G

WE HEREBY CERTIFY THE ABOVE BOLTS HAVE BEEN MANUFACTURED BY ROCKFORD BOLT AND STEEL AT OUR FACILITY IN ROCKFORD, ILLINOIS, USA. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE USA. WE FURTHER CERIFY 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 REQUIREMENT PER ABOVE SPECIFICATION.

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS

6th DAY OF November, 20 17 — Linda McComas — APPROVED SIGNATORY — 11/6/17 DATE

Merry F. Shane

OFFICIAL SEAL
MERRY F. SHANE
NOTARY PUBLIC – STATE OF ILLINOIS
MY COMMISSION EXPIRES OCTOBER 3, 2018

Figure B-31. ⅝-in. Dia., 14-in. Long Guardrail Bolt, Test Nos. STBRT-1 and STBRT-2

**CERTIFICATE OF COMPLIANCE**

**ROCKFORD BOLT & STEEL CO.**
**126 MILL STREET**
**ROCKFORD, IL 61101**
**815-968-0514 FAX# 815-968-3111**

**CUSTOMER NAME:** GREGORY INDUSTRIES

**CUSTOMER PO:** 39864

**SHIPPER #:** 063466
**DATE SHIPPED:** 05/24/2018

**LOT#:** 30920-B

**SPECIFICATION:** ASTM A307, GRADE A MILD CARBON STEEL BOLTS

**TENSILE:** SPEC: 60,000 psi*min RESULTS: 79,300 / 76,800

**HARDNESS:** 100 max 90.00 / 90.80

*Pounds Per Square Inch.

**COATING:** ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE
**AZZ GALVANIZING:** 30920-B

**CHEMICAL COMPOSITION**

| MILL | GRADE | HEAT# | C | Mn | P | S | Si |
|---|---|---|---|---|---|---|---|
| MID AMERICAN STEEL & WIRE | 1012 | 1721198 | .13 | .51 | .016 | .027 | .19 |

20,700 PCS 5/8" X 10" GUARD RAIL BOLT
P/N 1010G

WE HEREBY CERTIFY THE ABOVE BOLTS HAVE BEEN MANUFACTURED BY ROCKFORD BOLT AND STEEL AT OUR FACILITY IN ROCKFORD, ILLINOIS, USA. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE USA. WE FURTHER CERIFY 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 REQUIREMENT PER ABOVE SPECIFICATION.

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS

31st DAY OF May, 20 18 — Linda McComas — APPROVED SIGNATORY — 5/31/18 DATE

Merry F Shane

OFFICIAL SEAL
MERRY F. SHANE
NOTARY PUBLIC – STATE OF ILLINOIS
MY COMMISSION EXPIRES OCTOBER 3, 2018

Figure B-32. ⅝-in. Dia., 10-in. Long Guardrail Bolt, Test Nos. STBRT-1 and STBRT-2

**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

**Melted in USA Manufactured in USA**

**CHARTER STEEL TEST REPORT**

Rockford Bolt & Steel
126 Mill St.
Rockford,IL-61101
Kind Attn :Linda McComas

| | |
|---|---|
| Cust P.O. | P38843-10 |
| Customer Part # | 100905 |
| Charter Sales Order | 70091993 |
| Heat # | 10626360 |
| Ship Lot # | 4612760 |
| Grade | 1010 A AK FG RHQ 19/32 RNDCOIL |
| Process | HRSA |
| Finish Size | 19/32 |
| Ship date | 16-OCT-19 |

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.

Lab Code: 7388

Test results of Heat Lot # 10626360

| CHEM %Wt | C | MN | P | S | SI | NI | CR | MO | CU | SN | V |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | .09 | .37 | .008 | .009 | .090 | .04 | .08 | .01 | .08 | .006 | .001 |
| | AL | N | B | TI | NB | | | | | | |
| | .036 | .0080 | .0001 | .001 | .001 | | | | | | |

Test results of Rolling Lot # 1280744

REDUCTION RATIO=109:1

Specifications: Manufactured per Charter Steel Quality Manual Rev Date 05/12/17
Charter Steel certifies this product is indistinguishable from background radiation levels by having process radiation detectors in place to measure for the presence of radiation within our process & products.
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29/A29M Revision = 16 Dated = 01-DEC-16

Additional Comments:

Melt Source:
Charter Steel
Saukville, WI, USA

Trip: 1393507

ACCREDITED Testing Laboratory

This MTR supersedes all previously dated MTRs for this order

Janice Barnard Division Mgr. of Quality Assurance
barnardJ@chartersteel.com
Printed Date : 10/16/2019

Figure B-33. ⅝-in. Dia., 2-in. Long Guardrail Bolt, Test Nos. STBRT-1 and STBRT-2

CHARTER STEEL
A Division of Charter Manufacturing Company, Inc.

LOAD

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
Fax (262) 268-2570

**CHARTER STEEL TEST REPORT**

65172

Melted in USA Manufactured in USA

| | |
|---|---|
| Cust P.O. | 040048854 |
| Customer Part # | 09007018 |
| Charter Sales Order | 70095515 |
| Heat # | 10641050 |
| Ship Lot # | 4635987 |
| Grade | 1018 R SK FG RHQ 19/32 RNDCOIL |
| Process | HRCC |
| Finish Size | 19/32 |
| Ship date | 03-APR-20 |

Fastenal Company
5800 Industrial Ave,
Loves Park,IL-61111

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 # 10641050

Lab Code: 7388
CHEM
%Wt

| C | MN | P | S | SI | NI | CR | MO | CU | SN | V |
|---|---|---|---|---|---|---|---|---|---|---|
| .16 | .75 | .009 | .006 | .190 | .04 | .09 | .02 | .07 | .005 | .003 |
| AL | N | B | TI | NB | | | | | | |
| .037 | .0080 | .0001 | .002 | .001 | | | | | | |

JOMINY(HRC)

| J1 | J2 | J3 |
|---|---|---|
| 42 | 23 | 21 |

JOMINY SAMPLE TYPE ENGLISH=C

Test results of Rolling Lot # 1293231

| | # of Tests | Min Value | Max Value | Mean Value | |
|---|---|---|---|---|---|
| TENSILE (KSI) | 1 | 71.1 | 71.1 | 71.1 | TENSILE LAB = 0358-02 |
| REDUCTION OF AREA (%) | 1 | 43 | 43 | 43 | RA LAB = 0358-02 |
| ROCKWELL B (HRBW) | 1 | 76 | 76 | 76 | RB LAB = 0358-02 |

REDUCTION RATIO=109:1

Specifications: Manufactured per Charter Steel Quality Manual Rev Date 05/12/17
Charter Steel certifies this product is indistinguishable from background radiation levels by having process radiation detectors in place to measure for the presence of radiation within our process & products.
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM F2282 Revision = 18 Dated = 01-MAY-19

Additional Comments:

Melt Source:
Charter Steel
Saukville, WI, USA

Trip: 1426166

ACCREDITED
Testing Laboratory

This MTR supersedes all previously dated MTRs for this order

Janice Barnard Division Mgr. of Quality Assurance
barnardJ@chartersteel.com
Printed Date : 04/03/2020

Figure B-34. ⅝-in. Dia., 1¼-in. Long Guardrail Bolt, Test Nos. STBRT-1 and STBRT-2

## Certificate of Compliance

Birmingham Fastener Manufacturing
PO Box 10323
Birmingham, AL 35202
(205) 595-3512

Customer: Midwest Machinery & Supply — Date Shipped: 11/28/2018

Customer Order Number: 3664 — BFM Order Number: 1553751

### Item Description

Description: 5/8"-11 x 10" Hex Bolt — Qty: 298

Lot #: 81342 — Specification: ASTM A307-14 Gr A — Finish: ASTM F2329

### Raw Material Analysis

Heat#: JK18104124

Chemical Composition (wt% Heat Analysis) By Material Supplier

| C | Mn | P | S | Si | Cu | Ni | Cr | Mo |
|---|---|---|---|---|---|---|---|---|
| 0.18 | 1.19 | 0.012 | 0.034 | 0.20 | 0.29 | 0.13 | 0.11 | 0.04 |

### Mechanical Properties

| Sample # | Hardness | Tensile Strength (lbs) | Tensile Strength (psi) |
|---|---|---|---|
| 1 | 93 HRBW | 22,049 | 99,410 |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |

This information represents the most recent analysis of the product supplied on the stated customer order. The samples tested conform to the ASTM standard listed above.
All steel melted and manufactured in the U.S.A.

Authorized Signature: Brian Hughes, Quality Assurance — Date: 11/29/2018

Figure B-35. ⅝-in. Dia., 10 in. Long Hex Bolt, Test Nos. STBRT-1 and STBRT-2

# CERTIFIED MATERIAL TEST REPORT
# FOR ASTM A307, GRADE A - MACHINE BOLTS

FACTORY: IFI & MORGAN LTD. REPORT DATE:2019/4/2
ADDRESS: No.583-28, Chang'an North Road, Wuyuan Town, Haiyan, Zhejiang, China MANUFACTURE DATE:2019/3/14

CUSTOMER: FASTENAL MFG LOT NUMBER:M-2019HT138-5
SAMPE SIZE: ACC. TO ASME B18.18 CATEGORY 2-2011; ASTM F1470-12 TABLE 3
MANU QTY: 2450PCS SHIPPED QTY:2400PCS
SIZE: 5/8-11X1 1/2 HDG
HEADMARKS: 307A PLUS NY PO NUMBER:210179696
PART NO:1191919

STEEL PROPERTIES:
MATERIAL TYPE:Q195C HEAT NUMBER:5-01570

| CHEMISTRY SPEC: | C %*100 | Mn%*100 | P %*1000 | S %*1000 |
|---|---|---|---|---|
| Grade A ASTM A307-12 | 0.29max | 1.20 max | 0.04max | 0.15max |
| TEST: | 0.07 | 0.33 | 0.015 | 0.022 |

DIMENSIONAL INSPECTIONS **Unit:inch** SPECIFICATION: ASME B18.2.1 - 2012

| CHARACTERISTICS | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|
| ********************** | ************************************ | ******************* | ******** | ******** |
| VISUAL | ASTM F788-2013 | PASSED | 18 | 0 |
| THREAD | ASME B1.1-2003, 3A GO, 2A NO GO | PASSED | 13 | 0 |
| WIDTH A/F | 0.906-0.938 | 0.916-0.928 | 3 | 0 |
| WIDTH A/C | 1.033-1.083 | 1.048-1.057 | 3 | 0 |
| HEAD HEIGHT | 0.378-0.444 | 0.394-0.428 | 3 | 0 |
| BODY DIA. | 0.605-0.642 | 0.617-0.634 | 3 | 0 |
| THREAD LENGTH | 1.420-1.560 | 1.436-1.543 | 13 | 0 |
| LENGTH | 1.420-1.560 | 1.436-1.543 | 13 | 0 |

MECHANICAL PROPERTIES: SPECIFICATION: ASTM A307 - 14e1 GR.A

| CHARACTERISTICS | TEST METHOD | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|
| ********************* | ****************** | ****************** | ****************** | ******** | ******** |
| CORE HARDNESS : | ASTM F606/F606M-2016 | 69-100 HRB | 75-80 HRB | 3 | 0 |
| WEDGE TENSILE: | ASTM F606/F606M-2016 | Min 60 KSI | 65-69 KSI | 3 | 0 |

| CHARACTERISTICS | TEST METHOD | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|
| COATINGS OF ZINC: | | SPECIFIATION: ASTM F2329/F2329M-2015 | | | |
| HOT DIP GALVANIZED | ASTM B568-98(2014) | Min 0.0017" | 0.0017" -0.0018" | 3 | 0 |

We hereby certify that above products supplied are in compliance with all the requirements of the order.
We here by certify that this MTR is in compliance to DIN EN 10204 3.1 content.
ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.
Maker's ISO 9001:2015 SGS Certificate # HK04/0105

IFI & MORGAN LTD. 检验专用章 QUALITY CONTROL

(SIGNATURE OF Q.A. LAB MGR.)
(NAME OF MANUFACTURER)

Figure B-36. ⅝-in. Dia., 1½-in. Long Hex Bolt, Test Nos. STBRT-1 and STBRT-2

**Portland Bolt & MANUFACTURING COMPANY**

Phone: 800-547-6758 | Fax: 503-227-4634
3441 NW Guam Street, Portland, OR 97210
Web: www.portlandbolt.com | Email: sales@portlandbolt.com

**CERTIFICATE OF CONFORMANCE**

**For:** MIDWEST ROADSIDE SAFETY FACIL
**PB Invoice#:** 132406
**Cust PO#:** STBRT
**Date:** 7/16/2020
**Shipped:** 7/17/2020

**We certify that the following items were manufactured and tested in accordance with the chemical, mechanical, dimensional and thread fit requirements of the specifications referenced.**

---

**Description:** 3/4 X 7-1/2 GALV ASTM A449 ROUND HEAD BOLT

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Heat#:** 3090536 | | | **Base Steel:** 1045 | | | **Diam:** 3/4 | | | |
| **Source:** COMMERCIAL METALS CO | | | | | | **Proof Load:** 28,400 LBF | | | |
| **C :** | .460 | **Mn:** | .750 | **P :** | .011 | **Hardness:** 269 HBN | | | |
| **S :** | .021 | **Si:** | .250 | **Ni:** | .070 | **Tensile:** 48,000 LBF | | **RA:** | .00% |
| **Cr:** | .110 | **Mo:** | .040 | **Cu:** | .280 | **Yield:** 0 | | **Elon:** | .00% |
| **Pb:** | .000 | **V :** | .000 | **Cb:** | .001 | **Sample Length:** 0 | | | |
| **N :** | .010 | | | **CE:** | .6057 | **Charpy:** | | **CVN Temp:** | |

LOT#19779

---

**Description:** 3/4 X 21 GALV ASTM A449 ROUND HEAD BOLT

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Heat#:** 3090536 | | | **Base Steel:** 1045 | | | **Diam:** 3/4 | | | |
| **Source:** COMMERCIAL METALS CO | | | | | | **Proof Load:** 28,400 LBF | | | |
| **C :** | .460 | **Mn:** | .750 | **P :** | .011 | **Hardness:** 269 HBN | | | |
| **S :** | .021 | **Si:** | .250 | **Ni:** | .070 | **Tensile:** 48,000 LBF | | **RA:** | .00% |
| **Cr:** | .110 | **Mo:** | .040 | **Cu:** | .280 | **Yield:** 0 | | **Elon:** | .00% |
| **Pb:** | .000 | **V :** | .000 | **Cb:** | .001 | **Sample Length:** 0 | | | |
| **N :** | .010 | | | **CE:** | .6057 | **Charpy:** | | **CVN Temp:** | |

LOT#19779

---

Figure B-37. Round Head Bolts, Test Nos. STBRT-1 and STBRT-2

**Portland Bolt**
**& MANUFACTURING COMPANY**

Phone: 800-547-6758 | Fax: 503-227-4634
3441 NW Guam Street, Portland, OR 97210
Web: www.portlandbolt.com | Email: sales@portlandbolt.com

**CERTIFICATE OF CONFORMANCE**

**For:** MIDWEST ROADSIDE SAFETY FACIL
**PB Invoice#:** 115687
**Cust PO#:** JIM HOLLOWAY
**Date:** 12/10/2018
**Shipped:** 12/12/2018

**We certify that the following items were manufactured and tested in accordance with the chemical, mechanical, dimensional and thread fit requirements of the specifications referenced.**

**Description:** 3/4 X 9-1/2 GALV ASTM F3125 GRADE A325 HEAVY HEX BOLT

**Heat#:** 3078659 | **Base Steel:** 1045 | **Diam:** 3/4

**Source:** COMMERCIAL METALS CO | **Proof Load:** 28,560 LBF

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **C :** | .440 | **Mn:** | .740 | **P :** | .014 | **Hardness:** | 285 HBN | | |
| **S :** | .024 | **Si:** | .210 | **Ni:** | .070 | **Tensile:** | 48,220 LBF | **RA:** | .00% |
| **Cr:** | .100 | **Mo:** | .013 | **Cu:** | .210 | **Yield:** | 0 | **Elon:** | .00% |
| **Pb:** | .000 | **V :** | .000 | **Cb:** | .000 | **Sample Length:** | 0 | | |
| **N :** | .000 | | | **CE:** | .5818 | **Charpy:** | | **CVN Temp:** | |

LOT#19059

**Coatings:**
ITEMS HOT DIP GALVANIZED PER ASTM F2329/A153C

**Other:**
ALL ITEMS MELTED & MANUFACTURED IN THE USA

By: Certification Department Quality Assurance
Dane McKinnon

Figure B-38. Heavy Hex and Round Head Bolts, Test Nos. STBRT-1 and STBRT-2

**Portland Bolt**
**& MANUFACTURING COMPANY**

Phone: 800-547-6758 | Fax: 503-227-4634
3441 NW Guam Street, Portland, OR 97210
Web: www.portlandbolt.com | Email: sales@portlandbolt.com

**CERTIFICATE OF CONFORMANCE**

**For:** MIDWEST ROADSIDE SAFETY FACIL
**PB Invoice#:** 119891
**Cust PO#:** 70ACCT
**Date:** 4/17/2019
**Shipped:** 4/25/2019

**We certify that the following items were manufactured and tested in accordance with the chemical, mechanical, dimensional and thread fit requirements of the specifications referenced.**

**Description:** 7/8 X 8 GALV ASTM A307A HEX BOLT

**Heat#:** 489517 | **Base Steel:** A36 | **Diam:** 7/8

**Source:** CASCADE STEEL RLG MILL | **Proof Load:** 0

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **C :** | .180 | **Mn:** | .680 | **P :** | .013 | **Hardness:** | 0 | | |
| **S :** | .015 | **Si:** | .240 | **Ni:** | .080 | **Tensile:** | 72,500 PSI | **RA:** | 42.00% |
| **Cr:** | .130 | **Mo:** | .028 | **Cu:** | .240 | **Yield:** | 48,800 PSI | **Elon:** | 24.00% |
| **Pb:** | .000 | **V :** | .000 | **Cb:** | .000 | **Sample Length:** | 8 INCH | | |
| **N :** | .000 | | | **CE:** | .3157 | **Charpy:** | | **CVN Temp:** | |

**Coatings:**
ITEMS HOT DIP GALVANIZED PER ASTM F2329/A153C

By: Certification Department Quality Assurance
Dane McKinnon

Figure B-39. ⅞-in. Dia., 8-in. Long Hex Bolt, Test Nos. STBRT-1 and STBRT-2

**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

**Melted in USA Manufactured in USA**

| | |
|---|---|
| Cust P.O. | 135820 |
| Customer Part # | 955612619A1 |
| Charter Sales Order | 10240117 |
| Heat # | 10552460 |
| Ship Lot # | 4534855 |
| Grade | LEBA1 M SK FG RHQ 1-1/32 RNDCOIL |
| Process | HRCC |
| Finish Size | 1-1/32 |
| Ship date | 11-JUN-18 |

**Fontana Fasteners Inc**
**3595 West State Road 28**
**Frankfort,IN-46041**

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 # 10552460**

Lab Code: 7388

| CHEM | C | MN | P | S | SI | NI | CR | MO | CU | SN | V |
|---|---|---|---|---|---|---|---|---|---|---|---|
| %Wt | .31 | .92 | .007 | .007 | .230 | .05 | .17 | .09 | .09 | .006 | .003 |
| | AL | N | B | TI | NB | SB | AS | | | | |
| | .027 | .0070 | .0028 | .023 | .002 | .001 | .003 | | | | |

JOMINY(HRC)

| J1 | J2 | J3 | J4 | J5 | J6 | J7 | J8 | J9 | J10 | J11 | J12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | 50 | 50 | 49 | 48 | 48 | 43 | 37 | 34 | 31 | 28 | 27 |
| J13 | J14 | J15 | J16 | J18 | J20 | J22 | J24 | J26 | J28 | | |
| 25 | 25 | 25 | 24 | 23 | 22 | 21 | 21 | 20 | 20 | | |

JOMINY LAB=0358-01 JOMINY SAMPLE TYPE ENGLISH=R CAT DI=3.22

**Test results of Rolling Lot # 1241818**

| | # of Tests | Min Value | Max Value | Mean Value | |
|---|---|---|---|---|---|
| ROCKWELL B (HRBW) | 3 | 81 | 83 | 82 | RB LAB = 0358-02 |
| ROD SIZE (Inch) | 12 | 1.024 | 1.037 | 1.030 | |
| ROD OUT OF ROUND (Inch) | 6 | .005 | .008 | .007 | |

NUM DECARB=1
REDUCTION RATIO=36:1
AVE DECARB (Inch)=.005

Specifications: Manufactured per Charter Steel Quality Manual Rev Date 05/12/17
Charter Steel certifies this product is indistinguishable from background radiation levels by having process radiation detectors in place to measure for the presence of radiation within our process & products.
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = LE 1.1 Revision = 9 Dated = 27-NOV-07

Additional Comments: GRADE 30 Cr Mn B1

Melt Source:
Charter Steel
Saukville, WI, USA

Trip: 1271794

ACCREDITED
Testing Laboratory

This MTR supersedes all previously dated MTRs for this order

Janice Barnard Division Mgr. of Quality Assurance
barnardJ@chartersteel.com
Printed Date : 06/11/2018

Page 1 of 2

Figure B-40. 1-in. Dia, 3½-in. Long Heavy Hex Bolt, Test Nos. STBRT-1 and STBRT-2

**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

**Melted in USA Manufactured in USA**

**Fontana Fasteners Inc**
**3595 West State Road 28**
**Frankfort,IN-46041**

| | |
|---|---|
| Cust P.O. | 118874 |
| Customer Part # | 955610992A1 |
| Charter Sales Order | 30106122 |
| Heat # | 10415990 |
| Ship Lot # | 4385224 |
| Grade | LEBA1 M SK FG RHQ 25/64 |
| Process | HRCC |
| Finish Size | 25/64 |
| Ship date | 09-JAN-16 |

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 # 10415990**

Lab Code: 7388

| CHEM | C | MN | P | S | SI | NI | CR | MO | CU | SN | V |
|---|---|---|---|---|---|---|---|---|---|---|---|
| %Wt | .32 | .91 | .007 | .008 | .220 | .04 | .17 | .08 | .08 | .006 | .004 |
| | AL | N | B | TI | NB | SB | AS | | | | |
| | .023 | .0060 | .0028 | .022 | .001 | .002 | .004 | | | | |

JOMINY(HRC)

| J1 | J2 | J3 | J4 | J5 | J6 | J7 | J8 | J9 | J10 | J11 | J12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | 51 | 51 | 50 | 49 | 48 | 45 | 39 | 33 | 30 | 27 | 25 |
| J13 | J14 | J15 | J16 | J18 | J20 | J22 | | | | | |
| 24 | 23 | 23 | 22 | 21 | 21 | 20 | | | | | |

JOMINY LAB=0358-01 JOMINY SAMPLE TYPE ENGLISH=R CAT DI=3.18

**Test results of Rolling Lot # 1174376**

| | # of Tests | Min Value | Max Value | Mean Value | |
|---|---|---|---|---|---|
| TENSILE (KSI) | 1 | 91.7 | 91.7 | 91.7 | TENSILE LAB = 0358-02 |
| REDUCTION OF AREA (%) | 1 | 65 | 65 | 65 | RA LAB = 0358-02 |
| ROCKWELL B (HRBW) | 1 | 91 | 91 | 91 | RB LAB = 0358-02 |
| ROD SIZE (Inch) | 4 | .388 | .393 | .391 | |
| ROD OUT OF ROUND (Inch) | 1 | .005 | .005 | .005 | |

NUM DECARB=1
REDUCTION RATIO=252:1
AVE DECARB (Inch)=.003

Specifications: Manufactured per Charter Steel Quality Manual Rev Date 12/12/13
Charter Steel certifies this product is indistinguishable from background radiation levels by having process radiation detectors in place to measure for the presence of radiation within our process & products.
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = LE 1.1 Revision = 9 Dated = 27-NOV-07

Additional Comments: GRADE 30 Cr Mn B1

Melt Source:
Charter Steel
Saukville, WI, USA

Rem: Load1,Fax0,Mail0

ACCREDITED
Testing Laboratory

This MTR supersedes all previously dated MTRs for this order
Janice Barnard
Manager of Quality Assurance
Printed Date : 01/09/2016

Page 1 of 2

Figure B-41. 1-in. Dia., 2¼-in. Long Heavy Hex Bolt, Test Nos. STBRT-1 and STBRT-2

# TEST REPORT

## USS FLAT WASHER, HDG

| | |
|---|---|
| CUSTOMER: | DATE: **30/12/2018** |
| PO NUMBER: **180164126** | MFG LOT NUMBER: **M-SWE0412454-8** |
| SIZE: **5/8** | PART NO: **1133185** |
| HEADMARKS: | QNTY: **6,000 PCS** |

DIMENSIONAL INSPECTIONS SPECIFICATION: **ASME B18.21.1(2009)**

| CHARACTERISTICS | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|
| ********************** | ************************************ | ******************* | ******** | ******** |
| APPEARANCE | **ASTM F788-07** | **PASSED** | **100** | **0** |
| OUTSIDE DIA | **1.743-1.780** | **1.752-1.756** | **8** | **0** |
| INSIDE DIA | **0.681-0.718** | **0.700-0.707** | **8** | **0** |
| THICKNESS | **0.108-0.160** | **0.114-0.119** | **8** | **0** |
| HOT DIP GALVANIZED | **ASTM A153 class C. RoHS Compliant** **Min 0.0017"** | **Min 0.0019 In** | **8** | **0** |

*ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION.*
*WE CERTIFY THAT THIS DAIA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.*
*MFG ISO 9001:2015 SGS Certificate # HK04/0105*
**We hereby certify that above products supplied are in compliance with all the requirements of the order.**
**We here by certify that this MTR is in compliance to DIN EN 10204 3.1 content.**

IFI & MORGAN LTD. 检验专用章

(SIGNATURE OF Q.A. LAB MGR.)
(NAME OF MANUFACTURER)

***IFI & MORGAN LTD.*** ***ADDRESS: Chang'an North Road, Wuyuan Town, Haiyan, Zhejiang, China***

Figure B-42. ⅝-in. Dia. SAE Plain Round Washer, Test Nos. STBRT-1 and STBRT-2

CERTIFIED MATERIAL TEST REPORT
FOR USS FLAT WASHERS HDG

FACTORY: IFI & Morgan Ltd — REPORT DATE: 23/4/2019
ADDRESS: Chang'an North Road, Wuyuan Town, Haiyan,Zhejiang, China

MFG LOT NUMBER: 1844804

SAMPLING PLAN PER ASME B18.18-11 — PO NUMBER: 170089822
SIZE: USS 7/8 HDG — QNTY(Lot size): 7200PCS
HEADMARKS: NO MARK — PART NO: 33187

DIMENSIONAL INSPECTIONS — SPECIFICATION: ASTM B18.21.1-2011

| CHARACTERISTICS | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|
| APPEARANCE | ASTM F844 | PASSED | 100 | 0 |
| OUTSIDE DIA | 2.243-2.280 | 2.246-2.254 | 10 | 0 |
| INSIDE DIA | 0.931-0.968 | 0.956-0.965 | 10 | 0 |
| THICKNESS | 0.136-0.192 | 0.136-0.157 | 10 | 0 |

| CHARACTERISTICS | TEST METHOD | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|
| HOT DIP GALVANIZED | ASTM F2329-13 | Min 0.0017" | 0.0017-0.0020 in | 8 | 0 |

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DAIA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.
ISO 9001:2015 SGS Certificate # HK04/0105

IFI & MORGAN LTD. 检验专用章 QUANLITY CONTROL

(SIGNATURE OF Q.A. LAB MGR.)

Figure B-43. ⅞-in. Dia. USS Plain Round Washer, Test Nos. STBRT-1 and STBRT-2

CERTIFIED MATERIAL TEST REPORT
FOR USS FLAT WASHERS HDG

FACTORY: IFI & Morgan Ltd — REPORT DATE: 22/10/2018
ADDRESS: Chang'an North Road, Wuyuan Town, Haiyan,Zhejiang, China

SAMPLING PLAN PER ASME B18.18-11 — PO NUMBER: 210151571
SIZE: USS 1 HDG — QNTY(Lot size): 3240PCS
HEADMARKS: NO MARK — PART NO: 33188

DIMENSIONAL INSPECTIONS — SPECIFICATION: ASTM B18.21.1-2011

| CHARACTERISTICS | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|
| APPEARANCE | ASTM F844 | PASSED | 100 | 0 |
| OUTSIDE DIA | 2.492-2.529 | 2.496-2.504 | 10 | 0 |
| INSIDE DIA | 1.055-1.092 | 1.080-1.089 | 10 | 0 |
| THICKNESS | 0.135-0.192 | 0.135-0.157 | 10 | 0 |

| CHARACTERISTICS | TEST METHOD | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|
| HOT DIP GALVANIZED | ASTM F2329-13 | Min 0.0017" | 0.0017-0.0020 in | 8 | 0 |

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DAIA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.
ISO 9001:2015 SGS Certificate # HK04/0105

IFI & MORGAN LTD. 检验专用章 QUANLITY CONTROL

(SIGNATURE OF Q.A. LAB MGR.)

Figure B-44. 1-in. Dia. USS Plain Round Washer, Test Nos. STBRT-1 and STBRT-2

# HEXICO ENTERPRISE CO., LTD.

NO.355-3,SEC. 3,CHUNG SHAN ROAD,KAU-JEN,TAINAN,TAIWAN,R.O.C.
TEL : 886 - 6 - 2390616 FAX : 886 - 6 - 2308947

## INSPECTION CERTIFICATE

| | | | |
|---|---|---|---|
| CUSTOMER | **FASTENAL COMPANY** | REPORT DATE | 2020/1/14 |
| PART NAME | Flat Washer , SAE , EcoGuard | | |
| SIZE | 3/4" | MAF. DATE | 2019/11/20 |
| PART NO. | W2A2C6003S2LK7 | REPORT NO. | 1090114-22 |
| CUST. PART NO. | 11137087 | ORDER NO. | 210199442 |
| MATERIAL | 10B21 / 24 mm | MAT. CER. NO. | 10707001 |
| HEAT(COIL) NO. | 1P791 | LOT NO. | 8C2C6FNR6 |
| LOT QTY | 8,960 PCS | MAF. QTY | 8,960 PCS |

THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH REQUIREMENT OF THE ORDER.

THE REPORT IS ISSUED ACCORDING TO EN10204 3.1

| | |
|---|---|
| SAMPLING PLAN STANDARD | ASME B18.18-2017 / ASTM F1470-2018 |
| DIMENSION STANDARD | ASME B18.21.1 -2009 |
| COATING STANDARD | FNL.C.1000.ECO.S REV-002 |
| HARDNESS TEST METHOD | ASTM F606/F606M-2016 |
| COATING TEST METHOD | |
| SALT SPRAY TEST METHOD | ASTM B117-2016 |
| MECHANICAL PROPERTIES | ASTM F436/F436M |

DIMENSIONS IN inch

| INSPECTION ITEM | | SPECIFICATION | TEST QTY | INSPECTION RESULTS MIN. | INSPECTION RESULTS MAX. | INSPECTION EQUIPMENT |
|---|---|---|---|---|---|---|
| 1 | OUTSIDE DIAMETER | 1.462 - 1.499 | 8 | 1.4720 | 1.4874 | Caliper |
| 2 | INSIDE DIAMETER | 0.805 - 0.842 | 8 | 0.8350 | 0.8370 | Caliper |
| 3 | THICKNESS | 0.108 - 0.160 | 8 | 0.1161 | 0.1185 | Caliper |
| 4 | HARDNESS | HRC 38 - 45 | 5 | 40.8 | 42.4 | Hardness tester |
| 5 | COATING | GEOMET 321+PLUSL | 5 | OK | | |
| 6 | SALT SPRAY TEST | 1000 Hrs No Red Rust | 5 | OK | | S.S.T tester |
| 7 | APPEARANCE | VISUAL | 100 | OK | | |

INSPECTED BY *YutainLin* CERTIFIED BY *Alex.tsao*

Figure B-45. ¾-in. Dia. SAE Hardened Flat Washer, Test Nos. STBRT-1 and STBRT-2

**STEEL AND PIPE SUPPLY**
SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

# METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 12/19/2017
TIME 12:50:41
USER WILLIAMR

SOLD TO
66031-1127

SHIP TO
18271
SPS Warehouse 0045
401 New Century Parkway
NEW CENTURY KS

| Order | Material No. | Description | Quantity | Weight | Customer Part | Customer PO | Ship Date |
|---|---|---|---|---|---|---|---|
| 40299425-0020 | 70872178 | 1/4 72 X 178 A36 STP MIL PLT | 6 | 5,452.140 | | | 12/19/2017 |

## Chemical Analysis

Heat No. 17126641 Vendor BIG RIVER STEEL LLC DOMESTIC Mill BIG RIVER STEEL LLC Melted and Manufactured in the USA
Produced from Coil

| Carbon | Manganese | Phosphorus | Sulphur | Silicon | Nickel | Chromium | Molybdenum | Boron | Copper | Aluminum | Titanium | Vanadium | Columbium | Nitrogen | Tin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1900 | 0.8200 | 0.0070 | 0.0020 | 0.0300 | 0.0400 | 0.0500 | 0.0120 | 0.0001 | 0.1100 | 0.0260 | 0.0010 | 0.0040 | 0.0020 | 0.0077 | 0.0055 |

## Mechanical / Physical Properties

Mill Coil No. 17126641-05

| Tensile | Yield | Elong | Rckwl | Grain | Charpy | Charpy Dr | Charpy Sz | Temperature | Olsen |
|---|---|---|---|---|---|---|---|---|---|
| 75700.000 | 54100.000 | 28.10 | | | 0 | NA | | | |
| 71300.000 | 52000.000 | 30.60 | | | 0 | NA | | | |
| 71800.000 | 52000.000 | 33.20 | | | 0 | NA | | | |
| 74900.000 | 55400.000 | 28.70 | | | 0 | NA | | | |

Batch 0005075120 6 EA 5,452.140 LB

Batch 0005075119 7 EA 6,360.830 LB

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.
The material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

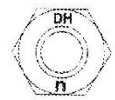
Figure B-46. ¼-in. Thick, 2¼-in. Square Washer, Test Nos. STBRT-1 and STBRT-2

**NUCOR**
**FASTENER DIVISION**

LOT NO.
426929D

Post Office Box 6100
Saint Joe, Indiana 46785
Telephone 260/337-1600

CUSTOMER NO/NAME
8001 FASTENAL COMPANY-KS — NUCOR ORDER # 188482
TEST REPORT SERIAL# FB616906 — CUST PART # 38208
TEST REPORT ISSUE DATE 10/30/19
DATE SHIPPED 2/25/20 — CUSTOMER P.O. # 210211604
NAME OF LAB SAMPLER: KELLEY HARTER, LAB TECHNICIAN




****************CERTIFIED MATERIAL TEST REPORT****************

| NUCOR PART NO | QUANTITY | LOT NO. | DESCRIPTION |
|---|---|---|---|
| 175657 | 1800 | 426929D | 3/4-10 GR DH HV H.D.G. HEX NUT HDG/GREEN LUBE |

MANUFACTURE DATE 8/05/19

--CHEMISTRY — MATERIAL GRADE -1045L
**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER — NUCOR STEEL - NEBRASKA

| MATERIAL NUMBER | HEAT NUMBER | C | MN | P | S | SI |
|---|---|---|---|---|---|---|
| RM033367 | 100798971 | .44 | .65 | .006 | .015 | .19 |

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A563-15

| SURFACE HARDNESS (R30N) | CORE HARDNESS (RC) | PROOF LOAD 50100 LBS | TENSILE STRENGTH DEG-WEDGE (LBS) | STRESS (PSI) |
|---|---|---|---|---|
| N/A | 25.1 | PASS | N/A | N/A |
| N/A | 26.0 | PASS | N/A | N/A |
| N/A | 27.9 | PASS | N/A | N/A |
| N/A | 26.6 | PASS | N/A | N/A |
| N/A | 27.4 | PASS | N/A | N/A |
| AVERAGE VALUES FROM TESTS | 26.6 | | | |

PRODUCTION LOT SIZE 200000 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A563-15 — 160 PCS. SAMPLED — LOT PASSED

--COATING - HOT DIP GALVANIZED TO ASTM F2329-15 - GALVANIZING PERFORMED IN THE U.S.A.
1. 0.00499 2. 0.00453 3. 0.00263 4. 0.00321 5. 0.00262 6. 0.00270 7. 0.00219
8. 0.00266 9. 0.00356 10. 0.00240 11. 0.00329 12. 0.00355 13. 0.00777 14. 0.00288
15. 0.00319
AVERAGE THICKNESS FROM 15 TESTS .00348

--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 | 1.404 | 1.415 |
| Thickness | 32 | 0.723 | 0.740 |

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 INTENTIONAL ADDITIONS OF BISMUTH, SELENIUM, TELLURIUM, OR LEAD WERE USED IN THE STEEL USED TO PRODUCE THIS PRODUCT.
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. CERTIFICATION FORMAT MEETS EN10204 3.1

ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 12/31/19

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

BOB HAYWOOD
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

Figure B-47. ¾-in. 10 UNC Heavy Hex Nut, Test Nos. STBRT-1 and STBRT-2

**CHARTER STEEL**
A Division of
Charter Manufacturing Company, Inc.

**Melted In USA Manufactured In USA**

EMAIL

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
Fax (262) 268-2570

**CHARTER STEEL TEST REPORT**

**Decker Manufacturing Corp.**
**703 N. Clark St.**
**Albion,MI-49224**

| | |
|---|---|
| Cust P.O. | 50366-1909 |
| Customer Part # | 1.125 1010 |
| Charter Sales Order | 30175614 |
| Heat # | 10624590 |
| Ship Lot # | 4610588 |
| Grade | 1010 A AK FG RHQ 1-1/8 RNDCOIL |
| Process | HRCC |
| Finish Size | 1-1/8 |
| Ship date | 29-SEP-19 |

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 # 10624590

Lab Code: 7388

| CHEM | C | MN | P | S | SI | NI | CR | MO | CU | SN | V |
|---|---|---|---|---|---|---|---|---|---|---|---|
| %Wt | .11 | .45 | .008 | .010 | .070 | .05 | .09 | .02 | .08 | .005 | .001 |
| | AL | N | B | TI | NB | | | | | | |
| | .024 | .0070 | .0001 | .001 | .001 | | | | | | |

Test results of Rolling Lot # 1279032

| | # of Tests | Min Value | Max Value | Mean Value | |
|---|---|---|---|---|---|
| ROCKWELL B (HRBW) | 1 | 82 | 62 | 62 | RB LAB = 0356-02 |
| ROD SIZE (Inch) | 12 | 1.123 | 1.131 | 1.127 | |
| ROD OUT OF ROUND (Inch) | 6 | .004 | .007 | .008 | |

REDUCTION RATIO=30:1

**Specifications:** Manufactured per Charter Steel Quality Manual Rev Date 06/12/17
Charter Steel certifies this product is indistinguishable from background radiation levels by having process radiation detectors in place to measure for the presence of radiation within our process & products.
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29/A29M Revision = 16 Dated = 01-DEC-16

**Additional Comments:**

Melt Source:
Charter Steel
Saukville, WI, USA

Trip: 1390021

ACCREDITED
Testing Laboratory

Page 1 of 2

This MTR supersedes all previously dated MTRs for this order

Janice Barnard Division Mgr. of Quality Assurance
barnardJ@chartersteel.com
Printed Date : 09/29/2019

Figure B-48. ⅝-in. Dia. Guardrail Nut, Test Nos. STBRT-1 and STBRT-2

ISO/TS 16949
BUREAU VERITAS
Certification

## GEM-YEAR TESTING LABORATORY
### CERTIFICATE OF INSPECTION

MANUFACTURER :GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA

Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2017/03/23

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 110216407
COMMODITY : FINISHED HEX NUT GR-A
SIZE : 5/8-11 NC O/T 0.51MM
LOT NO : 1N1680027
SHIP QUANTITY : 23,400 PCS
LOT QUANTITY 170,278 PCS
HEADMARKS :
MANUFACTURE DATE : 2016/08/26
COUNTRY OF ORIGIN : CHINA

PACKING NO : GEM160919007
INVOICE NO : GEM/FNL-160929WI
PART NO : 36713
SAMPLING PLAN : ASME B18.18-2011(Category.2)/ASTM F1470-2012
HEAT NO : 331608011
MATERIAL : ML08
FINISH : HOT DIP GALVANIZED PER ASTM A153-2009/ASTM F2329-2013

R#17-507 H#331608011
BCT Cable Bracket Nuts

PERCENTAGE COMPOSITION OF CHEMISTRY:ACCORDING TO ASTM A563-2007

| Chemistry | AL% | C% | MN% | P% | S% | SI% |
|---|---|---|---|---|---|---|
| Spec. : MIN. | | | | | | |
| MAX. | | 0.5800 | | 0.1300 | 0.2300 | |
| Test Value | 0.0350 | 0.0700 | 0.4100 | 0.0160 | 0.0060 | 0.0500 |

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME B18.2.2-2010

SAMPLED BY : DWTING

| INSPECTIONS ITEM | SAMPLE | SPECIFIED | | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|---|
| WIDTH ACROSS CORNERS | 6PCS | ASME B18.2.2-2010 | 1.0510-1.0830 inch | 1.0560-1.0690 inch | 6 | 0 |
| FIM | 15PCS | | Max. 0.0210 inch | 0.0020-0.0040 inch | 15 | 0 |
| THICKNESS | 6PCS | | 0.5350-0.5590 inch | 0.5390-0.5570 inch | 6 | 0 |
| WIDTH ACROSS FLATS | 6PCS | | 0.9220-0.9380 inch | 0.9240-0.9340 inch | 6 | 0 |
| SURFACE DISCONTINUITIES | 29PCS | | ASTM F812-2012 | PASSED | 29 | 0 |
| THREAD | 15PCS | | GAGING SYSTEM 21 | PASSED | 15 | 0 |

MECHANICAL PROPERTIES : ACCORDING TO ASTM A563-2007

SAMPLED BY : GDAN LIAN

| INSPECTIONS ITEM | SAMPLE | TEST METHOD | REF | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|---|---|
| CORE HARDNESS | 15PCS | ASTM F606-2014 | | 68-107 HRB | 79-81 HRB | 15 | 0 |
| PROOF LOAD | 4PCS | ASTM F606-2014 | | Min. 90 KSI | OK | 4 | 0 |
| PLATING THICKNESS( μm) | 5PCS | ASTM B568-1998 | | >=53 | 70.02-75.81 | 5 | 0 |

WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY .WHICH ACCREDITED BY ISO/IEC17025(CERTIFICATE NUMBER:3358.01)
WE CERTIFY THAT THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH THE REQUIREMENTS OF THE ORDER

Quality Supervisor: Erin

page 1 of 1

Figure B-49. ⅝-in. Dia. Hex Nut, Test Nos. STBRT-1 and STBRT-2

## GEM-YEAR TESTING LABORATORY
### CERTIFICATE OF INSPECTION

MANUFACTURER GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA

Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2019/04/23

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 210167591
COMMODITY : FINISHED HEX NUT GR-A
SIZE : 7/8-9 NC O/T 0.56MM
LOT NO : 1N1880113
SHIP QUANTITY : 2,250 PCS
LOT QUANTITY 31,764 PCS
HEADMARKS :

PACKING NO : GEM181128011
INVOICE NO : GEM/FNL-181212ED-1
PART NO : 36717
SAMPLING PLAN : ASME B18.18-2017(Category.2)/ASTM F1470-2018
HEAT NO : 18108473-3
MATERIAL : X1008A
FINISH : HOT DIP GALVANIZED PER ASTM A153-2009/ASTM F2329-2013

MANUFACTURE DATE : 2018/10/12
COUNTRY OF ORIGIN : CHINA

PERCENTAGE COMPOSITION OF CHEMISTRY:ACCORDING TO ASTM A563-2015

| Chemistry | AL% | C% | MN% | P% | S% | SI% |
|---|---|---|---|---|---|---|
| Spec. : MIN. | | | | | | |
| MAX. | | 0.5800 | | 0.1300 | 0.2300 | |
| Test Value | 0.0300 | 0.0600 | 0.2800 | 0.0160 | 0.0060 | 0.0300 |

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME B18.2.2-2015

SAMPLED BY : WANGYAN

| INSPECTIONS ITEM | SAMPLE | SPECIFIED | | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|---|
| WIDTH ACROSS CORNERS | 4PCS | | 1.4470-1.5160 inch | 1.4650-1.4690 inch | 4 | 0 |
| FIM | 15PCS | ASME B18.2.2-2015 | Max. 0.0250 inch | 0.0040-0.0060 inch | 15 | 0 |
| THICKNESS | 4PCS | | 0.7240-0.7760 inch | 0.7430-0.7460 inch | 4 | 0 |
| WIDTH ACROSS FLATS | 4PCS | | 1.2690-1.3120 inch | 1.2830-1.2840 inch | 4 | 0 |
| SURFACE DISCONTINUITIES | 29PCS | | ASTM F812-2012 | PASSED | 29 | 0 |
| THREAD | 15PCS | | GAGING SYSTEM 21 | PASSED | 15 | 0 |
| MINOR DIAMETER | 15PCS | | 0.7890-0.7970 inch | PASSED | 15 | 0 |

MECHANICAL PROPERTIES : ACCORDING TO ASTM A563-2015

SAMPLED BY : GDAN LIAN

| INSPECTIONS ITEM | SAMPLE | TEST METHOD | REF | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|---|---|
| CORE HARDNESS | 13 PCS | ASTM F606-2014 | | 116-302 HRB | 81-82 HRB | 13 | 0 |
| PROOF LOAD | 3 PCS | ASTM F606-2014 | | Min. 90 KSI | OK | 3 | 0 |
| PLATING THICKNESS(μm) | 5 PCS | ASTM B568-1998 | | >=53 | 72.03-95.08 | 5 | 0 |

WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY .WHICH ACCREDITED BY ISO/IEC17025(CERTIFICATE NUMBER:3358.01)
WE CERTIFY THAT THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH THE REQUIREMENTS OF THE ORDER
WE CERTIFY THAT ALL PRODUCTS WE SUPPLIED ARE IN COMPLIANCE WITH DIN EN 10204 3.1 CONTENT

Quality Supervisor:

page 1 of 1

Figure B-50. ⅞-in. Dia. Hex Nut, Test Nos. STBRT-1 and STBRT-2

IATF 16949:2016 BUREAU VERITAS Certification

## GEM-YEAR TESTING LABORATORY
### CERTIFICATE OF INSPECTION

MANUFACTURER GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA

Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2019/04/23

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 210167591
COMMODITY : FINISHED HEX NUT GR-A
SIZE : 7/8-9 NC O/T 0.56MM
LOT NO : 1N18BC001
SHIP QUANTITY : 2,250 PCS
LOT QUANTITY 3,910 PCS
HEADMARKS :

PACKING NO : GEM181128011
INVOICE NO : GEM/FNL-181212ED-1
PART NO : 36717
SAMPLING PLAN : ASME B18.18-2017(Category.2)/ASTM F1470-2018
HEAT NO : 18108472-3
MATERIAL : X1008A
FINISH : HOT DIP GALVANIZED PER ASTM A153-2009/ASTM F2329-2013

MANUFACTURE DATE : 2018/11/05
COUNTRY OF ORIGIN : CHINA

PERCENTAGE COMPOSITION OF CHEMISTRY:ACCORDING TO ASTM A563-2015

| Chemistry | AL% | C% | MN% | P% | S% | SI% |
|---|---|---|---|---|---|---|
| Spec. : MIN | | | | | | |
| MAX | | 0.5800 | | 0.1300 | 0.2300 | |
| Test Value | 0.0300 | 0.0700 | 0.2700 | 0.0080 | 0.0050 | 0.0300 |

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME B18.2.2-2015

SAMPLED BY : YUQIAN

| INSPECTIONS ITEM | SAMPLE | SPECIFIED | | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|---|
| WIDTH ACROSS CORNERS | 4PCS | | 1.4470-1.5160 inch | 1.4730-1.4770 inch | 4 | 0 |
| FIM | 15PCS | ASME B18.2.2-2015 | Max. 0.0250 inch | 0.0010-0.0050 inch | 15 | 0 |
| THICKNESS | 4PCS | | 0.7240-0.7760 inch | 0.7280-0.7480 inch | 4 | 0 |
| WIDTH ACROSS FLATS | 4PCS | | 1.2690-1.3120 inch | 1.2840-1.2990 inch | 4 | 0 |
| SURFACE DISCONTINUITIES | 22PCS | | ASTM F812-2012 | PASSED | 22 | 0 |
| THREAD | 15PCS | | GAGING SYSTEM 21 | PASSED | 15 | 0 |
| MINOR DIAMETER | 15PCS | | 0.7890-0.7970 inch | PASSED | 15 | 0 |

MECHANICAL PROPERTIES : ACCORDING TO ASTM A563-2015

SAMPLED BY : GDAN LIAN

| INSPECTIONS ITEM | SAMPLE | TEST METHOD | REF | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|---|---|---|---|---|---|---|---|
| CORE HARDNESS | 13 PCS | ASTM F606-2014 | | 116-302 HRB | 81-82 HRB | 13 | 0 |
| PROOF LOAD | 3 PCS | ASTM F606-2014 | | Min. 90 KSI | OK | 3 | 0 |
| PLATING THICKNESS(μm) | 5 PCS | ASTM B568-1998 | | >=53 | 70.22-75.66 | 5 | 0 |

WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY .WHICH ACCREDITED BY ISO/IEC17025(CERTIFICATE NUMBER:3358.01)
WE CERTIFY THAT THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH THE REQUIREMENTS OF THE ORDER
WE CERTIFY THAT ALL PRODUCTS WE SUPPLIED ARE IN COMPLIANCE WITH DIN EN 10204 3.1 CONTENT

Quality Supervisor: [signature]

page 1 of 1

Figure B-51. ⅞-in. Dia. Hex Nut, Test Nos. STBRT-1 and STBRT-2

Nov. 26. 2018 3:47PM Fastenal-NELIN No. 5947 P. 2

FASTENAL®

# Certificate of Compliance

**Sold To:**

UNL TRANSPORTATION

**Purchase Order:** STBR

**Job:** Item# f3, h1 and i1

**Invoice Date:** 11/8/2018

THIS IS TO CERTIFY THAT WE HAVE SUPPLIED YOU WITH THE FOLLOWING PARTS.
THESE PARTS WERE PURCHASED TO THE FOLLOWING SPECIFICATIONS.

80 PCS 1"-8 Hot Dipped Galvanized A563 Grade DH Heavy Hex Nut Made In USA SUPPLIED UNDER OUR TRACE NUMBER 210157128 AND UNDER PART NUMBER 38210

450 PCS 3/4"-10 Hot Dipped Galvanized A563 Grade DH Heavy Hex Nut Made In USA SUPPLIED UNDER OUR TRACE NUMBER 210169774 AND UNDER PART NUMBER 38208

80 PCS 1"-8 Hot Dipped Galvanized A563 Grade DH Heavy Hex Nut Made In USA SUPPLIED UNDER OUR TRACE NUMBER 210157128 AND UNDER PART NUMBER 38210

This is to certify that the above document is true and accurate to the best of my knowledge.

[signature]

**Fastenal Account Representative Signature**

Ashly Stanczyk

**Printed Name**

11/29/18

**Date**

Please check current revision to avoid using obsolete copies.

This document was printed on 11/26/2018 and was current at that time.

**Fastenal Store Location/Address**

*3201 N. 23rd Street STE 1*
*LINCOLN, NE 68521*
*Phone #: (402)476-7900*
*Fax #: 402/476-7958*

Page 1 of 1

Figure B-52. 1-in. 8 UNC Heavy Hex Nut, Test Nos. STBRT-1 and STBRT-2

Apr. 17. 2019 2:15PM Fastenal-NELIN No. 6648 P. 2

FASTENAL®

## Certificate of Compliance

| | | | |
|---|---|---|---|
| **Sold To:** | | **Purchase Order:** | 70acct BCTAnchorCableHardware |
| UNL TRANSPORTATION/Midwest Roadside Safe | | **Job:** | |
| | | **Invoice Date:** | 10/19/2018 |

THIS IS TO CERTIFY THAT WE HAVE SUPPLIED YOU WITH THE FOLLOWING PARTS.
THESE PARTS WERE PURCHASED TO THE FOLLOWING SPECIFICATIONS.

200 PCS 1" x 2.500" OD Low Carbon Hot Dipped Galvanized Finish Steel USS General Purpose Flat Washer SUPPLIED UNDER OUR TRACE NUMBER 210151571 AND UNDER PART NUMBER 33188

200 PCS 1"-8 Hot Dipped Galvanized A563 Grade DH Heavy Hex Nut Made In USA SUPPLIED UNDER OUR TRACE NUMBER 210157128 AND UNDER PART NUMBER 38210

This is to certify that the above document is true and accurate to the best of my knowledge.

AFerguson

Fastenal Account Representative Signature

Abigail Ferguson

Printed Name

4/17/2019

Date

Please check current revision to avoid using obsolete copies.

This document was printed on 04/17/2019 and was current at that time.

**Fastenal Store Location/Address**

*3201 N. 23rd Street STE 1*
*LINCOLN, NE 68521*
*Phone #: (402)476-7900*
*Fax #: 402/476-7958*

Page 1 of 1

Figure B-53. 1-in. Dia. Hex Nut, Test Nos. STBRT-1 and STBRT-2

**EXLTUBE**

1000 BURLINGTON STREET, NORTH KANSAS CITY, MO 64116 1-816-474-5210 TOLL FREE 1-800-892-TUBE

STEEL VENTURES, LLC dba EXLTUBE

## Certified Test Report

| Customer: | Size: 04.00X06.00 | Customer Order No: | Customer Part No: |
|---|---|---|---|
| SPS - New Century<br>401 New Century Parkway<br>NEW CENTURY KS 66031-1127 | Gauge: 1/4 | E450000425 | 6660040025040 |
| | Date: 04/20/2020 | Delivery No: 83573496<br>Load No: 4295161 | Length: 40 FT |
| | Specification: ASTM A500-13 Gr.B/C | | |

| Heat No | Yield KSI | Tensile KSI | Elongation % 2 Inch |
|---|---|---|---|
| 90992C | 61.9 | 77.6 | 29.00 |

| Heat No | C | MN | P | S | SI | CU | NI | CR | MO | V |
|---|---|---|---|---|---|---|---|---|---|---|
| 90992C | 0.2300 | 0.8100 | 0.0110 | 0.0070 | 0.0150 | 0.0200 | 0.0100 | 0.0400 | 0.0000 | 0.0000 |

This material was melted & manufactured in the U.S.A. This material meets the Buy America requirement of 23 CFR 635.410.
Coil Producing Mill: UNITED STATES STEEL, Granite City, IL

We hereby certify that all test results shown in this report are correct as contained in the records of our company. All testing and manufacturing is in accordance to A.S.T.M. parameters encompassed within the scope of the specifications denoted in the specification and grade tiles above. This product was manufactured in accordance with your purchase order requirements.

This material has not come into direct contact with mercury, any of its compounds, or any mercury bearing devices during our manufacturing process, testing, or inspections.

This material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

Tensile test completed using test specimen with 3/4" reduced area.

STEEL VENTURES, LLC dba EXLTUBE

Jonathan Wolfe
Quality Assurance Manager

Figure B-54. HSS6x4x¼, Test Nos. STBRT-1 and STBRT-2

**STEEL AND PIPE SUPPLY**
**SPS Coil Processing Tulsa**
**5275 Bird Creek Ave.**
**Port of Catoosa, OK 74015**

# METALLURGICAL TEST REPORT

**PAGE** 1 of 1
**DATE** 02/03/2020
**TIME** 06:13:30

SOLD TO
66031-1127

SHIP TO
13716
Kansas City Warehouse
401 New Century Parkway
NEW CENTURY KS

| Order | Material No. | Description | Quantity | Weight | Customer Part | Customer PO | Ship Date |
|---|---|---|---|---|---|---|---|
| 40343212-0010 | 72896240A2 | 1/4 96 X 240 A572GR50 MILL PLATE | 1 | 1,633.600 | | | 01/31/2020 |

## Chemical Analysis

Heat No. B9L648 Vendor SSAB - MONTPELIER WORKS DOMESTIC Mill SSAB - MONTPELIER WORKS **Melted and Manufactured in the USA**
**Produced from Coil**

| Carbon | Manganese | Phosphorus | Sulphur | Silicon | Nickel | Chromium | Molybdenum | Boron | Copper | Aluminum | Titanium | Vanadium | Columbium | Nitrogen | Tin |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1600 | 0.8400 | 0.0100 | 0.0030 | 0.0400 | 0.1500 | 0.1300 | 0.0400 | 0.0000 | 0.3300 | 0.0350 | 0.0060 | 0.0180 | 0.0010 | 0.0000 | 0.0000 |

## Mechanical / Physical Properties

Mill Coil No. B9L6480434

| Tensile | Yield | Elong | Rckwl | Grain | Charpy | Charpy Dr | Charpy Sz | Temperature | Olsen |
|---|---|---|---|---|---|---|---|---|---|
| 74700.000 | 56200.000 | 28.50 | | | 66 | Longitudinal | 5.0 | -20 F | |
| 75900.000 | 57000.000 | 27.30 | | | 60 | Longitudinal | 5.0 | -20 F | |
| 76200.000 | 58100.000 | 25.00 | | | 62 | Longitudinal | 5.0 | -20 F | |
| 77600.000 | 59600.000 | 25.90 | | | 0 | NA | | | |

Batch 0006190954 1 EA 1,633.600 LB
Batch 0006190945 6 EA 9,801.600 LB
Batch 0006190939 6 EA 9,801.600 LB
Batch 0006190860 6 EA 9,801.600 LB

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.
The material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1


Figure B-55. ¼-in. Plates, Test Nos. STBRT-1 and STBRT-2

22Jan20 13:49 T E S T C E R T I F I C A T E No: DCR 244763

NUCOR TUBULAR PRODUCTS INC.
DECATUR DIVISION
2000 INDEPENDENCE AVENUE N.W.
DECATUR, AL 35601
Tel: 256 340-7420 Fax: 256 340-7415

P/O No 4500342208
Rel
S/O No DCR 120285-001
B/L No DCR 85166-002 Shp 22Jan20
Inv No Inv

Sold To: ( 5017)
STEEL & PIPE SUPPLY
401 NEW CENTURY PARKWAY
KANSAS CITY WHSE.
NEW CENTURY, KS 66031

Tel: 913-768-4333 Fax: 913 768-6683

Ship To: ( 1)
STEEL & PIPE SUPPLY
401 NEW CENTURY PKWY
NEW CENTURY, KS 66031

CERTIFICATE of ANALYSIS and TESTS Cert. No: DCR 244763
20Jan20

| Part No | | Pcs | Wgt |
|---|---|---|---|
| TUBING A500 GRADE B(C) 12" X 4" X 1/4" X 20' | | 12 | 6,196 |

| Heat Number | Tag No | Pcs | Wgt |
|---|---|---|---|
| NJ8018 | 90266<br>YLD=65100/TEN=71800/ELG=27.5 | 6 | 3,098 |
| NJ8018 | 90267<br>YLD=65100/TEN=71800/ELG=27.5 | 6 | 3,098 |

Heat Number *** Chemical Analysis ***
NJ8018 C=0.0500 Mn=0.3800 P=0.0090 S=0.0010 Si=0.2460 Al=0.0220
Cu=0.0900 Cr=0.0400 Mo=0.0100 V=0.0020 Ni=0.0300 Nb=0.0090
Cb=0.0090 Sn=0.0030 N=0.0055 B=0.0002 Ti=0.0010 Ca=0.0011
MELTED AND MANUFACTURED IN THE USA

WE PROUDLY MANUFACTURE ALL OUR PRODUCTS IN THE USA
NUCOR TUBULAR PRODUCTS ARE MANUFACTURED, TESTED
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.
MATERIAL IDENTIFIED AS A500 GRADE B(C) MEETS BOTH
ASTM A500 GRADE B AND A500 GRADE C SPECIFICATIONS.

CURRENT STANDARDS:
A252-10
A500/A500M-18
A513/A513M-15
ASTM A53/A53M-12 | ASME SA-53/SA-53M-13
A847/A847M-14
A1085/A1085M-15
IN COMPLIANCE WITH EN 10204 SECTION 4.1
INSPECTION CERTIFICATE TYPE 3.1

Page: 1 .... Last

Figure B-56. HSS12x4x¼ Transition Rail, Test Nos. STBRT-1 and STBRT-2

Atlas Tube Arkansas
5039N County Road 1015
Blytheville Arkansas USA
72315
Tel:
Fax:

**Atlas Tube**
*A DIVISION OF ZEKELMAN INDUSTRIES*

**REF.B/L:** 80953912
**Date:** 05/29/2020
**Customer:** 179

## MATERIAL TEST REPORT

**Sold To**
Steel & Pipe Supply Company
PO Box 1688
MANHATTAN KS 66505
USA

**Shipped To**
Steel & Pipe Supply Company
401 New Century Parkway
NEW CENTURY KS 66031
USA

**Material:** 8.0x6.0x250x40'0"0(3x2). **Material No:** 800602504000 **Made in:** USA
**Melted in:** USA
**Sales Order:** 1521653 **Purchase Order:** C452003663 **Cust Material#:** 6680060025040

| Heat No | C | Mn | P | S | Si | Al | Cu | Cb | Mo | Ni | Cr | V | Ti | B | N | Ca |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19197161 | 0.220 | 0.760 | 0.012 | 0.002 | 0.030 | 0.028 | 0.090 | 0.001 | 0.018 | 0.060 | 0.050 | 0.003 | 0.001 | 0.0002 | 0.0073 | 0.0028 |

| Bundle No | PCs | Yield | Tensile | Eln.2in | Certification | CE: 0.38 |
|---|---|---|---|---|---|---|
| M500297076 | 6 | 059854 Psi | 075134 Psi | 34 % | ASTM A500-18 GRADE B&C | |

| Heat | MILL | Mill Location | Method | Recycled_Content | Post_Consumer | Pre-Consumer (Post Industrial) | % Harvested | Within Miles of Location |
|---|---|---|---|---|---|---|---|---|
| 19197161 | BIGRIVER | Osceola,AR | EAF | 76.00% | 95.00% | 5.00 % | 75% | 500 |

**Material Note:**
**Sales Or. Note:**

**Authorized by Quality Assurance:** [signature]

The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
CE calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Metals Service Center Institute

Page: 1 of 1

Figure B-57. HSS8x6x¼ Transition Rails, Test No. STBRT-1

# EXLTUBE

1000 BURLINGTON STREET, NORTH KANSAS CITY, MO 64116 1-816-474-5210 TOLL FREE 1-800-892-TUBE

STEEL VENTURES, LLC dba EXLTUBE

## Certified Test Report

| | | | |
|---|---|---|---|
| Customer: State Steel of Omaha, 13433 Centech Road, Omaha NE 68138-3492 | Size: 08.00X08.00<br>Gauge: 1/4 | Customer Order No: P00227JT021 | Customer Part No: |
| | Date: 02/28/2020 | Delivery No: 83546706<br>Load No: 1277120 | Length: 40 FT |
| | Specification: ASTM A500-13 Gr.B/C | | |

| Heat No | Yield KSI | Tensile KSI | Elongation % 2 Inch |
|---|---|---|---|
| 87705C | 55.5 | 68.7 | 34.00 |

| Heat No | C | MN | P | S | SI | CU | NI | CR | MO | V |
|---|---|---|---|---|---|---|---|---|---|---|
| 87705C | 0.2200 | 0.8000 | 0.0060 | 0.0060 | 0.0110 | 0.0500 | 0.0100 | 0.0400 | 0.0000 | 0.0000 |

This material was melted & manufactured in the U.S.A. This material meets the Buy America requirement of 23 CFR 635.410.
Coil Producing Mill: UNITED STATES STEEL, Granite City, IL

We hereby certify that all test results shown in this report are correct as contained in the records of our company. All testing and manufacturing is in accordance to A.S.T.M. parameters encompassed within the scope of the specifications denoted in the specification and grade titles above. This product was manufactured in accordance with your purchase order requirements.

This material has not come into direct contact with mercury, any of its compounds, or any mercury bearing devices during our manufacturing process, testing, or inspections.

This material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

Tensile test completed using test specimen with 3/4" reduced area.

STEEL VENTURES, LLC dba EXLTUBE

Jonathan Wolfe
Quality Assurance Manager

*P00227JT02107*

*87705C*

Figure B-58. HSS8x6x¼ Transition Rails, Test No. STBRT-2

# Appendix C. Shop Drawings for Transition Tube Rails

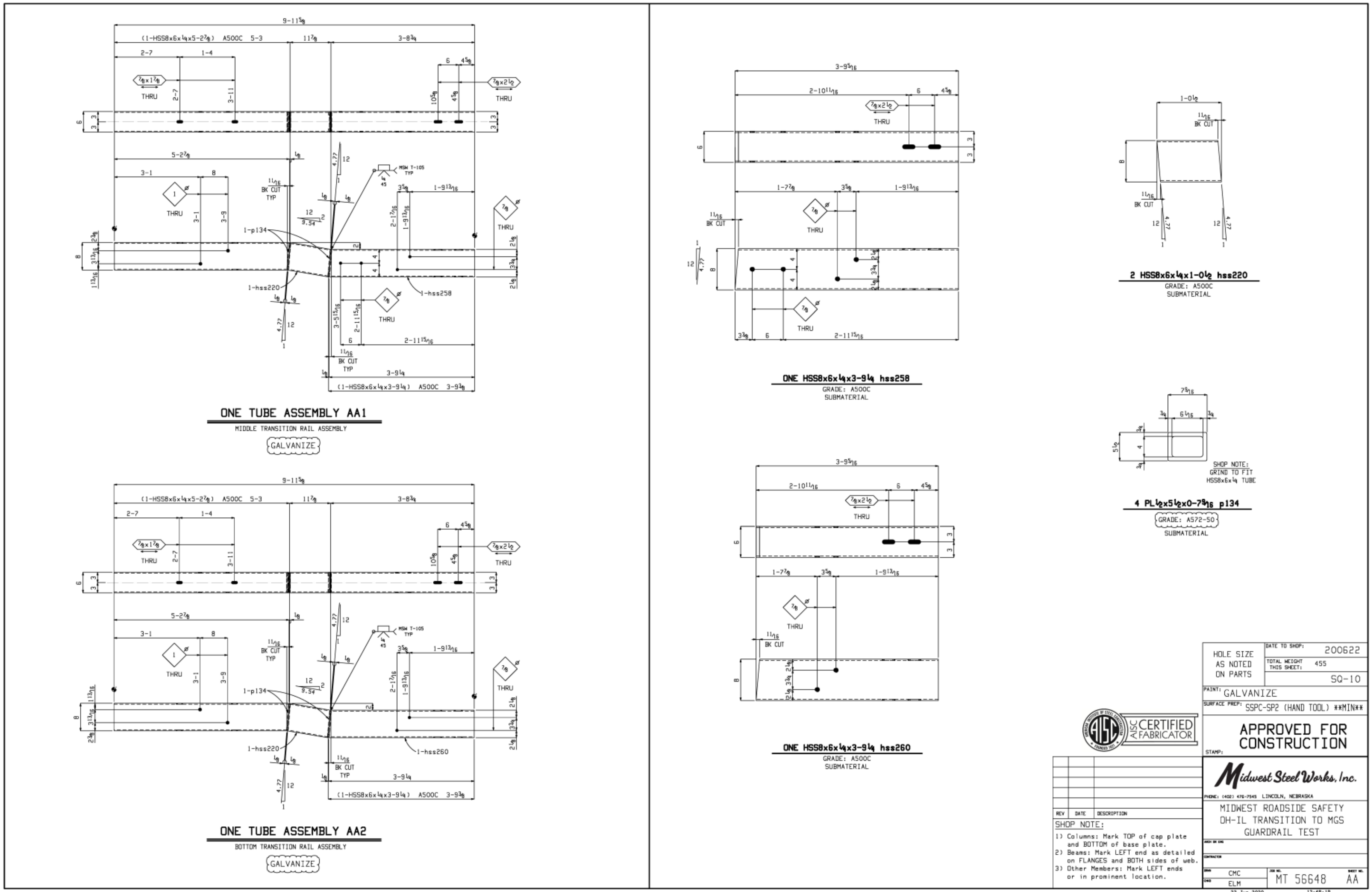



Figure C-1. Shop Drawings for Middle and Lower Transition Tube Rails

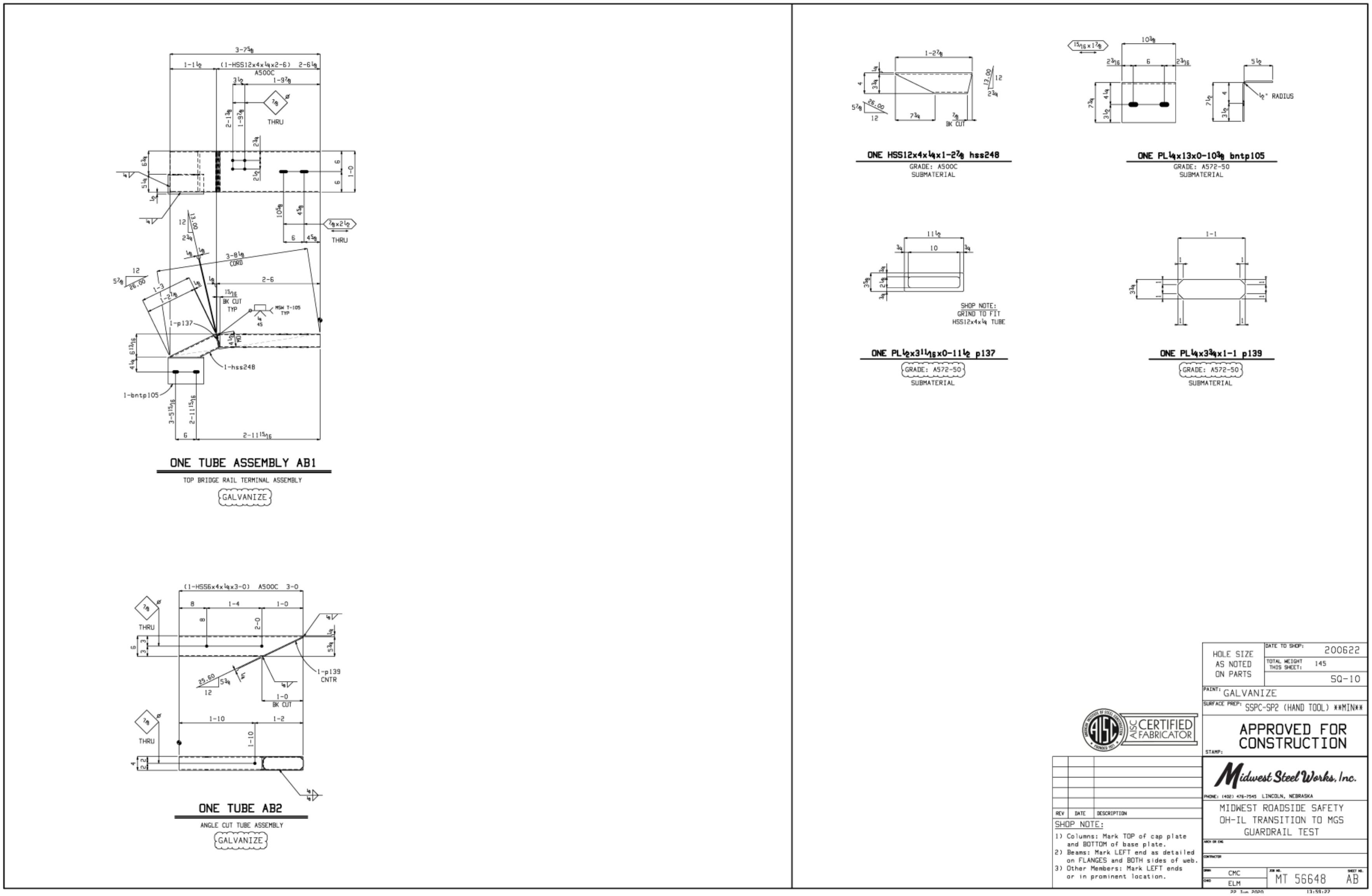



Figure C-2. Shop Drawings for Upper Transition Tube Rail

# Appendix D. Vehicle Center of Gravity Determination

| | | | | | |
|---|---|---|---|---|---|
| Date: | 8/24/2020 | Test Name: | STBRT-1 | VIN: | kmhcn46c69u367008 |
| Model Year: | 2009 | Make: | Hyundai | Model: | Accent |

**Vehicle CG Determination**

| | Vehicle Equipment | Weight (lb) | Vertical CG (in.) | Vertical M (lb-in.) |
|---|---|---|---|---|
| + | Unballasted Car (Curb) | 2447 | 22.811 | 55819.1 |
| + | Hub | 19 | 10.625 | 201.875 |
| + | Brake activation cylinder & frame | 7 | 16.0 | 112.0 |
| + | Pneumatic tank (Nitrogen) | 30 | 13.0 | 390.0 |
| + | Strobe/Brake Battery | 5 | 19.0 | 95.0 |
| + | Brake Receiver/Wires | 5 | 31.0 | 155.0 |
| + | CG Plate including DAQ | 22 | 17.0 | 374.0 |
| - | Battery | -30 | 26.0 | -780.0 |
| - | Oil | -7 | 9.5 | -66.5 |
| - | Interior | -63 | 14.0 | -882.0 |
| - | Fuel | -19 | 10.0 | -190.0 |
| - | Coolant | -7 | 21.0 | -147.0 |
| - | Washer fluid | -9 | 18.0 | -162.0 |
| + | Water Ballast (In Fuel Tank) | 0 | | 0 |
| + | Onboard Supplemental Battery | | | 0 |
| | | | | 0 |
| | | | | 0 |
| | | | | 54919.5 |

Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle

Estimated Total Weight (lb) 2400

**Vehicle Dimensions for C.G. Calculations**

| | | | | |
|---|---|---|---|---|
| Wheel Base: | 98.5 in. | | Front Track Width: | 57.5 in. |
| Roof Height: | 57.75 in. | | Rear Track Width: | 57.188 in. |

| Center of Gravity | 1100C MASH Targets | Test Inertial | Difference |
|---|---|---|---|
| Test Inertial Weight (lb) | 2420 ± 55 | 2404 | -16.0 |
| Longitudinal CG (in.) | 39 ± 4 | 35.483 | -3.517 |
| Lateral CG (in.) | NA | 0.429 | NA |
| Vertical CG (in.) | NA | 22.883 | NA |

Note: Long. CG is measured from front axle of test vehicle

Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

**CURB WEIGHT (lb)**

| | Left | Right |
|---|---|---|
| Front | 810 | 740 |
| Rear | 445 | 452 |

| | | |
|---|---|---|
| FRONT | 1550 | lb |
| REAR | 897 | lb |
| TOTAL | 2447 | lb |

**TEST INERTIAL WEIGHT (lb)**

| | Left | Right |
|---|---|---|
| Front | 760 | 778 |
| Rear | 424 | 442 |

| | | |
|---|---|---|
| FRONT | 1538 | lb |
| REAR | 866 | lb |
| TOTAL | 2404 | lb |

Figure D-1. Vehicle Mass Distribution, Test No. STBRT-1

| | | | | | |
|---|---|---|---|---|---|
| Date: | 9/22/2020 | Test Name: | STBRT-2 | VIN: | 1C6RR6FT9ES238613 |
| Model Year: | 2014 | Make: | Dodge | Model: | Ram 1500 Quad Cab |

**Vehicle CG Determination**

| | Vehicle Equipment | Weight (lb) | Vertical CG (in.) | Vertical M (lb-in.) |
|---|---|---|---|---|
| + | Unballasted Truck (Curb) | 5133 | 28.464038 | 146105.91 |
| + | Hub | 19 | 15 | 285 |
| + | Brake activation cylinder & frame | 7 | 28 1/2 | 199.5 |
| + | Pneumatic tank (Nitrogen) | 30 | 27 | 810 |
| + | Strobe/Brake Battery | 5 | 26 | 130 |
| + | Brake Receiver/Wires | 6 | 52 | 312 |
| + | CG Plate including DAQ | 30 | 31 1/8 | 933.75 |
| - | Battery | -53 | 40 | -2120 |
| - | Oil | -13 | 16 | -208 |
| - | Interior | -97 | 29 | -2813 |
| - | Fuel | -163 | 18 | -2934 |
| - | Coolant | -12 | 36 | -432 |
| - | Washer fluid | -8 | 36 | -288 |
| + | Water Ballast (In Fuel Tank) | 109 | 16 | 1744 |
| + | Onboard Supplemental Battery | 5 | 26 | 130 |
| | | | | 0 |
| | | | | 0 |
| | | | | 141855.16 |

Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle

| | |
|---|---|
| Estimated Total Weight (lb) | 4998 |
| Vertical CG Location (in.) | 28.3824 |

**Vehicle Dimensions for C.G. Calculations**

| | | | | | |
|---|---|---|---|---|---|
| Wheel Base: | 140.5 | in. | Front Track Width: | 68.0625 | in. |
| | | | Rear Track Width: | 67.875 | in. |

| Center of Gravity | 2270P MASH Targets | Test Inertial | Difference |
|---|---|---|---|
| Test Inertial Weight (lb) | 5000 ± 110 | 5007 | 7.0 |
| Longitudinal CG (in.) | 63 ± 4 | 60.975934 | -2.02407 |
| Lateral CG (in.) | NA | 0.2782823 | NA |
| Vertical CG (in.) | 28 or greater | 28.38 | 0.38238 |

Note: Long. CG is measured from front axle of test vehicle

Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

**CURB WEIGHT (lb.)**

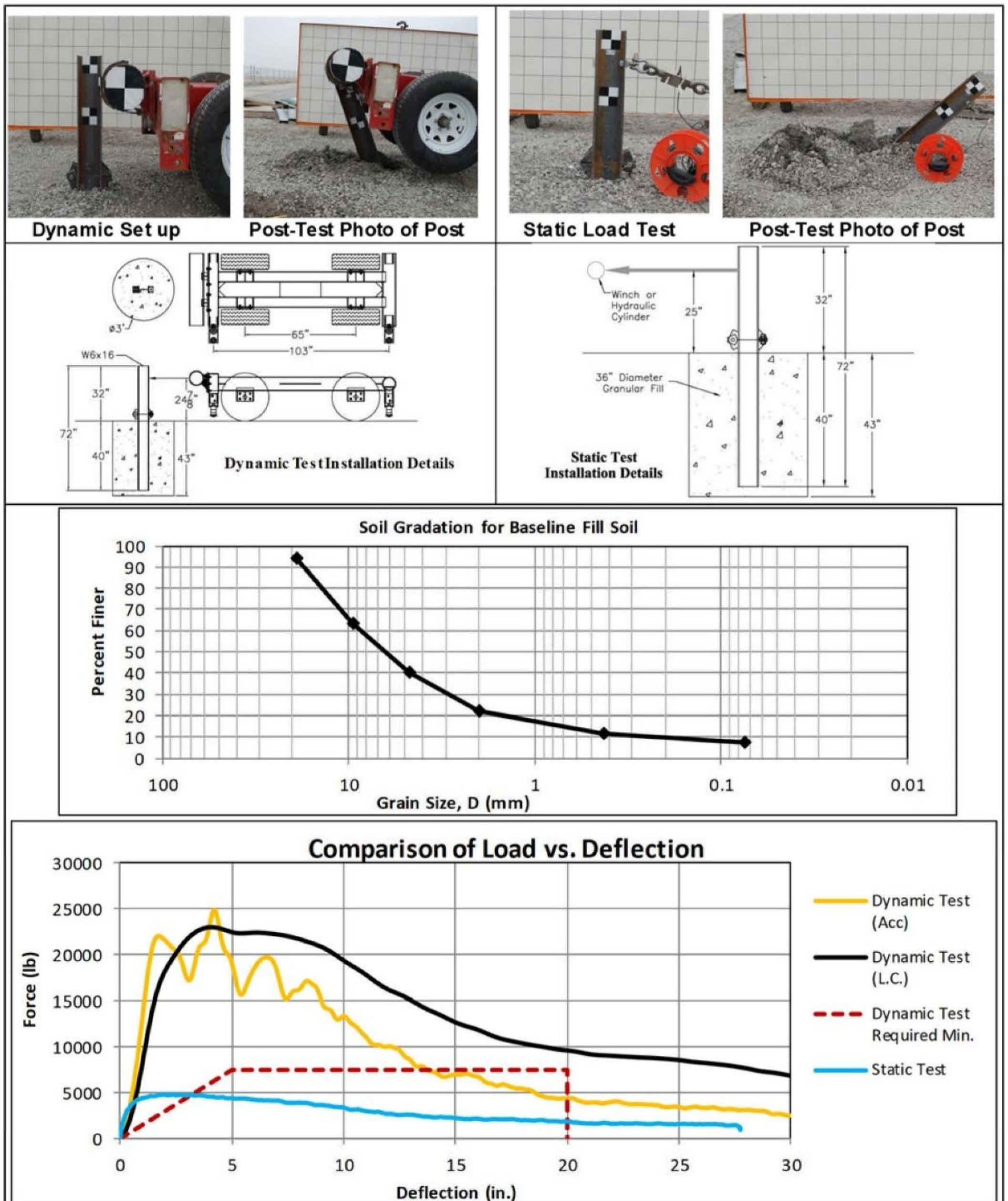
| | Left | Right |
|---|---|---|
| Front | 1476 | 1446 |
| Rear | 1121 | 1090 |
| FRONT | 2922 | lb |
| REAR | 2211 | lb |
| TOTAL | 5133 | lb |

**TEST INERTIAL WEIGHT (lb.)**

| | Left | Right |
|---|---|---|
| Front | 1412 | 1422 |
| Rear | 1071 | 1102 |
| FRONT | 2834 | lb |
| REAR | 2173 | lb |
| TOTAL | 5007 | lb |

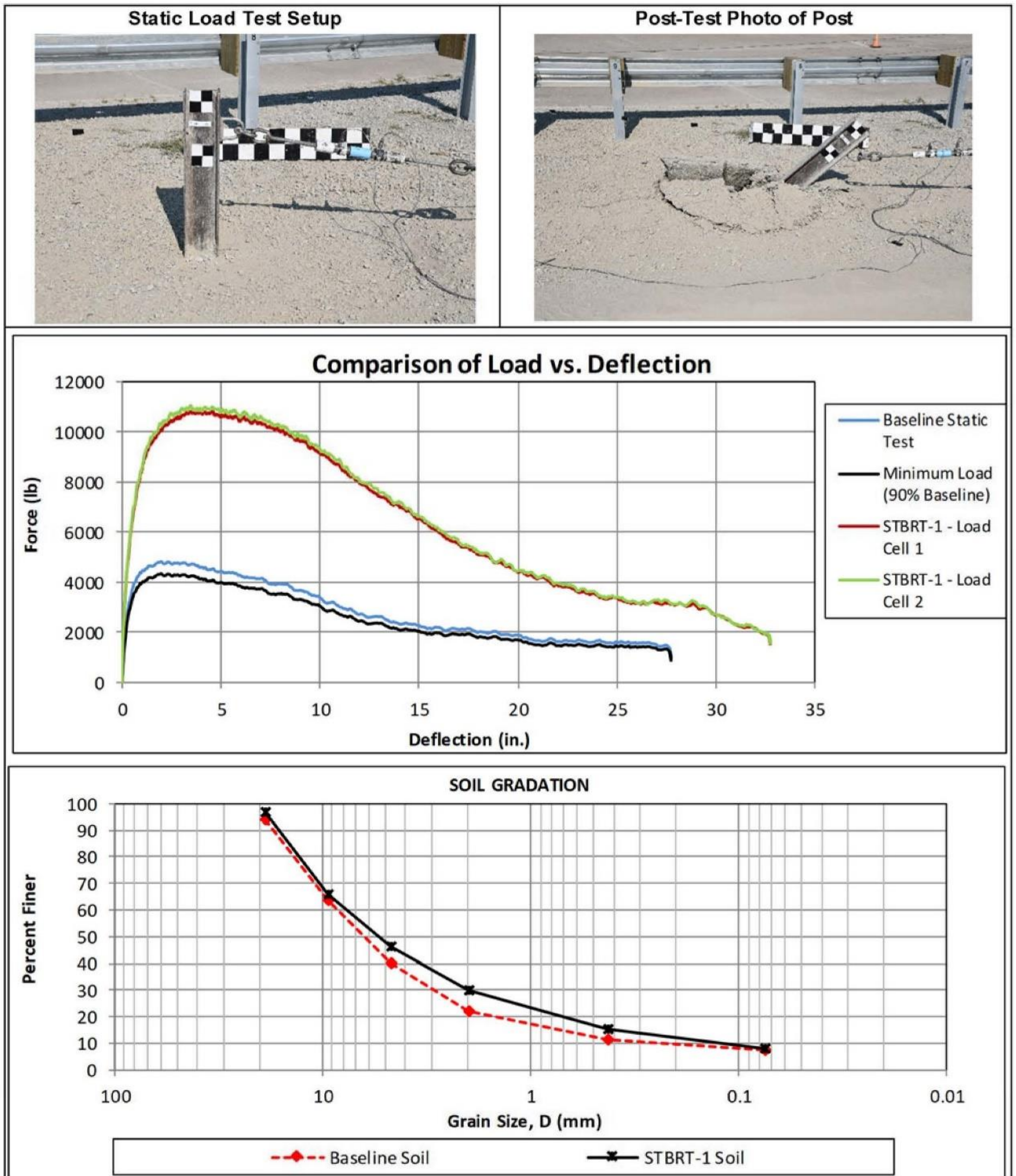
Figure D-2. Vehicle Mass Distribution, Test No. STBRT-2

# Appendix E. Static Soil Tests



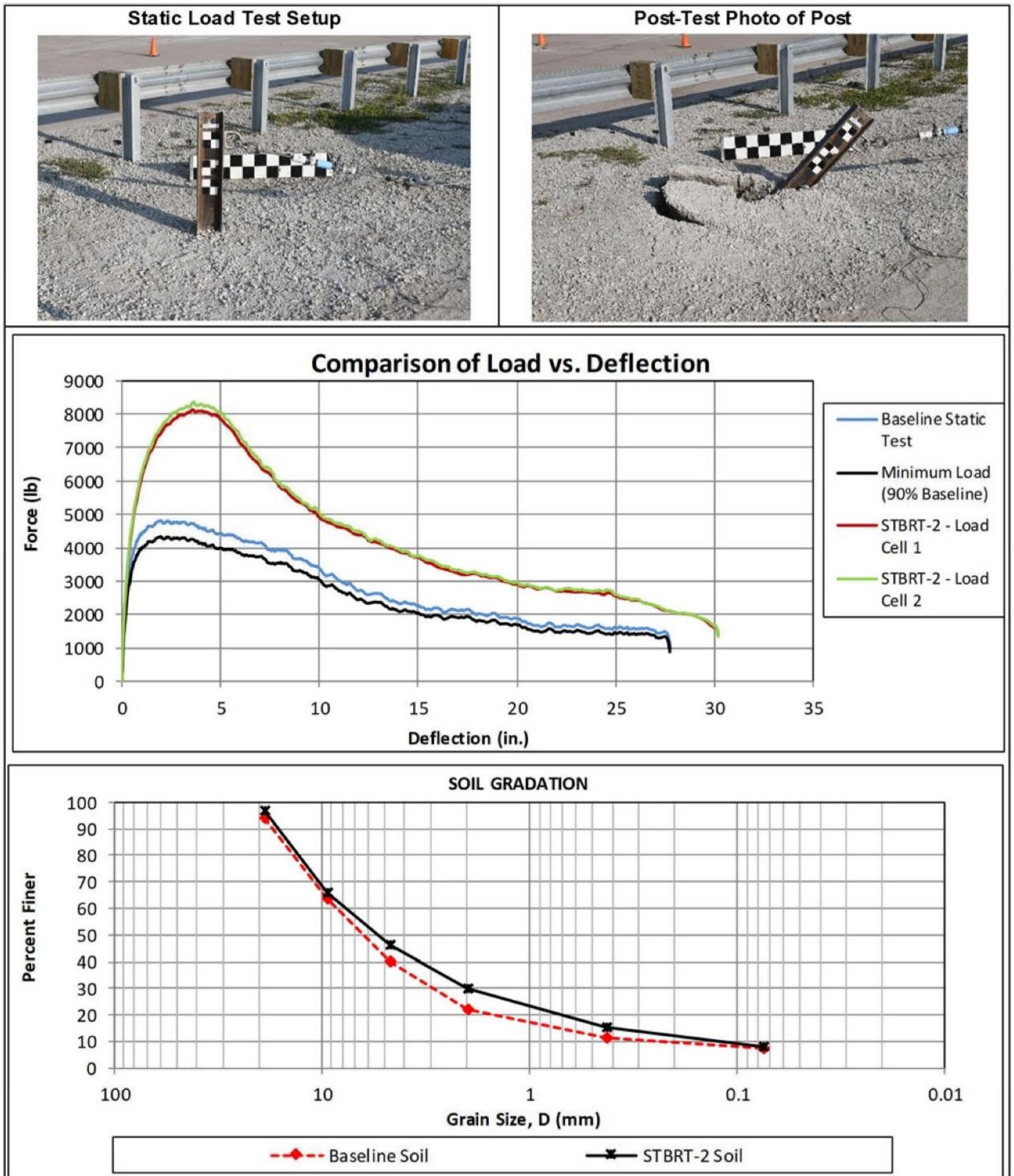

| | | | | |
|---|---|---|---|---|
| Date.................................................... | 2/16/2018 | | | |
| Test Facility & Site Location..................... | Midwest Roadside Safety Facility | | | |
| In situ soil description (ASTM D2487)......... | Well-Graded Gravel (GW) | | | |
| Fill material description (ASTM D2487)...... | Well-Graded Gravel (GW) (see sieve analyses above) | | | |
| Description of fill placement procedure..... | H.E.-8 | | | |
| Bogie Weight........................................... | 1786 | lb | 810 kg | |
| Impact Velocity....................................... | 20.9 | mph | 33.7 km/h | |

Figure E-1. Soil Strength, Initial Calibration Tests




| | |
|---|---|
| Date | 8/24/2020 |
| Test Facility & Site Location | Midwest Roadside Safety Facility |
| In situ soil description (ASTM D2487) | Well-Graded Gravel (GW) |
| Fill material description (ASTM D2487) | Well-Graded Gravel (GW) (see sieve analyses above) |
| Description of fill placement procedure | 8-inch lifts tamped with a pneumatic compactor |

Figure E-2. Static Soil Test, Test No. STBRT-1




| | |
|---|---|
| Date | 9/22/2020 |
| Test Facility & Site Location | Midwest Roadside Safety Facility |
| In situ soil description (ASTM D2487) | Well-Graded Gravel (GW) |
| Fill material description (ASTM D2487) | Well-Graded Gravel (GW) (see sieve analyses above) |
| Description of fill placement procedure | 8-inch lifts tamped with a pneumatic compactor |

Figure E-3. Static Soil Test, Test No. STBRT-2

# Appendix F. Vehicle Deformation Records

The following figures and tables describe all occupant compartment measurements taken on the test vehicles used in full-scale crash testing herein. MASH 2016 defines intrusion as the occupant compartment being deformed and reduced in size with no penetration. Outward deformations, which are denoted as negative numbers within this Appendix, are not considered as crush toward the occupant, and are not subject to evaluation by MASH 2016 criteria.

Date: 8/24/2020 Test Name: STBRT-1 VIN: kmhcn46c69u367008
Model Year: 2009 Make: Hyundai Model: Accent

### VEHICLE DEFORMATION
### DRIVER SIDE FLOOR PAN - SET 1

| | POINT | Pretest X (in.) | Pretest Y (in.) | Pretest Z (in.) | Posttest X (in.) | Posttest Y (in.) | Posttest Z (in.) | ΔX[A] (in.) | ΔY[A] (in.) | ΔZ[A] (in.) | Total Δ (in.) | Crush[B] (in.) | Directions for Crush[C] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOE PAN - WHEEL WELL (X, Z) | 1 | 62.0338 | -9.4107 | 5.0833 | 62.0159 | -9.4286 | 5.4051 | 0.0179 | -0.0179 | -0.3218 | 0.3228 | 0.0179 | X |
| | 2 | 62.0252 | -5.5753 | 4.9334 | 61.9871 | -5.6487 | 5.1358 | 0.0381 | -0.0734 | -0.2024 | 0.2186 | 0.0381 | X |
| | 3 | 62.2922 | -2.0541 | 5.0758 | 62.2486 | -2.1352 | 5.3228 | 0.0436 | -0.0811 | -0.2470 | 0.2636 | 0.0436 | X |
| | 4 | 62.2564 | 2.3796 | 5.1833 | 62.2220 | 2.3490 | 5.3264 | 0.0344 | 0.0306 | -0.1431 | 0.1503 | 0.0344 | X |
| | 5 | 61.2730 | 6.5975 | 4.1885 | 61.3415 | 6.4596 | 4.4846 | -0.0685 | 0.1379 | -0.2961 | 0.3337 | 0.0000 | NA |
| | 6 | 58.3594 | -9.6809 | 7.3854 | 58.3603 | -9.7459 | 7.6636 | -0.0009 | -0.0650 | -0.2782 | 0.2857 | 0.0000 | NA |
| | 7 | 58.2978 | -5.8793 | 7.1394 | 58.2335 | -5.9483 | 7.4196 | 0.0643 | -0.0690 | -0.2802 | 0.2956 | 0.0643 | X |
| | 8 | 58.6160 | -1.8061 | 7.3725 | 58.5823 | -1.8557 | 7.6303 | 0.0337 | -0.0496 | -0.2578 | 0.2647 | 0.0337 | X |
| | 9 | 58.4404 | 2.5768 | 7.4444 | 58.3883 | 2.6080 | 7.6556 | 0.0521 | -0.0312 | -0.2112 | 0.2198 | 0.0521 | X |
| | 10 | 57.6906 | 6.6181 | 4.2630 | 57.6855 | 6.5304 | 4.4359 | 0.0051 | 0.0877 | -0.1729 | 0.1939 | 0.0051 | X |
| FLOOR PAN (Z) | 11 | 53.6791 | -13.6107 | 7.9989 | 53.6336 | -13.6896 | 8.2356 | 0.0455 | -0.0789 | -0.2367 | 0.2536 | -0.2367 | Z |
| | 12 | 53.8357 | -7.9186 | 7.8975 | 53.7744 | -7.9604 | 8.1601 | 0.0613 | -0.0418 | -0.2626 | 0.2729 | -0.2626 | Z |
| | 13 | 53.5725 | -3.4742 | 7.9065 | 53.5244 | -3.5249 | 8.1651 | 0.0481 | -0.0507 | -0.2586 | 0.2679 | -0.2586 | Z |
| | 14 | 53.3841 | 1.3082 | 8.1473 | 53.3480 | 1.2091 | 8.0313 | 0.0361 | 0.0991 | 0.1160 | 0.1568 | 0.1160 | Z |
| | 15 | 53.0631 | 6.6084 | 4.3081 | 53.0497 | 6.4591 | 4.5211 | 0.0134 | 0.1493 | -0.2130 | 0.2605 | -0.2130 | Z |
| | 16 | 47.7564 | -13.5655 | 8.3695 | 47.6936 | -13.6362 | 8.5990 | 0.0628 | -0.0707 | -0.2295 | 0.2482 | -0.2295 | Z |
| | 17 | 47.8853 | -8.0150 | 8.0368 | 47.8476 | -8.0660 | 8.2884 | 0.0377 | -0.0510 | -0.2516 | 0.2595 | -0.2516 | Z |
| | 18 | 47.8196 | -3.5540 | 8.0631 | 47.8254 | -3.6748 | 8.3112 | -0.0058 | -0.1208 | -0.2481 | 0.2760 | -0.2481 | Z |
| | 19 | 47.9734 | 1.5755 | 8.7853 | 47.9355 | 1.5167 | 8.8953 | 0.0379 | 0.0588 | -0.1100 | 0.1304 | -0.1100 | Z |
| | 20 | 47.4528 | 6.4130 | 4.7611 | 47.4708 | 6.2984 | 4.8963 | -0.0180 | 0.1146 | -0.1352 | 0.1781 | -0.1352 | Z |
| | 21 | 43.0473 | -13.5155 | 8.3682 | 43.0437 | -13.5888 | 8.5952 | 0.0036 | -0.0733 | -0.2270 | 0.2386 | -0.2270 | Z |
| | 22 | 43.4944 | -7.9832 | 8.0941 | 43.4521 | -8.0525 | 8.3267 | 0.0423 | -0.0693 | -0.2326 | 0.2464 | -0.2326 | Z |
| | 23 | 43.9211 | -3.4231 | 8.1341 | 43.9245 | -3.5119 | 8.3556 | -0.0034 | -0.0888 | -0.2215 | 0.2387 | -0.2215 | Z |
| | 24 | 44.1804 | 1.6905 | 8.7740 | 44.1565 | 1.6258 | 8.9537 | 0.0239 | 0.0647 | -0.1797 | 0.1925 | -0.1797 | Z |
| | 25 | 44.2930 | 6.5204 | 4.7187 | 44.2855 | 6.4337 | 4.7796 | 0.0075 | 0.0867 | -0.0609 | 0.1062 | -0.0609 | Z |
| | 26 | 38.9248 | -12.1649 | 8.1463 | 38.9105 | -12.1926 | 8.3603 | 0.0143 | -0.0277 | -0.2140 | 0.2163 | -0.2140 | Z |
| | 27 | 39.2065 | -8.0162 | 8.1456 | 39.2048 | -8.1046 | 8.3477 | 0.0017 | -0.0884 | -0.2021 | 0.2206 | -0.2021 | Z |
| | 28 | 39.1903 | -3.7194 | 8.2053 | 39.1788 | -3.8511 | 8.4227 | 0.0115 | -0.1317 | -0.2174 | 0.2544 | -0.2174 | Z |
| | 29 | 39.1796 | 1.8061 | 8.2482 | 39.1514 | 1.7030 | 8.4247 | 0.0282 | 0.1031 | -0.1765 | 0.2063 | -0.1765 | Z |
| | 30 | 39.9680 | 6.7025 | 4.5455 | 39.8945 | 6.5543 | 4.6819 | 0.0735 | 0.1482 | -0.1364 | 0.2144 | -0.1364 | Z |

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

| Pretest Floor Pan | Posttest Floor Pan |
|---|---|
|  |  |

Figure F-1. Floor Pan Deformation Data – Set 1, Test No. STBRT-1

Date: 8/24/2020 Test Name: STBRT-1 VIN: kmhcn46c69u367008
Model Year: 2009 Make: Hyundai Model: Accent

**VEHICLE DEFORMATION**
**DRIVER SIDE FLOOR PAN - SET 2**

| | POINT | Pretest X (in.) | Pretest Y (in.) | Pretest Z (in.) | Posttest X (in.) | Posttest Y (in.) | Posttest Z (in.) | ΔX[A] (in.) | ΔY[A] (in.) | ΔZ[A] (in.) | Total Δ (in.) | Crush[B] (in.) | Directions for Crush[C] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOE PAN - WHEEL WELL (X, Z) | 1 | 62.7125 | -24.6301 | 4.7239 | 62.7493 | -24.5256 | 4.4140 | -0.0368 | 0.1045 | 0.3099 | 0.3291 | 0.3099 | Z |
| | 2 | 62.5877 | -20.7963 | 4.5861 | 62.5827 | -20.7014 | 4.2285 | 0.0050 | 0.0949 | 0.3576 | 0.3700 | 0.3576 | X, Z |
| | 3 | 62.7493 | -17.2691 | 4.7383 | 62.7454 | -17.1704 | 4.4625 | 0.0039 | 0.0987 | 0.2758 | 0.2930 | 0.2758 | X, Z |
| | 4 | 62.5806 | -12.8388 | 4.8600 | 62.5736 | -12.7142 | 4.5425 | 0.0070 | 0.1246 | 0.3175 | 0.3411 | 0.3176 | X, Z |
| | 5 | 61.4656 | -8.6494 | 3.8834 | 61.5506 | -8.6177 | 3.7196 | -0.0850 | 0.0317 | 0.1638 | 0.1872 | 0.1638 | Z |
| | 6 | 59.0598 | -25.0177 | 7.0438 | 59.1164 | -25.0011 | 6.7394 | -0.0566 | 0.0166 | 0.3044 | 0.3101 | 0.3044 | Z |
| | 7 | 58.8825 | -21.2190 | 6.8101 | 58.9137 | -21.1556 | 6.5363 | -0.0312 | 0.0634 | 0.2738 | 0.2828 | 0.2738 | Z |
| | 8 | 59.0792 | -17.1387 | 7.0543 | 59.1444 | -17.0969 | 6.8006 | -0.0652 | 0.0418 | 0.2537 | 0.2653 | 0.2537 | Z |
| | 9 | 58.7721 | -12.7634 | 7.1409 | 58.7625 | -12.6594 | 6.9148 | 0.0096 | 0.1040 | 0.2261 | 0.2491 | 0.2263 | X, Z |
| | 10 | 57.8846 | -8.7370 | 3.9762 | 57.9349 | -8.6918 | 3.7918 | -0.0503 | 0.0452 | 0.1844 | 0.1964 | 0.1844 | Z |
| FLOOR PAN (Z) | 11 | 54.5031 | -29.0885 | 7.6687 | 54.5120 | -29.0169 | 7.3192 | -0.0089 | 0.0716 | 0.3495 | 0.3569 | 0.3495 | Z |
| | 12 | 54.4878 | -23.3939 | 7.5843 | 54.4997 | -23.3673 | 7.3165 | -0.0119 | 0.0266 | 0.2678 | 0.2694 | 0.2678 | Z |
| | 13 | 54.0910 | -18.9595 | 7.6086 | 54.1503 | -18.9131 | 7.3884 | -0.0593 | 0.0464 | 0.2202 | 0.2327 | 0.2202 | Z |
| | 14 | 53.7600 | -14.1858 | 7.8655 | 53.7808 | -14.1971 | 7.3276 | -0.0208 | -0.0113 | 0.5379 | 0.5384 | 0.5379 | Z |
| | 15 | 53.2598 | -8.8862 | 4.0446 | 53.2964 | -8.8747 | 3.8930 | -0.0366 | 0.0115 | 0.1516 | 0.1564 | 0.1516 | Z |
| | 16 | 48.5838 | -29.2228 | 8.0693 | 48.6306 | -29.2243 | 7.7391 | -0.0468 | -0.0015 | 0.3302 | 0.3335 | 0.3302 | Z |
| | 17 | 48.5438 | -23.6699 | 7.7535 | 48.5908 | -23.6015 | 7.5227 | -0.0470 | 0.0684 | 0.2308 | 0.2453 | 0.2308 | Z |
| | 18 | 48.3440 | -19.2130 | 7.7941 | 48.3740 | -19.2084 | 7.6121 | -0.0300 | 0.0046 | 0.1820 | 0.1845 | 0.1820 | Z |
| | 19 | 48.3470 | -14.0834 | 8.5317 | 48.3935 | -14.0344 | 8.2678 | -0.0465 | 0.0490 | 0.2639 | 0.2724 | 0.2639 | Z |
| | 20 | 47.6603 | -9.2518 | 4.5255 | 47.6933 | -9.2183 | 4.3633 | -0.0330 | 0.0335 | 0.1622 | 0.1689 | 0.1622 | Z |
| | 21 | 43.8754 | -29.3147 | 8.0921 | 43.9325 | -29.2506 | 7.8229 | -0.0571 | 0.0641 | 0.2692 | 0.2826 | 0.2692 | Z |
| | 22 | 44.1543 | -23.7706 | 7.8332 | 44.1576 | -23.7396 | 7.6257 | -0.0033 | 0.0310 | 0.2075 | 0.2098 | 0.2075 | Z |
| | 23 | 44.4438 | -19.1999 | 7.8853 | 44.4731 | -19.1798 | 7.7130 | -0.0293 | 0.0201 | 0.1723 | 0.1759 | 0.1723 | Z |
| | 24 | 44.5523 | -14.0827 | 8.5400 | 44.6145 | -14.0594 | 8.3802 | -0.0622 | 0.0233 | 0.1598 | 0.1731 | 0.1598 | Z |
| | 25 | 44.4985 | -9.2395 | 4.4995 | 44.5657 | -9.1867 | 4.3075 | -0.0672 | 0.0528 | 0.1920 | 0.2102 | 0.1920 | Z |
| | 26 | 39.7130 | -28.0882 | 7.8954 | 39.7125 | -27.9958 | 7.6513 | 0.0005 | 0.0924 | 0.2441 | 0.2610 | 0.2441 | Z |
| | 27 | 39.8696 | -23.9329 | 7.9063 | 39.9411 | -23.8777 | 7.7052 | -0.0715 | 0.0552 | 0.2011 | 0.2205 | 0.2011 | Z |
| | 28 | 39.7244 | -19.6387 | 7.9796 | 39.7823 | -19.6947 | 7.8408 | -0.0579 | -0.0560 | 0.1388 | 0.1605 | 0.1388 | Z |
| | 29 | 39.5476 | -14.1162 | 8.0399 | 39.5768 | -14.0849 | 7.9148 | -0.0292 | 0.0313 | 0.1251 | 0.1322 | 0.1251 | Z |
| | 30 | 40.1692 | -9.1872 | 4.3487 | 40.2619 | -9.1881 | 4.2389 | -0.0927 | -0.0009 | 0.1098 | 0.1437 | 0.1098 | Z |

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

| Pretest Floor Pan | Posttest Floor Pan |
|---|---|
|  |  |

Figure F-2. Floor Pan Deformation Data – Set 2, Test No. STBRT-1

Model Year: 2009 | Test Name: STBRT-1 | VIN: kmhcn46c69u367008
Make: Hyundai | Model: Accent

**VEHICLE DEFORMATION**
**DRIVER SIDE INTERIOR CRUSH - SET 1**

| | POINT | Pretest X (in.) | Pretest Y (in.) | Pretest Z (in.) | Posttest X (in.) | Posttest Y (in.) | Posttest Z (in.) | ΔX[A] (in.) | ΔY[A] (in.) | ΔZ[A] (in.) | Total Δ (in.) | Crush[B] (in.) | Directions for Crush[C] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DASH (X, Y, Z) | 1 | 49.2387 | -12.9290 | -19.6555 | 49.1732 | -12.7047 | -19.6351 | 0.0655 | 0.2243 | 0.0204 | 0.2346 | 0.2346 | X, Y, Z |
| | 2 | 45.8383 | -3.2440 | -23.0668 | 45.9069 | -3.0902 | -23.3240 | -0.0686 | 0.1538 | -0.2572 | 0.3074 | 0.3074 | X, Y, Z |
| | 3 | 47.8732 | 10.7719 | -20.5296 | 47.5001 | 10.8874 | -20.8794 | 0.3731 | -0.1155 | -0.3498 | 0.5243 | 0.5243 | X, Y, Z |
| | 4 | 46.8492 | -11.9394 | -14.2077 | 46.7888 | -11.4223 | -14.2915 | 0.0604 | 0.5171 | -0.0838 | 0.5273 | 0.5273 | X, Y, Z |
| | 5 | 47.3210 | -2.2229 | -8.9880 | 47.2687 | -1.6727 | -8.9264 | 0.0523 | 0.5502 | 0.0616 | 0.5561 | 0.5561 | X, Y, Z |
| | 6 | 44.2722 | 10.3204 | -13.7701 | 44.4168 | 10.4874 | -14.0118 | -0.1446 | -0.1670 | -0.2417 | 0.3274 | 0.3274 | X, Y, Z |
| SIDE PANEL (Y) | 7 | 53.3647 | -16.4832 | -0.4209 | 53.2176 | -15.8508 | -0.2558 | 0.1471 | 0.6324 | 0.1651 | 0.6699 | 0.6324 | Y |
| | 8 | 52.9343 | -16.4776 | 2.0083 | 52.7831 | -16.1073 | 2.2001 | 0.1512 | 0.3703 | 0.1918 | 0.4436 | 0.3703 | Y |
| | 9 | 58.5201 | -16.4210 | -0.1028 | 58.2787 | -15.8269 | 0.0612 | 0.2414 | 0.5941 | 0.1640 | 0.6619 | 0.5941 | Y |
| IMPACT SIDE DOOR (Y) | 10 | 21.6106 | -17.4118 | -10.4384 | 21.0447 | -18.3052 | -10.4261 | 0.5659 | -0.8934 | 0.0123 | 1.0576 | -0.8934 | Y |
| | 11 | 34.2756 | -17.7942 | -10.1962 | 33.6415 | -19.3081 | -10.1785 | 0.6341 | -1.5139 | 0.0177 | 1.6414 | -1.5139 | Y |
| | 12 | 41.9941 | -17.5270 | -9.6849 | 41.3063 | -18.2631 | -9.6701 | 0.6878 | -0.7361 | 0.0148 | 1.0075 | -0.7361 | Y |
| | 13 | 24.1893 | -17.6423 | -1.8429 | 23.7446 | -17.9923 | -1.8041 | 0.4447 | -0.3500 | 0.0388 | 0.5672 | -0.3500 | Y |
| | 14 | 33.3005 | -17.8006 | 0.5099 | 32.7966 | -18.2775 | 0.4406 | 0.5039 | -0.4769 | -0.0693 | 0.6972 | -0.4769 | Y |
| | 15 | 41.2641 | -18.3032 | -0.1252 | 40.7189 | -18.9613 | -0.0478 | 0.5452 | -0.6581 | 0.0774 | 0.8581 | -0.6581 | Y |
| ROOF - (Z) | 16 | 29.5019 | -6.7293 | -37.2458 | 29.2837 | -7.5686 | -37.3585 | 0.2182 | -0.8393 | -0.1127 | 0.8745 | -0.1127 | Z |
| | 17 | 30.0719 | -2.9207 | -37.4913 | 29.8483 | -3.7691 | -37.5875 | 0.2236 | -0.8484 | -0.0962 | 0.8826 | -0.0962 | Z |
| | 18 | 30.4496 | 1.3648 | -37.7033 | 30.2743 | 0.4544 | -37.7477 | 0.1753 | 0.9104 | -0.0444 | 0.9282 | -0.0444 | Z |
| | 19 | 30.6437 | 5.4836 | -37.8331 | 30.4908 | 4.5482 | -37.8386 | 0.1529 | 0.9354 | -0.0055 | 0.9478 | -0.0055 | Z |
| | 20 | 30.6693 | 9.8390 | -37.8998 | 30.5595 | 8.9637 | -37.8549 | 0.1098 | 0.8753 | 0.0449 | 0.8833 | 0.0449 | Z |
| | 21 | 25.1038 | -6.3399 | -37.9790 | 24.9552 | -7.1879 | -38.0755 | 0.1486 | -0.8480 | -0.0965 | 0.8663 | -0.0965 | Z |
| | 22 | 25.3062 | -2.7921 | -38.2782 | 25.1436 | -3.6436 | -38.3573 | 0.1626 | -0.8515 | -0.0791 | 0.8705 | -0.0791 | Z |
| | 23 | 25.7935 | 1.2363 | -38.4849 | 25.6429 | 0.3998 | -38.5618 | 0.1506 | 0.8365 | -0.0769 | 0.8534 | -0.0769 | Z |
| | 24 | 25.9378 | 5.2250 | -38.6299 | 25.7851 | 4.4079 | -38.6973 | 0.1527 | 0.8171 | -0.0674 | 0.8340 | -0.0674 | Z |
| | 25 | 26.0441 | 9.3540 | -38.6864 | 25.8713 | 8.4344 | -38.6020 | 0.1728 | 0.9196 | 0.0844 | 0.9395 | 0.0844 | Z |
| | 26 | 21.9347 | -6.1441 | -38.3438 | 21.7362 | -6.9886 | -38.4499 | 0.1985 | -0.8445 | -0.1061 | 0.8740 | -0.1061 | Z |
| | 27 | 21.9750 | -2.3437 | -38.6840 | 21.7791 | -3.1818 | -38.7890 | 0.1959 | -0.8381 | -0.1050 | 0.8671 | -0.1050 | Z |
| | 28 | 22.4967 | 0.9718 | -38.8497 | 22.3146 | 0.1489 | -38.9670 | 0.1821 | 0.8229 | -0.1173 | 0.8509 | -0.1173 | Z |
| | 29 | 22.1143 | 4.8291 | -39.0551 | 21.9602 | 4.0094 | -39.2032 | 0.1541 | 0.8197 | -0.1481 | 0.8471 | -0.1481 | Z |
| | 30 | 21.9122 | 8.1583 | -39.1516 | 21.7678 | 7.3374 | -39.0625 | 0.1444 | 0.8209 | 0.0891 | 0.8383 | 0.0891 | Z |
| A-PILLAR Maximum (X, Y, Z) | 31 | 54.0879 | -15.6599 | -21.9489 | 53.8660 | -15.4327 | -21.8969 | 0.2219 | 0.2272 | 0.0520 | 0.3218 | 0.3218 | X, Y, Z |
| | 32 | 51.4069 | -15.1918 | -23.9788 | 51.2036 | -15.0747 | -23.9766 | 0.2033 | 0.1171 | 0.0022 | 0.2346 | 0.2346 | X, Y, Z |
| | 33 | 48.3190 | -14.5501 | -25.9179 | 48.1593 | -14.6211 | -26.0051 | 0.1597 | -0.0710 | -0.0872 | 0.1953 | 0.1597 | X |
| | 34 | 44.5102 | -13.7040 | -28.1781 | 44.3952 | -13.9933 | -28.3458 | 0.1150 | -0.2893 | -0.1677 | 0.3536 | 0.1150 | X |
| | 35 | 41.5367 | -13.0324 | -29.7878 | 41.3759 | -13.4588 | -29.9806 | 0.1608 | -0.4264 | -0.1928 | 0.4948 | 0.1608 | X |
| | 36 | 35.2953 | -11.8009 | -32.4490 | 35.1157 | -12.5014 | -32.6573 | 0.1796 | -0.7005 | -0.2083 | 0.7526 | 0.1796 | X |
| A-PILLAR Lateral (Y) | 31 | 54.0879 | -15.6599 | -21.9489 | 53.8660 | -15.4327 | -21.8969 | 0.2219 | 0.2272 | 0.0520 | 0.3218 | 0.2272 | Y |
| | 32 | 51.4069 | -15.1918 | -23.9788 | 51.2036 | -15.0747 | -23.9766 | 0.2033 | 0.1171 | 0.0022 | 0.2346 | 0.1171 | Y |
| | 33 | 48.3190 | -14.5501 | -25.9179 | 48.1593 | -14.6211 | -26.0051 | 0.1597 | -0.0710 | -0.0872 | 0.1953 | -0.0710 | Y |
| | 34 | 44.5102 | -13.7040 | -28.1781 | 44.3952 | -13.9933 | -28.3458 | 0.1150 | -0.2893 | -0.1677 | 0.3536 | -0.2893 | Y |
| | 35 | 41.5367 | -13.0324 | -29.7878 | 41.3759 | -13.4588 | -29.9806 | 0.1608 | -0.4264 | -0.1928 | 0.4948 | -0.4264 | Y |
| | 36 | 35.2953 | -11.8009 | -32.4490 | 35.1157 | -12.5014 | -32.6573 | 0.1796 | -0.7005 | -0.2083 | 0.7526 | -0.7005 | Y |
| B-PILLAR Maximum (X, Y, Z) | 37 | 11.5590 | -10.8227 | -33.6200 | 11.4298 | -11.4960 | -33.6623 | 0.1292 | -0.6733 | -0.0423 | 0.6869 | 0.1292 | X |
| | 38 | 15.6318 | -14.0523 | -26.7138 | 15.5015 | -14.6730 | -26.6357 | 0.1303 | -0.6207 | 0.0781 | 0.6390 | 0.1519 | X, Z |
| | 39 | 12.7403 | -14.9742 | -22.8698 | 12.5675 | -15.5150 | -22.8600 | 0.1728 | -0.5408 | 0.0098 | 0.5678 | 0.1731 | X, Z |
| | 40 | 16.9767 | -15.4978 | -20.1327 | 16.8387 | -16.2293 | -20.1096 | 0.1380 | -0.7315 | 0.0231 | 0.7448 | 0.1399 | X, Z |
| B-PILLAR Lateral (Y) | 37 | 11.5590 | -10.8227 | -33.6200 | 11.4298 | -11.4960 | -33.6623 | 0.1292 | -0.6733 | -0.0423 | 0.6869 | -0.6733 | Y |
| | 38 | 15.6318 | -14.0523 | -26.7138 | 15.5015 | -14.6730 | -26.6357 | 0.1303 | -0.6207 | 0.0781 | 0.6390 | -0.6207 | Y |
| | 39 | 12.7403 | -14.9742 | -22.8698 | 12.5675 | -15.5150 | -22.8600 | 0.1728 | -0.5408 | 0.0098 | 0.5678 | -0.5408 | Y |
| | 40 | 16.9767 | -15.4978 | -20.1327 | 16.8387 | -16.2293 | -20.1096 | 0.1380 | -0.7315 | 0.0231 | 0.7448 | -0.7315 | Y |

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Figure F-3. Interior Crush Deformation Data – Set 1, Test No. STBRT-1

Model Year: 2009 | Test Name: STBRT-1 | VIN: kmhcn46c69u367008
Make: Hyundai | Model: Accent

**VEHICLE DEFORMATION**
**DRIVER SIDE INTERIOR CRUSH - SET 2**

| | POINT | Pretest X (in.) | Pretest Y (in.) | Pretest Z (in.) | Posttest X (in.) | Posttest Y (in.) | Posttest Z (in.) | ΔX[A] (in.) | ΔY[A] (in.) | ΔZ[A] (in.) | Total Δ (in.) | Crush[B] (in.) | Directions for Crush[C] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DASH (X, Y, Z) | 1 | 49.8303 | -28.2403 | -20.0855 | 49.8229 | -27.6413 | -20.4973 | 0.0074 | 0.5990 | -0.4118 | 0.7269 | 0.7269 | X, Y, Z |
| | 2 | 46.1182 | -18.6472 | -23.4308 | 46.1806 | -18.0916 | -23.9974 | -0.0624 | 0.5556 | -0.5666 | 0.7960 | 0.7960 | X, Y, Z |
| | 3 | 47.7597 | -4.5870 | -20.8545 | 47.3347 | -4.1044 | -21.3677 | 0.4250 | 0.4826 | -0.5132 | 0.8227 | 0.8227 | X, Y, Z |
| | 4 | 47.4573 | -27.3420 | -14.6147 | 47.4734 | -26.5179 | -15.1028 | -0.0161 | 0.8241 | -0.4881 | 0.9579 | 0.9579 | X, Y, Z |
| | 5 | 47.6851 | -17.6353 | -9.3605 | 47.7000 | -16.8357 | -9.6006 | -0.0149 | 0.7996 | -0.2401 | 0.8350 | 0.8350 | X, Y, Z |
| | 6 | 44.2290 | -5.1697 | -14.0680 | 44.3655 | -4.7079 | -14.4648 | -0.1365 | 0.4618 | -0.3968 | 0.6240 | 0.6240 | X, Y, Z |
| SIDE PANEL (Y) | 7 | 54.2164 | -31.7429 | -0.8990 | 54.2490 | -30.9262 | -1.2248 | -0.0326 | 0.8167 | -0.3258 | 0.8799 | 0.8167 | Y |
| | 8 | 53.8059 | -31.7591 | 1.5336 | 53.8586 | -31.2326 | 1.2329 | -0.0527 | 0.5265 | -0.3007 | 0.6086 | 0.5265 | Y |
| | 9 | 59.3701 | -31.5298 | -0.6222 | 59.3104 | -30.7345 | -0.9775 | 0.0597 | 0.7953 | -0.3553 | 0.8731 | 0.7953 | Y |
| IMPACT SIDE DOOR (Y) | 10 | 22.4226 | -33.5707 | -10.6639 | 22.0350 | -34.3282 | -10.9841 | 0.3876 | -0.7575 | -0.3202 | 0.9092 | -0.7575 | Y |
| | 11 | 35.0950 | -33.5802 | -10.5253 | 34.6608 | -34.9051 | -10.9258 | 0.4342 | -1.3249 | -0.4005 | 1.4506 | -1.3249 | Y |
| | 12 | 42.8062 | -33.0873 | -10.0751 | 42.2924 | -33.6071 | -10.5080 | 0.5138 | -0.5198 | -0.4329 | 0.8495 | -0.5198 | Y |
| | 13 | 25.0771 | -33.7571 | -2.0904 | 24.8462 | -34.0475 | -2.3966 | 0.2309 | -0.2904 | -0.3062 | 0.4810 | -0.2904 | Y |
| | 14 | 34.2080 | -33.6552 | 0.1882 | 33.9339 | -34.0566 | -0.2819 | 0.2741 | -0.4014 | -0.4701 | 0.6762 | -0.4014 | Y |
| | 15 | 42.1775 | -33.9202 | -0.5130 | 41.8670 | -34.4631 | -0.8900 | 0.3105 | -0.5429 | -0.3770 | 0.7303 | -0.5429 | Y |
| ROOF - (Z) | 16 | 29.7762 | -22.5602 | -37.4913 | 29.5189 | -22.9312 | -37.8655 | 0.2573 | -0.3710 | -0.3742 | 0.5864 | -0.3742 | Z |
| | 17 | 30.2317 | -18.7355 | -37.7264 | 29.9513 | -19.1117 | -38.0458 | 0.2804 | -0.3762 | -0.3194 | 0.5676 | -0.3194 | Z |
| | 18 | 30.4812 | -14.4400 | -37.9244 | 30.2318 | -14.8743 | -38.1491 | 0.2494 | -0.4343 | -0.2247 | 0.5489 | -0.2247 | Z |
| | 19 | 30.5527 | -10.3168 | -38.0394 | 30.3082 | -10.7746 | -38.1821 | 0.2445 | -0.4578 | -0.1427 | 0.5383 | -0.1427 | Z |
| | 20 | 30.4494 | -5.9623 | -38.0890 | 30.2273 | -6.3595 | -38.1338 | 0.2221 | -0.3972 | -0.0448 | 0.4573 | -0.0448 | Z |
| | 21 | 25.3627 | -22.2980 | -38.1876 | 25.1702 | -22.6877 | -38.5167 | 0.1925 | -0.3897 | -0.3291 | 0.5452 | -0.3291 | Z |
| | 22 | 25.4580 | -18.7447 | -38.4743 | 25.2345 | -19.1355 | -38.7485 | 0.2235 | -0.3908 | -0.2742 | 0.5271 | -0.2742 | Z |
| | 23 | 25.8246 | -14.7029 | -38.6689 | 25.5937 | -15.0748 | -38.8997 | 0.2309 | -0.3719 | -0.2308 | 0.4949 | -0.2308 | Z |
| | 24 | 25.8501 | -10.7111 | -38.7992 | 25.5982 | -11.0627 | -38.9776 | 0.2519 | -0.3516 | -0.1784 | 0.4679 | -0.1784 | Z |
| | 25 | 25.8342 | -6.5807 | -38.8402 | 25.5495 | -7.0374 | -38.8237 | 0.2847 | -0.4567 | 0.0165 | 0.5384 | 0.0165 | Z |
| | 26 | 22.1863 | -22.1944 | -38.5261 | 21.9413 | -22.5928 | -38.8436 | 0.2450 | -0.3984 | -0.3175 | 0.5653 | -0.3175 | Z |
| | 27 | 22.1118 | -18.3933 | -38.8514 | 21.8505 | -18.7823 | -39.1266 | 0.2613 | -0.3890 | -0.2752 | 0.5434 | -0.2752 | Z |
| | 28 | 22.5342 | -15.0632 | -39.0082 | 22.2703 | -15.4331 | -39.2625 | 0.2639 | -0.3699 | -0.2543 | 0.5207 | -0.2543 | Z |
| | 29 | 22.0366 | -11.2181 | -39.1952 | 21.7821 | -11.5839 | -39.4364 | 0.2545 | -0.3658 | -0.2412 | 0.5067 | -0.2412 | Z |
| | 30 | 21.7356 | -7.8961 | -39.2769 | 21.4792 | -8.2667 | -39.2436 | 0.2564 | -0.3706 | 0.0333 | 0.4519 | 0.0333 | Z |
| A-PILLAR Maximum (X, Y, Z) | 31 | 54.7390 | -30.8184 | -22.4287 | 54.5725 | -30.1752 | -22.8641 | 0.1665 | 0.6432 | -0.4354 | 0.7944 | 0.6644 | X, Y |
| | 32 | 52.0289 | -30.4221 | -24.4350 | 51.8699 | -29.8782 | -24.9012 | 0.1590 | 0.5439 | -0.4662 | 0.7338 | 0.5667 | X, Y |
| | 33 | 48.9077 | -29.8645 | -26.3467 | 48.7833 | -29.4993 | -26.8804 | 0.1244 | 0.3652 | -0.5337 | 0.6585 | 0.3858 | X, Y |
| | 34 | 45.0572 | -29.1227 | -28.5727 | 44.9669 | -28.9665 | -29.1592 | 0.0903 | 0.1562 | -0.5865 | 0.6136 | 0.1804 | X, Y |
| | 35 | 42.0521 | -28.5332 | -30.1556 | 41.9081 | -28.5117 | -30.7440 | 0.1440 | 0.0215 | -0.5884 | 0.6061 | 0.1456 | X, Y |
| | 36 | 35.7557 | -27.4765 | -32.7615 | 35.5814 | -27.7295 | -33.3193 | 0.1743 | -0.2530 | -0.5578 | 0.6368 | 0.1743 | X |
| A-PILLAR Lateral (Y) | 31 | 54.7390 | -30.8184 | -22.4287 | 54.5725 | -30.1752 | -22.8641 | 0.1665 | 0.6432 | -0.4354 | 0.7944 | 0.6432 | Y |
| | 32 | 52.0289 | -30.4221 | -24.4350 | 51.8699 | -29.8782 | -24.9012 | 0.1590 | 0.5439 | -0.4662 | 0.7338 | 0.5439 | Y |
| | 33 | 48.9077 | -29.8645 | -26.3467 | 48.7833 | -29.4993 | -26.8804 | 0.1244 | 0.3652 | -0.5337 | 0.6585 | 0.3652 | Y |
| | 34 | 45.0572 | -29.1227 | -28.5727 | 44.9669 | -28.9665 | -29.1592 | 0.0903 | 0.1562 | -0.5865 | 0.6136 | 0.1562 | Y |
| | 35 | 42.0521 | -28.5332 | -30.1556 | 41.9081 | -28.5117 | -30.7440 | 0.1440 | 0.0215 | -0.5884 | 0.6061 | 0.0215 | Y |
| | 36 | 35.7557 | -27.4765 | -32.7615 | 35.5814 | -27.7295 | -33.3193 | 0.1743 | -0.2530 | -0.5578 | 0.6368 | -0.2530 | Y |
| B-PILLAR Maximum (X, Y, Z) | 37 | 11.9920 | -27.1947 | -33.7373 | 11.8631 | -27.5170 | -33.9813 | 0.1289 | -0.3223 | -0.2440 | 0.4243 | 0.1289 | X |
| | 38 | 16.2145 | -30.3285 | -26.8770 | 16.1403 | -30.6542 | -27.0597 | 0.0742 | -0.3257 | -0.1827 | 0.3807 | 0.0742 | X |
| | 39 | 13.3830 | -31.3496 | -23.0136 | 13.2908 | -31.6497 | -23.2566 | 0.0922 | -0.3001 | -0.2430 | 0.3970 | 0.0922 | X |
| | 40 | 17.6552 | -31.7582 | -20.3128 | 17.6228 | -32.2577 | -20.5765 | 0.0324 | -0.4995 | -0.2637 | 0.5658 | 0.0324 | X |
| B-PILLAR Lateral (Y) | 37 | 11.9920 | -27.1947 | -33.7373 | 11.8631 | -27.5170 | -33.9813 | 0.1289 | -0.3223 | -0.2440 | 0.4243 | -0.3223 | Y |
| | 38 | 16.2145 | -30.3285 | -26.8770 | 16.1403 | -30.6542 | -27.0597 | 0.0742 | -0.3257 | -0.1827 | 0.3807 | -0.3257 | Y |
| | 39 | 13.3830 | -31.3496 | -23.0136 | 13.2908 | -31.6497 | -23.2566 | 0.0922 | -0.3001 | -0.2430 | 0.3970 | -0.3001 | Y |
| | 40 | 17.6552 | -31.7582 | -20.3128 | 17.6228 | -32.2577 | -20.5765 | 0.0324 | -0.4995 | -0.2637 | 0.5658 | -0.4995 | Y |

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Figure F-4. Interior Crush Deformation Data – Set 2, Test No. STBRT-1

| Date: | 8/24/2020 | Test Name: | STBRT-1 | VIN: | kmhcn46c69u367008 |
|---|---|---|---|---|---|
| Model Year: | 2009 | Make: | Hyundai | Model: | Accent |

**Driver Side Maximum Deformations**

| Reference Set 1 | | | | | Reference Set 2 | | | |
|---|---|---|---|---|---|---|---|---|
| Location | Maximum Deformation[A,B] (in.) | MASH Allowable Deformation (in.) | Directions of Deformation[C] | | Location | Maximum Deformation[A,B] (in.) | MASH Allowable Deformation (in.) | Directions of Deformation[C] |
| Roof | 0.1 | ≤ 4 | Z | | Roof | 0.0 | ≤ 4 | Z |
| Windshield[D] | 2.1 | ≤ 3 | X, Z | | Windshield[D] | NA | ≤ 3 | X, Z |
| A-Pillar Maximum | 0.3 | ≤ 5 | X, Y, Z | | A-Pillar Maximum | 0.7 | ≤ 5 | X, Y |
| A-Pillar Lateral | 0.2 | ≤ 3 | Y | | A-Pillar Lateral | 0.6 | ≤ 3 | Y |
| B-Pillar Maximum | 0.2 | ≤ 5 | X, Z | | B-Pillar Maximum | 0.1 | ≤ 5 | X |
| B-Pillar Lateral | 0.2 | ≤ 3 | Y | | B-Pillar Lateral | -0.5 | ≤ 3 | Y |
| Toe Pan - Wheel Well | 0.1 | ≤ 9 | X | | Toe Pan - Wheel Well | 0.4 | ≤ 9 | X, Z |
| Side Front Panel | 0.6 | ≤ 12 | Y | | Side Front Panel | 0.8 | ≤ 12 | Y |
| Side Door (above seat) | -1.5 | ≤ 9 | Y | | Side Door (above seat) | -1.3 | ≤ 9 | Y |
| Side Door (below seat) | -0.7 | ≤ 12 | Y | | Side Door (below seat) | -0.5 | ≤ 12 | Y |
| Floor Pan | 0.1 | ≤ 12 | Z | | Floor Pan | 0.5 | ≤ 12 | Z |
| Dash - no MASH requirement | 0.6 | NA | X, Y, Z | | Dash - no MASH requirement | 0.6 | NA | X, Y, Z |

[A] Items highlighted in red do not meet MASH allowable deformations.

[B] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

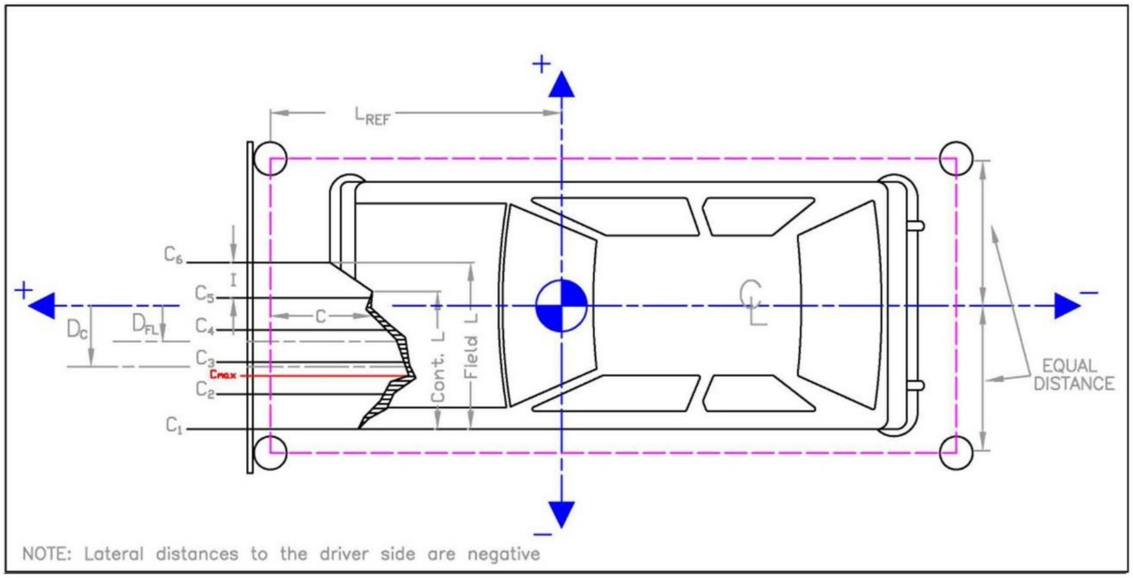
[C] For Toe Pan - Wheel Well the direction of defromation may include X and Z direction. For A-Pillar Maximum and B-Pillar Maximum the direction of deformation may include X, Y, and Z directions. The direction of deformation for Toe Pan -Wheel Well, A-Pillar Maximum, and B-Pillar Maximum only include components where the deformation is positive and intruding into the occupant compartment. If direction of deformation is "NA" then no intrusion is recorded and deformation will be 0.

[D] If deformation is observered for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

**Notes on vehicle crush:**

Figure F-5. Max. Occupant Compartment Deformations by Location, Test No. STBRT-1

| | | | | | |
|---|---|---|---|---|---|
| **Date:** | 8/28/2020 | **Test Name:** | STBRT-1 | **VIN:** | kmhcn46c69u367008 |
| **Model Year:** | 2009 | **Make:** | Hyundai | **Model:** | Accent |



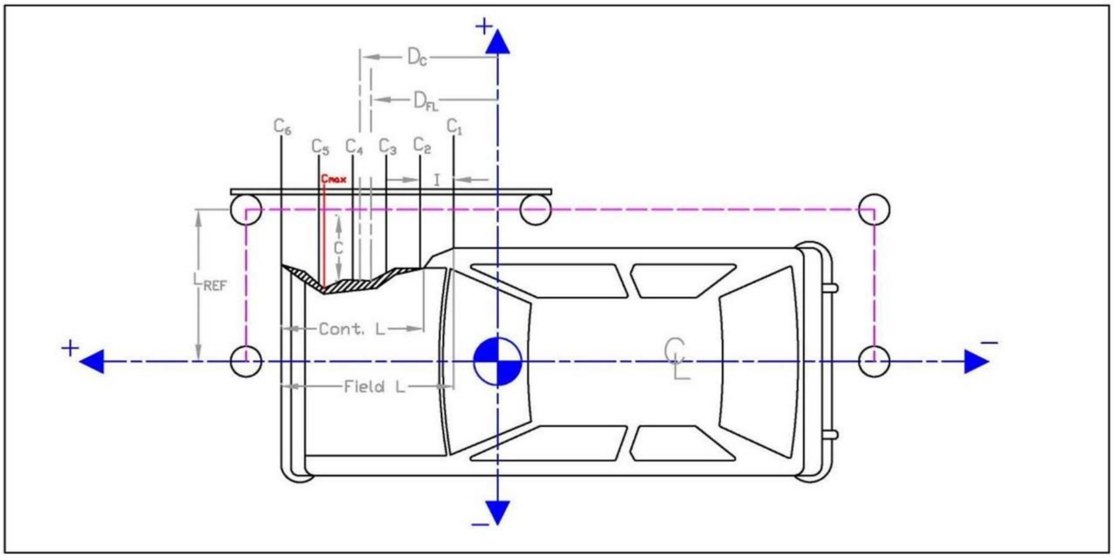

| | in. | (mm) |
|---|---|---|
| Distance from C.G. to reference line - $L_{REF}$: | 74 5/8 | (1895) |
| Total Width of Vehicle: | 66 | (1676) |
| Width of contact and induced crush - Field L: | 18 | (457) |
| Crush measurement spacing interval (L/5) - I: | 3 5/8 | (92) |
| Distance from center of vehicle to center of Field L - $D_{FL}$: | 24 | (610) |
| Width of Contact Damage: | 18 | (457) |
| Distance from center of vehicle to center of contact damage - $D_C$: | 24 | (610) |

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

| Crush Measurement | | | Lateral Location | | Original Profile Measurement | | Dist. Between Ref. Lines | | Actual Crush | |
|---|---|---|---|---|---|---|---|---|---|---|
| | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) |
| $C_1$ | 6 3/4 | (171) | 15 | (381) | 3 5/8 | (92) | 3 7/8 | (98) | - 3/4 | -(19) |
| $C_2$ | 7 3/4 | (197) | 18 5/8 | (473) | 4 3/8 | (111) | | | - 1/2 | -(13) |
| $C_3$ | 9 1/5 | (233) | 22 1/4 | (565) | 5 3/4 | (146) | | | - 4/9 | -(11) |
| $C_4$ | 12 | (305) | 25 7/8 | (657) | 7 7/8 | (200) | | | 1/4 | (6) |
| $C_5$ | N/A | NA | 29 1/2 | (749) | 13 3/4 | (349) | | | NA | NA |
| $C_6$ | N/A | NA | 33 1/8 | (841) | 19 7/8 | (505) | | | NA | NA |
| $C_{MAX}$ | 12 | (305) | 25 | (635) | 7 3/8 | (187) | | | 3/4 | (19) |

Figure F-6. Exterior Vehicle Crush (NASS) - Front, Test No. STBRT-1

| | | | | | |
|---|---|---|---|---|---|
| Date: | 8/28/2020 | Test Name: | STBRT-1 | VIN: | kmhcn46c69u367008 |
| Model Year: | 2009 | Make: | Hyundai | Model: | Accent |




| | in. | (mm) |
|---|---|---|
| Distance from centerline to reference line - $L_{REF}$: | 39 1/2 | (1003) |
| Total Vehicle Length: | 168 1/4 | (4274) |
| Distance from vehicle c.g. to 1/2 of Vehicle total length: | -12 5/8 | -(321) |
| Width of contact and induced crush - Field L: | 168 1/4 | (4274) |
| Crush measurement spacing interval (L/5) - I: | 33 5/8 | (854) |
| Distance from vehicle c.g. to center of Field L - $D_{FL}$: | -15 7/8 | -(403) |
| Width of Contact Damage: | 168 1/4 | (4274) |
| Distance from vehicle c.g. to center of contact damage - $D_C$: | -15 7/8 | -(403) |

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been removed)
NOTE: All values must be filled out above before crush measurements are filled out.

| | Crush Measurement | | Longitudinal Location | | Original Profile Measurement | | Dist. Between Ref. Lines | | Actual Crush | |
|---|---|---|---|---|---|---|---|---|---|---|
| | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) |
| $C_1$ | N/A | NA | -100 | -(2540) | 36 | (914) | 3 1/2 | (89) | NA | NA |
| $C_2$ | N/A | NA | -66 3/8 | -(1686) | 4 | (102) | | | NA | NA |
| $C_3$ | 7 3/4 | (197) | -32 3/4 | -(832) | 3 3/8 | (86) | | | 7/8 | (22) |
| $C_4$ | 8 3/4 | (222) | 7/8 | (22) | 3 1/4 | (83) | | | 2 | (51) |
| $C_5$ | N/A | NA | 34 1/2 | (876) | 3 1/2 | (89) | | | NA | NA |
| $C_6$ | N/A | NA | 68 1/8 | (1730) | 23 5/8 | (600) | | | NA | NA |
| $C_{MAX}$ | 10 1/4 | (260) | 14 3/4 | (375) | 3 1/4 | (83) | | | 3 1/2 | (89) |

Figure F-7. Exterior Vehicle Crush (NASS) - Side, Test No. STBRT-1

Date: 9/22/2020 | Test Name: STBRT-2 | VIN: 1C6RR6FT9ES238613
Model Year: 2014 | Make: Dodge | Model: Ram 1500 Quad Cab

**VEHICLE DEFORMATION**
**DRIVER SIDE FLOOR PAN - SET 1**

| | POINT | Pretest X (in.) | Pretest Y (in.) | Pretest Z (in.) | Posttest X (in.) | Posttest Y (in.) | Posttest Z (in.) | ΔX[A] (in.) | ΔY[A] (in.) | ΔZ[A] (in.) | Total Δ (in.) | Crush[B] (in.) | Directions for Crush[C] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOE PAN - WHEEL WELL (X, Z) | 1 | 57.7222 | -22.4783 | -2.1482 | 57.2549 | -22.1189 | -2.0935 | 0.4673 | 0.3594 | -0.0547 | 0.5921 | 0.4673 | X |
| | 2 | 58.9884 | -19.0746 | -0.8223 | 58.5764 | -18.7658 | -0.7648 | 0.4120 | 0.3088 | -0.0575 | 0.5181 | 0.4120 | X |
| | 3 | 59.2205 | -15.5699 | -0.4845 | 59.0776 | -15.3795 | -0.3354 | 0.1429 | 0.1904 | -0.1491 | 0.2809 | 0.1429 | X |
| | 4 | 58.6744 | -10.3003 | -0.5678 | 58.5439 | -10.0122 | -0.3365 | 0.1305 | 0.2881 | -0.2313 | 0.3918 | 0.1305 | X |
| | 5 | 55.9283 | -4.6685 | -1.7346 | 55.8727 | -4.4702 | -1.5538 | 0.0556 | 0.1983 | -0.1808 | 0.2740 | 0.0556 | X |
| | 6 | 54.2006 | -23.9109 | 2.1900 | 53.4935 | -23.2746 | 2.1008 | 0.7071 | 0.6363 | 0.0892 | 0.9554 | 0.7127 | X, Z |
| | 7 | 54.1463 | -19.0590 | 2.2361 | 53.7553 | -18.6609 | 2.1523 | 0.3910 | 0.3981 | 0.0838 | 0.5643 | 0.3999 | X, Z |
| | 8 | 54.0653 | -14.2442 | 2.2844 | 53.8922 | -13.8977 | 2.5472 | 0.1731 | 0.3465 | -0.2628 | 0.4681 | 0.1731 | X |
| | 9 | 54.1150 | -8.7859 | 2.2530 | 54.1037 | -8.4394 | 2.5031 | 0.0113 | 0.3465 | -0.2501 | 0.4275 | 0.0113 | X |
| | 10 | 52.7552 | -4.0075 | -1.0263 | 52.6868 | -3.7438 | -0.8342 | 0.0684 | 0.2637 | -0.1921 | 0.3333 | 0.0684 | X |
| FLOOR PAN (Z) | 11 | 47.9191 | -24.2377 | 5.1207 | 47.8992 | -23.7750 | 5.8099 | 0.0199 | 0.4627 | -0.6892 | 0.8304 | -0.6892 | Z |
| | 12 | 47.7495 | -19.0934 | 5.0725 | 47.7628 | -18.7272 | 5.6476 | -0.0133 | 0.3662 | -0.5751 | 0.6819 | -0.5751 | Z |
| | 13 | 47.7369 | -14.5965 | 5.0860 | 47.7285 | -14.1821 | 5.4865 | 0.0084 | 0.4144 | -0.4005 | 0.5764 | -0.4005 | Z |
| | 14 | 47.8387 | -9.4217 | 5.1003 | 47.8075 | -9.0587 | 5.3273 | 0.0312 | 0.3630 | -0.2270 | 0.4293 | -0.2270 | Z |
| | 15 | 46.1846 | -4.4397 | 0.5500 | 46.1243 | -4.2043 | 0.7240 | 0.0603 | 0.2354 | -0.1740 | 0.2989 | -0.1740 | Z |
| | 16 | 44.1711 | -24.5310 | 5.1710 | 44.1481 | -24.0936 | 5.8227 | 0.0230 | 0.4374 | -0.6517 | 0.7852 | -0.6517 | Z |
| | 17 | 44.0780 | -18.8540 | 5.0985 | 44.0767 | -18.4927 | 5.6414 | 0.0013 | 0.3613 | -0.5429 | 0.6521 | -0.5429 | Z |
| | 18 | 43.8919 | -14.2521 | 5.1205 | 43.9147 | -13.8323 | 5.4951 | -0.0228 | 0.4198 | -0.3746 | 0.5631 | -0.3746 | Z |
| | 19 | 43.9520 | -8.8986 | 5.1392 | 43.9158 | -8.5199 | 5.3408 | 0.0362 | 0.3787 | -0.2016 | 0.4305 | -0.2016 | Z |
| | 20 | 42.8127 | -4.7389 | 1.2900 | 42.7683 | -4.4695 | 1.3673 | 0.0444 | 0.2694 | -0.0773 | 0.2838 | -0.0773 | Z |
| | 21 | 38.2428 | -24.3285 | 5.1853 | 38.2716 | -23.9835 | 5.7489 | -0.0288 | 0.3450 | -0.5636 | 0.6614 | -0.5636 | Z |
| | 22 | 38.0740 | -18.7248 | 5.1778 | 38.0715 | -18.4396 | 5.6567 | 0.0025 | 0.2852 | -0.4789 | 0.5574 | -0.4789 | Z |
| | 23 | 37.9489 | -13.9594 | 5.1949 | 37.9352 | -13.6427 | 5.4748 | 0.0137 | 0.3167 | -0.2799 | 0.4229 | -0.2799 | Z |
| | 24 | 37.9827 | -8.7621 | 5.2277 | 37.9472 | -8.4319 | 5.3628 | 0.0355 | 0.3302 | -0.1351 | 0.3585 | -0.1351 | Z |
| | 25 | 37.4955 | -4.8234 | 0.8767 | 37.4572 | -4.6028 | 1.0074 | 0.0383 | 0.2206 | -0.1307 | 0.2593 | -0.1307 | Z |
| | 26 | 32.7568 | -23.6803 | 4.4189 | 32.7732 | -23.3752 | 4.6720 | -0.0164 | 0.3051 | -0.2531 | 0.3968 | -0.2531 | Z |
| | 27 | 32.6418 | -17.8509 | 4.4316 | 32.7048 | -17.5909 | 4.6316 | -0.0630 | 0.2600 | -0.2000 | 0.3340 | -0.2000 | Z |
| | 28 | 32.5114 | -13.0068 | 4.4577 | 32.5288 | -12.6801 | 4.5952 | -0.0174 | 0.3267 | -0.1375 | 0.3549 | -0.1375 | Z |
| | 29 | 32.5285 | -8.2196 | 4.4489 | 32.5139 | -7.8790 | 4.5174 | 0.0146 | 0.3406 | -0.0685 | 0.3477 | -0.0685 | Z |
| | 30 | 32.4292 | -4.7914 | 1.3750 | 32.3690 | -4.5925 | 1.4895 | 0.0602 | 0.1989 | -0.1145 | 0.2373 | -0.1145 | Z |

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

**Pretest Floor Pan**

**Posttest Floor Pan**

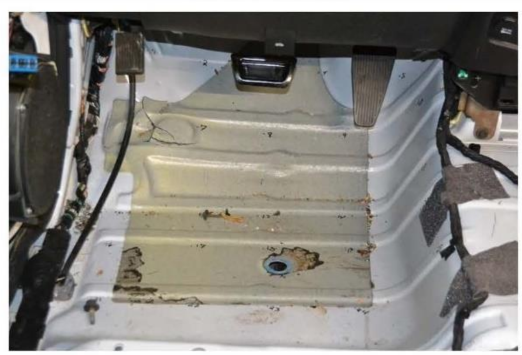


Figure F-8. Floor Pan Deformation Data – Set 1, Test No. STBRT-2

Date: 9/22/2020 Test Name: STBRT-2 VIN: 1C6RR6FT9ES238613
Model Year: 2014 Make: Dodge Model: Ram 1500 Quad Cab

**VEHICLE DEFORMATION**
**DRIVER SIDE FLOOR PAN - SET 2**

| | POINT | Pretest X (in.) | Pretest Y (in.) | Pretest Z (in.) | Posttest X (in.) | Posttest Y (in.) | Posttest Z (in.) | ΔX[A] (in.) | ΔY[A] (in.) | ΔZ[A] (in.) | Total Δ (in.) | Crush[B] (in.) | Directions for Crush[C] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOE PAN - WHEEL WELL (X, Z) | 1 | 58.9641 | -42.4677 | -6.2105 | 58.4970 | -42.3306 | -6.2802 | 0.4671 | 0.1371 | 0.0697 | 0.4918 | 0.4723 | X, Z |
| | 2 | 60.2751 | -39.0868 | -4.8700 | 59.8633 | -39.0053 | -4.9272 | 0.4118 | 0.0815 | 0.0572 | 0.4237 | 0.4158 | X, Z |
| | 3 | 60.5558 | -35.5869 | -4.5197 | 60.4113 | -35.6293 | -4.4747 | 0.1445 | -0.0424 | -0.0450 | 0.1572 | 0.1445 | X |
| | 4 | 60.0844 | -30.3099 | -4.5862 | 59.9532 | -30.2551 | -4.4413 | 0.1312 | 0.0548 | -0.1449 | 0.2030 | 0.1312 | X |
| | 5 | 57.4210 | -24.6359 | -5.7403 | 57.3625 | -24.6681 | -5.6265 | 0.0585 | -0.0322 | -0.1138 | 0.1319 | 0.0585 | X |
| | 6 | 55.4122 | -43.8651 | -1.8856 | 54.7123 | -43.4607 | -2.1000 | 0.6999 | 0.4044 | 0.2144 | 0.8363 | 0.7320 | X, Z |
| | 7 | 55.4263 | -39.0131 | -1.8230 | 55.0390 | -38.8516 | -2.0176 | 0.3873 | 0.1615 | 0.1946 | 0.4626 | 0.4334 | X, Z |
| | 8 | 55.4131 | -34.1978 | -1.7585 | 55.2422 | -34.0935 | -1.5911 | 0.1709 | 0.1043 | -0.1674 | 0.2610 | 0.1709 | X |
| | 9 | 55.5401 | -28.7407 | -1.7712 | 55.5306 | -28.6386 | -1.5989 | 0.0095 | 0.1021 | -0.1723 | 0.2005 | 0.0095 | X |
| | 10 | 54.2558 | -23.9325 | -5.0373 | 54.1858 | -23.9017 | -4.9075 | 0.0700 | 0.0308 | -0.1298 | 0.1507 | 0.0700 | X |
| FLOOR PAN (Z) | 11 | 49.1196 | -44.1130 | 1.0290 | 49.1050 | -43.9066 | 1.5964 | 0.0146 | 0.2064 | -0.5674 | 0.6040 | -0.5674 | Z |
| | 12 | 49.0227 | -38.9666 | 0.9980 | 49.0399 | -38.8564 | 1.4671 | -0.0172 | 0.1102 | -0.4691 | 0.4822 | -0.4691 | Z |
| | 13 | 49.0736 | -34.4701 | 1.0269 | 49.0699 | -34.3104 | 1.3359 | 0.0037 | 0.1597 | -0.3090 | 0.3478 | -0.3090 | Z |
| | 14 | 49.2485 | -29.2974 | 1.0590 | 49.2212 | -29.1876 | 1.2106 | 0.0273 | 0.1098 | -0.1516 | 0.1892 | -0.1516 | Z |
| | 15 | 47.6760 | -24.2771 | -3.4781 | 47.6147 | -24.2799 | -3.3634 | 0.0613 | -0.0028 | -0.1147 | 0.1301 | -0.1147 | Z |
| | 16 | 45.3677 | -44.3534 | 1.0694 | 45.3497 | -44.1724 | 1.6008 | 0.0180 | 0.1810 | -0.5314 | 0.5617 | -0.5314 | Z |
| | 17 | 45.3550 | -38.6755 | 1.0162 | 45.3575 | -38.5700 | 1.4563 | -0.0025 | 0.1055 | -0.4401 | 0.4526 | -0.4401 | Z |
| | 18 | 45.2338 | -34.0715 | 1.0534 | 45.2614 | -33.9069 | 1.3404 | -0.0276 | 0.1646 | -0.2870 | 0.3320 | -0.2870 | Z |
| | 19 | 45.3695 | -28.7195 | 1.0905 | 45.3375 | -28.5942 | 1.2211 | 0.0320 | 0.1253 | -0.1306 | 0.1838 | -0.1306 | Z |
| | 20 | 44.2984 | -24.5312 | -2.7471 | 44.2542 | -24.5020 | -2.7276 | 0.0442 | 0.0292 | -0.0195 | 0.0564 | -0.0195 | Z |
| | 21 | 39.4428 | -44.0672 | 1.0704 | 39.4756 | -43.9790 | 1.5178 | -0.0328 | 0.0882 | -0.4474 | 0.4572 | -0.4474 | Z |
| | 22 | 39.3532 | -38.4618 | 1.0816 | 39.3536 | -38.4325 | 1.4619 | -0.0004 | 0.0293 | -0.3803 | 0.3814 | -0.3803 | Z |
| | 23 | 39.2954 | -33.6951 | 1.1147 | 39.2852 | -33.6330 | 1.3113 | 0.0102 | 0.0621 | -0.1966 | 0.2064 | -0.1966 | Z |
| | 24 | 39.4025 | -28.4989 | 1.1654 | 39.3707 | -28.4222 | 1.2336 | 0.0318 | 0.0767 | -0.0682 | 0.1074 | -0.0682 | Z |
| | 25 | 38.9815 | -24.5391 | -3.1734 | 38.9424 | -24.5581 | -3.0972 | 0.0391 | -0.0190 | -0.0762 | 0.0877 | -0.0762 | Z |
| | 26 | 33.9684 | -43.3390 | 0.2932 | 33.9882 | -43.2864 | 0.4357 | -0.0198 | 0.0526 | -0.1425 | 0.1532 | -0.1425 | Z |
| | 27 | 33.9357 | -37.5086 | 0.3255 | 34.0013 | -37.5014 | 0.4333 | -0.0656 | 0.0072 | -0.1078 | 0.1264 | -0.1078 | Z |
| | 28 | 33.8737 | -32.6633 | 0.3679 | 33.8944 | -32.5885 | 0.4290 | -0.0207 | 0.0748 | -0.0611 | 0.0988 | -0.0611 | Z |
| | 29 | 33.9585 | -27.8768 | 0.3754 | 33.9473 | -27.7873 | 0.3828 | 0.0112 | 0.0895 | -0.0074 | 0.0905 | -0.0074 | Z |
| | 30 | 33.9151 | -24.4372 | -2.6870 | 33.8540 | -24.4793 | -2.6236 | 0.0611 | -0.0421 | -0.0634 | 0.0976 | -0.0634 | Z |

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

**Pretest Floor Pan**

**Posttest Floor Pan**

Figure F-9. Floor Pan Deformation Data – Set 2, Test No. STBRT-2

Model Year: 2014 | Test Name: STBRT-2 | VIN: 1C6RR6FT9ES238613
Make: Dodge | Model: Ram 1500 Quad Cab

**VEHICLE DEFORMATION**
**DRIVER SIDE INTERIOR CRUSH - SET 1**

| | POINT | Pretest X (in.) | Pretest Y (in.) | Pretest Z (in.) | Posttest X (in.) | Posttest Y (in.) | Posttest Z (in.) | ΔX[A] (in.) | ΔY[A] (in.) | ΔZ[A] (in.) | Total Δ (in.) | Crush[B] (in.) | Directions for Crush[C] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DASH (X, Y, Z) | 1 | 44.7943 | -25.5194 | -26.7423 | 44.7566 | -25.1076 | -26.6690 | 0.0377 | 0.4118 | 0.0733 | 0.4200 | 0.4200 | X, Y, Z |
| | 2 | 41.3286 | -13.8267 | -29.6817 | 41.4057 | -13.3973 | -29.6573 | -0.0771 | 0.4294 | 0.0244 | 0.4369 | 0.4369 | X, Y, Z |
| | 3 | 43.4547 | 3.5109 | -27.8708 | 43.6974 | 3.9255 | -27.9271 | -0.2427 | -0.4146 | -0.0563 | 0.4837 | 0.4837 | X, Y, Z |
| | 4 | 40.2527 | -25.0599 | -16.2534 | 40.1967 | -24.4403 | -16.1907 | 0.0560 | 0.6196 | 0.0627 | 0.6253 | 0.6253 | X, Y, Z |
| | 5 | 38.2248 | -14.2603 | -15.6618 | 38.2107 | -13.6790 | -15.6506 | 0.0141 | 0.5813 | 0.0112 | 0.5816 | 0.5816 | X, Y, Z |
| | 6 | 36.8454 | 4.4709 | -16.7907 | 37.0307 | 4.9768 | -16.8705 | -0.1853 | -0.5059 | -0.0798 | 0.5446 | 0.5446 | X, Y, Z |
| SIDE PANEL (Y) | 7 | 49.0428 | -27.7458 | -2.1969 | 48.9883 | -25.9191 | -1.9420 | 0.0545 | 1.8267 | 0.2549 | 1.8452 | 1.8267 | Y |
| | 8 | 51.7873 | -27.6273 | -0.8357 | 51.7468 | -26.4597 | -0.7131 | 0.0405 | 1.1676 | 0.1226 | 1.1747 | 1.1676 | Y |
| | 9 | 52.0463 | -27.8069 | -4.2682 | 51.9809 | -26.1790 | -4.1942 | 0.0654 | 1.6279 | 0.0740 | 1.6309 | 1.6279 | Y |
| IMPACT SIDE DOOR (Y) | 10 | 18.3548 | -30.7730 | -16.0679 | 17.7941 | -31.2478 | -16.0794 | 0.5607 | -0.4748 | -0.0115 | 0.7348 | -0.4748 | Y |
| | 11 | 29.7133 | -31.0263 | -15.7576 | 29.1180 | -30.9384 | -15.9862 | 0.5953 | 0.0879 | -0.2286 | 0.6437 | 0.0879 | Y |
| | 12 | 36.6057 | -30.1765 | -15.2744 | 36.0185 | -29.5949 | -15.6562 | 0.5872 | 0.5816 | -0.3818 | 0.9104 | 0.5816 | Y |
| | 13 | 18.2492 | -30.2937 | -2.4419 | 17.8774 | -30.4980 | -2.4253 | 0.3718 | -0.2043 | 0.0166 | 0.4246 | -0.2043 | Y |
| | 14 | 27.8184 | -31.0621 | -2.8867 | 27.4879 | -31.1784 | -3.0354 | 0.3305 | -0.1163 | -0.1487 | 0.3806 | -0.1163 | Y |
| | 15 | 35.9511 | -30.5065 | -3.1760 | 35.5356 | -30.2981 | -3.5266 | 0.4155 | 0.2084 | -0.3506 | 0.5822 | 0.2084 | Y |
| ROOF - (Z) | 16 | 26.2264 | -16.5087 | -45.1174 | 26.3488 | -16.5336 | -45.1327 | -0.1224 | -0.0249 | -0.0153 | 0.1258 | -0.0153 | Z |
| | 17 | 27.6867 | -10.1813 | -45.3916 | 27.7840 | -10.1609 | -45.4220 | -0.0973 | 0.0204 | -0.0304 | 0.1040 | -0.0304 | Z |
| | 18 | 28.4419 | -3.8030 | -45.5801 | 28.4986 | -3.8033 | -45.6292 | -0.0567 | -0.0003 | -0.0491 | 0.0750 | -0.0491 | Z |
| | 19 | 29.0228 | 2.2933 | -45.6074 | 29.1500 | 2.2701 | -45.6483 | -0.1272 | 0.0232 | -0.0409 | 0.1356 | -0.0409 | Z |
| | 20 | 28.9618 | 8.0091 | -45.5966 | 29.0644 | 8.0147 | -45.6483 | -0.1026 | -0.0056 | -0.0517 | 0.1150 | -0.0517 | Z |
| | 21 | 20.1432 | -15.8230 | -45.9652 | 20.1495 | -15.8111 | -45.9907 | -0.0063 | 0.0119 | -0.0255 | 0.0288 | -0.0255 | Z |
| | 22 | 21.4378 | -9.0336 | -46.2363 | 21.5253 | -9.0940 | -46.2666 | -0.0875 | -0.0604 | -0.0303 | 0.1106 | -0.0303 | Z |
| | 23 | 22.0233 | -3.5251 | -46.4764 | 22.1467 | -3.5425 | -46.5233 | -0.1234 | -0.0174 | -0.0469 | 0.1332 | -0.0469 | Z |
| | 24 | 22.5354 | 2.0963 | -46.5381 | 22.6405 | 2.0355 | -46.5984 | -0.1051 | 0.0608 | -0.0603 | 0.1356 | -0.0603 | Z |
| | 25 | 22.8890 | 7.5532 | -46.4953 | 23.0024 | 7.5562 | -46.5640 | -0.1134 | -0.0030 | -0.0687 | 0.1326 | -0.0687 | Z |
| | 26 | 12.4536 | -15.7544 | -46.3695 | 12.6078 | -15.7497 | -46.3900 | -0.1542 | 0.0047 | -0.0205 | 0.1556 | -0.0205 | Z |
| | 27 | 12.4747 | -9.5681 | -46.7381 | 12.5712 | -9.6243 | -46.7738 | -0.0965 | -0.0562 | -0.0357 | 0.1172 | -0.0357 | Z |
| | 28 | 12.8898 | -2.4109 | -46.9103 | 13.0438 | -2.4360 | -46.9658 | -0.1540 | -0.0251 | -0.0555 | 0.1656 | -0.0555 | Z |
| | 29 | 13.4204 | 1.9233 | -47.0321 | 13.5699 | 1.8644 | -47.0982 | -0.1495 | 0.0589 | -0.0661 | 0.1737 | -0.0661 | Z |
| | 30 | 13.3879 | 7.7196 | -47.0226 | 13.5809 | 7.7359 | -47.1053 | -0.1930 | -0.0163 | -0.0827 | 0.2106 | -0.0827 | Z |
| A-PILLAR Maximum (X, Y, Z) | 31 | 47.0777 | -26.0110 | -29.8539 | 47.2151 | -25.8424 | -29.8127 | -0.1374 | 0.1686 | 0.0412 | 0.2214 | 0.1736 | Y, Z |
| | 32 | 43.1356 | -24.9353 | -32.6026 | 43.2849 | -24.8172 | -32.5769 | -0.1493 | 0.1181 | 0.0257 | 0.1921 | 0.1209 | Y, Z |
| | 33 | 39.7963 | -24.2260 | -34.9352 | 39.9735 | -24.1652 | -34.9723 | -0.1772 | 0.0608 | -0.0371 | 0.1910 | 0.0608 | Y |
| | 34 | 36.6738 | -23.5748 | -37.0020 | 36.8205 | -23.4891 | -37.0295 | -0.1467 | 0.0857 | -0.0275 | 0.1721 | 0.0857 | Y |
| | 35 | 33.0305 | -23.0957 | -39.1498 | 33.2713 | -23.0619 | -39.1620 | -0.2408 | 0.0338 | -0.0122 | 0.2435 | 0.0338 | Y |
| | 36 | 30.2982 | -21.7922 | -41.4069 | 30.4750 | -21.7752 | -41.4196 | -0.1768 | 0.0170 | -0.0127 | 0.1781 | 0.0170 | Y |
| A-PILLAR Lateral (Y) | 31 | 47.0777 | -26.0110 | -29.8539 | 47.2151 | -25.8424 | -29.8127 | -0.1374 | 0.1686 | 0.0412 | 0.2214 | 0.1686 | Y |
| | 32 | 43.1356 | -24.9353 | -32.6026 | 43.2849 | -24.8172 | -32.5769 | -0.1493 | 0.1181 | 0.0257 | 0.1921 | 0.1181 | Y |
| | 33 | 39.7963 | -24.2260 | -34.9352 | 39.9735 | -24.1652 | -34.9723 | -0.1772 | 0.0608 | -0.0371 | 0.1910 | 0.0608 | Y |
| | 34 | 36.6738 | -23.5748 | -37.0020 | 36.8205 | -23.4891 | -37.0295 | -0.1467 | 0.0857 | -0.0275 | 0.1721 | 0.0857 | Y |
| | 35 | 33.0305 | -23.0957 | -39.1498 | 33.2713 | -23.0619 | -39.1620 | -0.2408 | 0.0338 | -0.0122 | 0.2435 | 0.0338 | Y |
| | 36 | 30.2982 | -21.7922 | -41.4069 | 30.4750 | -21.7752 | -41.4196 | -0.1768 | 0.0170 | -0.0127 | 0.1781 | 0.0170 | Y |
| B-PILLAR Maximum (X, Y, Z) | 37 | 4.3937 | -23.0996 | -40.8050 | 4.4786 | -23.0585 | -40.7198 | -0.0849 | 0.0411 | 0.0852 | 0.1271 | 0.0946 | Y, Z |
| | 38 | 8.1045 | -25.8486 | -33.2139 | 8.0748 | -25.7656 | -33.1533 | 0.0297 | 0.0830 | 0.0606 | 0.1070 | 0.1070 | X, Y, Z |
| | 39 | 5.2701 | -27.0596 | -28.9675 | 5.3259 | -26.9247 | -28.9175 | -0.0558 | 0.1349 | 0.0500 | 0.1543 | 0.1439 | Y, Z |
| | 40 | 8.9739 | -27.5905 | -23.9149 | 9.0370 | -27.4627 | -23.8506 | -0.0631 | 0.1278 | 0.0643 | 0.1564 | 0.1431 | Y, Z |
| B-PILLAR Lateral (Y) | 37 | 4.3937 | -23.0996 | -40.8050 | 4.4786 | -23.0585 | -40.7198 | -0.0849 | 0.0411 | 0.0852 | 0.1271 | 0.0411 | Y |
| | 38 | 8.1045 | -25.8486 | -33.2139 | 8.0748 | -25.7656 | -33.1533 | 0.0297 | 0.0830 | 0.0606 | 0.1070 | 0.0830 | Y |
| | 39 | 5.2701 | -27.0596 | -28.9675 | 5.3259 | -26.9247 | -28.9175 | -0.0558 | 0.1349 | 0.0500 | 0.1543 | 0.1349 | Y |
| | 40 | 8.9739 | -27.5905 | -23.9149 | 9.0370 | -27.4627 | -23.8506 | -0.0631 | 0.1278 | 0.0643 | 0.1564 | 0.1278 | Y |

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Figure F-10. Interior Crush Deformation Data – Set 1, Test No. STBRT-2

Model Year: 2014 | Test Name: STBRT-2 | VIN: 1C6RR6FT9ES238613
Make: Dodge | Model: Ram 1500 Quad Cab

**VEHICLE DEFORMATION**
**DRIVER SIDE INTERIOR CRUSH - SET 2**

| | POINT | Pretest X (in.) | Pretest Y (in.) | Pretest Z (in.) | Posttest X (in.) | Posttest Y (in.) | Posttest Z (in.) | ΔX[A] (in.) | ΔY[A] (in.) | ΔZ[A] (in.) | Total Δ (in.) | Crush[B] (in.) | Directions for Crush[C] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DASH (X, Y, Z) | 1 | 46.0656 | -45.2535 | -30.8309 | 46.0427 | -44.9479 | -30.8798 | 0.0229 | 0.3056 | -0.0489 | 0.3103 | 0.3103 | X, Y, Z |
| | 2 | 42.7727 | -33.5047 | -33.7450 | 42.8602 | -33.1726 | -33.7957 | -0.0875 | 0.3321 | -0.0507 | 0.3472 | 0.3472 | X, Y, Z |
| | 3 | 45.1376 | -16.2041 | -31.8775 | 45.3819 | -15.8949 | -31.9378 | -0.2443 | 0.3092 | -0.0603 | 0.3987 | 0.3987 | X, Y, Z |
| | 4 | 41.5026 | -44.7607 | -20.3529 | 41.4613 | -44.2915 | -20.4103 | 0.0413 | 0.4692 | -0.0574 | 0.4745 | 0.4745 | X, Y, Z |
| | 5 | 39.6253 | -33.9353 | -19.7348 | 39.6201 | -33.5082 | -19.8006 | 0.0052 | 0.4271 | -0.0658 | 0.4322 | 0.4322 | X, Y, Z |
| | 6 | 38.5126 | -15.1834 | -20.8122 | 38.6973 | -14.8300 | -20.8932 | -0.1847 | 0.3534 | -0.0810 | 0.4069 | 0.4069 | X, Y, Z |
| SIDE PANEL (Y) | 7 | 50.2161 | -47.6109 | -6.2810 | 50.1895 | -45.9889 | -6.1471 | 0.0266 | 1.6220 | 0.1339 | 1.6277 | 1.6220 | Y |
| | 8 | 52.9584 | -47.5349 | -4.9122 | 52.9368 | -46.5756 | -4.9140 | 0.0216 | 0.9593 | -0.0018 | 0.9595 | 0.9593 | Y |
| | 9 | 53.2241 | -47.7082 | -8.3445 | 53.1850 | -46.2739 | -8.3924 | 0.0391 | 1.4343 | -0.0479 | 1.4356 | 1.4343 | Y |
| IMPACT SIDE DOOR (Y) | 10 | 19.5261 | -50.1655 | -20.2423 | 18.9680 | -50.7941 | -20.4112 | 0.5581 | -0.6286 | -0.1689 | 0.8574 | -0.6286 | Y |
| | 11 | 30.8791 | -50.5796 | -19.9026 | 30.2946 | -50.6395 | -20.2831 | 0.5845 | -0.0599 | -0.3805 | 0.7000 | -0.0599 | Y |
| | 12 | 37.7815 | -49.8282 | -19.3986 | 37.2118 | -49.3923 | -19.9239 | 0.5697 | 0.4359 | -0.5253 | 0.8891 | 0.4359 | Y |
| | 13 | 19.3905 | -49.7244 | -6.6153 | 19.0208 | -50.1405 | -6.7519 | 0.3697 | -0.4161 | -0.1366 | 0.5731 | -0.4161 | Y |
| | 14 | 28.9492 | -50.6261 | -7.0369 | 28.6229 | -50.9475 | -7.3391 | 0.3263 | -0.3214 | -0.3022 | 0.5487 | -0.3214 | Y |
| | 15 | 37.0896 | -50.1842 | -7.3029 | 36.6834 | -50.1733 | -7.8010 | 0.4062 | 0.0109 | -0.4981 | 0.6428 | 0.0109 | Y |
| ROOF - (Z) | 16 | 27.6759 | -35.9290 | -49.2287 | 27.8081 | -35.9959 | -49.3360 | -0.1322 | -0.0669 | -0.1073 | 0.1829 | -0.1073 | Z |
| | 17 | 29.2259 | -29.6220 | -49.4803 | 29.3307 | -29.6415 | -49.5765 | -0.1048 | -0.0195 | -0.0962 | 0.1436 | -0.0962 | Z |
| | 18 | 30.0712 | -23.2545 | -49.6481 | 30.1322 | -23.2928 | -49.7371 | -0.0610 | -0.0383 | -0.0890 | 0.1145 | -0.0890 | Z |
| | 19 | 30.7379 | -17.1669 | -49.6559 | 30.8661 | -17.2289 | -49.7119 | -0.1282 | -0.0620 | -0.0560 | 0.1530 | -0.0560 | Z |
| | 20 | 30.7572 | -11.4508 | -49.6284 | 30.8586 | -11.4837 | -49.6719 | -0.1014 | -0.0329 | -0.0435 | 0.1151 | -0.0435 | Z |
| | 21 | 21.6053 | -35.1553 | -50.0907 | 21.6218 | -35.1831 | -50.2068 | -0.0165 | -0.0278 | -0.1161 | 0.1205 | -0.1161 | Z |
| | 22 | 22.9960 | -28.3841 | -50.3383 | 23.0895 | -28.4836 | -50.4317 | -0.0935 | -0.0995 | -0.0934 | 0.1654 | -0.0934 | Z |
| | 23 | 23.6596 | -22.8836 | -50.5607 | 23.7872 | -22.9394 | -50.6477 | -0.1276 | -0.0558 | -0.0870 | 0.1642 | -0.0870 | Z |
| | 24 | 24.2509 | -17.2699 | -50.6044 | 24.3568 | -17.3682 | -50.6823 | -0.1059 | -0.0983 | -0.0779 | 0.1642 | -0.0779 | Z |
| | 25 | 24.6811 | -11.8186 | -50.5446 | 24.7936 | -11.8534 | -50.6083 | -0.1125 | -0.0348 | -0.0637 | 0.1339 | -0.0637 | Z |
| | 26 | 13.9186 | -34.9774 | -50.5151 | 14.0829 | -35.0162 | -50.6274 | -0.1643 | -0.0388 | -0.1123 | 0.2028 | -0.1123 | Z |
| | 27 | 14.0277 | -28.7909 | -50.8655 | 14.1306 | -28.8884 | -50.9684 | -0.1029 | -0.0975 | -0.1029 | 0.1752 | -0.1029 | Z |
| | 28 | 14.5438 | -21.6398 | -51.0155 | 14.7014 | -21.7061 | -51.1087 | -0.1576 | -0.0663 | -0.0932 | 0.1947 | -0.0932 | Z |
| | 29 | 15.1358 | -17.3132 | -51.1232 | 15.2863 | -17.4124 | -51.2094 | -0.1505 | -0.0992 | -0.0862 | 0.1998 | -0.0862 | Z |
| | 30 | 15.1847 | -11.5171 | -51.0966 | 15.3771 | -11.5417 | -51.1754 | -0.1924 | -0.0246 | -0.0788 | 0.2094 | -0.0788 | Z |
| A-PILLAR Maximum (X, Y, Z) | 31 | 48.3503 | -45.7681 | -33.9379 | 48.5004 | -45.6941 | -34.0215 | -0.1501 | 0.0740 | -0.0836 | 0.1871 | 0.0740 | Y |
| | 32 | 44.4311 | -44.6291 | -36.6938 | 44.5927 | -44.5963 | -36.7898 | -0.1616 | 0.0328 | -0.0960 | 0.1908 | 0.0328 | Y |
| | 33 | 41.1084 | -43.8661 | -39.0332 | 41.2976 | -43.8827 | -39.1901 | -0.1892 | -0.0166 | -0.1569 | 0.2464 | 0.0000 | NA |
| | 34 | 38.0010 | -43.1650 | -41.1064 | 38.1602 | -43.1494 | -41.2516 | -0.1592 | 0.0156 | -0.1452 | 0.2160 | 0.0156 | Y |
| | 35 | 34.3706 | -42.6285 | -43.2625 | 34.6235 | -42.6591 | -43.3912 | -0.2529 | -0.0306 | -0.1287 | 0.2854 | 0.0000 | NA |
| | 36 | 31.6631 | -41.2800 | -45.5229 | 31.8517 | -41.3188 | -45.6478 | -0.1886 | -0.0388 | -0.1249 | 0.2295 | 0.0000 | NA |
| A-PILLAR Lateral (Y) | 31 | 48.3503 | -45.7681 | -33.9379 | 48.5004 | -45.6941 | -34.0215 | -0.1501 | 0.0740 | -0.0836 | 0.1871 | 0.0740 | Y |
| | 32 | 44.4311 | -44.6291 | -36.6938 | 44.5927 | -44.5963 | -36.7898 | -0.1616 | 0.0328 | -0.0960 | 0.1908 | 0.0328 | Y |
| | 33 | 41.1084 | -43.8661 | -39.0332 | 41.2976 | -43.8827 | -39.1901 | -0.1892 | -0.0166 | -0.1569 | 0.2464 | -0.0166 | Y |
| | 34 | 38.0010 | -43.1650 | -41.1064 | 38.1602 | -43.1494 | -41.2516 | -0.1592 | 0.0156 | -0.1452 | 0.2160 | 0.0156 | Y |
| | 35 | 34.3706 | -42.6285 | -43.2625 | 34.6235 | -42.6591 | -43.3912 | -0.2529 | -0.0306 | -0.1287 | 0.2854 | -0.0306 | Y |
| | 36 | 31.6631 | -41.2800 | -45.5229 | 31.8517 | -41.3188 | -45.6478 | -0.1886 | -0.0388 | -0.1249 | 0.2295 | -0.0388 | Y |
| B-PILLAR Maximum (X, Y, Z) | 37 | 5.7412 | -42.2245 | -44.9938 | 5.8382 | -42.2531 | -45.0319 | -0.0970 | -0.0286 | -0.0381 | 0.1081 | 0.0000 | NA |
| | 38 | 9.3925 | -45.0475 | -37.4009 | 9.3749 | -45.0614 | -37.4741 | 0.0176 | -0.0139 | -0.0732 | 0.0766 | 0.0176 | X |
| | 39 | 6.5299 | -46.2308 | -33.1657 | 6.5979 | -46.2124 | -33.2545 | -0.0680 | 0.0184 | -0.0888 | 0.1133 | 0.0184 | Y |
| | 40 | 10.2121 | -46.8285 | -28.1048 | 10.2863 | -46.8361 | -28.1808 | -0.0742 | -0.0076 | -0.0760 | 0.1065 | 0.0000 | NA |
| B-PILLAR Lateral (Y) | 37 | 5.7412 | -42.2245 | -44.9938 | 5.8382 | -42.2531 | -45.0319 | -0.0970 | -0.0286 | -0.0381 | 0.1081 | -0.0286 | Y |
| | 38 | 9.3925 | -45.0475 | -37.4009 | 9.3749 | -45.0614 | -37.4741 | 0.0176 | -0.0139 | -0.0732 | 0.0766 | -0.0139 | Y |
| | 39 | 6.5299 | -46.2308 | -33.1657 | 6.5979 | -46.2124 | -33.2545 | -0.0680 | 0.0184 | -0.0888 | 0.1133 | 0.0184 | Y |
| | 40 | 10.2121 | -46.8285 | -28.1048 | 10.2863 | -46.8361 | -28.1808 | -0.0742 | -0.0076 | -0.0760 | 0.1065 | -0.0076 | Y |

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Figure F-11. Interior Crush Deformation Data – Set 2, Test No. STBRT-2

| Date: | 9/22/2020 | Test Name: | STBRT-2 | VIN: | 1C6RR6FT9ES238613 |
|---|---|---|---|---|---|
| Model Year: | 2014 | Make: | Dodge | Model: | Ram 1500 Quad Cab |

**Driver Side Maximum Deformation**

| Reference Set 1 | | | | Reference Set 2 | | | |
|---|---|---|---|---|---|---|---|
| Location | Maximum Deformation[A,B] (in.) | MASH Allowable Deformation (in.) | Directions of Deformation[C] | Location | Maximum Deformation[A,B] (in.) | MASH Allowable Deformation (in.) | Directions of Deformation[C] |
| Roof | -0.1 | ≤ 4 | Z | Roof | -0.1 | ≤ 4 | Z |
| Windshield[D] | 0.0 | ≤ 3 | X, Z | Windshield[D] | NA | ≤ 3 | X, Z |
| A-Pillar Maximum | 0.2 | ≤ 5 | Y, Z | A-Pillar Maximum | 0.1 | ≤ 5 | Y |
| A-Pillar Lateral | 0.2 | ≤ 3 | Y | A-Pillar Lateral | 0.1 | ≤ 3 | Y |
| B-Pillar Maximum | 0.1 | ≤ 5 | Y, Z | B-Pillar Maximum | 0.0 | ≤ 5 | Y |
| B-Pillar Lateral | 0.2 | ≤ 3 | Y | B-Pillar Lateral | 0.0 | ≤ 3 | Y |
| Toe Pan - Wheel Well | 0.7 | ≤ 9 | X, Z | Toe Pan - Wheel Well | 0.7 | ≤ 9 | X, Z |
| Side Front Panel | 1.8 | ≤ 12 | Y | Side Front Panel | 1.6 | ≤ 12 | Y |
| Side Door (above seat) | 0.6 | ≤ 9 | Y | Side Door (above seat) | 0.4 | ≤ 9 | Y |
| Side Door (below seat) | 0.2 | ≤ 12 | Y | Side Door (below seat) | 0.0 | ≤ 12 | Y |
| Floor Pan | -0.7 | ≤ 12 | Z | Floor Pan | -0.6 | ≤ 12 | Z |
| Dash - no MASH requirement | 0.6 | NA | X, Y, Z | Dash - no MASH requirement | 0.6 | NA | X, Y, Z |

[A] Items highlighted in red do not meet MASH allowable deformations.

[B] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

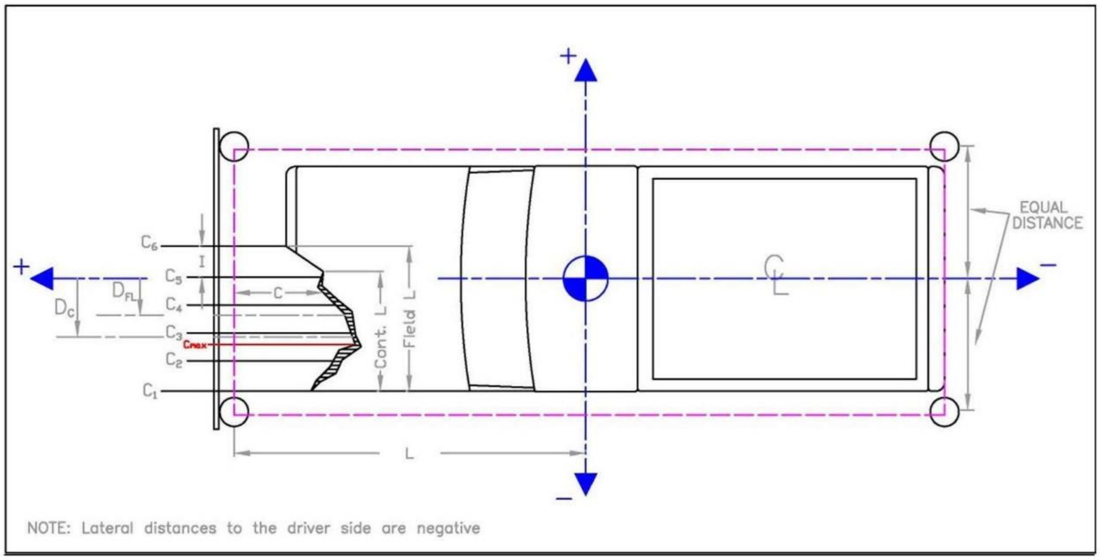
[C] For Toe Pan - Wheel Well the direction of defromation may include X and Z direction. For A-Pillar Maximum and B-Pillar Maximum the direction of deformation may include X, Y, and Z directions. The direction of deformation for Toe Pan -Wheel Well, A-Pillar Maximum, and B-Pillar Maximum only include components where the deformation is positive and intruding into the occupant compartment. If direction of deformation is "NA" then no intrusion is recorded and deformation will be 0.

[D] If deformation is observered for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

**Notes on vehicle interior crush:**

Figure F-12. Max. Occupant Compartment Deformations by Location, Test No. STBRT-2

| Date Measured: | 9/30/2020 | Test Name: | STBRT-2 | VIN: | 1C6RR6FT9ES238613 |
|---|---|---|---|---|---|
| Model Year: | 2014 | Make: | Dodge | Model: | Ram 1500 Quad Cab |




| | in. | (mm) |
|---|---|---|
| Distance from C.G. to reference line - $L_{REF}$: | 109 5/8 | (2784) |
| Total Vehicle Width: | 76 3/4 | (1949) |
| Width of contact and induced crush - Field L: | 36 3/8 | (924) |
| Crush measurement spacing interval (L/5) - I: | 7 1/4 | (184) |
| Distance from center of vehicle to center of Field L - $D_{FL}$: | 21 1/5 | (538) |
| Width of Contact Damage: | 23 7/8 | (606) |
| Distance from center of vehicle to center of contact damage - $D_C$: | 26 4/9 | (672) |

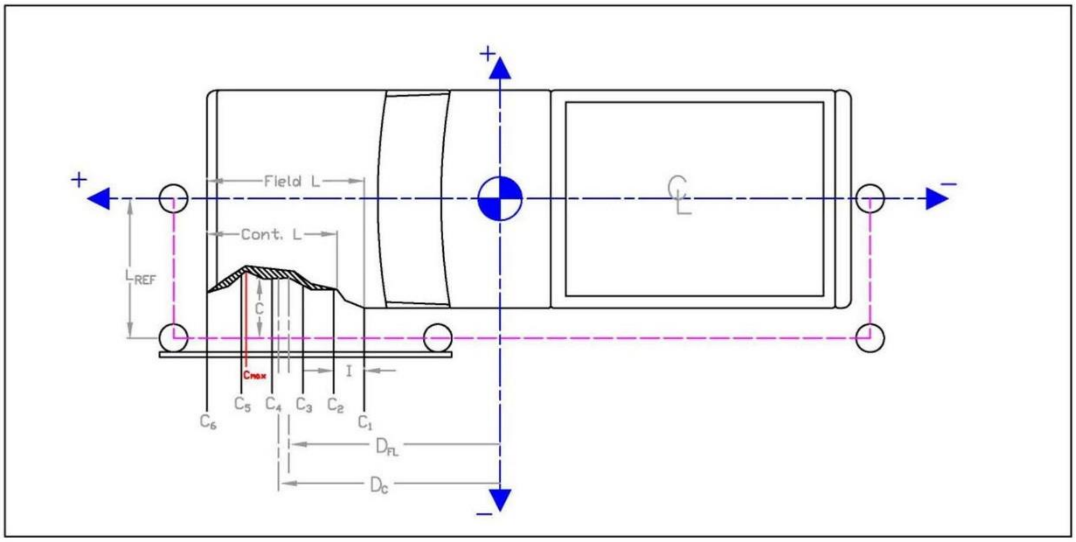
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

| | Crush Measurement | | Lateral Location | | Original Profile Measurement | | Dist. Between Ref. Lines | | Actual Crush | |
|---|---|---|---|---|---|---|---|---|---|---|
| | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) |
| $C_1$ | 7 1/2 | (191) | 3 | (76) | 4 | (102) | 4 5/8 | (117) | -1 1/8 | -(29) |
| $C_2$ | 9 3/4 | (248) | 10 1/4 | (260) | 4 3/8 | (111) | | | 3/4 | (19) |
| $C_3$ | 18 1/2 | (470) | 17 1/2 | (445) | 5 1/4 | (133) | | | 8 5/8 | (219) |
| $C_4$ | NA | N/A | 24 3/4 | (629) | 6 5/8 | (168) | | | N/A | N/A |
| $C_5$ | NA | N/A | 32 | (813) | 10 7/8 | (276) | | | N/A | N/A |
| $C_6$ | NA | N/A | 39 1/4 | (997) | 20 1/2 | (521) | | | N/A | N/A |
| $C_{MAX}$ | 30 1/2 | (775) | 24 | (610) | 6 3/8 | (162) | | | 19 1/2 | (495) |

Figure F-13. Exterior Vehicle Crush (NASS) - Front, Test No. STBRT-2

**Date Measured:** 9/30/2020 **Test Name:** STBRT-2 **VIN:** 1C6RR6FT9ES238613

**Model Year:** 2014 **Make:** Dodge **Model:** Ram 1500 Quad Cab




| | in. | (mm) |
|---|---|---|
| Distance from centerline to reference line - $L_{REF}$: | 46 | (1168) |
| Total Vehicle Length: | 229 1/4 | (5823) |
| Distance from vehicle c.g. to 1/2 of Vehicle total length: | -5 1/4 | -(133) |
| Width of contact and induced crush - Field L: | 229 1/4 | (5823) |
| Crush measurement spacing interval (L/5) - I: | 45 7/8 | (1165) |
| Distance from vehicle c.g. to center of Field L - $D_{FL}$: | -13 1/4 | -(337) |
| Width of Contact Damage: | 229 1/4 | (5823) |
| Distance from vehicle c.g. to center of contact damage - $D_C$: | -13 1/4 | -(337) |

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been removed)
NOTE: All values must be filled out above before crush measurements are filled out.

| | Crush Measurement | | Longitudinal Location | | Original Profile Measurement | | Dist. Between Ref. Lines | | Actual | Crush |
|---|---|---|---|---|---|---|---|---|---|---|
| | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) | in. | (mm) |
| $C_1$ | 14 1/4 | (362) | -127 7/8 | -(3248) | 33 1/2 | (851) | 2 | (51) | -21 1/4 | -(540) |
| $C_2$ | NA | N/A | -82 | -(2083) | 5 1/2 | (140) | | | N/A | N/A |
| $C_3$ | 7 5/8 | (194) | -36 1/8 | -(918) | 5 3/4 | (146) | | | - 1/8 | -(3) |
| $C_4$ | 7 3/8 | (187) | 9 3/4 | (248) | 5 | (127) | | | 3/8 | (10) |
| $C_5$ | NA | N/A | 55 5/8 | (1413) | 5 3/4 | (146) | | | N/A | N/A |
| $C_6$ | NA | N/A | 101 1/2 | (2578) | 10 1/8 | (257) | | | N/A | N/A |
| $C_{MAX}$ | 28 3/8 | (721) | 94 | (2388) | 6 1/2 | (165) | | | 19 7/8 | (505) |

Figure F-14. Exterior Vehicle Crush (NASS) - Side, Test No. STBRT-2

# Appendix G. Accelerometer and Rate Transducer Data Plots, Test No. STBRT-1

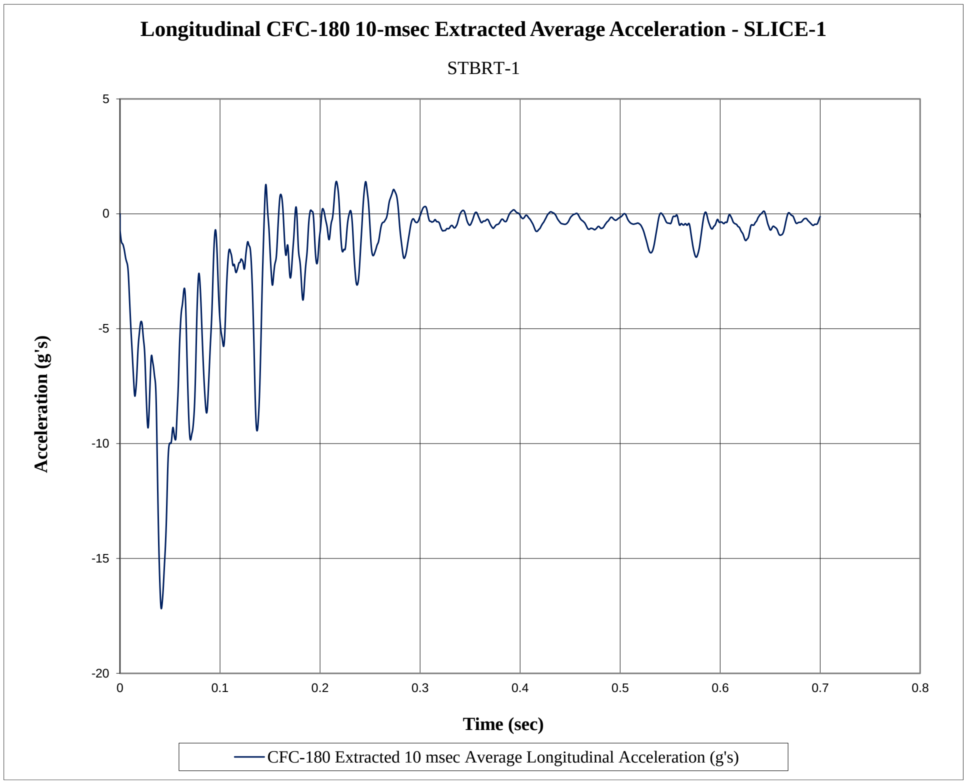



Figure G-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. STBRT-1

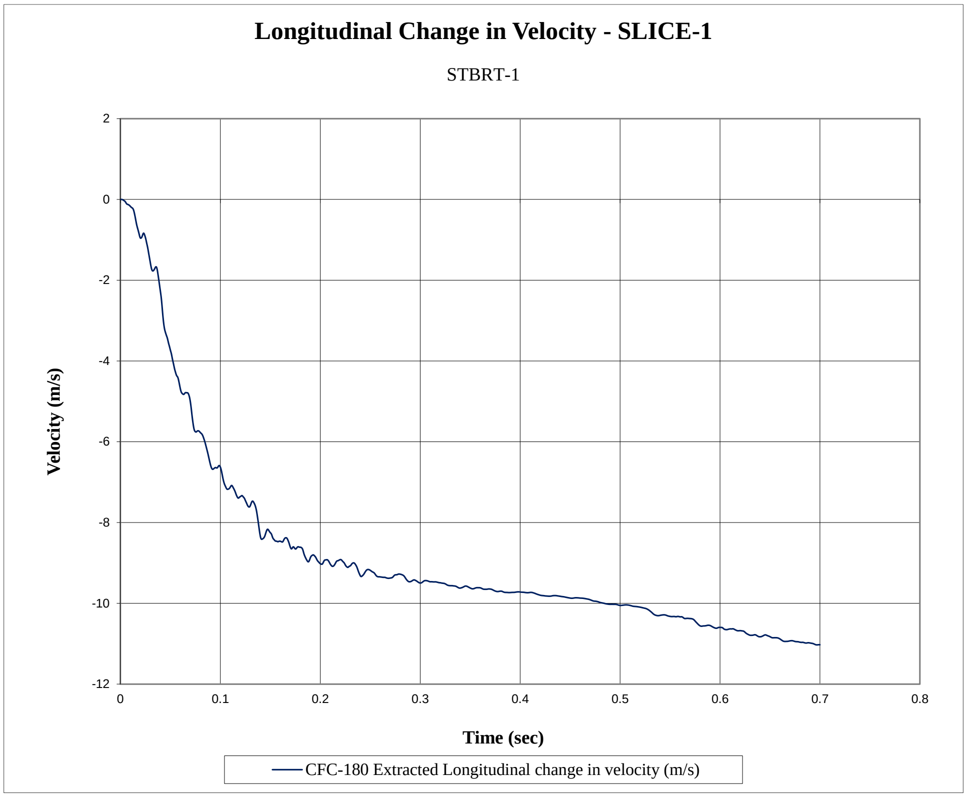



Figure G-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. STBRT-1

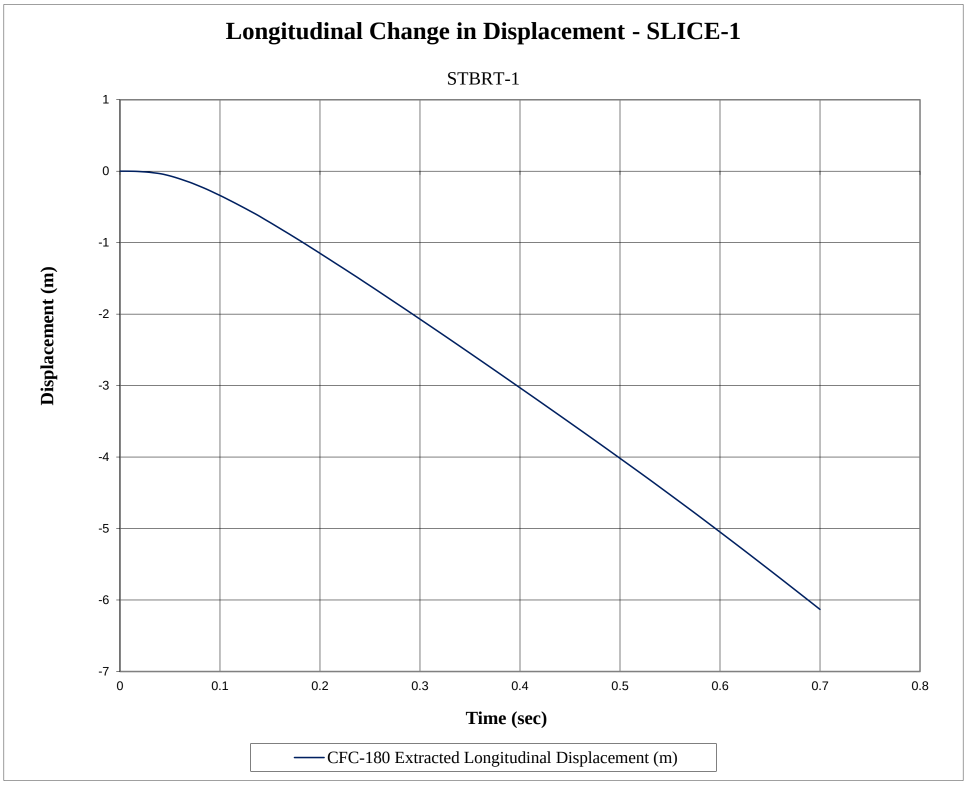



Figure G-3. Longitudinal Occupant Displacement (SLICE-1), Test No. STBRT-1

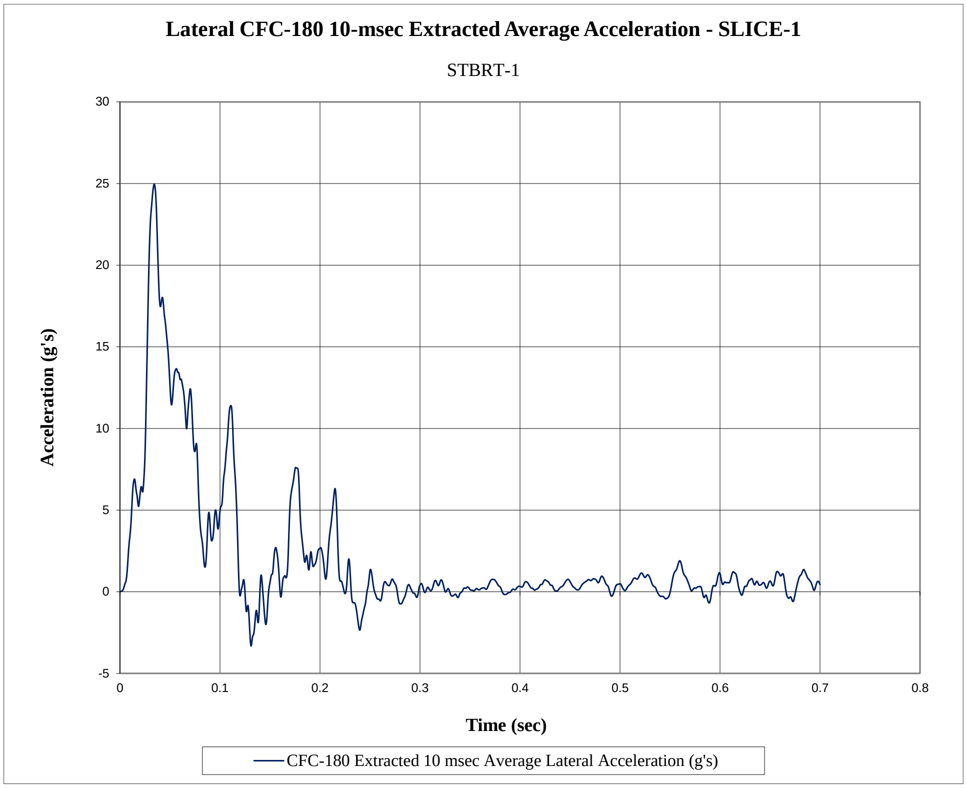



Figure G-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. STBRT-1

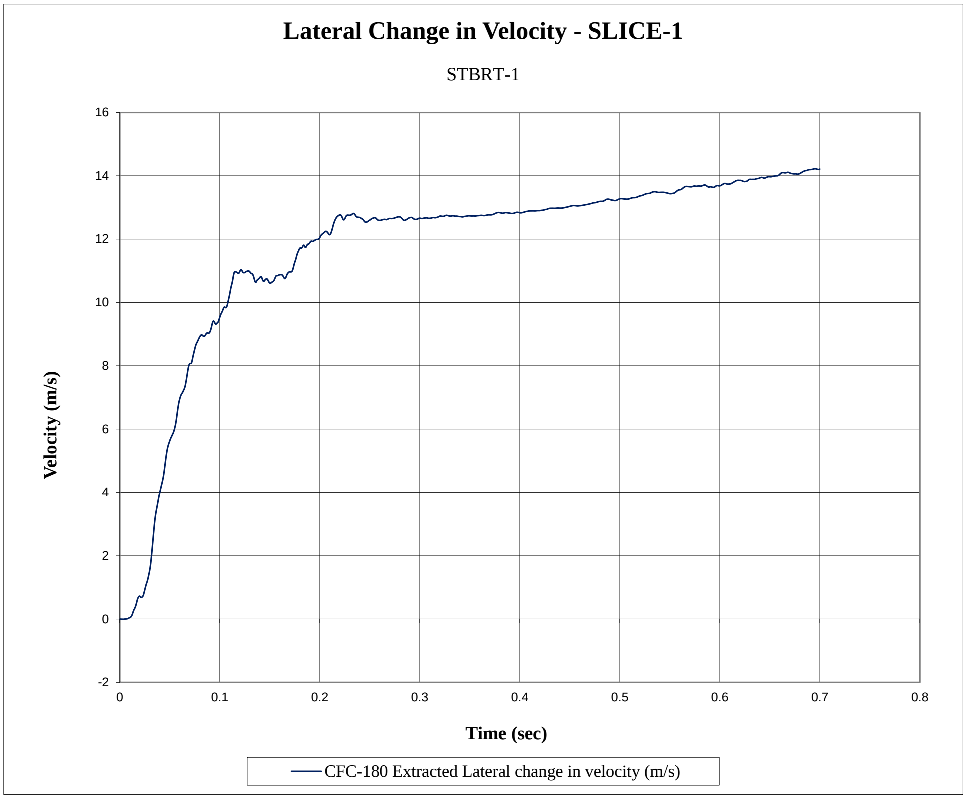



Figure G-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. STBRT-1


Figure G-6. Lateral Occupant Displacement (SLICE-1), Test No. STBRT-1

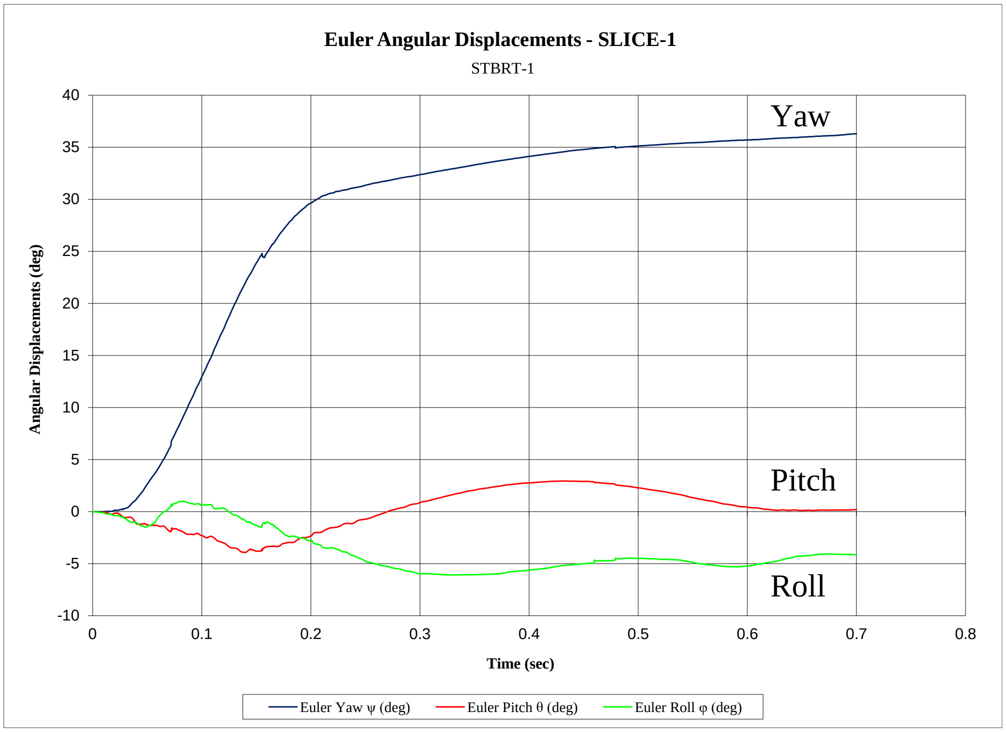



Figure G-7. Vehicle Angular Displacements (SLICE-1), Test No. STBRT-1

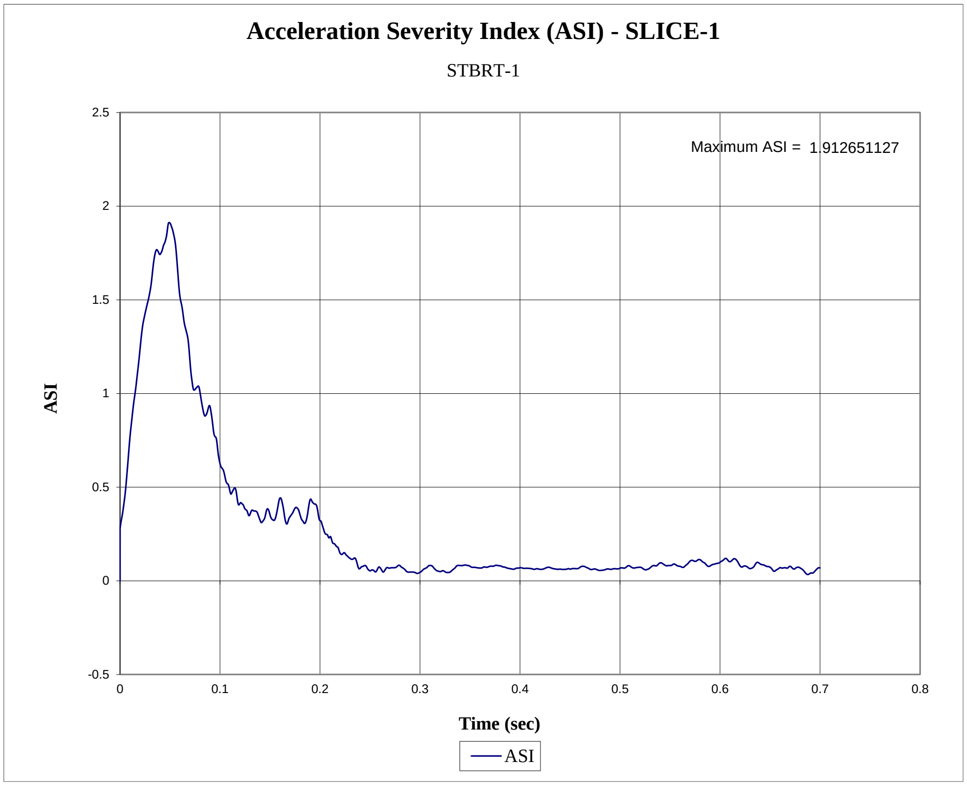



Figure G-8. Acceleration Severity Index (SLICE-1), Test No. STBRT-1

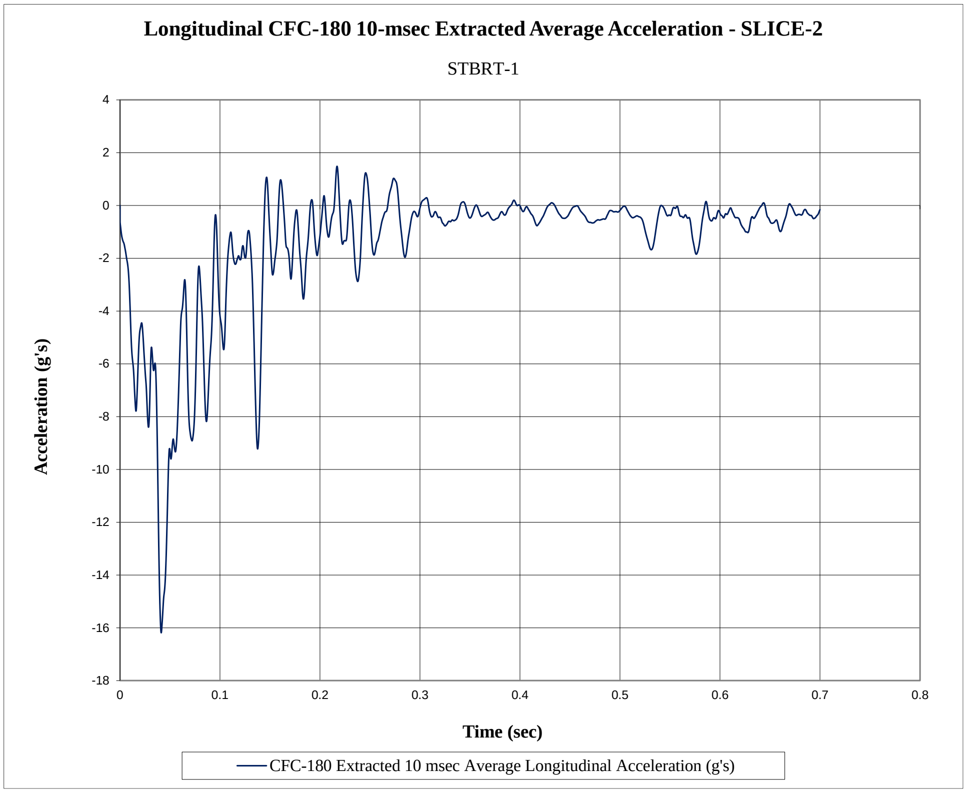



Figure G-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. STBRT-1

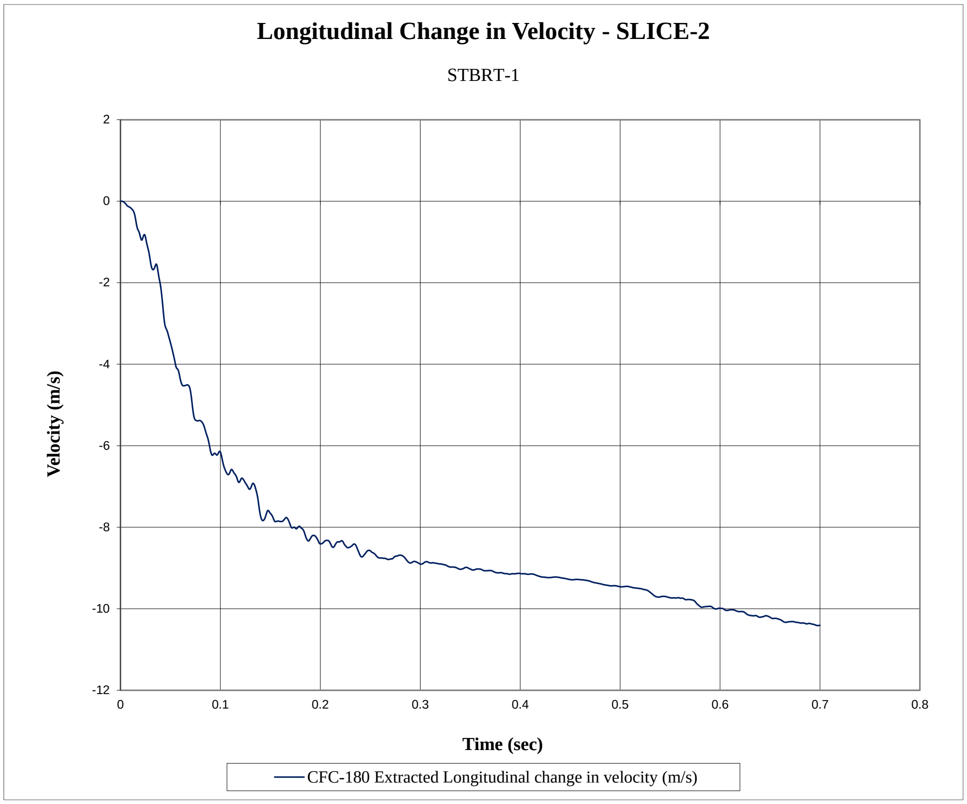



Figure G-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. STBRT-1

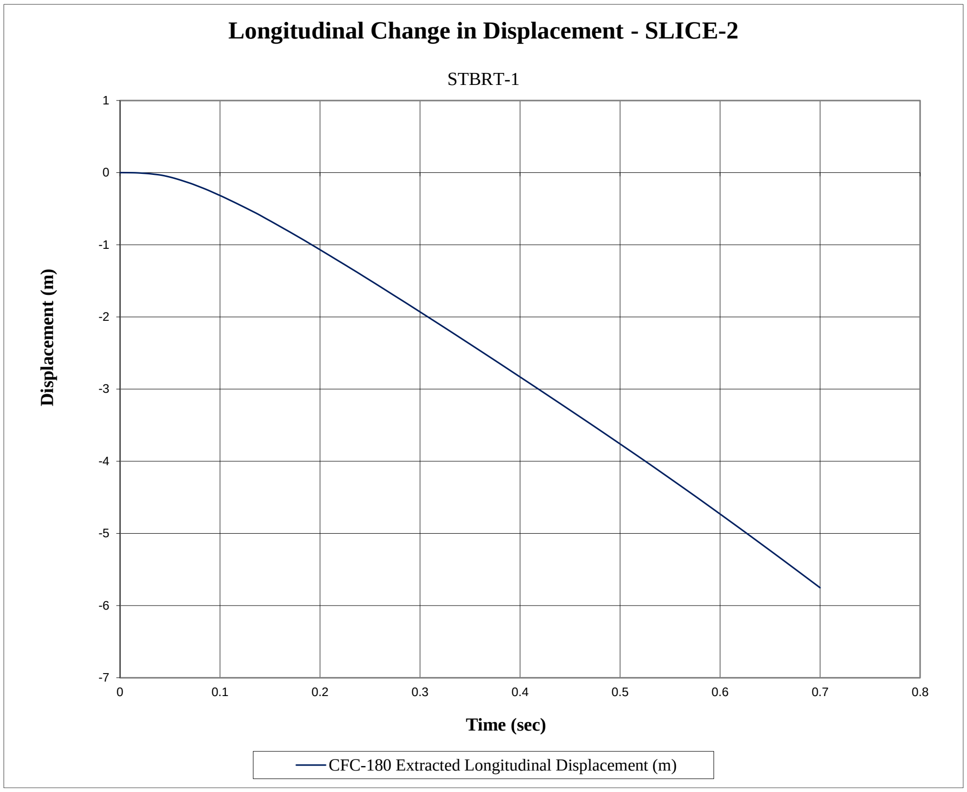



Figure G-11. Longitudinal Occupant Displacement (SLICE-2), Test No. STBRT-1

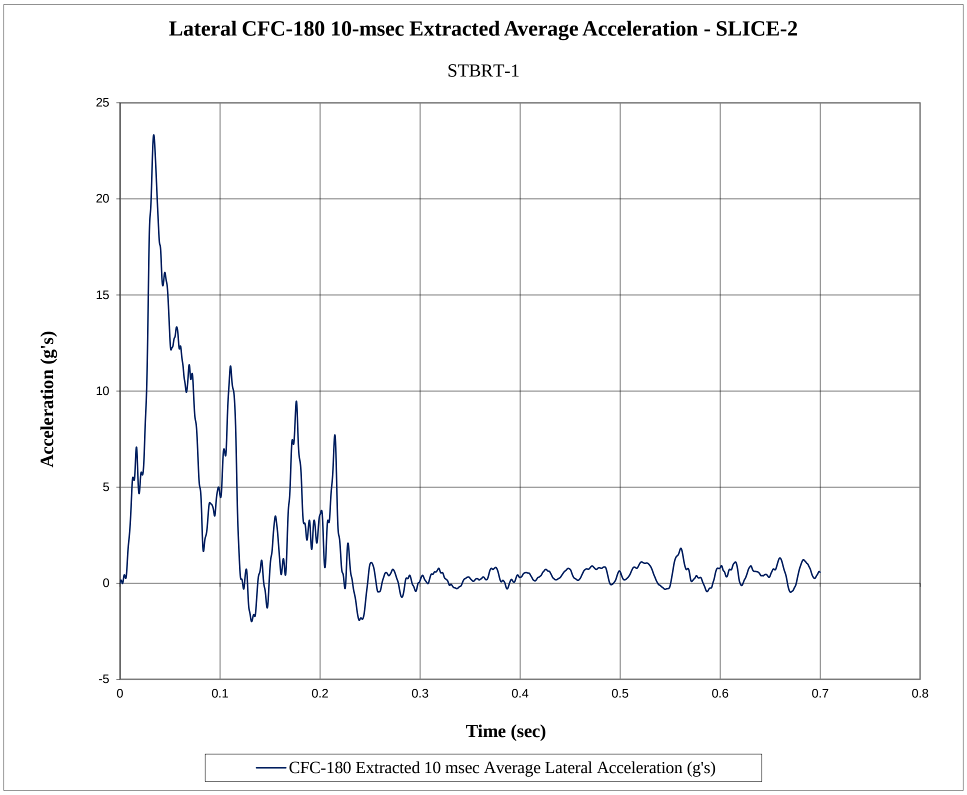



Figure G-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. STBRT-1

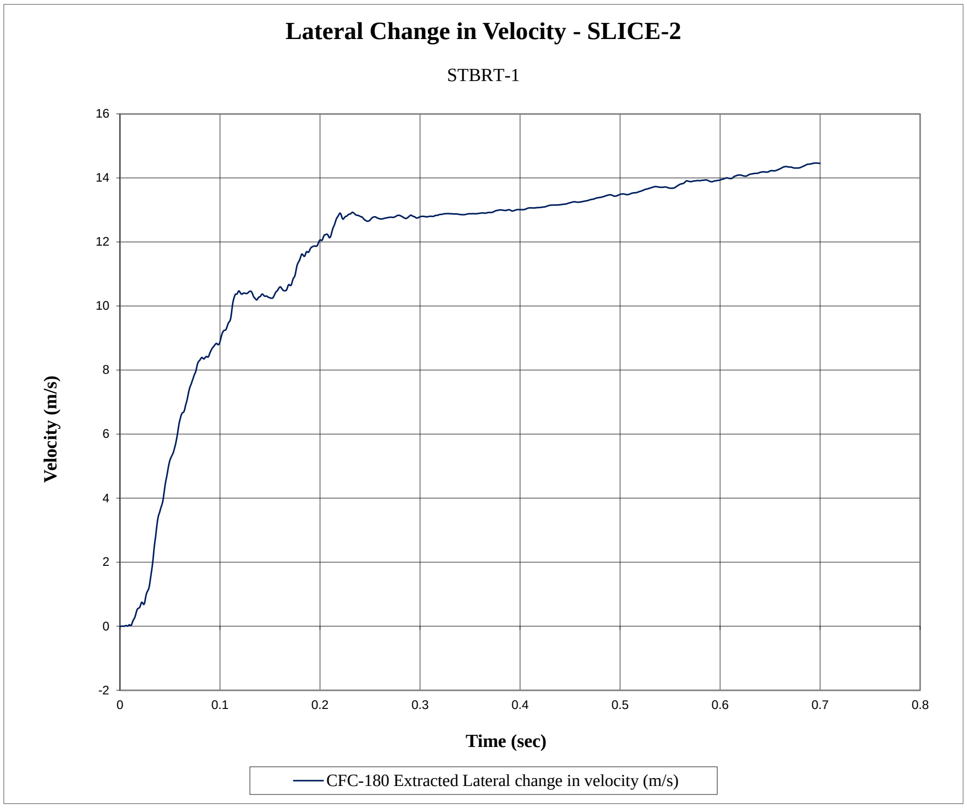



Figure G-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. STBRT-1

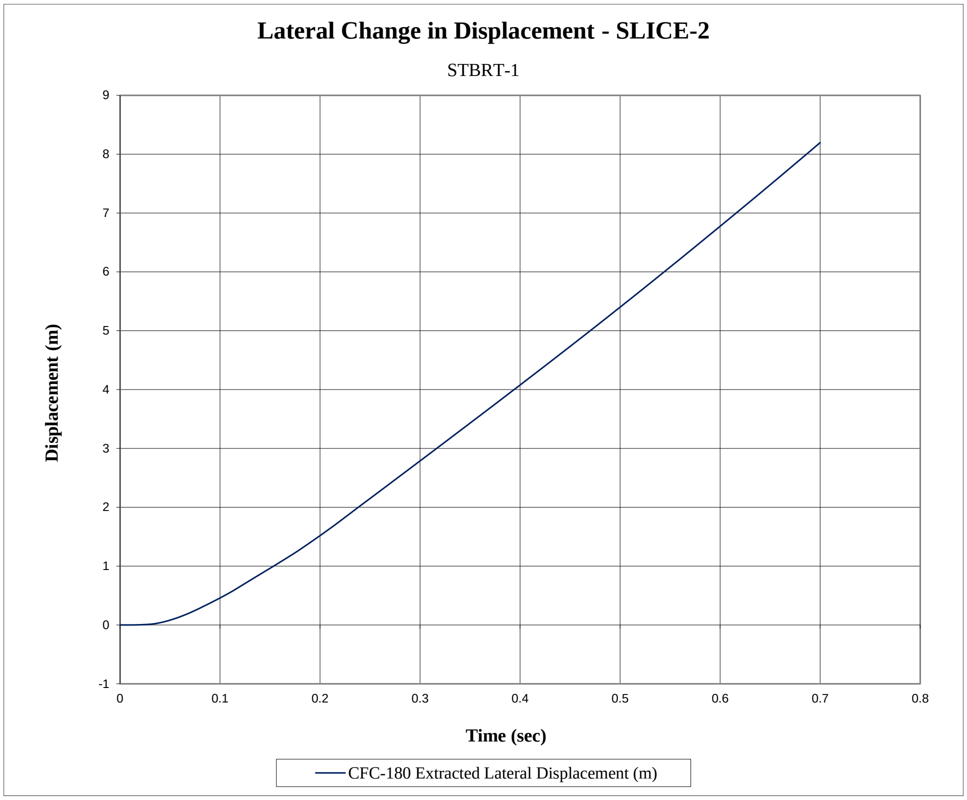



Figure G-14. Lateral Occupant Displacement (SLICE-2), Test No. STBRT-1

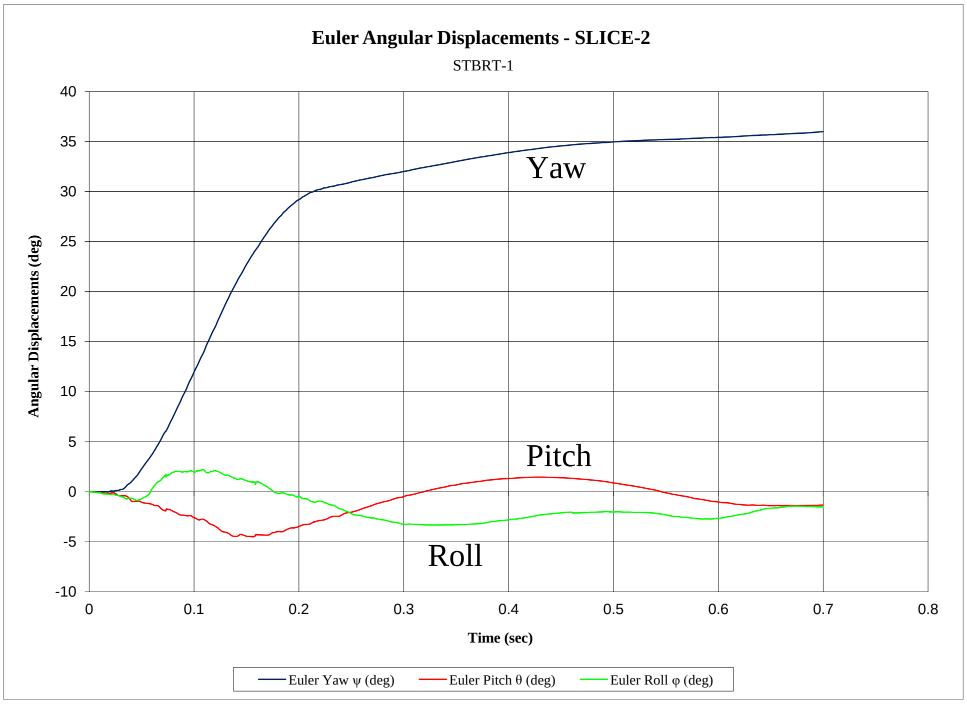



Figure G-15. Vehicle Angular Displacements (SLICE-2), Test No. STBRT-1

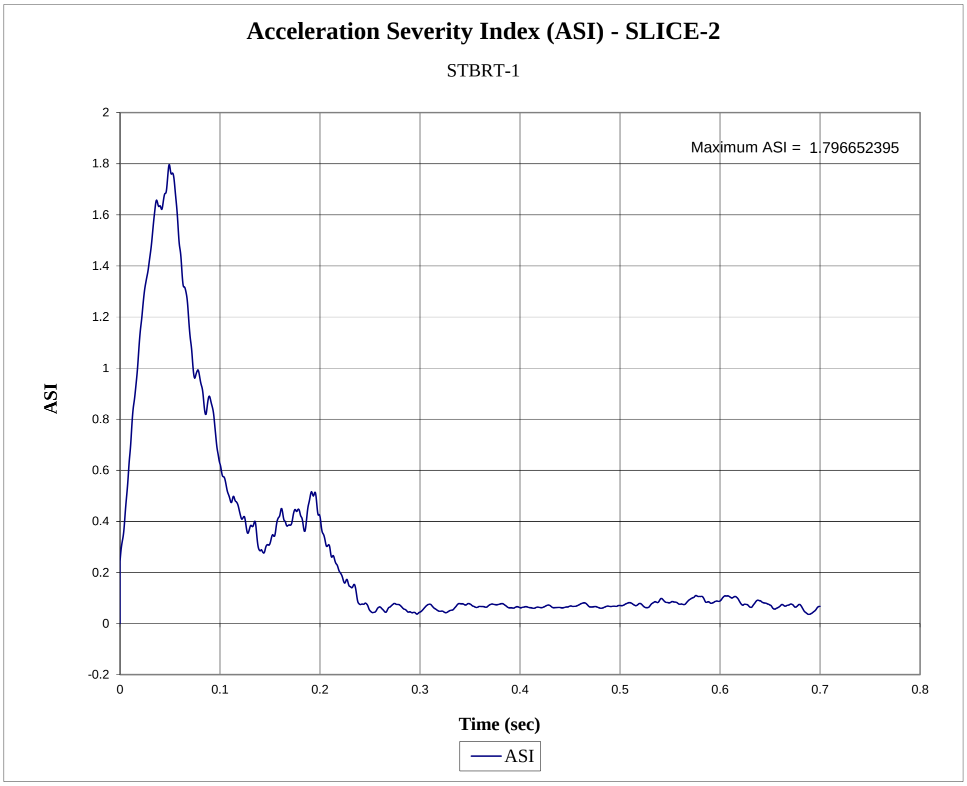



Figure G-16. Acceleration Severity Index (SLICE-2), Test No. STBRT-1

# Appendix H. Accelerometer and Rate Transducer Data Plots, Test No. STBRT-2

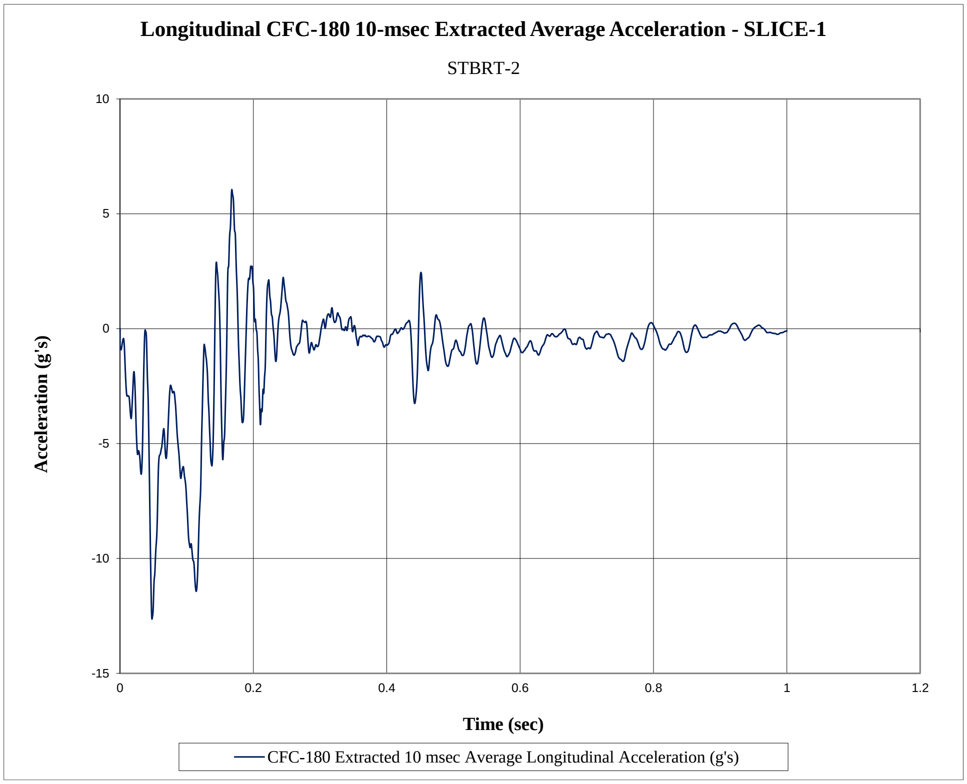



Figure H-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. STBRT-2

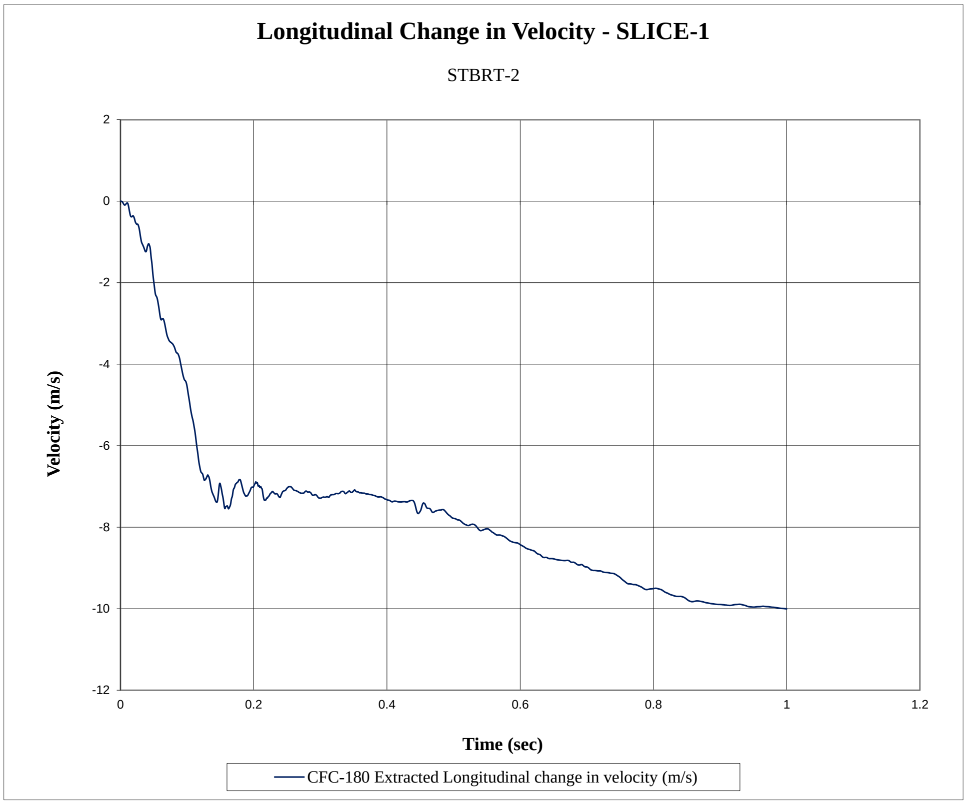



Figure H-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. STBRT-2

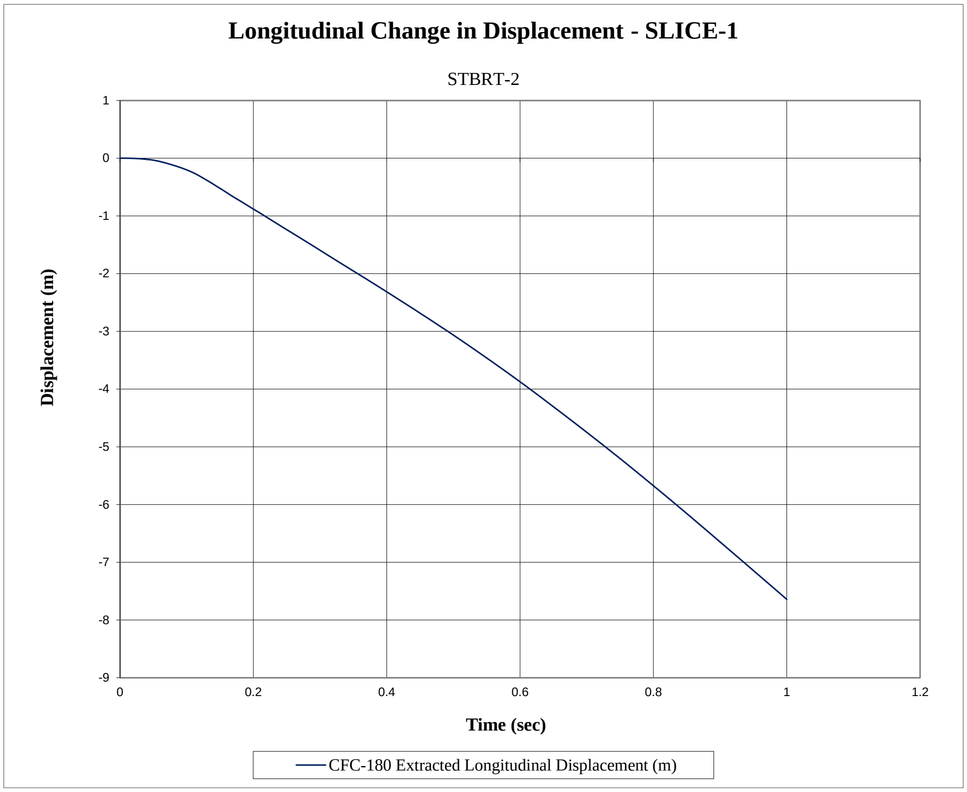



Figure H-3. Longitudinal Occupant Displacement (SLICE-1), Test No. STBRT-2

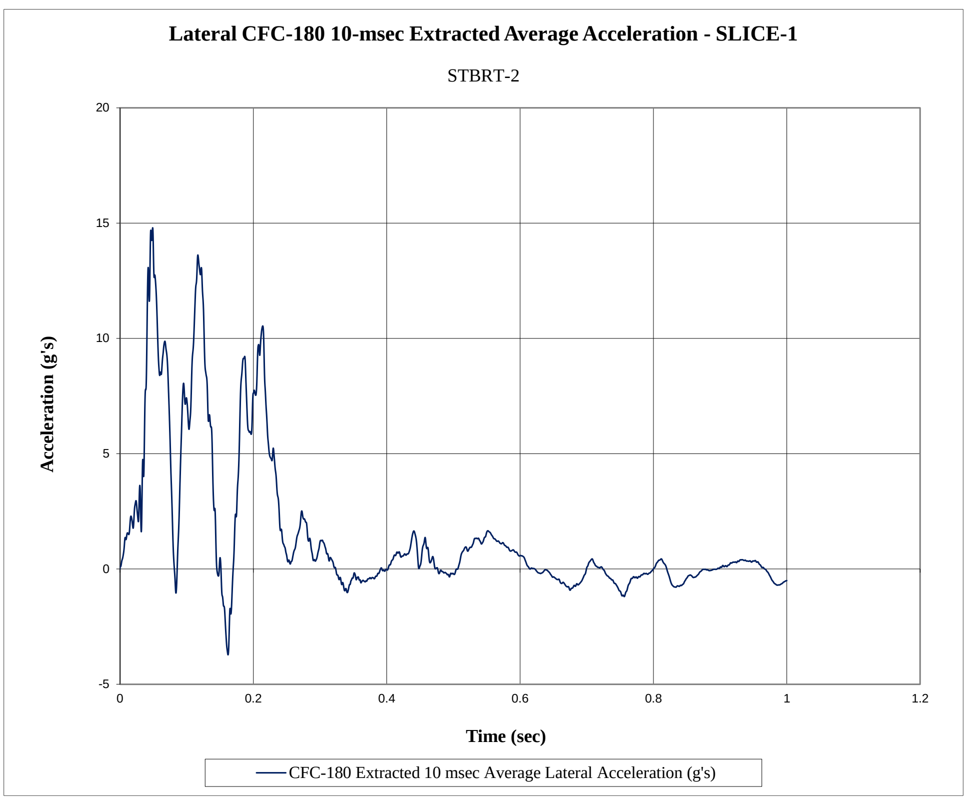



Figure H-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. STBRT-2

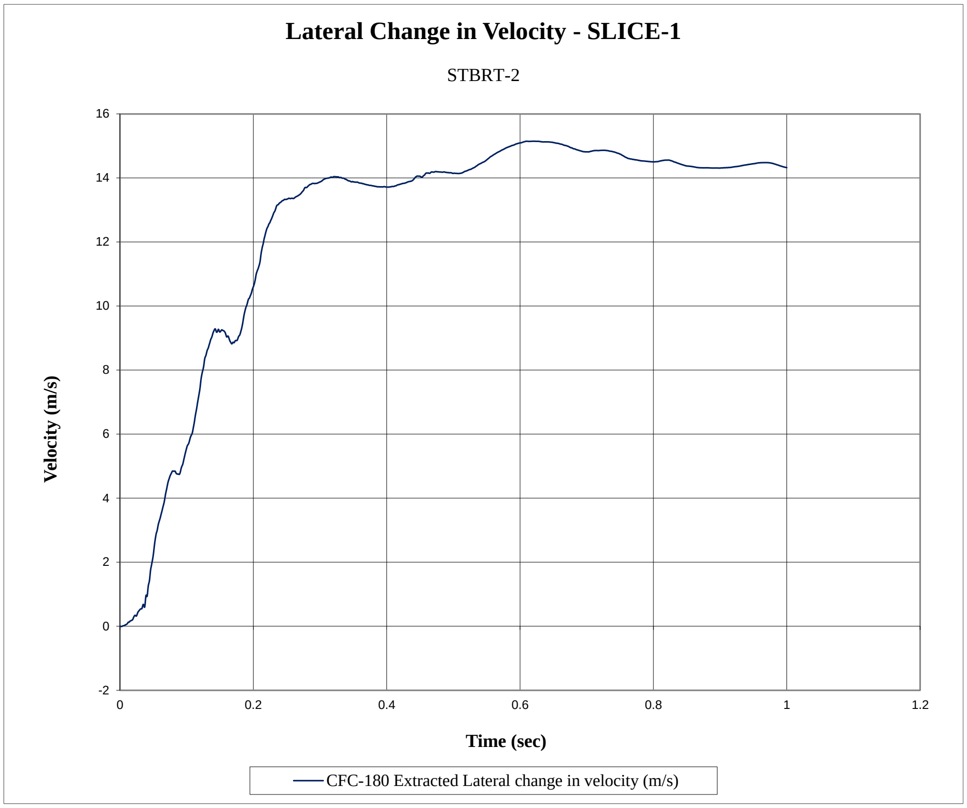



Figure H-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. STBRT-2

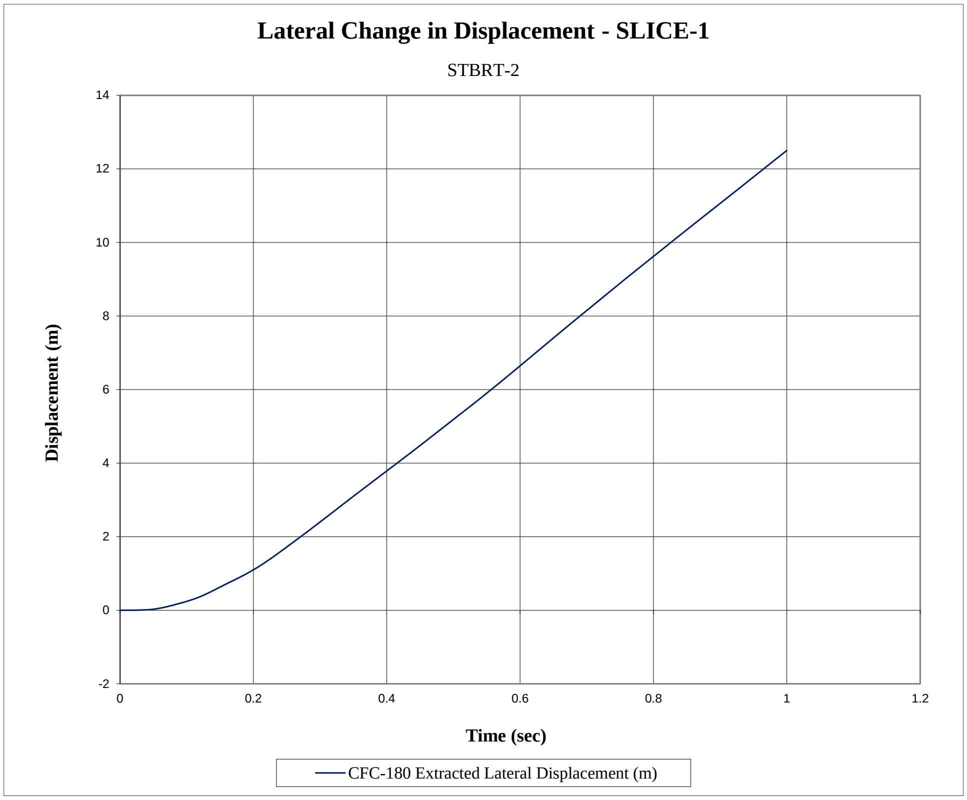



Figure H-6. Lateral Occupant Displacement (SLICE-1), Test No. STBRT-2

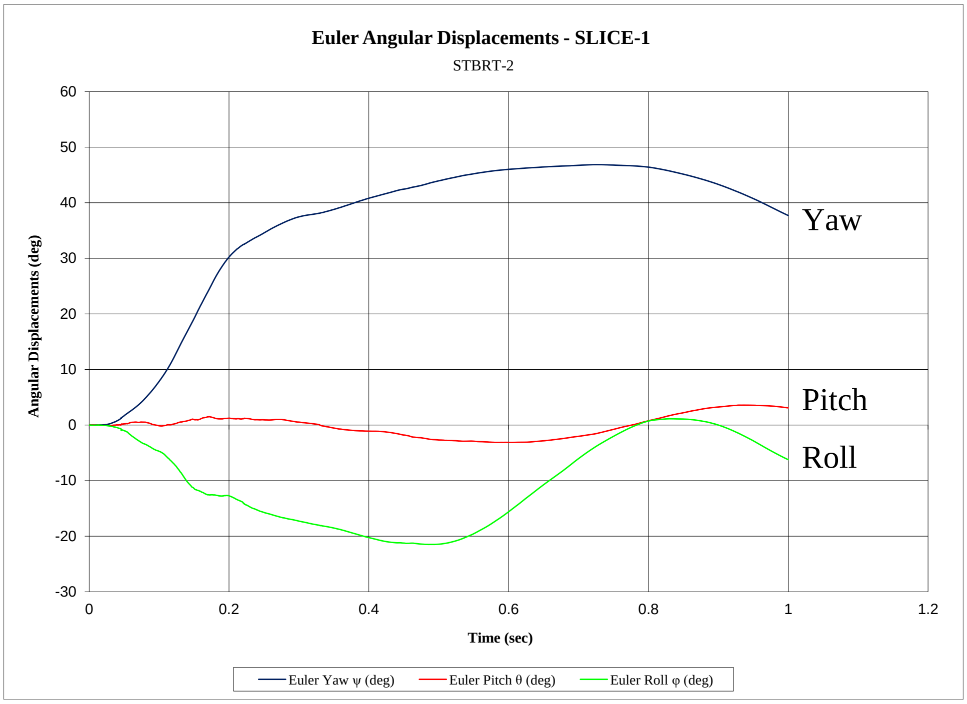



Figure H-7. Vehicle Angular Displacements (SLICE-1), Test No. STBRT-2

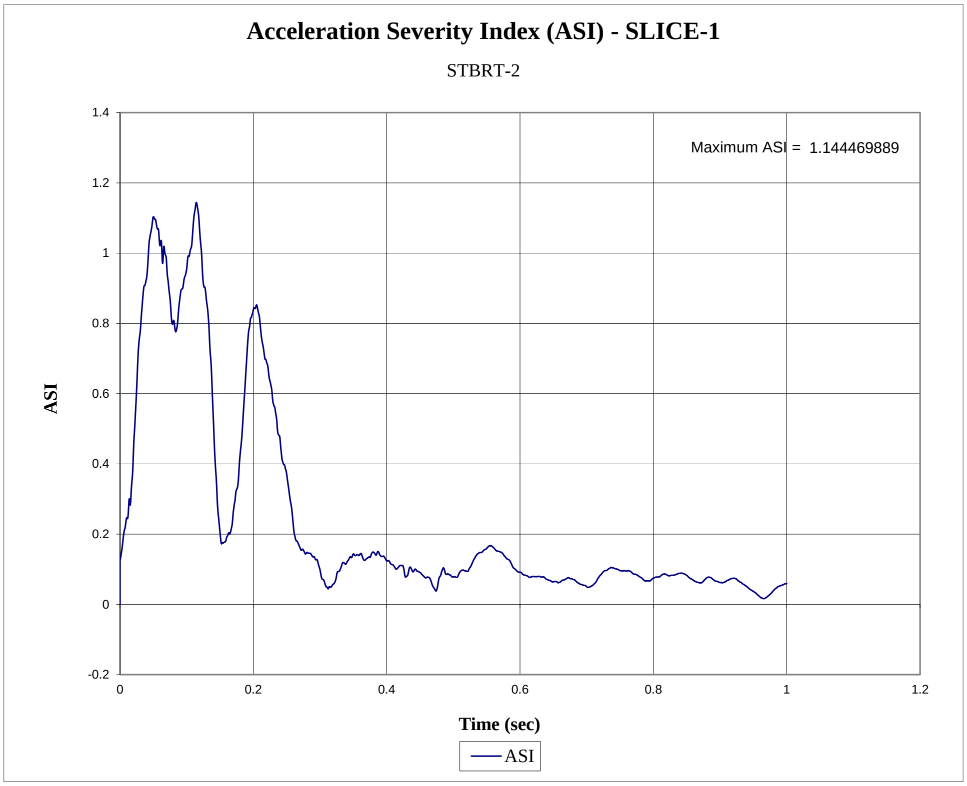



Figure H-8. Acceleration Severity Index (SLICE-1), Test No. STBRT-2

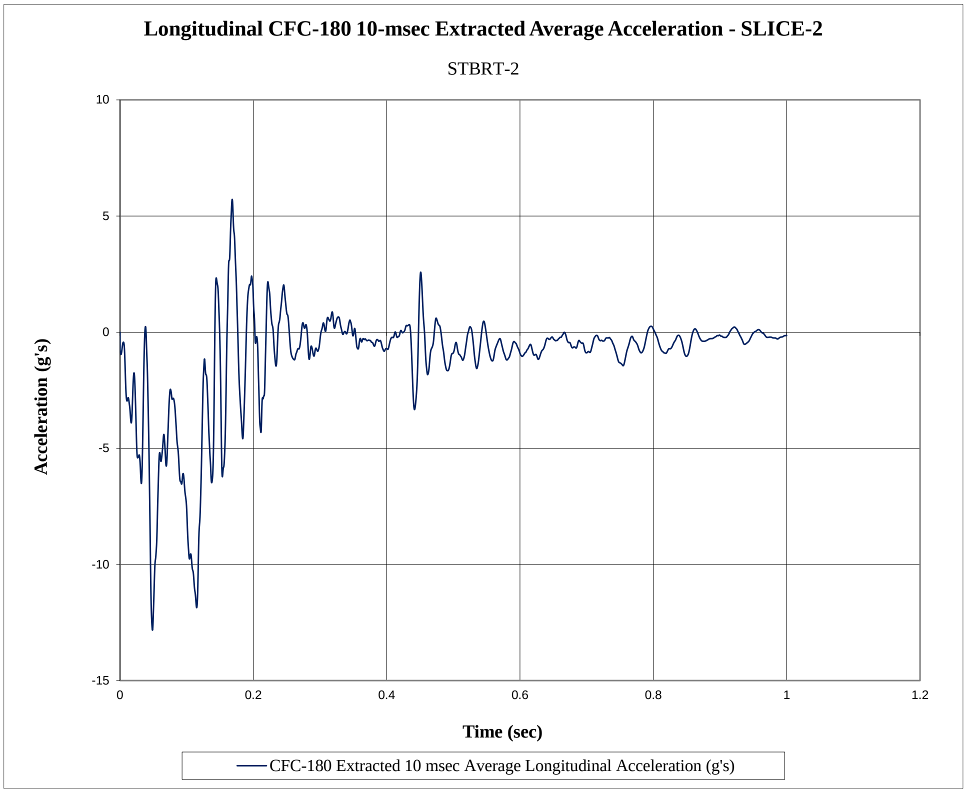



Figure H-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. STBRT-2

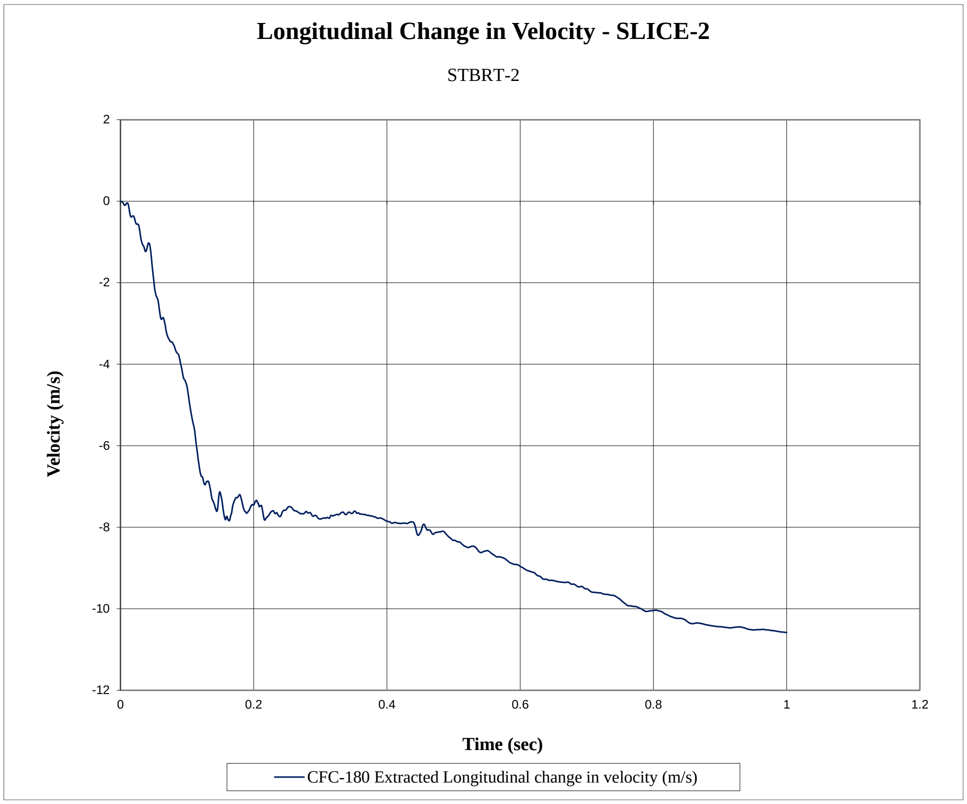



Figure H-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. STBRT-2

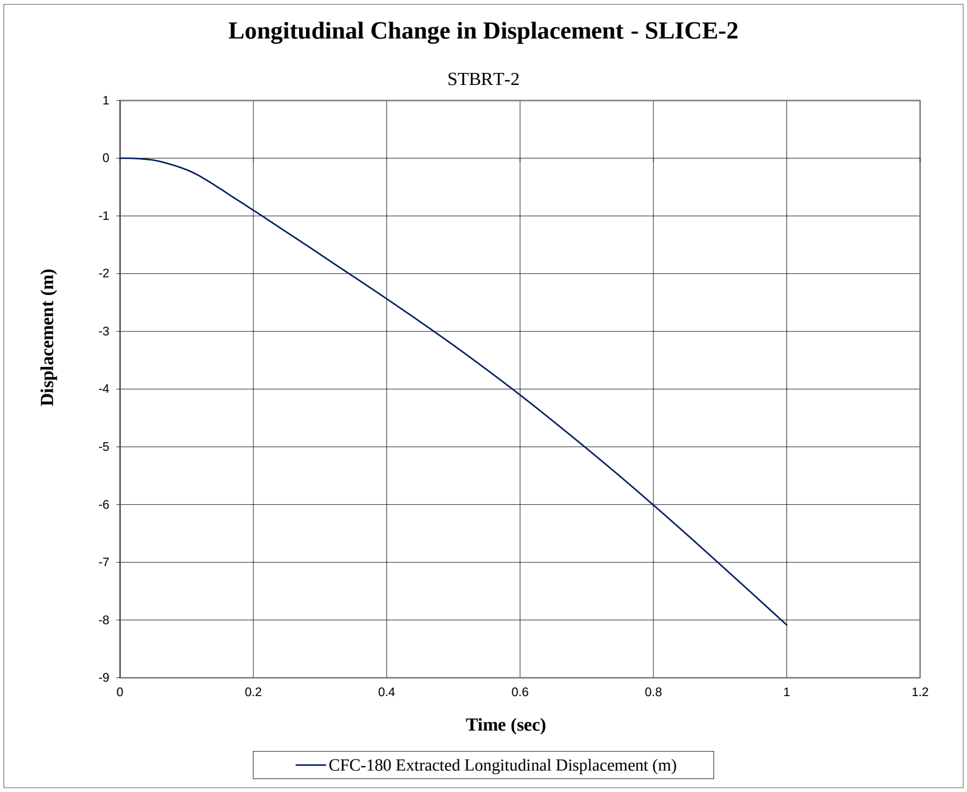



Figure H-11. Longitudinal Occupant Displacement (SLICE-2), Test No. STBRT-2

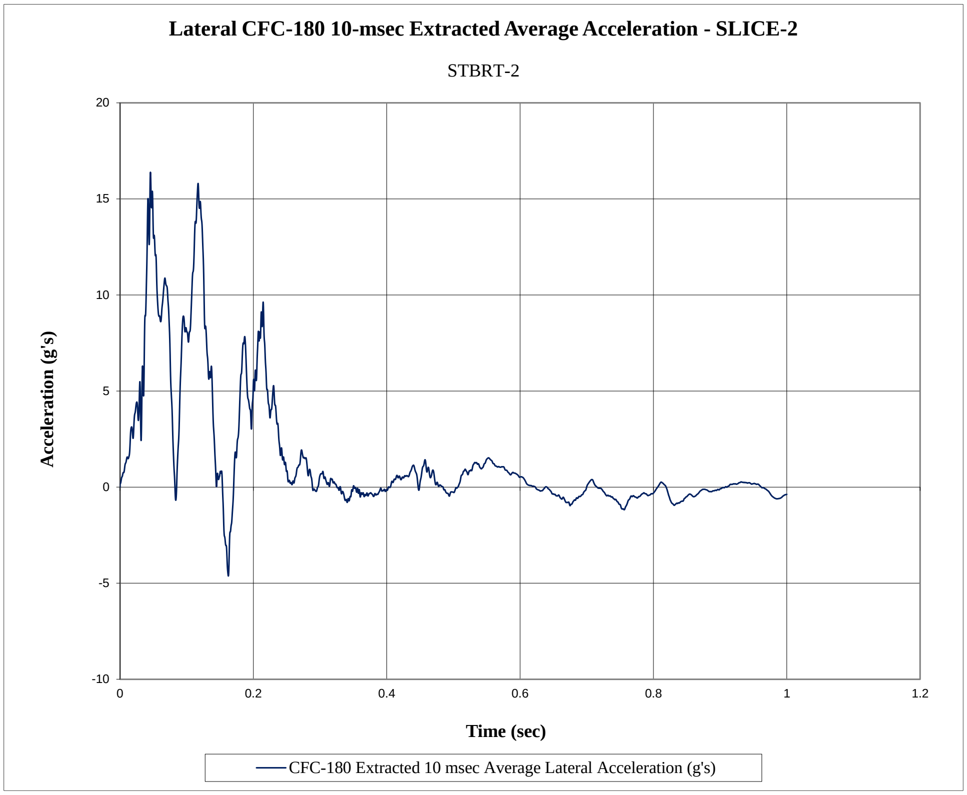



Figure H-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. STBRT-2

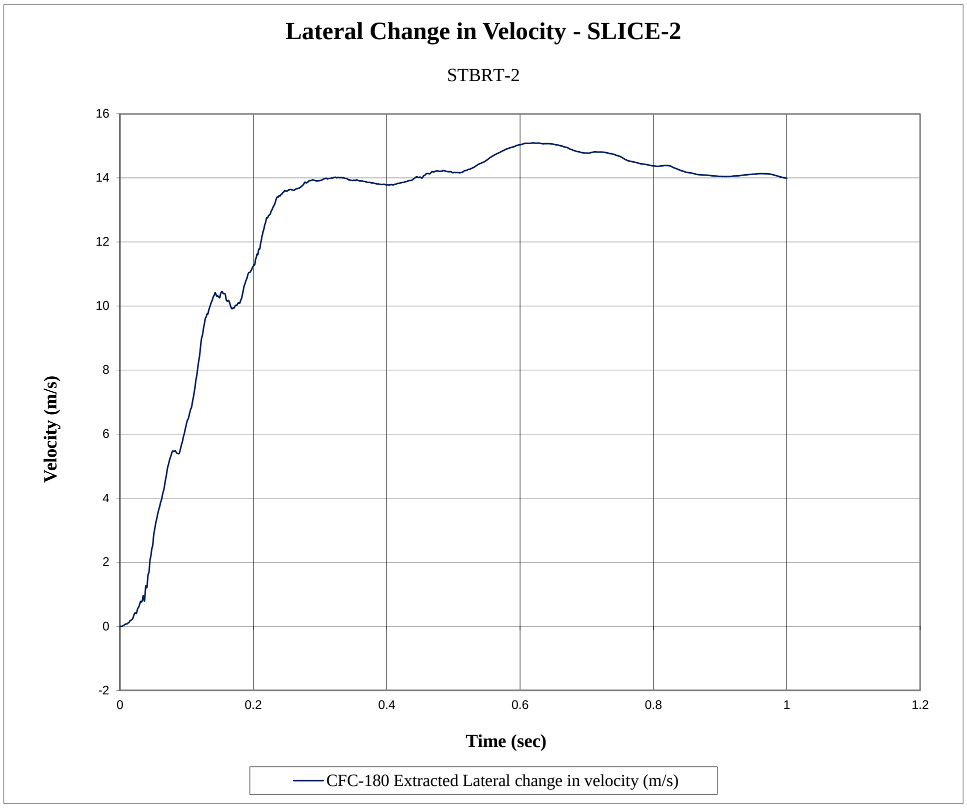



Figure H-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. STBRT-2

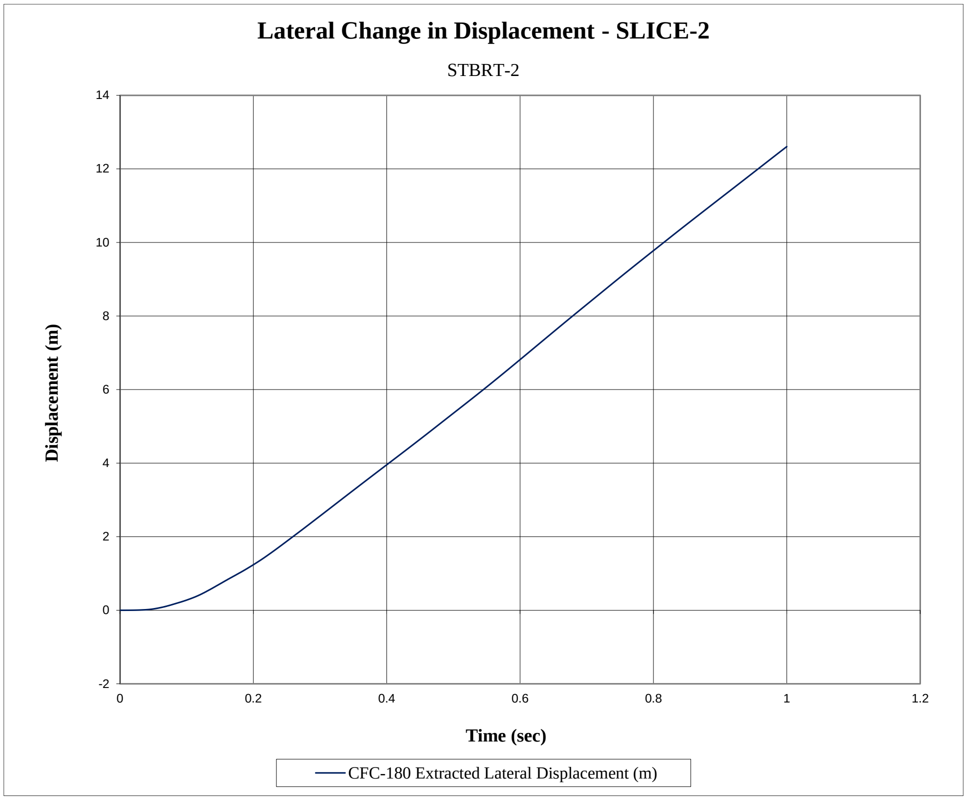



Figure H-14. Lateral Occupant Displacement (SLICE-2), Test No. STBRT-2

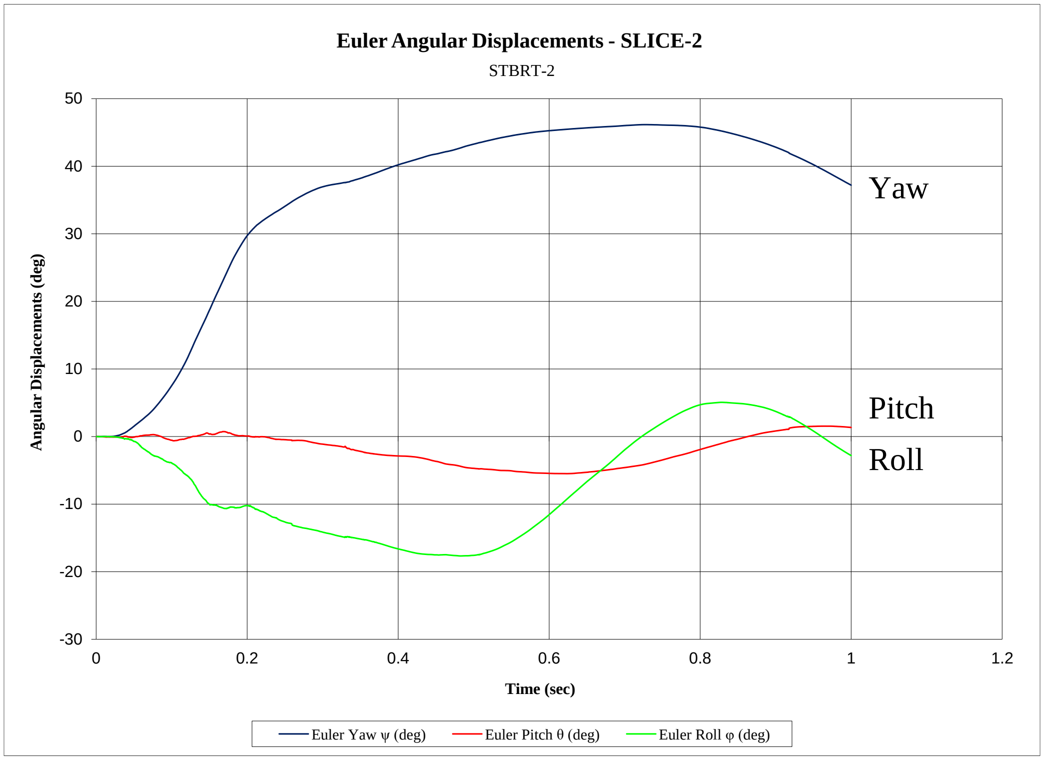



Figure H-15. Vehicle Angular Displacements (SLICE-2), Test No. STBRT-2

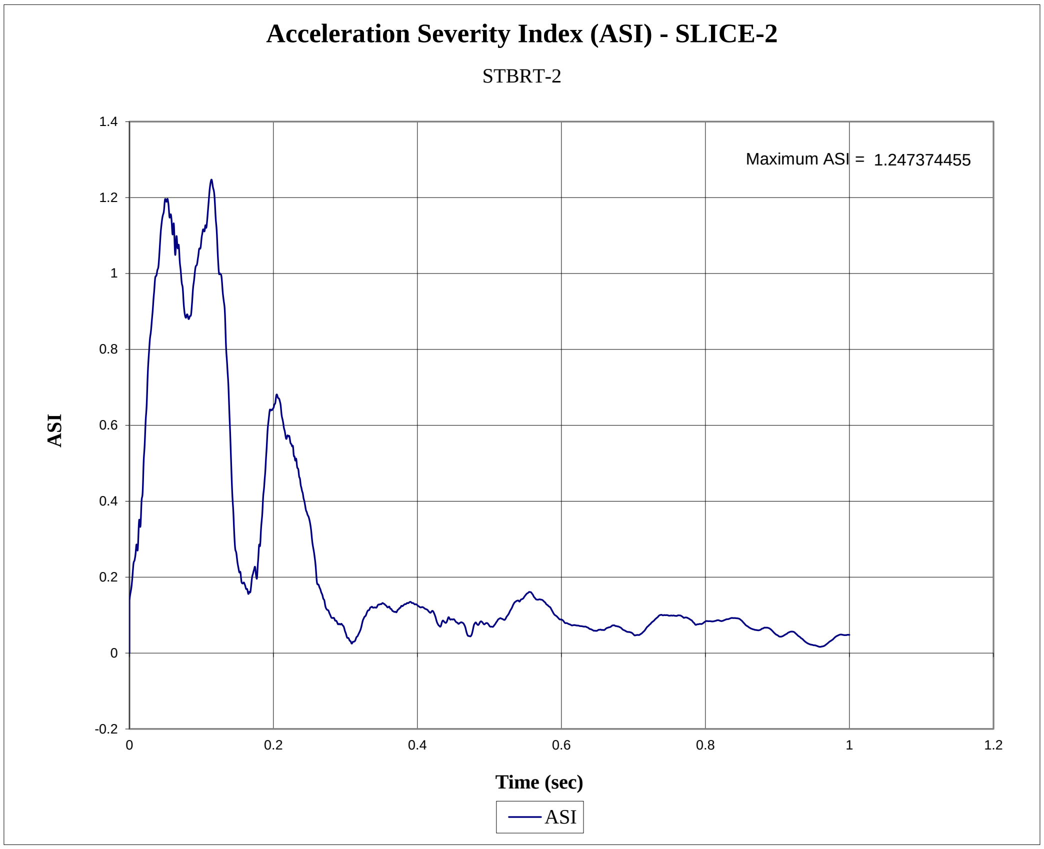



Figure H-16. Acceleration Severity Index (SLICE-2), Test No. STBRT-2

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