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Texas A&M Transportation Institute Proving Ground

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Test Report Date: July 2023

MASH TEST 2-11 ON W-BEAM GUARDRAIL WITH MODIFIED SPECIAL STEEL POSTS FOR CONCRETE STRUCTURE MOUNT

by

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16. Abstract

In the State of Florida, Modified Special Steel Posts are mounted on Concrete Structures in areas where standard posts embedded in soil are not applicable. The special posts and baseplates use a bolted connection with a concrete curb inlet to support the guardrail during impact. Because of the wide use of these special guardrail posts and baseplates, there is a need to evaluate their compliance to American Association of State Highway and Transportation Official (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) (*1*). This will allow Florida Department of Transportation (FDOT) to either continue using these posts or adopt a new design for future projects.

The objective of this research is to develop a *MASH* compliant version of Florida Department of Transportation's (FDOT) Modified Special Steel Posts for Concrete Structure Mount. With this goal, the research team will analyze the current FDOT Modified Special Steel Posts for Concrete Structure Mount detail, provide alternate solutions to the current detail, perform component pendulum testing on possible solutions, and perform *MASH* crash testing on the final selected design detail.

The Modified W-Beam Guardrail with Modified Special Steel Posts for Concrete Structure Mount met the performance criteria for *MASH* Test 2-11 for longitudinal barriers. Justification was provided for completing the critical *MASH* test 2-11. The research team concluded the W-Beam Guardrail with Modified Modified Special Steel Posts for Concrete Structure Mount was *MASH* compliant.

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Longitudinal barrier, guardrail, W-beam, structure mount, crash testing, roadside safety, *MASH*	Copyrighted. Not to be copied or reprinted without consent from the Roadside Safety Pooled Fund.

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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		
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yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
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gal	gallons	3.785	liters	L
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yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
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m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
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mL	milliliters	0.034	fluid ounces	oz
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m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in^2

*SI is the symbol for the International System of Units

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Chapter 1. INTRODUCTION

1.1. BACKGROUND

In the State of Florida, Modified Special Steel Posts are mounted on concrete structures in areas where standard posts embedded in soil are not applicable. The special posts and baseplates use a bolted connection with a concrete curb inlet to support the guardrail during impact. Because of the wide use of these special guardrail posts and baseplates, there is a need to evaluate their compliance to American Association of State Highway and Transportation Official (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) (*1*).

1.2. OBJECTIVE

The objective of this research is to develop a *MASH* compliant version of Florida Department of Transportation's (FDOT) Modified Special Steel Posts for Concrete Structure Mount. With this goal, the research team will analyze the current FDOT Modified Special Steel Posts for Concrete Structure Mount detail, provide alternate solutions to the current detail, perform component pendulum testing on possible solutions, and perform *MASH* crash testing on the final selected design detail.

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Chapter 2. DESIGN DEVELOPMENT

2.1. PRELIMINARY ANALYSIS

The TTI research team analyzed the FDOT Modified Special Steel Posts for Concrete Structure Mount detail for W-beam guardrail as shown in Figure 2.1 (*2*). This analysis included reviewing previous related research and a structural review of the standard design. A primary concern for surface mounted guardrail posts is the ability for the post to yield or fracture from the impacting vehicle. If the posts do not yield or fracture, vehicles may snag and exhibit excessive decelerations. Therefore, the objective of the analysis and design effort was to ensure the posts would yield or fracture under impact loading.

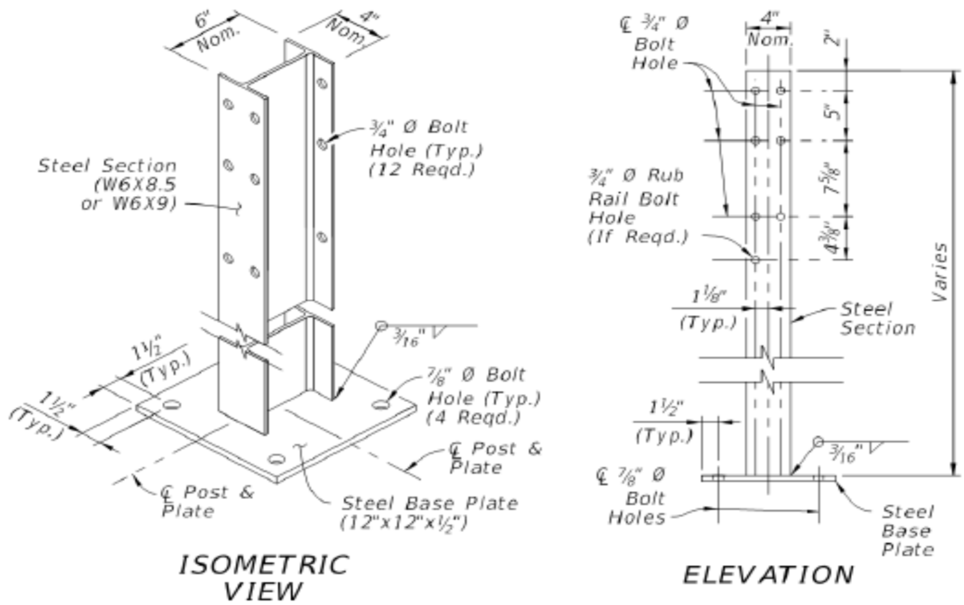

Figure 2.1. Modified Special Steel Posts for Concrete Structure Mount.

The research team reviewed previous research to develop alternative designs for further exploration. One possible concept explored was to replicate the design intent of the Universal Breakaway Steel Post (UBSP) developed by the Midwest Roadside Safety Facility (MwRSF) (*3*). This post was designed to split into two separate pieces when the connection bolts fracture upon impact. The bottom section remains embedded in the ground, while the top section is pushed or pulled away from the impact location. This concept could be modified using embedded or epoxy anchors in the concrete structure to replicate the release mechanism of the UBSP. Figure 2.2 shows the UBSP designed by the MwRSF.

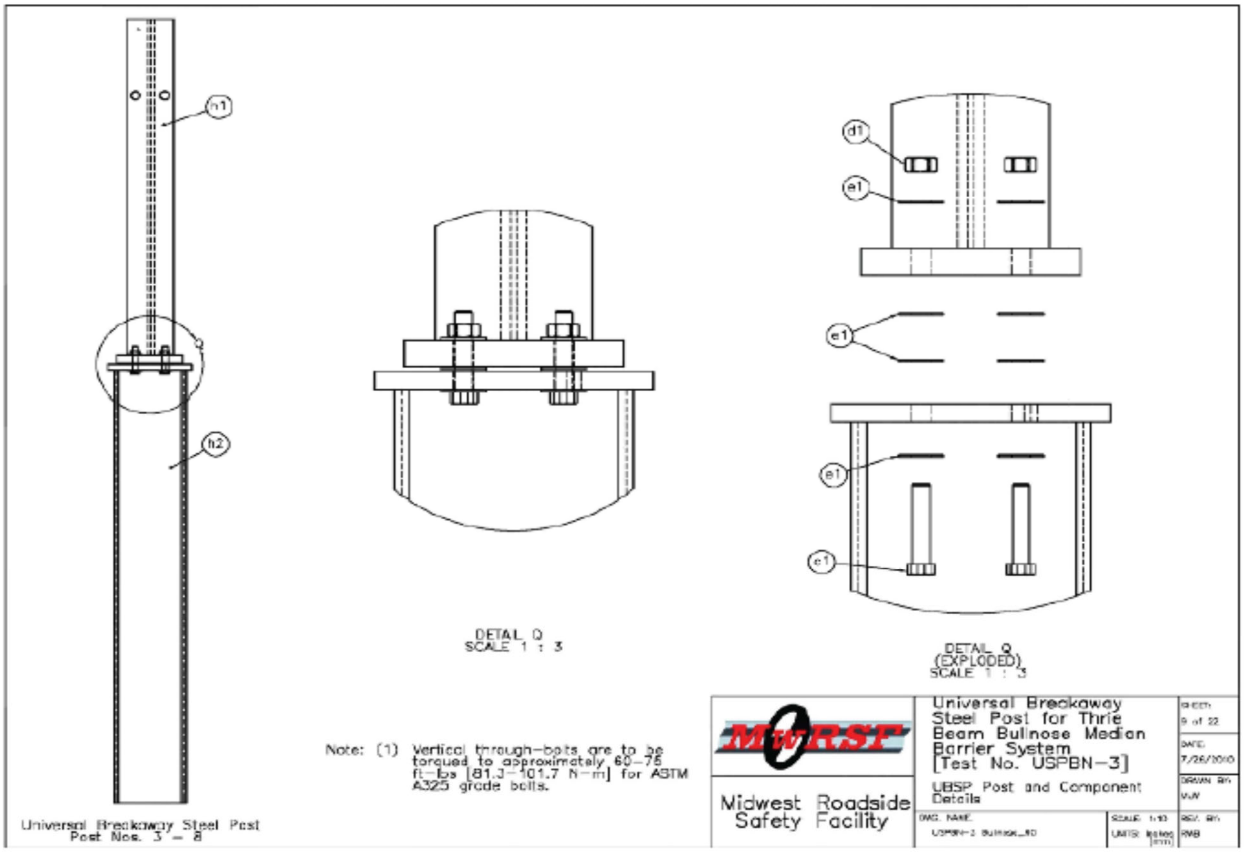

Figure 2.2. Universal Breakaway Steel Post (UBSP).

Another possible concept was the adaptation of the Texas Department of Transportation (TxDOT) T631 Bridge Rail (*4*). This design employs a weak post which yields during an impact. In the T631, bolts are run through a concrete deck and are tightened with washers and heavy hex nuts on the underside of the deck. This can be applied to the FDOT curb inlet detail by attaching bolts through the elevated 7-inch concrete slab. Figure 2.3 shows the T631 post design.

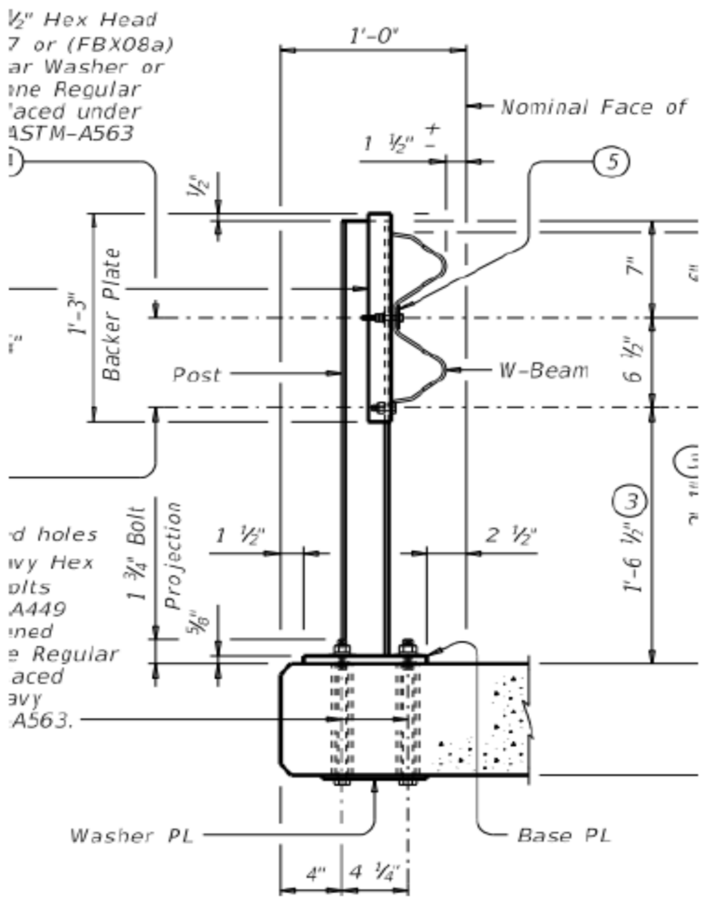

Figure 2.3. TxDOT T631 Sketch.

Another evaluated concept was utilizing a similar failure mechanism as designed with the TxDOT T6 post (*5*). In this design, a steel post is welded to a baseplate using a specific weld pattern. Upon impact, the welds are designed to fail, and therefore, the post is allowed to rotate away from impact. Figure 2.4 shows the welded connection which was designed to fail upon impact of the T6 post.

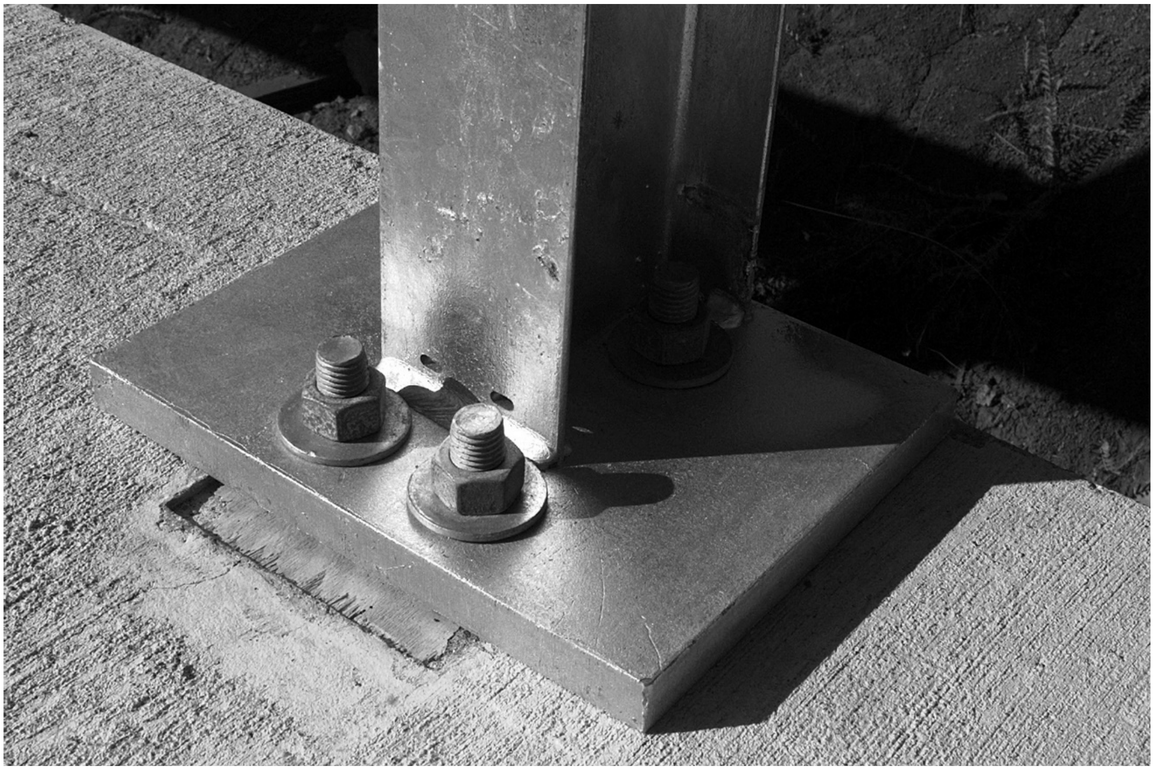

Figure 2.4. TxDOT T6 Steel Post Welded Connection.

2.2. DESIGN RECOMMENDATIONS

Following the analysis and design efforts, the research team prepared a series of recommended post designs for further options. The first design was the original FDOT Special Steel Post for Concrete Structure Mount. Each of the four alternative options was designed to promote the yielding or fracturing of a post during an impact.

2.2.1. Design Option 1: FDOT Modified Special Steel Posts for Concrete Structure Mount

The FDOT Modified Special Steel Posts for Concrete Structure Mount detail for W-beam guardrail is shown in Figure 2.5. This is the current design used by FDOT when a guardrail post is required to be mounted to the surface of a drainage inlet. The main concern with this design is the stiffness of the post compared to a standard guardrail post that is embedded in soil. A much stiffer post could possibly cause a pocketing issue to occur. Therefore, the research team developed several alternatives to this design, which can be found later in this memorandum. Table 2.1 lists a few advantages and disadvantages of this option when comparing it to the other design options listed in this document.

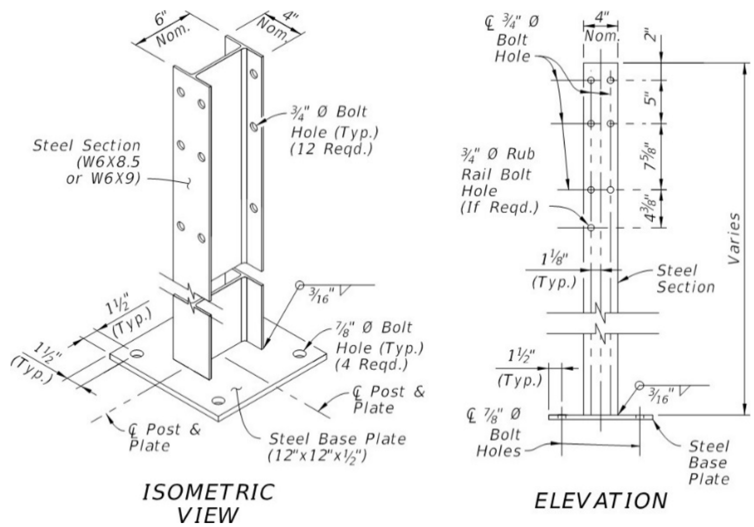

Figure 2.5. FDOT Modified Special Steel Posts for Concrete Structure Mount *(2)*

Table 2.1. Advantages and Disadvantages of the FDOT Modified Special Steel Posts for Concrete Structure Mount

Advantages	Disadvantages
Current FDOT standard	Rigid post could cause pocketing and snagging
	Uncertainty of the W6x8.5 post yielding
	Time consuming to replace if anchors are damaged

2.2.2. Design Option 2: Couple Nut Option

This design option uses Hilti HDI stainless steel anchors to connect the baseplate to the concrete slab. These anchors allow for a removable bolted connection that will permit the replacement of the baseplate if needed. Holes are first drilled into the concrete slab, and the anchors are subsequently set into these holes. This allows the top of the anchor to be below or flush with finished grade. Standard bolts will then be threaded through the baseplate and into the anchors. Consequently, the bolts can be removed, and the anchors left in place if the installation requires replacement. An S3x5.7 steel guardrail post is used for this design option because it will provide a larger possibility of the post yielding away during an impact. The S3x5.7 post provides less flexural resistance which will allow it to yield at a smaller load than a W6x8.5. The goal of this design is to increase the possibility of the post displacing during the test, and therefore replicating the stiffness of a soil embedded post. This similar stiffness will minimize the pocketing potential. Figure 2.6 shows a photo of a Hilti HDI anchor. Figure 2.6 shows a sketch of the proposed modified Special Baseplate Post with Hilti HDI anchors. Table 2.2 lists a few advantages and disadvantages of this option when compared to the other design options.

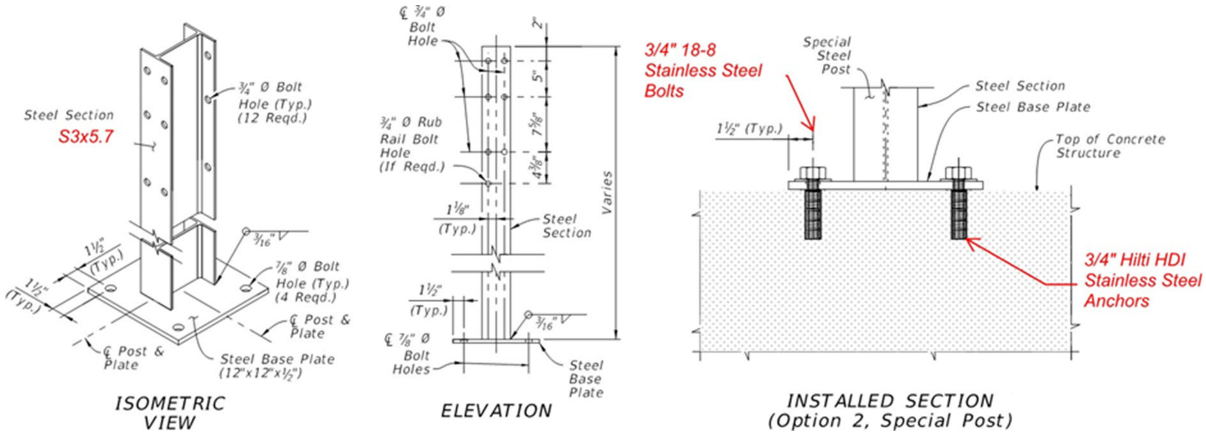

Figure 2.6. Sketch of Coupler Nut Option *(2)*

Table 2.2. Advantages and Disadvantages of Coupler Nut Option

Advantages	Disadvantages
Quick installation (no epoxy cure time)	If bolts are removed, open hole for water to pool
Removable connection	Hilti limits edge distance (possibly too conservatively)
Flush with concrete slab if plate is removed	Limited crash testing history

2.2.3. Design Option 3: Modified FDOT Modified Special Steel Posts for Concrete Structure Mount

This design option is a modification of the FDOT Modified Special Steel Posts for Concrete Structure Mount detail for W-beam guardrail design. The difference between this design option and the FDOT Modified Special Steel Posts for Concrete Structure Mount design is that an S3x5.7 post is used instead of a W6x8.5 post. Again, this change in post size is due to the desire for the posts to yield during an impact. Figure 2.7 shows a sketch of the proposed Modified FDOT Modified Special Steel Posts for Concrete Structure Mount. Table 2.3 lists a few advantages and disadvantages of this option when compared to the other design options.

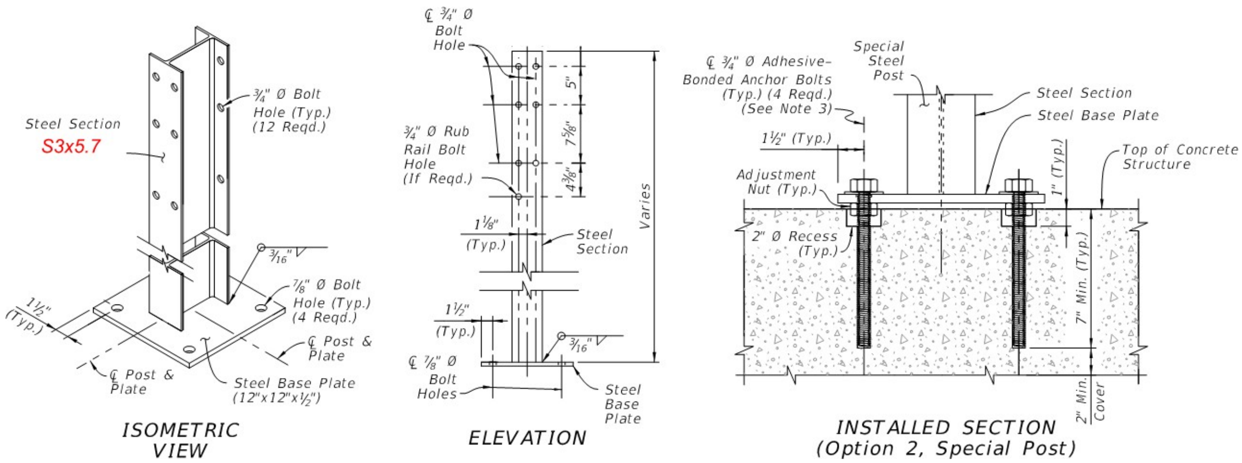

Figure 2.7. Modified FDOT Modified Special Steel Posts for Concrete Structure Mount (Florida Department of Transportation, 2017-2018)

Table 2.3. Advantages and Disadvantages of the Modified FDOT Modified Special Steel Posts for Concrete Structure Mount

Advantages	Disadvantages
Easy retrofit in the field (same bolt and baseplate configuration as existing design)	Time consuming to replace after vehicle impact if anchors are damaged
Weak post to minimize pocketing and snagging potential	Different post than current FDOT standard

2.2.4. Design Option 4: Optimized FDOT Modified Special Steel Posts for Concrete Structure Mount

This design option is an optimization of the detail found in Option 3. This design uses a 6"x6"x1/4" baseplate, which is a reduced baseplate compared to the FDOT Modified Special Steel Posts for Concrete Structure Mount design (12"x12"x1/2"). Instead of using the four 3/4" diameter anchor rods from the FDOT Modified Special Steel Posts for Concrete Structure Mount design, this design uses two 1/2-inch diameter anchor Rods. Figure 2.8 shows a sketch of the proposed Optimized FDOT Modified Special Steel Posts for Concrete Structure Mount. Table 2.4 lists a few advantages and disadvantages of this option when compared to the other design options.

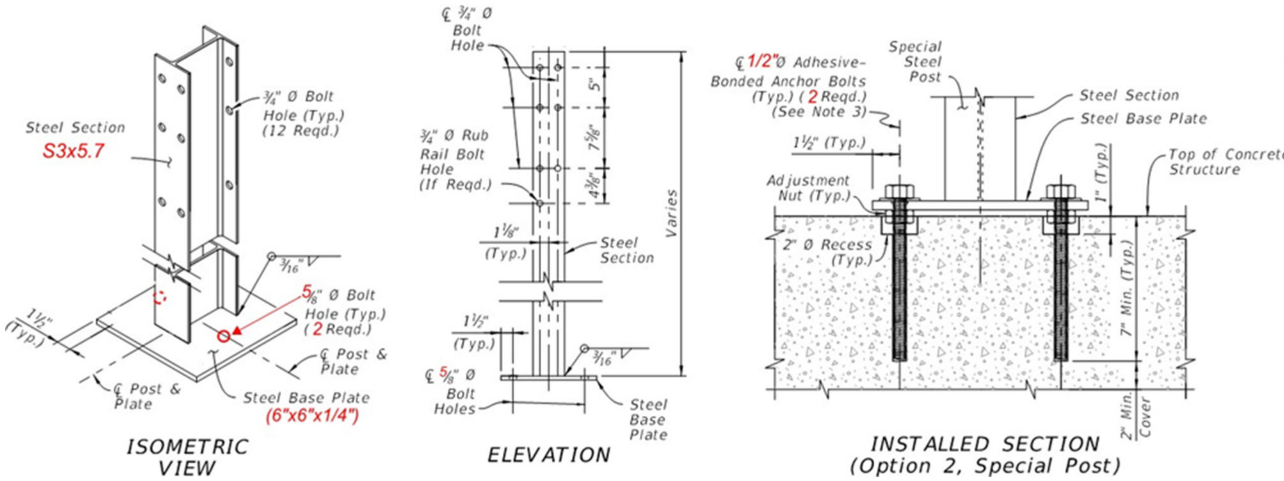

Figure 2.8. Optimized FDOT Modified Special Steel Posts for Concrete Structure Mount (Florida Department of Transportation, 2017- 2018)

Table 2.4. Advantages and Disadvantages of the Optimized FDOT Modified Special Steel Posts for Concrete Structure Mount

Advantages	Disadvantages
Smaller baseplate	Time consuming to replace after vehicle impact if anchor rods are damaged
Weak post to minimize pocketing and snagging potential	Different post than current FDOT standard
Reduced number of anchor rods	

2.2.5. Design Option 5: Slotted Steel Fracture Post

This design option was developed from the TxDOT T6 Bridge Rail. It incorporates a W6x8.5 post with two slots machined on the front face of the post. The post is secured to the baseplate using a specific weld pattern that was investigated through several iterations by TTI. The baseplate would be attached to the concrete surface using four 7/8” diameter anchor rods epoxied into the concrete. While this design failed NCHRP Report 350 TL-3 criteria, the research team believes it has a possibility of passing *MASH* TL-2 criteria in this application. The failure arose from excess deflection of the barrier during the crash test. In the TxDOT bridge rail application, the excess deflection was not acceptable because the vehicle could fall off of the side of the bridge. However, the FDOT roadside application could allow for this deflection. Additionally, the FDOT TL-2 application would also experience smaller deflections than the TxDOT TL-3 application. Figure 2.9 shows a sketch of the proposed Slotted Steel Fracture Post. Table 2.5 lists a few advantages and disadvantages of this option when compared to the other design options.

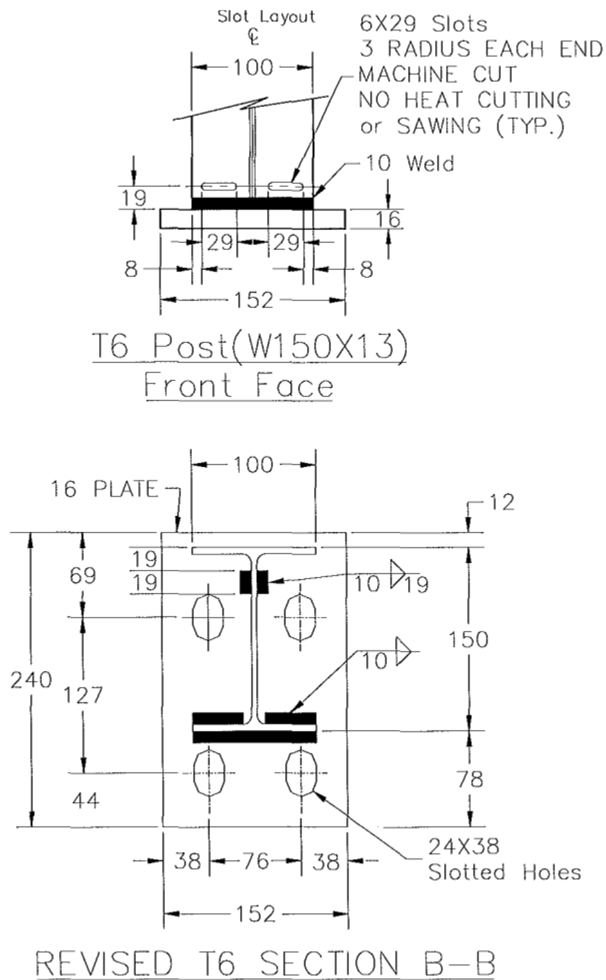

Figure 2.9. Slotted Steel Fracture Post (Buth, Williams, Bligh, & Menges, 1999)

Table 2.5. Advantages and Disadvantages of the Slotted Steel Fracture Post

Advantages	Disadvantages
Smaller baseplate	Time consuming to replace after vehicle impact if damaged
Slots and welds promote post fracture	Does not match current design (cannot reuse bolt pattern)
	Importance of precise welds and slots

Chapter 3. DYNAMIC PENDULUM TESTING

3.1. INTRODUCTION

Following the analysis and design development effort, the research team evaluated the designs through dynamic pendulum testing. The objective of the pendulum testing was to evaluate the yielding and/or fracturing release mechanisms intended for each of the respective designs. Ideally the posts would release during an impact scenario to mitigate snagging and excessive vehicular decelerations.

3.2. PENDULUM FACILITY

The special baseplate posts were tested at the Texas A&M Transportation Institute (TTI) outdoor pendulum testing facility. The utilized pendulum bogie, which was built according to the specifications of the Federal Outdoor Impact Laboratory's (FOIL) pendulum, and the testing area, are shown in Figure 3.1. Frontal crush of the aluminum honeycomb nose of the bogie simulates the crush of an actual vehicle. The crushable nose configuration is the FOIL ten stage bogie nose. Cartridges of expendable aluminum honeycomb material of differing densities are placed in a sliding nose. The pendulum impacts special baseplate posts at a target speed and height above the ground as determined for each test. After a test, the honeycomb material is replaced, and the bogie is reused. A sketch of the honeycomb configuration used for the pendulum bogie is shown in Appendix A. A brief description of the procedures used is presented in Appendix B.

Figure 3.1. TTI Proving Ground's Pendulum Testing Facility.

3.3. TEST ARTICLE DESIGN AND CONSTRUCTION

The test articles utilized for pendulum testing can be seen in Figure 3.4. Further details can be found in Appendix C.

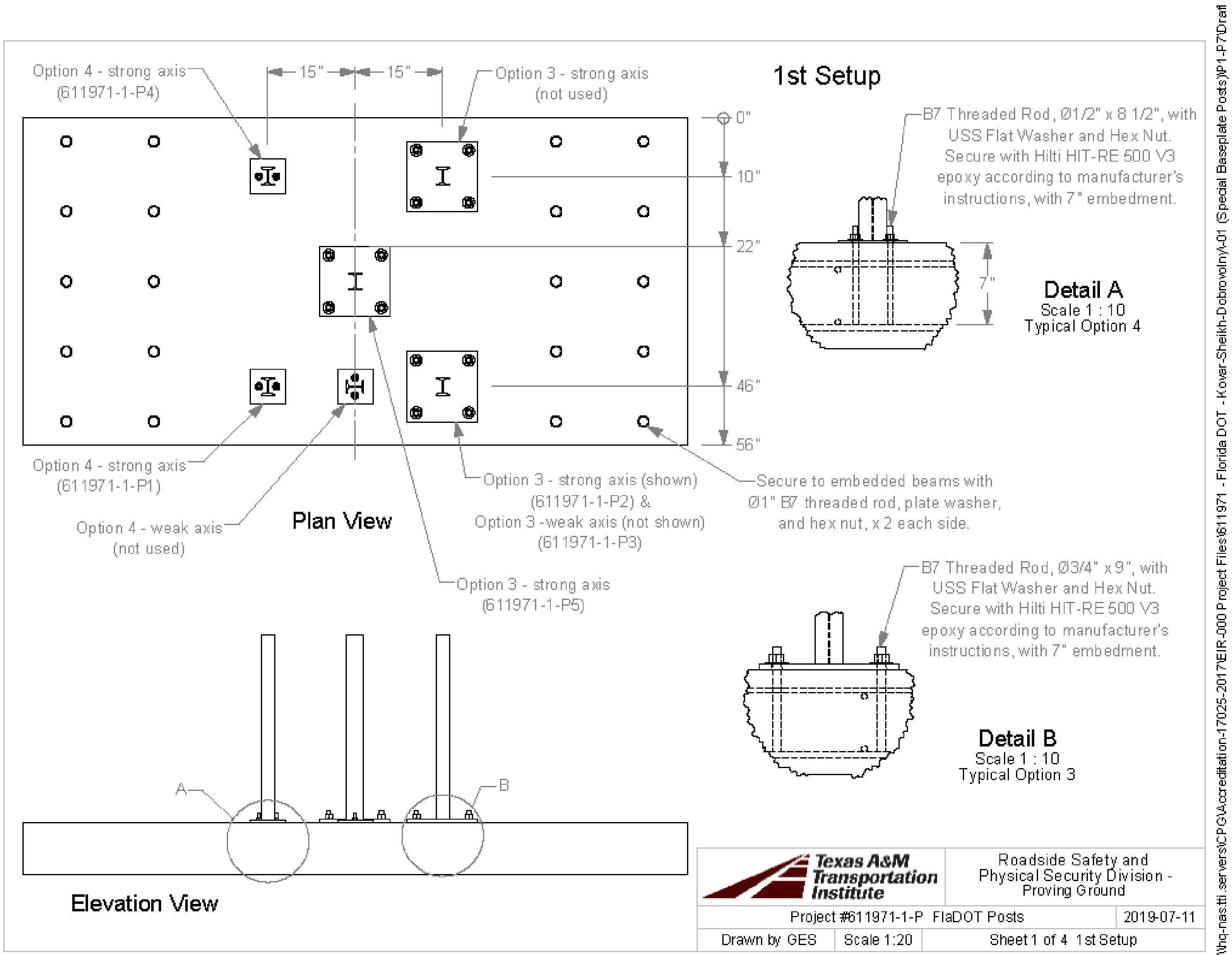

Figure 3.2. Pendulum Testing First Setup Drawing.

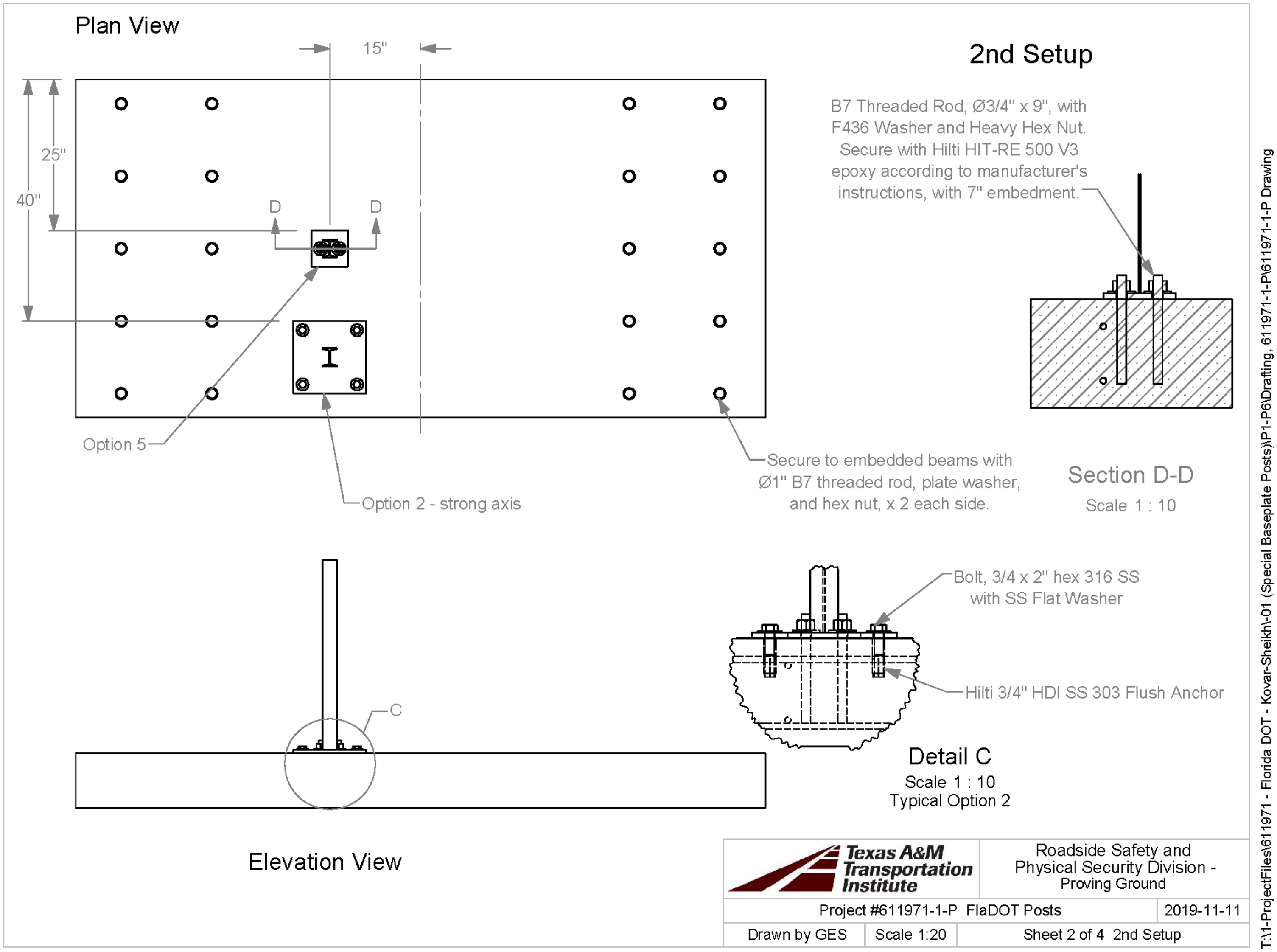

Figure 3.3. Pendulum Testing Second Setup Drawing.

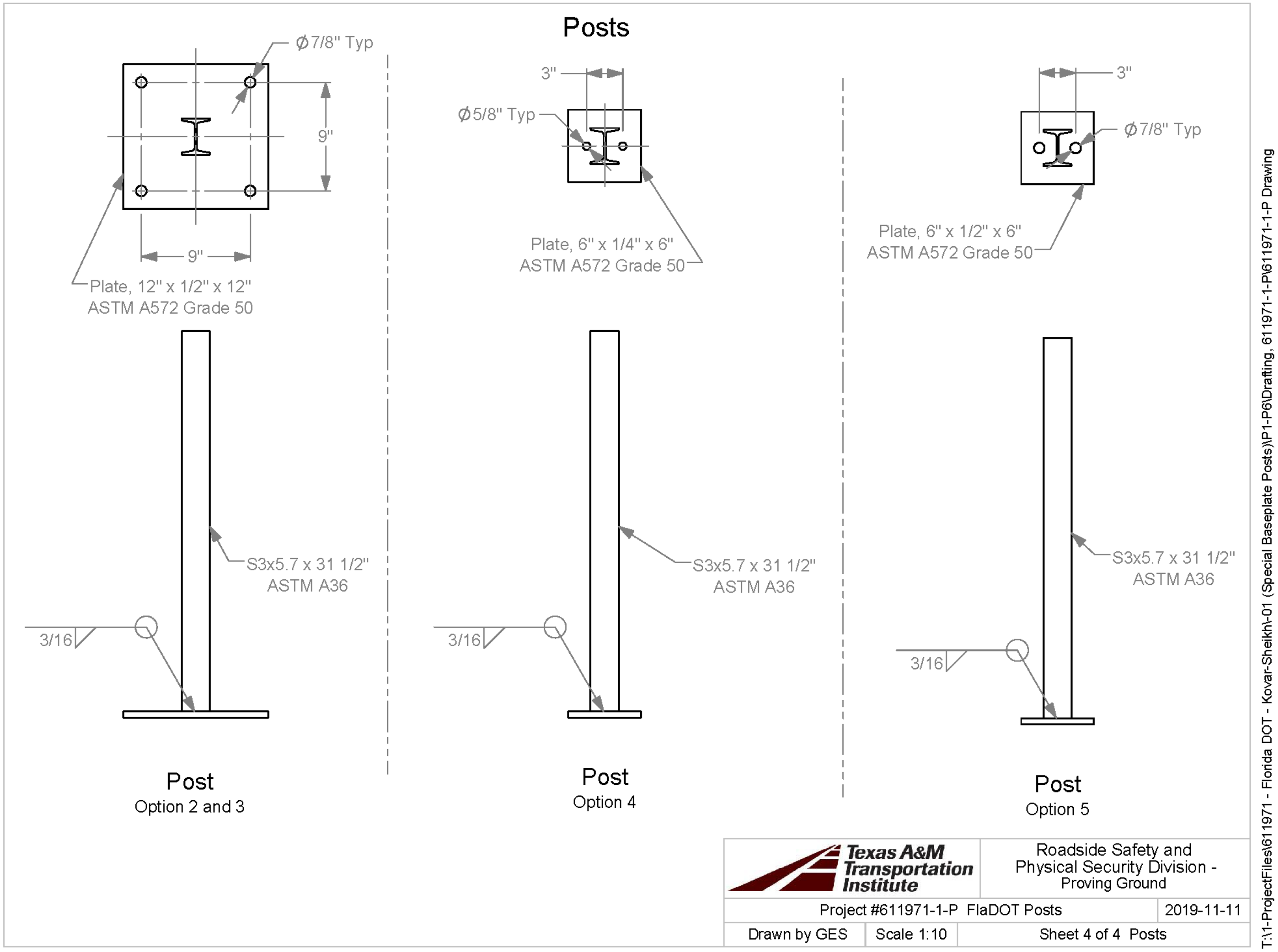

Figure 3.4. Pendulum Testing Post Detail Drawing.

3.4. PENDULUM TESTS

3.4.1. Test 611971-01 P1 – Option 4

3.4.1.1. Test Article Details

The post evaluated in this test was Option 4. This design utilized two ⅝-inch epoxy anchors, a 6-inch square baseplate, and an S3x5.7 post. Further details can be found in Figure 3.4 above and Appendix C.

3.4.1.2. Impact Conditions

The pendulum surrogate vehicle (bogie) impacted the post at 0 degrees (post loaded in strong axis) and at 21.8 mi/h. The center of the crushable bogie nose was aligned at 29.75 inches above grade.

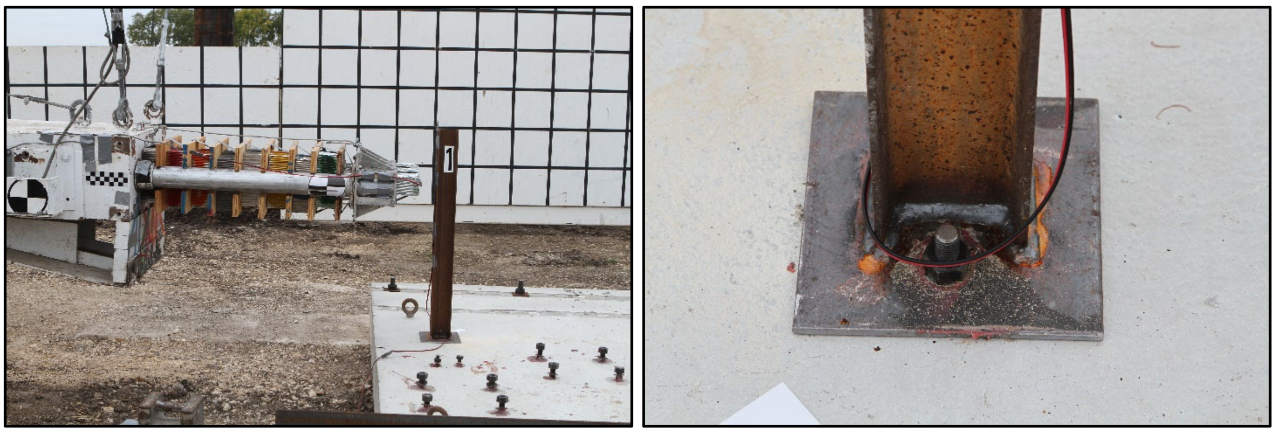

Figure 3.5. Post before Test No. 611971-01 P1.

3.4.1.3. Test Article Damage

The baseplate deformed and released from anchor bolts. The nuts and threaded ends released from the anchors. The post slightly deformed at the base plate. The anchor bolts sheared and released the baseplate.

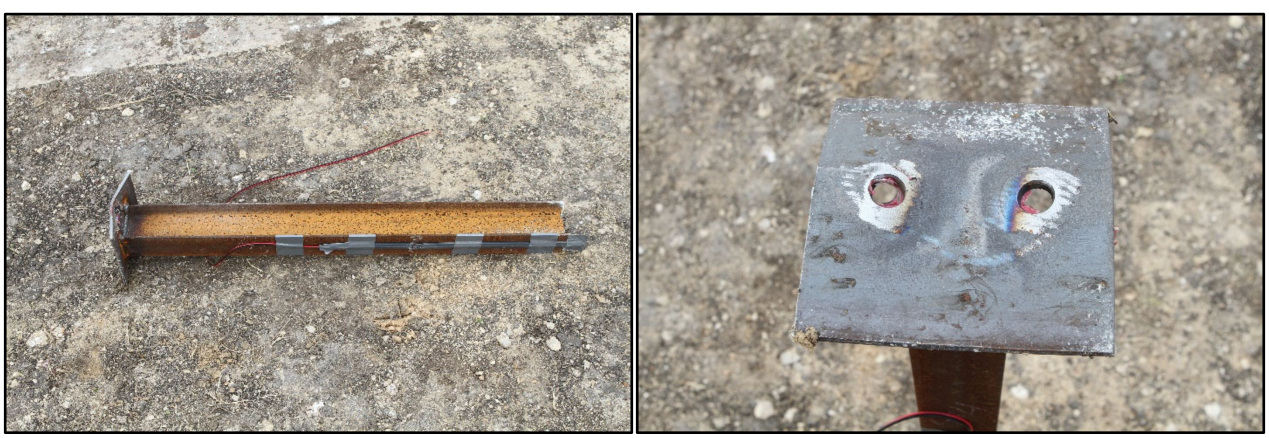

Figure 3.6. Post after Test No. 611971-01 P1.

Figure 3.7. Concrete after Test No. 611971-01 P1.

3.4.2. Test 611971-01 P2 – Option 3

3.4.2.1. Test Article Details

The post evaluated in this test was Option 3. This design utilized four epoxy anchors, a 12-inch square baseplate, and an S3x5.7 post. Further details can be found in Figure 3.4 above and Appendix C.

3.4.2.2. Impact Conditions

The pendulum surrogate vehicle (bogie) impacted the post at 90 degrees (post loaded in strong axis) and at 21.2 mi/h. The center of the crushable bogie nose was aligned at 27.75 inches above grade.

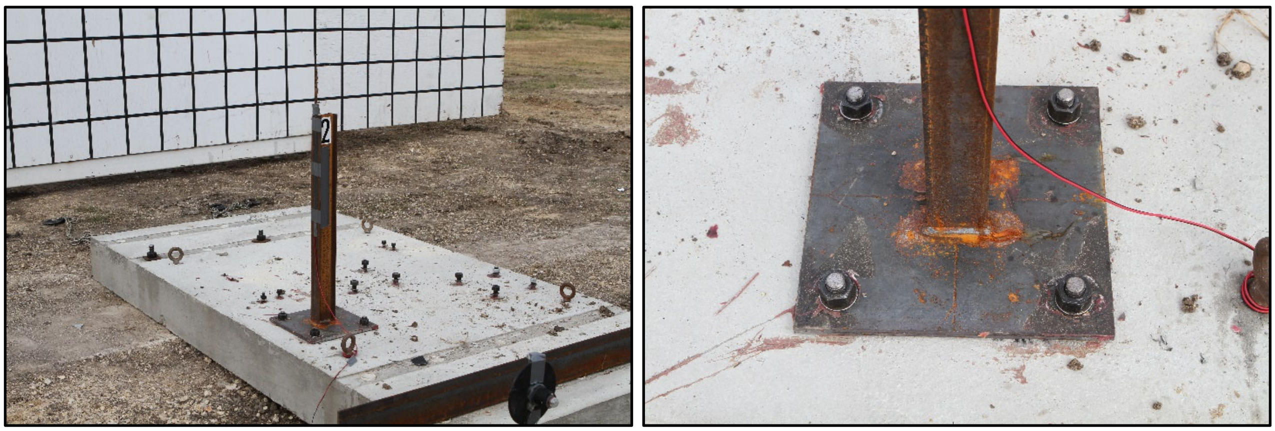

Figure 3.8. Post before Test No. 611971-01 P2.

3.4.2.3. Test Article Damage

The front flange released from welds, the web partially tore, and the post leaned toward the field side.

Figure 3.9. Post after Test No. 611971-01 P2.

3.4.3. Test 611971-01 P3 - Option 3

3.4.3.1. Test Article Details

The post evaluated in this test was Option 3. This design utilized four epoxy anchors, a 12-inch square baseplate, and an S3x5.7 post. Further details can be found in Figure 3.4 above and Appendix C.

3.4.3.2. Impact Conditions

The pendulum surrogate vehicle (bogie) impacted the post at 0 degrees (post loaded in weak axis) and at 21.9 mi/h. The center of the crushable bogie nose was aligned at 28.25 inches above grade.

Figure 3.10. Post before Test No. 611971-01 P3.

3.4.3.3. Test Article Damage

The post leaned 19.7 degrees toward field side.

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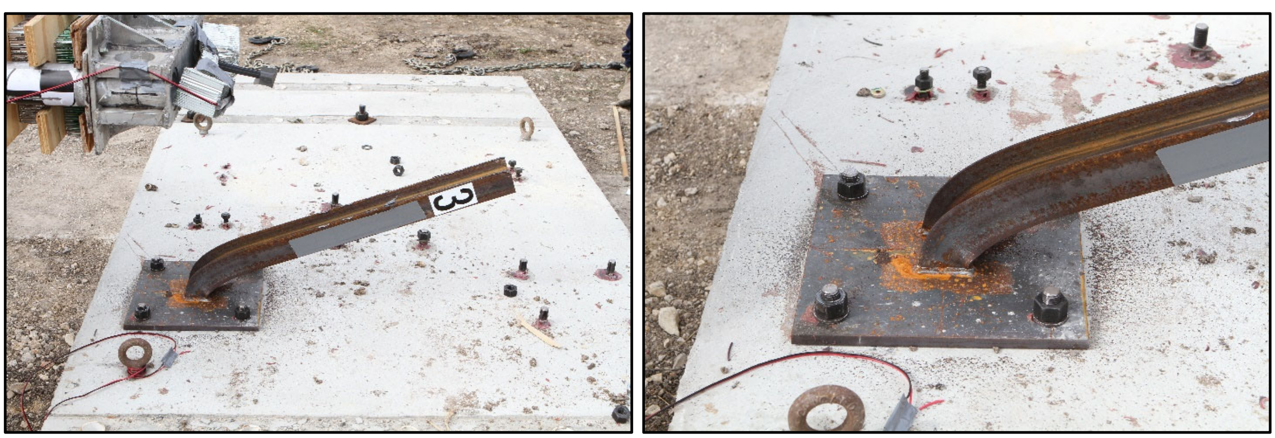


Figure 3.11. Post after Test No. 611971-01 P3.

3.4.4. Test 611971-01 P4 – Option 4

3.4.4.1. Test Article Details

The post evaluated in this test was Option 4. This design utilized two ⅝-inch epoxy anchors, a 6-inch square baseplate, and an S3x5.7 post. Further details can be found in Figure 3.4 above and Appendix C.

3.4.4.2. Impact Conditions

The pendulum surrogate vehicle (bogie) impacted the post at 90 degrees (post loaded in strong axis) and at a speed of 22.3 mi/h. The center of the crushable bogie nose was aligned at 26.25 inches above grade.

Figure 3.12. Post before Test No. 611971-01 P4.

3.4.4.3. Test Article Damage

The baseplate deformed, the post leaned away from the impact side, and the anchors sheared.

Figure 3.13. Post after Test No. 611971-01 P4.

3.4.5. Test 611971-01 P5 – Option 3

3.4.5.1. Test Article Details

The post evaluated in this test was Option 3. This design utilized four epoxy anchors, a 12-inch square baseplate, and an S3x5.7 post. Further details can be found in Figure 3.4 above and Appendix C.

3.4.5.2. Impact Conditions

The pendulum surrogate vehicle (bogie) impacted the post at 0 degrees (post loaded in strong axis) and at 21.9 mi/h. The center of the crushable bogie nose was aligned at 30.0 inches above grade.

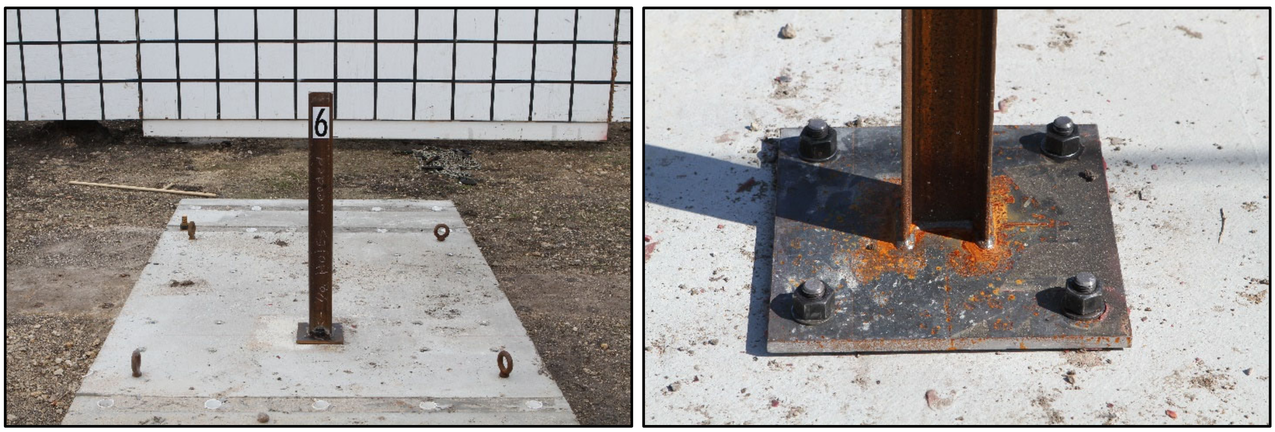


Figure 3.14. Post before Test No. 611971-01 P5.

3.4.5.1. Test Article Damage

The post released at the welds and partially tore. The baseplate and anchors remained in place.

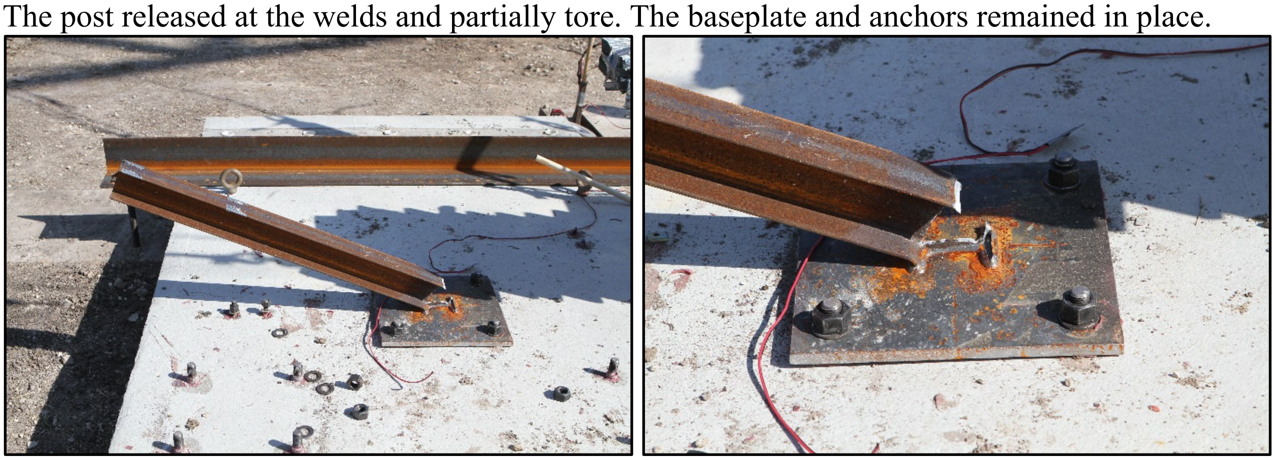


Figure 3.15. Post after Test No. 611971-01 P5.

3.4.6. Test 611971-01 P6 – Option 5

3.4.6.1. Test Article Details

The post evaluated in this test was Option 3. This design utilized two ⅞-inch epoxy anchors, a 6-inch square baseplate, and an S3x5.7 post. Further details can be found in Figure 3.4 above and Appendix C.

3.4.6.2. Impact Conditions

The pendulum surrogate vehicle (bogie) impacted the post at 90 degrees (post loaded in strong axis) and 21.8 mi/h. The center of the crushable bogie nose was aligned at 26.25 inches above grade.

Figure 3.16. Post before Test No. 611971-01 P6.

3.4.6.3. Test Article Damage

The baseplate deformed and released. The post remained attached to the baseplate. The anchors were sheared.

Figure 3.17. Post after Test No. 611971-01 P6.

3.4.7. Test 611971-01 P7 – Option 2

3.4.7.1. Test Article Details

The post evaluated in this test was Option 2. This design utilized four Hilti HDI SS 303 Flush Anchors, a 12-inch square baseplate, and an S3x5.7 post. Further details can be found in Figure 3.4 above and Appendix C.

3.4.7.2. Impact Conditions

The pendulum surrogate vehicle (bogie) impacted the post at 90 degrees (post loaded in strong axis) and 21.9 mi/h. The center of the crushable bogie nose was aligned at 28.875 inches above grade.

Figure 3.18. Post before Test No. 611971-01 P7.

3.4.7.3. Test Article Damage

The baseplate deformed the impact, the two impact side bolts released from concrete, and the concrete was damaged in the rear bolt mounting area

Figure 3.19. Post after Test No. 611971-01 P7.

3.5. SUMMARY AND CONCLUSIONS

The research team evaluated the performance of the several design alternatives. In particular, the research team was investigating reliable release of the post through yielding or fracturing. Ideally, the anchors would remain in place, and the concrete would exhibit minimal damage. This would allow for ease of replacement or repair.

Tests P2 and P3 (both Option 3) exhibited the ideal behavior which the research team desired. The posts fractured near the baseplate weld location, and the anchors remained intact. Test P2 was repeated in Test P5 to ensure repeatability of the release mechanism. Test P5 was also successful with the posts fracturing near the baseplate weld location, and the anchors remaining intact.

Tests P1 (Option 4), P4, (Option 4) and P6 (Option 5) exhibited bolts shearing near grade, which would cause repair or replacement to be more difficult. In test P7 (Option 2), the Hilti HDI SS 303 Flush Anchors were removed from the concrete structure during the impact. Furthermore, significant damage was found on the concrete structure.

From the results of these tests, the research team recommended the implementation of Option 3 into the full-scale system tested to *MASH* criteria.

Chapter 4. SYSTEM DETAILS FOR CRASH TESTING

4.1. TEST ARTICLE AND INSTALLATION DETAILS

The installation consisted of a W-beam guardrail system with a central weak post section that was mounted on a concrete storm sewer drop inlet and sidewalk (located downstream of the inlet). The installation included a curb which transitioned into the curb inlet. The installation was 156 feet 3 inches long, with the top of the W-beam rail at approximately 31 inches above grade.

The concrete structure mount post section spanned from post 10 through 17. These posts incorporated design Option 3 discussed in the previous chapters. Posts 10 through 14 had HSS 8×4×¼ blockouts. The W-beam was attached to posts 15, 16, and 17 with W-beam backup plates and no blockouts. Other W6×8.5 posts in the installation incorporated standard 8-inch deep timber blockouts. Post 9 was an exception, as it employed two 8-inch timber blockouts in tandem to avoid interference with the drop inlet paving.

Figure 4.1 presents the overall information on the W-Beam Guardrail with Modified Special Steel Posts for Concrete Structure Mount, and Figure 4.2 provides photographs of the installation. Appendix D provides further details on the W-Beam Guardrail with Modified Special Steel Posts for Concrete Structure Mount. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground. Construction was subcontracted, but supervised by TTI Proving Ground personnel.

4.2. DESIGN MODIFICATIONS DURING TESTS

No modification was made to the installation during the testing phase.

4.3. MATERIAL SPECIFICATIONS

The specified compressive strength of the concrete used in the curb and sidewalk was 3400 psi. On April 21, 2021, the day before the test, the average compressive strength of the concrete was 3173 psi at 12 days of age.

Appendix E provides material certification documents for the materials used to install/construct the W-Beam Guardrail with Modified Special Steel Posts for Concrete Structure Mount.

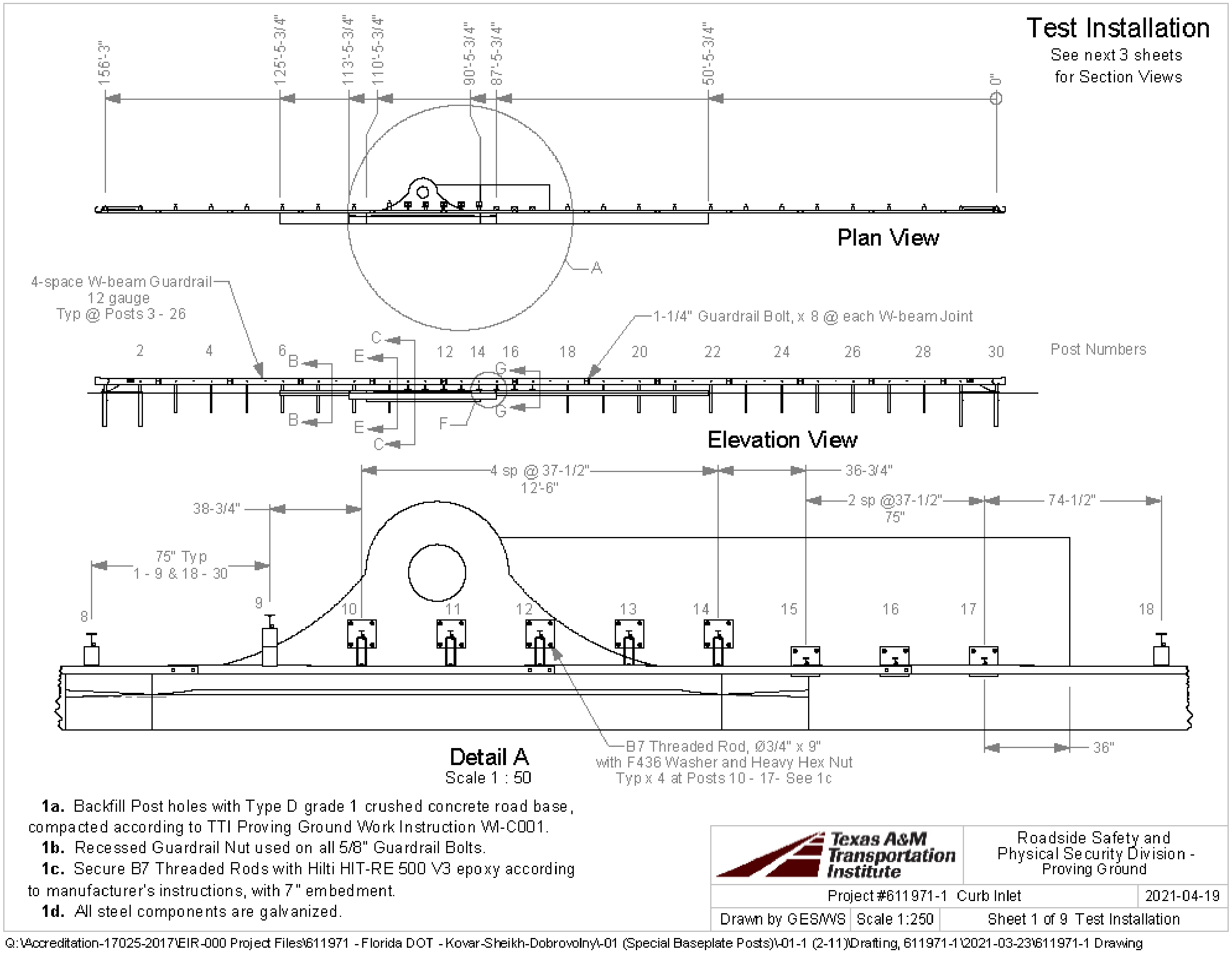


Figure 4.1. Details of W-Beam Guardrail with Modified Special Steel Posts for Concrete Structure Mount.

Figure 4.2. W-Beam Guardrail with Modified Special Steel Posts for Concrete Structure Mount prior to Testing.

4.4. SOIL CONDITIONS

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

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the W-Beam Guardrail with Modified Special Steel Posts for Concrete Structure Mount for full-scale crash testing, two 6-ft long W6×16 posts were installed in the immediate vicinity of the test installation using the same fill materials and installation procedures used in the test installation and the standard dynamic test. Table F.1 in Appendix F presents minimum soil strength properties established through the dynamic testing performed in accordance with *MASH* Appendix B.

As determined by the tests summarized in Appendix F, Table F.1, the minimum post loads required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, are 4420 lbf, 4981 lbf, and 5282 lbf (90 percent of static load for the initial standard installation). On the day of the test, April 22, 2021, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 5505 lbf, 6868 lbf, and 8434 lbf. Table F.2 in Appendix F shows the strength of the backfill material in which the W-Beam Guardrail with Modified Special Steel Posts for Concrete Structure Mount was installed met minimum *MASH* requirements for soil strength.

Chapter 5. CRASH TEST REQUIREMENTS AND EVALUATION CRITERIA

5.1. CRASH TEST PERFORMED/MATRIX

Table 5.1. shows the test conditions and evaluation criteria for *MASH* TL-2 for longitudinal barriers. The target critical impact points (CIPs) for each test were determined using the information provided in *MASH* Section 2.3.2 and previous crash testing experience. Figure 5.1 shows the target CIP for *MASH* Test 2-11 on the W-Beam Guardrail with Modified Special Steel Posts for Concrete Structure Mount. The crash tests and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 6 presents brief descriptions of these procedures.

Table 5.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-2 Longitudinal Barriers.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Longitudinal Barrier	2-10	1100C	44 mi/h	25°	A, D, F, H, I
	2-11	2270P	44 mi/h	25°	A, D, F, H, I

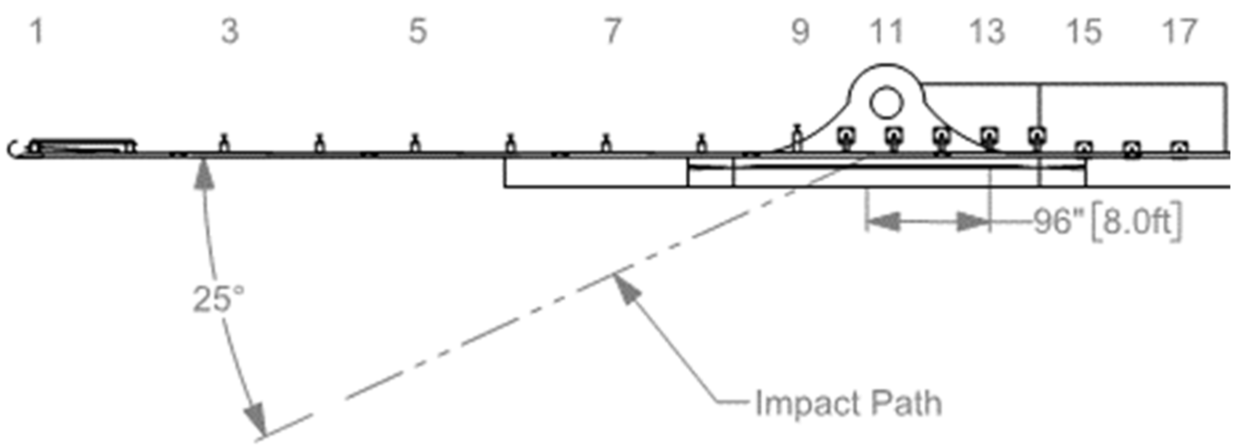


Figure 5.1. Target CIP for *MASH* Test 2-11 on W-Beam Guardrail with Modified Special Steel Posts for Concrete Structure Mount.

The research team concluded *MASH* Test 2-11 was more critical for crash testing than *MASH* test 2-20 based upon other completed crash testing. There were two factors in this conclusion; first, the effect the curb has on the trajectory of the small car, and second, the ability of the system to contain and redirect the small car.

If the trajectory of the vehicle is affected by the impact with the curb, the impact conditions could be worsened. In this investigation, the research team reviewed two research projects, both completed by TTI. The first project was sponsored by the Louisiana Department of Transportation and Development (*6*). In particular, the research team reviewed *MASH* Test 3-10 on a bridge rail system that incorporated a 10-inch curb (test number 606861-03). After the small car impacted the curb, it proceeded to impact the bridge railing. The research team reviewed the change in trajectory of the vehicle after the initial impact with the curb. The change in vertical trajectory of the vehicle was minimal and within standard range of motion of vehicle suspensions. The horizontal trajectory of the vehicle was also minimally affected by the curb impact. The change in horizontal trajectory was well within the allowable tolerance of *MASH* crash testing. To bracket performance with relation to curb heights, the research team also reviewed TTI test number 614091-01, which was sponsored by the Roadside Safety Pooled Fund (*7)*. This test evaluated the effect curb and sidewalks had on impact conditions for bridge railings. To accomplish this, a *MASH* small car traveled at TL-2 speeds (nominally 44 mph) when it initially traversed an 8-inch curb. Similar to the Louisiana DOTD test, this vehicle's trajectory was minimally affected by the curb interaction. The change in vertical trajectory of the vehicle was within standard range of motion of vehicle suspensions, and the horizontal trajectory of the vehicle was well within the allowable tolerance of *MASH* crash testing. Based on this evaluation, the research team concluded the curb included in the inlet structure evaluated under this project would not significantly affect the trajectory of the small car under impact conditions.

The research team also evaluated the ability of the railing to contain and redirect the *MASH* small car. In this investigation, the research team reviewed the results of TTI test 490023-6-2 sponsored by TxDOT (*8*). This *MASH* test 2-10 involved the small car impacting the TxDOT T631 bridge rail at a nominal impact speed of 44 mi/h. Both the TxDOT T631 design and the design explored through full-scale crash testing under this project utilize S3x5.7 surface mounted posts. The S3x5.7 post has historically been considered a "weak" post which easily yields during impact loading. In TTI test number 490023-6-2, this yielding behavior was exhibited, and the small car was successfully contained and redirected. Because of the similarities between the T631 design and the currently investigated design, the research team expects the design evaluated in this project to behavior similarly under *MASH* impact conditions. Therefore, this current design is expected to also successfully contain and redirect the small car in *MASH* test 2-10. Lastly, the structural adequacy of the FDOT design is evaluated under this project with *MASH* test 2-11. With its success with the pickup truck evaluation, the system is expected to safely contain and redirect the small car as well.

With the review of these previous crash tests, the research team concluded *MASH* test 3-11 to be more critical to complete than *MASH* test 3-10.

5.2. CRASH TEST EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2 and 5-1 of *MASH* were used to evaluate the crash test reported herein. Table 5.1. lists the test conditions and evaluation criteria required for *MASH* TL-2, and Table 5.2 provides detailed information on the evaluation criteria. An evaluation of the crash test results is presented in Chapter 8.

Table 5.2. Evaluation Criteria Required for *MASH* TL-2 Longitudinal Barriers.

Evaluation Factors	Evaluation Criteria	*MASH* Tests
Structural Adequacy	*A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	*2-10 and 2-11*
Occupant Risk	*D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone.* *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.*	*2-10 and 2-11*
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	*2-10 and 2-11*
	H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	*2-10 and 2-11*
	I. The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	*2-10 and 2-11*

Chapter 6. CRASH TEST CONDITIONS

6.1. TEST FACILITY

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

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

6.2. VEHICLE TOW AND GUIDANCE SYSTEM

The vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point and through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2:1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released and ran unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site.

6.3. DATA ACQUISITION SYSTEMS

6.3.1. Vehicle Instrumentation and Data Processing

Each test vehicle was instrumented with a self-contained onboard data acquisition system. The signal conditioning and acquisition system is a multi-channel data acquisition system (DAS) produced by Diversified Technical Systems Inc. The accelerometers, which measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra-small, solid-state units designed for crash test service. The data acquisition hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the channels is capable of providing precision amplification, scaling, and filtering based on transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 samples per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit in case the primary battery cable is severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data are downloaded from the DAS unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

Each DAS is returned to the factory annually for complete recalibration and to ensure that all instrumentation used in the vehicle conforms to the specifications outlined by SAE J211. All accelerometers are calibrated annually by means of an ENDEVCO□ 2901 precision primary vibration standard. This standard and its support instruments are checked annually and receive a National Institute of Standards Technology (NIST) traceable calibration. The rate transducers used in the data acquisition system receive calibration via a Genisco Rate-of-Turn table. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel per SAE J211. Calibrations and evaluations are also made anytime data are suspect. Acceleration data are measured with an expanded uncertainty of ±1.7 percent at a confidence factor of 95 percent (k = 2).

TRAP uses the DAS-captured data to compute the occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and highest 10-millisecond (ms) average ridedown acceleration. TRAP calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with an SAE Class 180-Hz low-pass digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

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

6.3.2. Anthropomorphic Dummy Instrumentation

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

6.3.3. Photographic Instrumentation Data Processing

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

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

- A third placed with a field of view parallel to and aligned with the installation at the downstream end.

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

Chapter 7. *MASH* TEST 2-11 (CRASH TEST NO. 611971-01-1)

7.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 2-11 involves a 2270P vehicle weighing 5000 lb ± 110 lb impacting the CIP of the longitudinal barrier at an impact speed of 44 mi/h ± 2.5 mi/h and an angle of 25 degrees ± 1.5 degrees. The CIP for *MASH* Test 2-11 on the W-Beam Guardrail with Modified Special Steel Posts for Concrete Structure Mount was 8 ft ± 1 ft upstream of the centerline of post 13. Figure 5.1 and Figure 7.1 depict the target impact setup.

Figure 7.1. Guardrail/Test Vehicle Geometrics for Test No. 611971-01-1.

The 2270P vehicle weighed 5032 lb, and the actual impact speed and angle were 45.7 mi/h and 25.2 degrees. The actual impact point was 8.1 ft upstream of the centerline of post 13. Minimum target IS was 52 kip-ft, and actual IS was 64 kip-ft.

7.2. WEATHER CONDITIONS

The test was performed on the morning of April 22, 2021. Weather conditions at the time of testing were as follows: wind speed: 8 mi/h; wind direction: 107 degrees (vehicle was traveling at a heading of 145 degrees); temperature: 67°F; relative humidity: 49 percent.

7.3. TEST VEHICLE

Figure 7.2 shows the 2015 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5032 lb, and its gross static weight was 5032 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 28.25 inches. Tables D.1 and D.2 in Appendix D.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

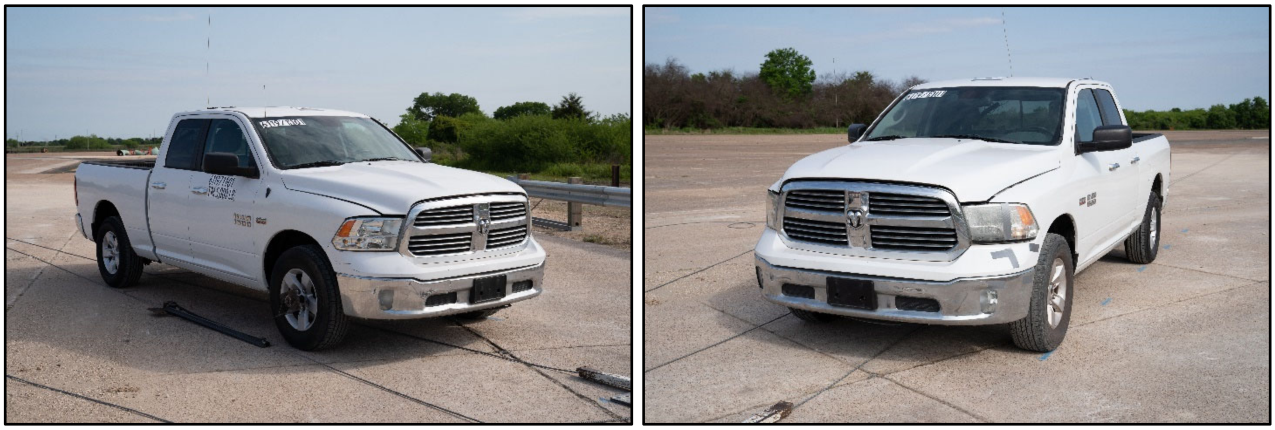


Figure 7.2. Test Vehicle before Test No. 611971-01-1.

7.4. TEST DESCRIPTION

Table 7.1 lists events that occurred during Test No. 611971-01-1. Figures D.1 and D.2 in Appendix D.2 present sequential photographs during the test.

Table 7.1. Events during Test No. 611971-01-1.

Time (s)	Events
0.0000	Vehicle impacted guardrail
0.0010	Left front tire impacted the curb
0.0250	Post 11 began to deflect towards the field side
0.0420	Vehicle began to redirect
0.2080	Left rear tire impacted the curb
0.2740	Left rear bumper contacted the guardrail
0.3240	Vehicle traveling parallel with guardrail
0.4750	Right rear tire lifted off of the pavement
0.8300	Vehicle lost contact with the guardrail while traveling at 22.7 mi/h, at a trajectory angle of 18.7°, and a heading angle of 11.7°

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied shortly after the vehicle lost contact with the guardrail, and the vehicle subsequently came to rest with the left front corner of the vehicle against the traffic face of the guardrail 2 ft downstream of post 26, which was 78.6 ft downstream of the actual impact point.

7.5. DAMAGE TO TEST INSTALLATION

Figure 7.3 and Figure 7.4 shows the damage to the guardrail. The vehicle had a secondary impact with the rail just before coming to rest 2 ft downstream of post 26. There was some concrete spalling on the traffic side face of the inlet at post 10. The rail had tears in two different locations. There were two tears located at post 11 measuring 2 and 3 inches, respectively. The other tear was approximately 3 inches long and was located downstream of the splice at post 17. The rail did not fully tear and maintained continuity. The dislodged blockouts and spacers created a debris field on the field side of the installation measuring 28 ft behind and 22 ft downstream from post 9. Posts 12 through 14 released from their blockouts and fractured at the base of the post. Post 15 separated from the base and landed 20 inches downstream.

Figure 7.4. Posts 11 through 18 after Test No. 611971-01-1.

Table 7.2 provides more information regarding damage to the installation. Working width* was 30.1 inches, and height of working width was 57.5 inches. Maximum dynamic deflection during the test was 23.0 inches, and maximum permanent deformation was 17.0 inches.

Figure 7.3. Guardrail after Test No. 611971-01-1.

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

Figure 7.4. Posts 11 through 18 after Test No. 611971-01-1.

Table 7.2. Post Movement during Test No. 611971-01-1.

	Soil Gap (inches)				Post Lean from Vertical (degrees)	
Post	**Disturbed?**	**U/S**	**F/S**	**T/S**	**D/S**	**F/S**
1	-	¾	-	-	-	-
2	✓	-	-	-	-	-
3-5	✓	-	-	-	-	-
8	-	¼	-	-	-	-
9	-	-	-	⅛	-	-
10	-	-	-	-	-	1°
11	-	-	-	-	-	16°
12	-	-	-	-	-	44°
13	-	-	-	-	-	72°
14	-	-	-	-	-	60°
15	-	-	-	-	-	73°
16	-	-	-	-	-	-
17	-	-	-	-	3.1°	-
18	-	-	⅜	-		1°
24	-	-	⅝	⅝	-	-
25	-	-	-	¾	-	1°
26	-	-	-	¼	-	-
27	✓	-	-	-	-	-

U/S=upstream; F/S=field side; T/S=traffic side; D/S=downstream;

7.6. DAMAGE TO TEST VEHICLE

Figure 7.5 shows the damage sustained by the vehicle. The front bumper, hood, grill, left front fender, left front tire and rim, left lower control arm, left front door, left exterior bed, left rear tire and rim, and rear bumper were damaged. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 8.0 inches in the side plane at the left front corner at bumper height. No occupant compartment deformation or intrusion were observed. Figure 7.6 shows the interior of the vehicle. Tables D.3 and D.4 in Appendix D.1 provide exterior crush and occupant compartment measurements.

7.7. OCCUPANT RISK FACTORS

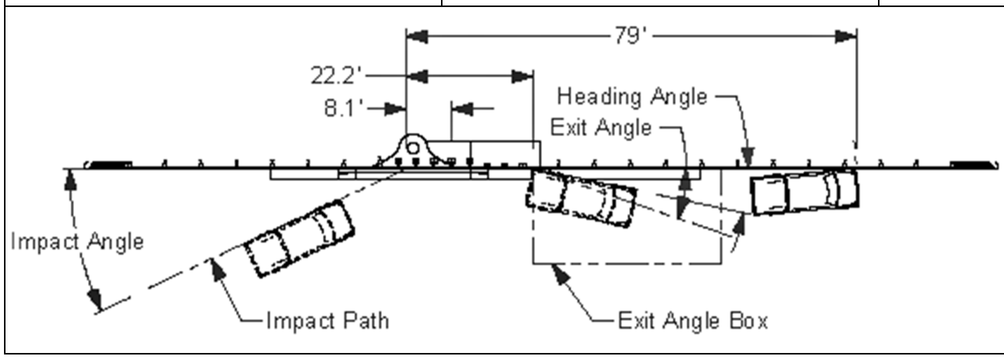
Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 7.3. Figure D.3 in Appendix D.3 shows the vehicle angular displacements, and Figures D.4 through D.6 in Appendix D.4 show acceleration versus time traces. Figure 7.7 summarizes pertinent information from the test.

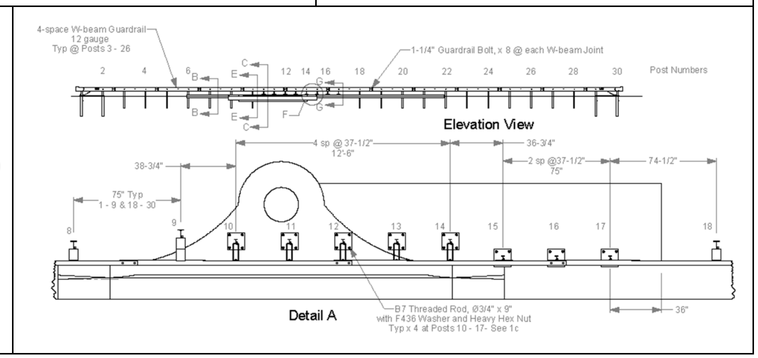
Figure 7.5. Test Vehicle after Test No. 611971-01-1.

Figure 7.6. Interior of Test Vehicle after Test No. 611971-01-1.

Table 7.3. Occupant Risk Factors for Test No. 611971-01-1.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)		
Longitudinal	15.0 ft/s	at 0.1664 s on left side of interior
Lateral	12.6 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	8.4 g	0.2795 - 0.2895 s
Lateral	4.7 g	0.3411 - 0.3511 s
Theoretical Head Impact Velocity (THIV)	5.7 m/s	at 0.1584 s on left side of interior
Acceleration Severity Index (ASI)	0.6	0.0742 - 0.1242 s
Maximum 50-ms Moving Average		
Longitudinal	−3.7 g	0.0262 - 0.0762 s
Lateral	4.2 g	0.0510 - 0.1010 s
Vertical	1.5 g	0.3432 - 0.3932 s
Maximum Yaw, Pitch, and Roll Angles		
Roll	8°	2.0000 s
Pitch	4°	0.6052 s
Yaw	40°	0.7078 s





General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 2-11
TTI Test No.	611971-01-1
Test Date	2021-04-22

Test Article

Type	Longitudinal Barrier—Guardrail
Name	W-Beam Guardrail with Modified Special Steel Posts for Concrete Structure Mount
Installation Length	156 ft-3 inches
Material or Key Elements	Surface mounted weak posts on concrete storm sewer drop inlet and sidewalk.
Soil Type and Condition	Posts backfilled with Type D, Grade 1 crushed concrete

Test Vehicle

Type/Designation	2270P
Make and Model	2015 RAM 1500 Pickup
Curb	5062 lb
Test Inertial	5032 lb
Dummy	No dummy
Gross Static	5032 lb

Impact Conditions

Speed	45.7 mi/h
Angle	25.2°
Location/Orientation	8.1 ft upstream of post 13
Impact Severity	64 kip-ft

Exit Conditions

Speed	22.7 mi/h
Trajectory/Heading Angle	18.7°/11.7°

Occupant Risk Values

Longitudinal OIV	15.0 ft/s
Lateral OIV	12.6 ft/s
Longitudinal Ridedown	8.4 g
Lateral Ridedown	4.7 g
THIV	5.7 m/s
ASI	0.6
Max. 0.050-s Average	
Longitudinal	−3.7 g
Lateral	4.2 g
Vertical	1.5 g

Post-Impact Trajectory

Stopping Distance	Against traffic face 79 ft d/s of Impact

Vehicle Stability

Maximum Roll Angle	8°
Maximum Pitch Angle	4°
Maximum Yaw Angle	40°
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	23.0 inches
Permanent	17.0 inches
Working Width	30.1 inches
Height of Working Width	57.5 inches

Vehicle Damage

VDS	11LFQ3
CDC	11FLEW3
Max. Exterior Deformation	8.0 inches
OCDI	LF0000000
Max. Occupant Compartment Deformation	None

Figure 7.7. Summary of Results for *MASH* Test 2-11 on W-Beam Guardrail with Modified Special Steel Posts for Concrete Structure Mount.

Chapter 8. SUMMARY, CONCLUSIONS, AND IMPLEMENTATION

8.1. ASSESSMENT OF TEST RESULTS

The crash test reported herein was performed in accordance with *MASH* Test 2-11. Table 8.1 provides an assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 2-11 longitudinal barriers.

8.2. CONCLUSIONS

Table 8.1 shows that the W-Beam Guardrail with Modified Special Steel Posts for Concrete Structure Mount met the performance criteria for *MASH* Test 2-11 for longitudinal barriers. The justification in Section 5.1 demonstrated the critical nature of *MASH* test 2-11 compared to *MASH* test 2-10. Consequently, the W-beam guardrail with Modified Special Steel Posts for Concrete Structure Mount is considered *MASH* compliant.

Table 8.1. Performance Evaluation Summary for *MASH* Test 2-11 on W-Beam Guardrail with Modified Special Steel Posts for Concrete Structure Mount.

Test Agency: Texas A&M Transportation Institute | Test No.: 611971-01-1 | Test Date: 2021-04-22

***MASH* Test 2-11 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> *A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 23.0 inches.	Pass
<u>Occupant Risk</u> *D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	One post separated from the rail and base plate, however, did not penetrate or show potential for penetrating the installation, or present undue hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	No occupant compartment deformation or intrusion was observed.	
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 8° and 4°.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	Longitudinal OIV was 15.0 ft/s, and lateral OIV was 12.6 ft/s.	Pass
I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Maximum longitudinal occupant ridedown acceleration was 8.4 g, and maximum lateral occupant ridedown acceleration was 4.7 g.	Pass

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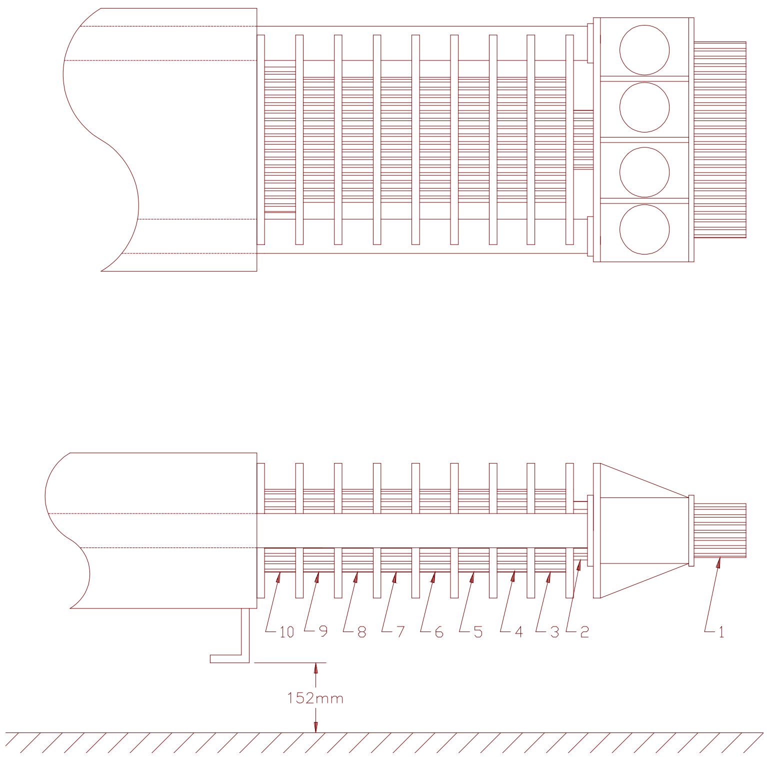
APPENDIX A. BOGIE NOSE DETAILS



Cartridge Number	Size (inches)	Area Effectively Removed by Pre-Crushing (inches^2)	Static Crush Strength (psi)	Total Nominal Crush Force for Each Cartridge (lbf)
1	2.75 × 16 × 3		130	5720
2	4 × 5 × 2		25	500
3	8 × 8 × 3	21	130	5590
4	8 × 8 × 3	15	230	11270
5	8 × 8 × 3	6	230	13340
6	8 × 8 × 3		230	14720
7	8 × 8 × 3	21	400	17200
8	8 × 8 × 3	12	400	20800
9	8 × 8 × 3		400	25600
10	8 × 10 × 3		400	32000

Figure A.1. Configuration of Pendulum Nose and Honeycomb

APPENDIX B. PENDULUM TEST PROCEDURES AND DATA ANALYSIS

The pendulum test and data analysis procedures were in accordance with guidelines presented TTI internal lab methods outlined in LM-PEN, *Pendulum Testing and Evaluation*. Brief descriptions of these procedures are presented as follows.

B.1. ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The bogie was instrumented with two accelerometers. One accelerometer is mounted at the rear of the bogie to measure longitudinal acceleration levels, the other is side-mounted at the CG of the bogey. The accelerometers are strain gage type with a linear millivolt output proportional to acceleration. Accelerometer data is compared after capture to ensure lack of anomalies that could affect test results.

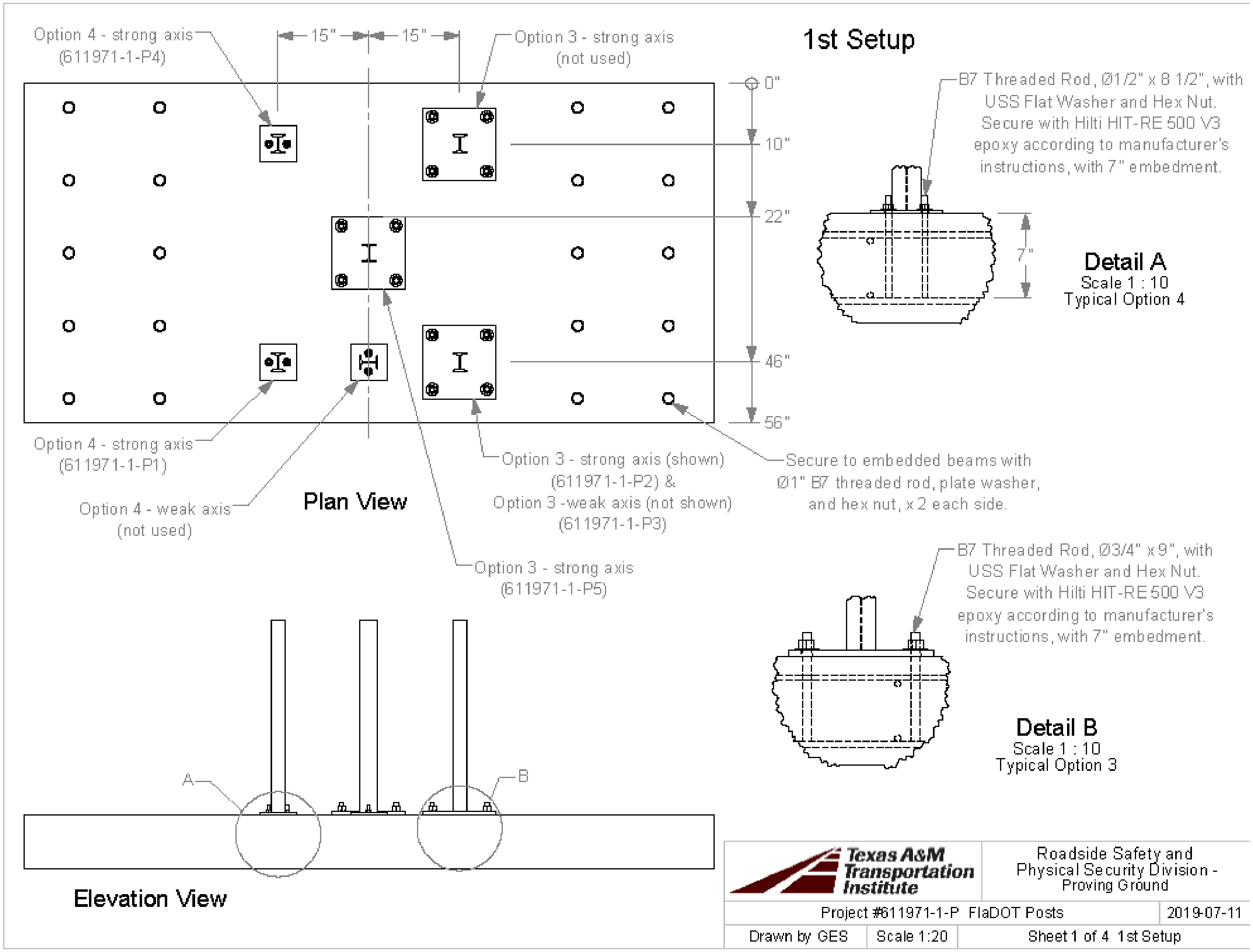
The electronic signals from the accelerometers were amplified and transmitted to a base station by means of constant bandwidth FM/FM telemetry radio link for recording. Calibration signals were recorded before and after the test and an accurate time reference signal was simultaneously recorded with the data. Pressure sensitive switches on the nose of the bogie were actuated by wooden dowel rods and initial contact to produce speed trap and "event" marks on the data record to establish the exact instant of contact with the installation, as well as impact velocity.

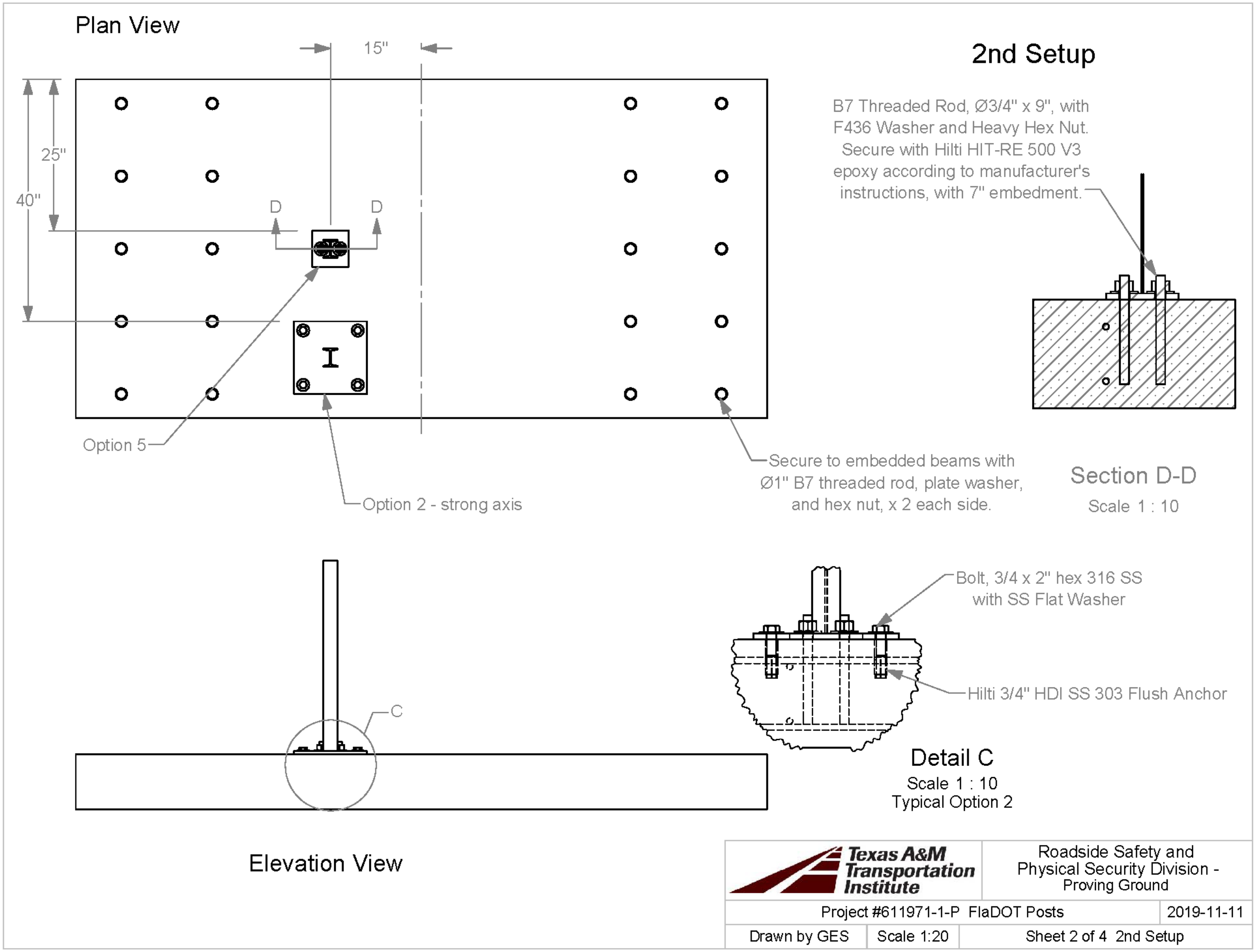
The multiplex of data channels, transmitted on one radio frequency, is received and demultiplexed onto TEAC® instrumentation data recorder. After the test, the data are played back from the TEAC® recorder and digitized. A proprietary software program (WinDigit) converts the analog data from each transducer into engineering units using the R-cal and pre-zero values at 10,000 samples per second, per channel. WinDigit also provides Society of Automotive Engineers (SAE) J211 class 180 phaseless digital filtering and bogie impact velocity.

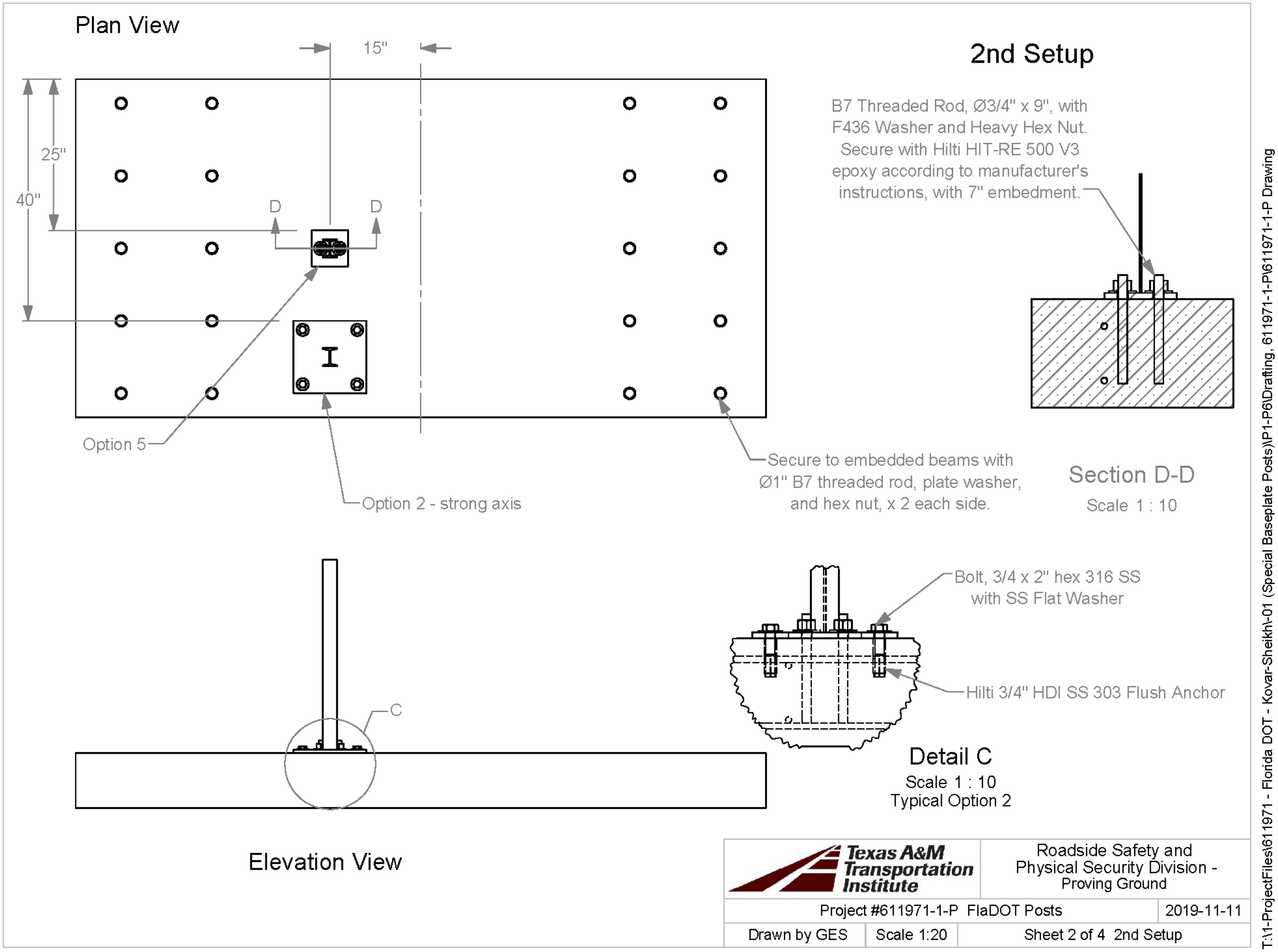
The Test Risk Assessment Program (TRAP) uses the data from WinDigit to compute occupant/compartment impact velocities, time of occupant/compartment impact after bogie impact, and the highest 10-ms average ridedown acceleration. TRAP calculates change in bogie velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms are computed. For reporting purposes, the data from the bogie-mounted accelerometers were then filtered with a 180 Hz digital filter and plotted using a commercially available software package (Microsoft EXCEL).

B.2. PHOTOGRAPHIC INSTRUMENTATION

A high-speed digital camera, positioned perpendicular to the path of the bogie and the test article, was used to record the collision period. The digital video files from this high-speed camera were analyzed on a computer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital video camera and still cameras were used to document the bogie nose and the test article before and after the test.


1st Setup
Option 4 - strong axis (611971-1-P4)
15"
15"
Option 3 - strong axis (not used)
0"
10"
22"
46"
56"
Option 4 - strong axis (611971-1-P1)
Option 4 - weak axis (not used)
Plan View
Option 3 - strong axis (shown) (611971-1-P2) & Option 3 -weak axis (not shown) (611971-1-P3)
Secure to embedded beams with Ø1" B7 threaded rod, plate washer, and hex nut, x 2 each side.
Option 3 - strong axis (611971-1-P5)
B7 Threaded Rod, Ø1/2" x 8 1/2", with USS Flat Washer and Hex Nut. Secure with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions, with 7" embedment.
7"
Detail A
Scale 1 : 10
Typical Option 4
B7 Threaded Rod, Ø3/4" x 9", with USS Flat Washer and Hex Nut. Secure with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions, with 7" embedment.
Detail B
Scale 1 : 10
Typical Option 3
A
B
Elevation View
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #611971-1-P FlaDOT Posts
2019-07-11
Drawn by GES
Scale 1:20
Sheet 1 of 4 1st Setup


Plan View
15"
25"
40"
D
D
Option 5
Option 2 - strong axis
2nd Setup
B7 Threaded Rod, Ø3/4" x 9", with F436 Washer and Heavy Hex Nut. Secure with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions, with 7" embedment.
Secure to embedded beams with Ø1" B7 threaded rod, plate washer, and hex nut, x 2 each side.
Section D-D
Scale 1 : 10
C
Elevation View
Bolt, 3/4 x 2" hex 316 SS with SS Flat Washer
Hilti 3/4" HDI SS 303 Flush Anchor
Detail C
Scale 1 : 10
Typical Option 2
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #611971-1-P FlaDOT Posts
2019-11-11
Drawn by GES
Scale 1:20
Sheet 2 of 4 2nd Setup


Plan View
15"
25"
40"
D
D
Option 5
Option 2 - strong axis
Secure to embedded beams with
Ø1" B7 threaded rod, plate washer,
and hex nut, x 2 each side.
2nd Setup
B7 Threaded Rod, Ø3/4" x 9", with
F436 Washer and Heavy Hex Nut.
Secure with Hilti HIT-RE 500 V3
epoxy according to manufacturer's
instructions, with 7" embedment.
Section D-D
Scale 1 : 10
C
Elevation View
Bolt, 3/4 x 2" hex 316 SS
with SS Flat Washer
Hilti 3/4" HDI SS 303 Flush Anchor
Detail C
Scale 1 : 10
Typical Option 2
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #611971-1-P FlaDOT Posts
2019-11-11
Drawn by GES
Scale 1:20
Sheet 2 of 4 2nd Setup
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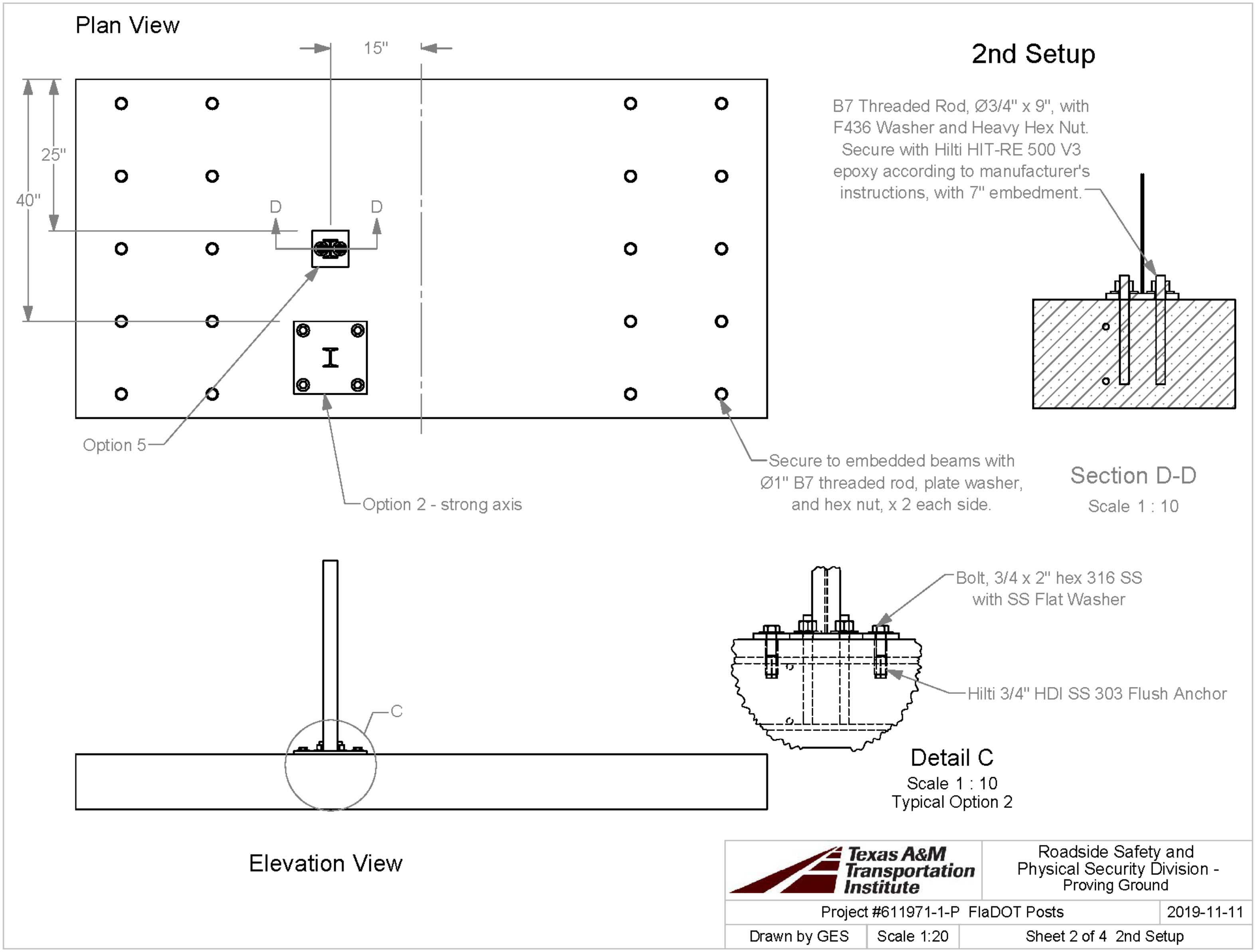

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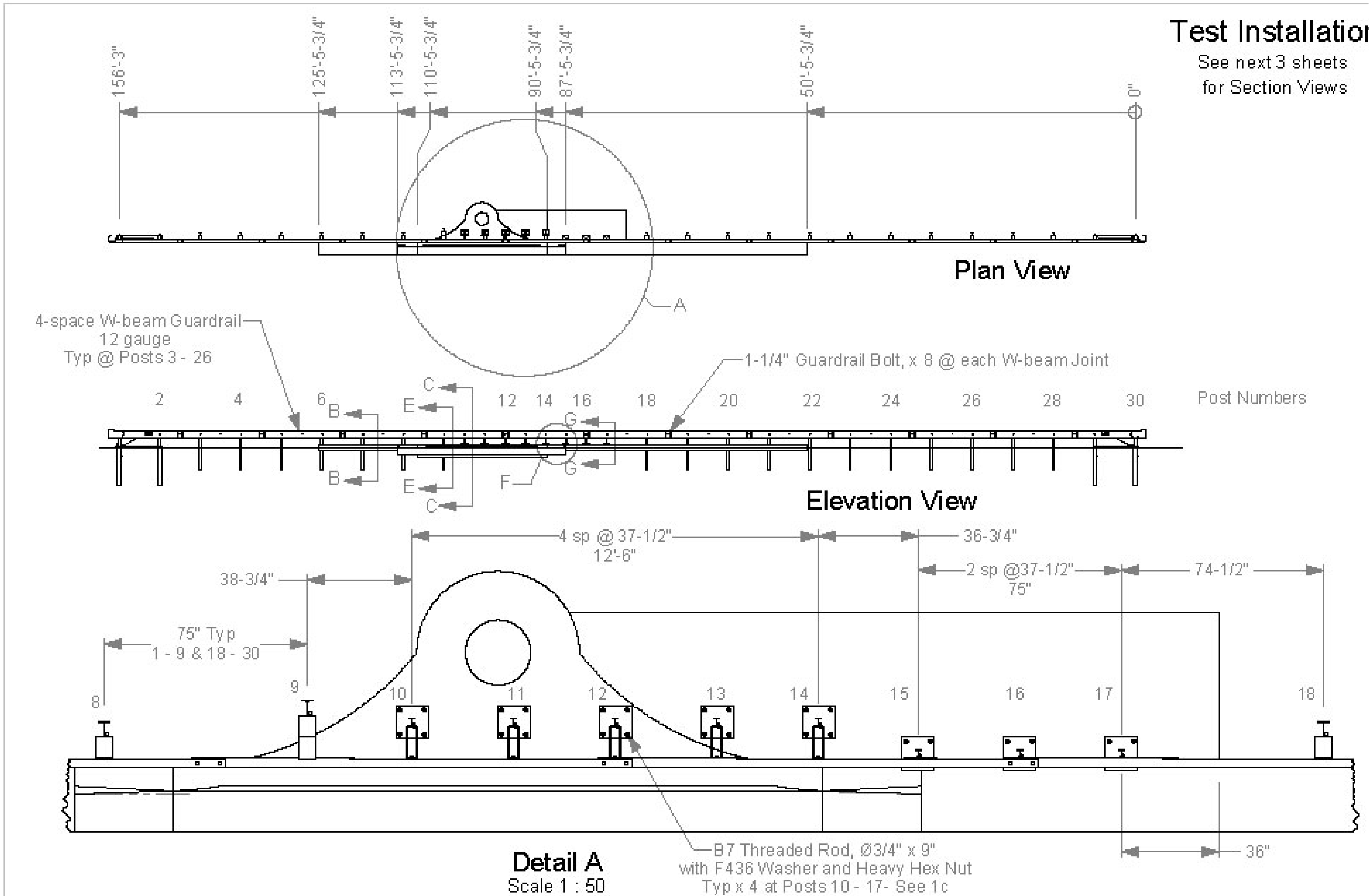
APPENDIX D. DETAILS OF W-BEAM GUARDRAIL WITH MODIFIED SPECIAL STEEL POSTSFOR CONCRETE STRUCTURE MOUNT

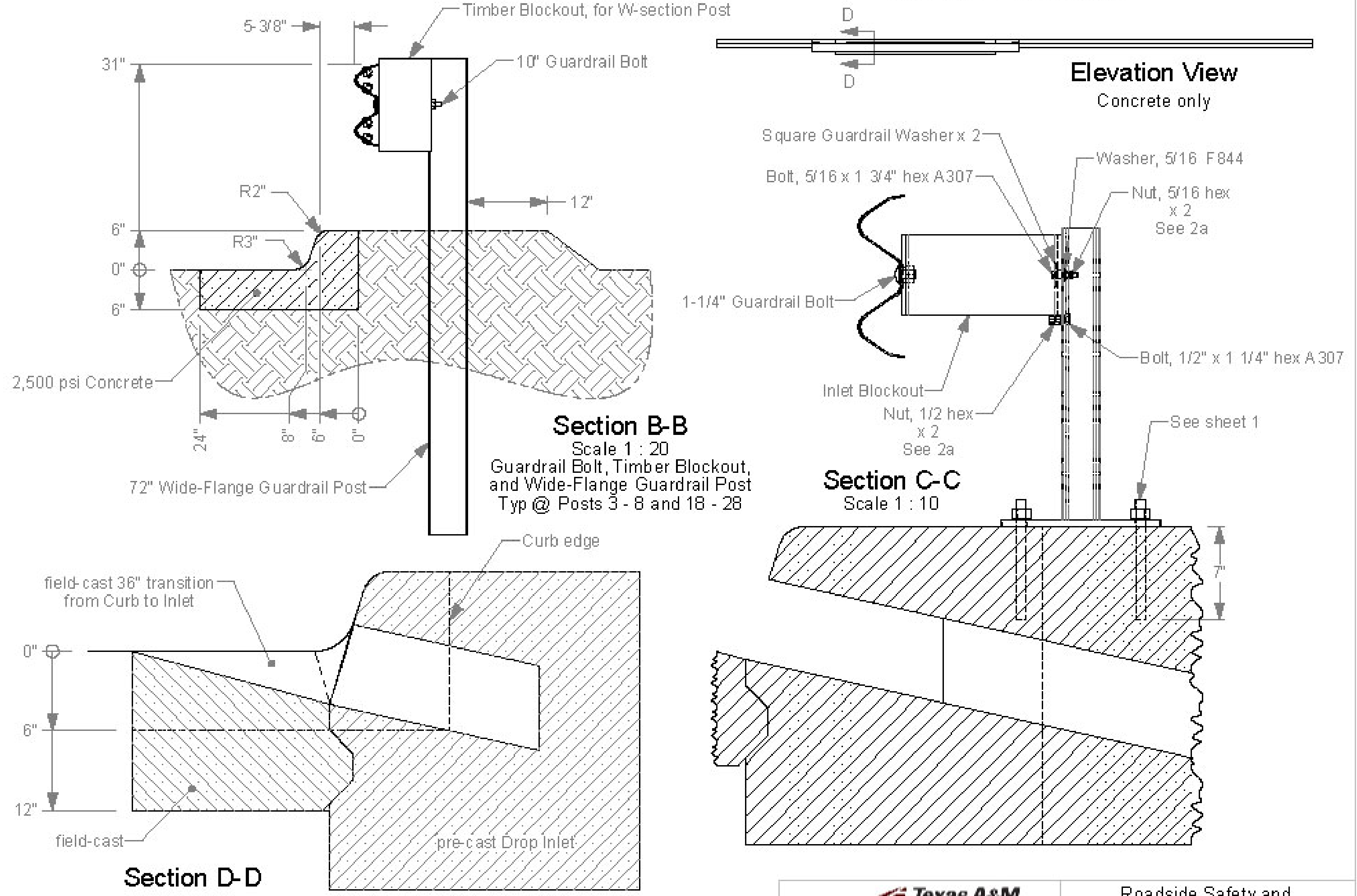


1a. Backfill Post holes with Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C001.
1b. Recessed Guardrail Nut used on all 5/8" Guardrail Bolts.
1c. Secure B7 Threaded Rods with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions, with 7" embedment.
1d. All steel components are galvanized.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #611971-1 Curb Inlet		2021-04-
Drawn by GES/WS	Scale 1:250	Sheet 1 of 9 Test Installation

Q:\Accreditation-17025-2017\EIR-000 Project Files\611971 - Florida DOT - Kovar-Sheikh-Dobrovolny\-01 (Special Baseplate Posts)\-01-1 (2-11)\Drafting, 611971-1\2021-03-23\611971-1 Drawing

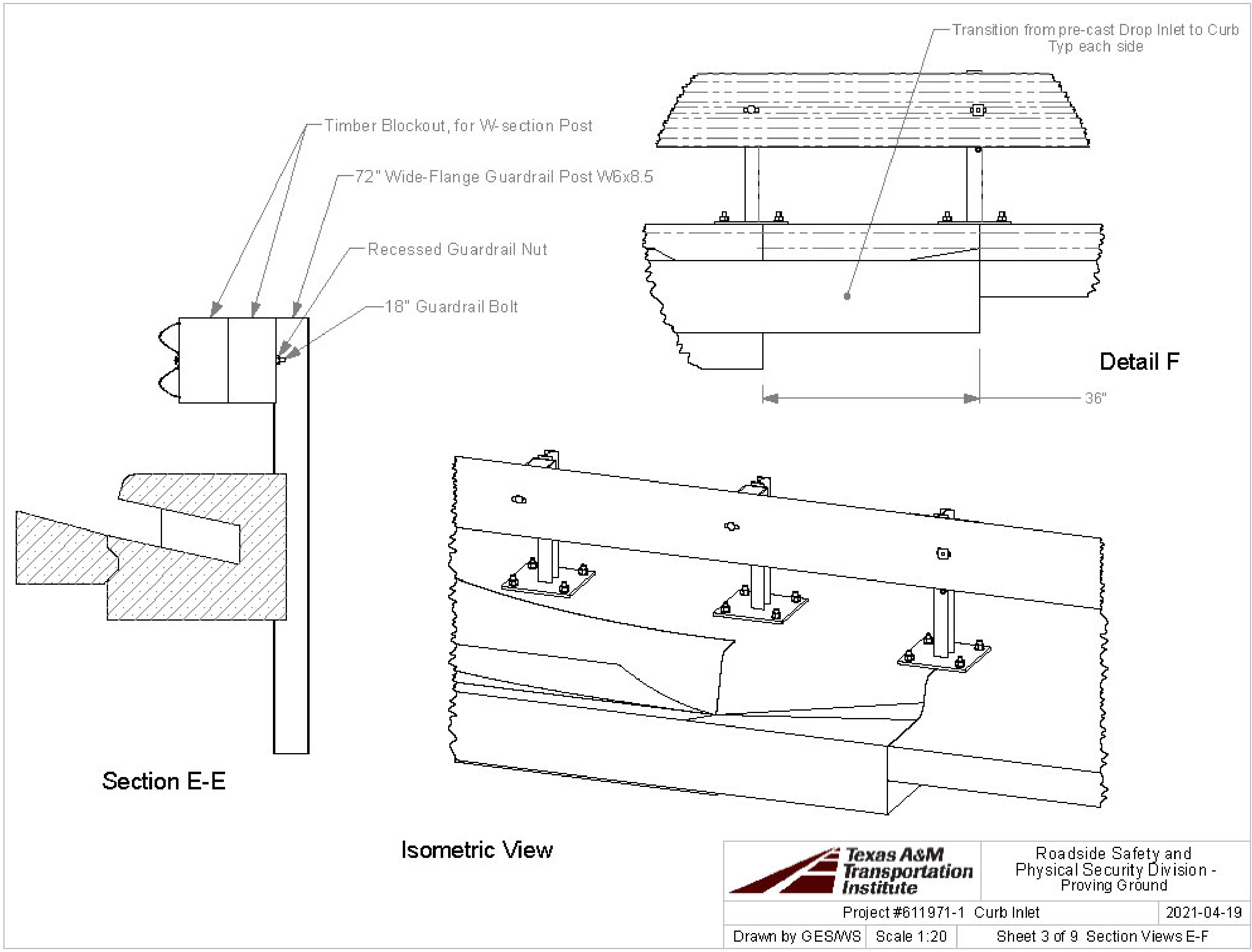
Section Views B-D



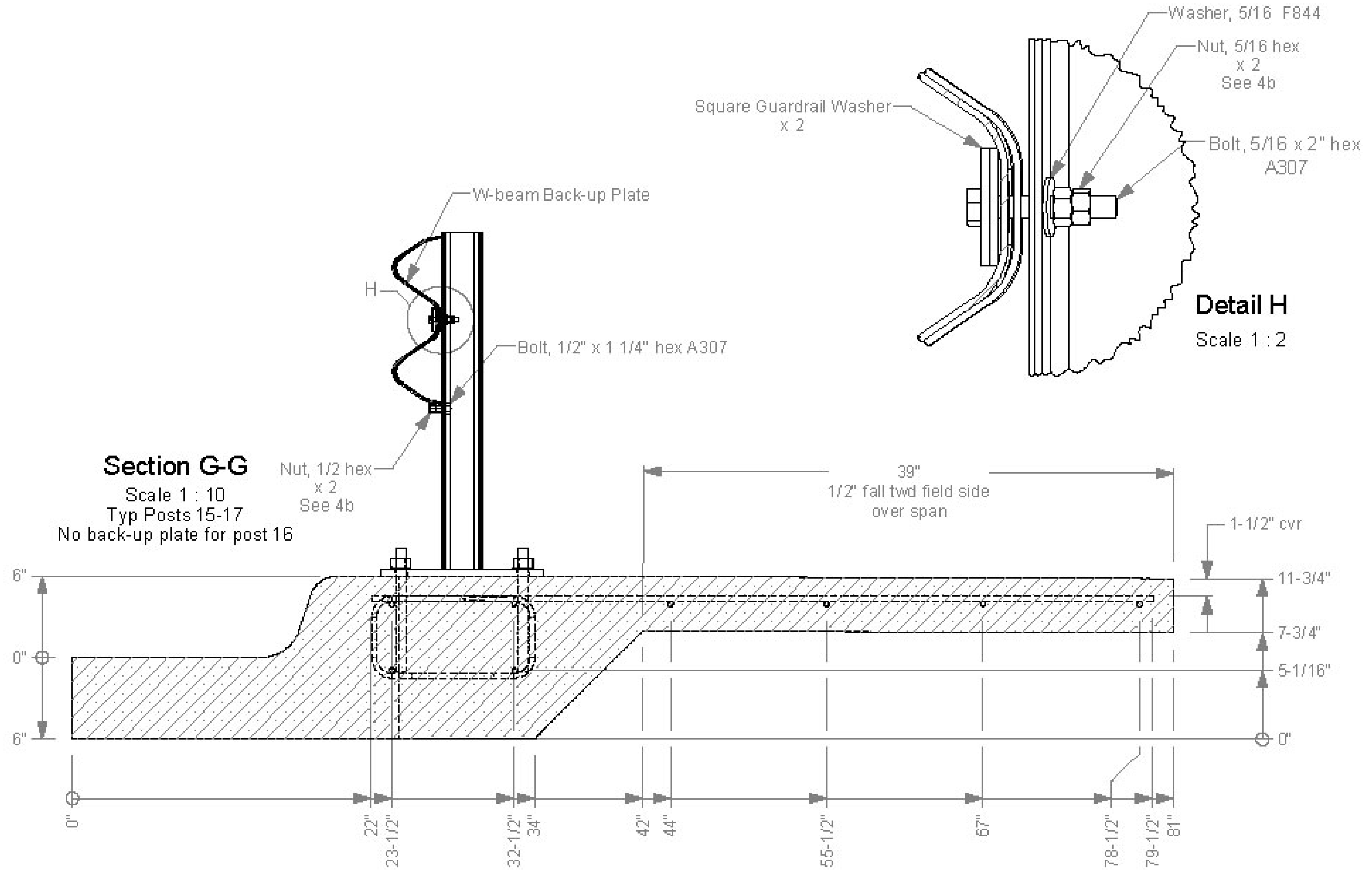
2a. Hand tighten first nut, with Blockout,Rail, and Post in contact, then tighten one more turn with wrench. Secure with second nut.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #611971-1 Curb Inlet		2021-04-19
Drawn by GES/WS	Scale 1:250	Sheet 2 of 9 Section Views B-D

Q:\Accreditation-17025-2017\EIR-000 Project Files\611971 - Florida DOT - Kovar-Sheikh-Dobrovolny\-01 (Special Baseplate Posts)\-01-1 (2-11)\Drafting, 611971-1\2021-03-23\611971-1 Drawing



Q:\Accreditation-17025-2017\EIR-000 Project Files\611971 - Florida DOT - Kovar-Sheikh-Dobrovolny\-01 (Special Baseplate Posts)\-01-1 (2-11)\Drafting, 611971-1\2021-03-23\611971-1 Drawing



4a. All rebar is #3 grade 60.

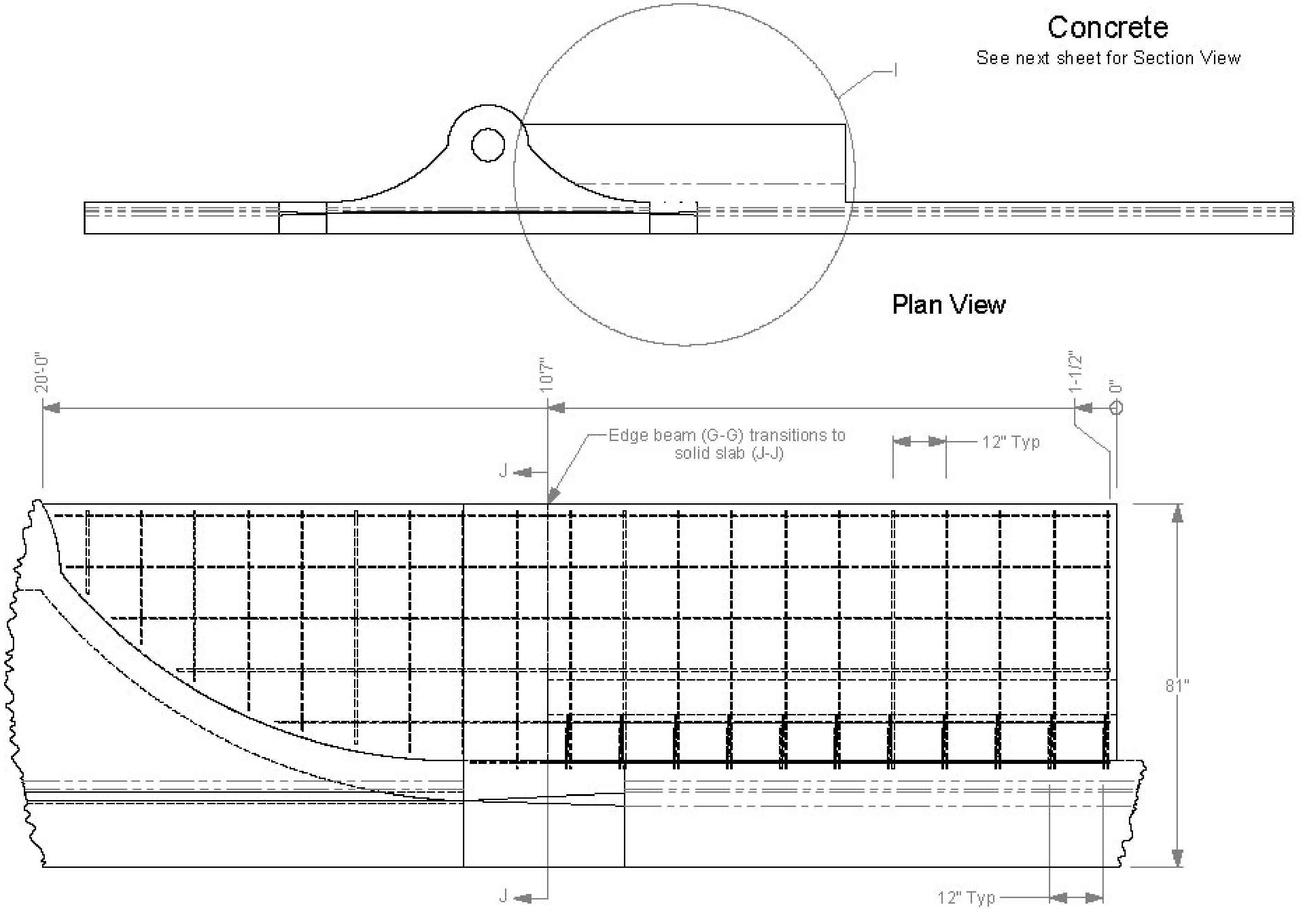
4b. Hand tighten first nut, with Backup Plate, Rail, and Post in contact, then tighten one more turn with wrench. Secure with second nut.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #611971-1 Curb Inlet		2021-04-19
Drawn by GES/WS	Scale 1:250	Sheet 4 of 9 Section Views G-H

Q:\Accreditation-17025-2017\EIR-000 Project Files\611971 - Florida DOT - Kovar-Sheikh-Dobrovolny\-01 (Special Baseplate Posts)\-01-1 (2-11)\Drafting, 611971-1\2021-03-23\611971-1 Drawing

Concrete

See next sheet for Section View

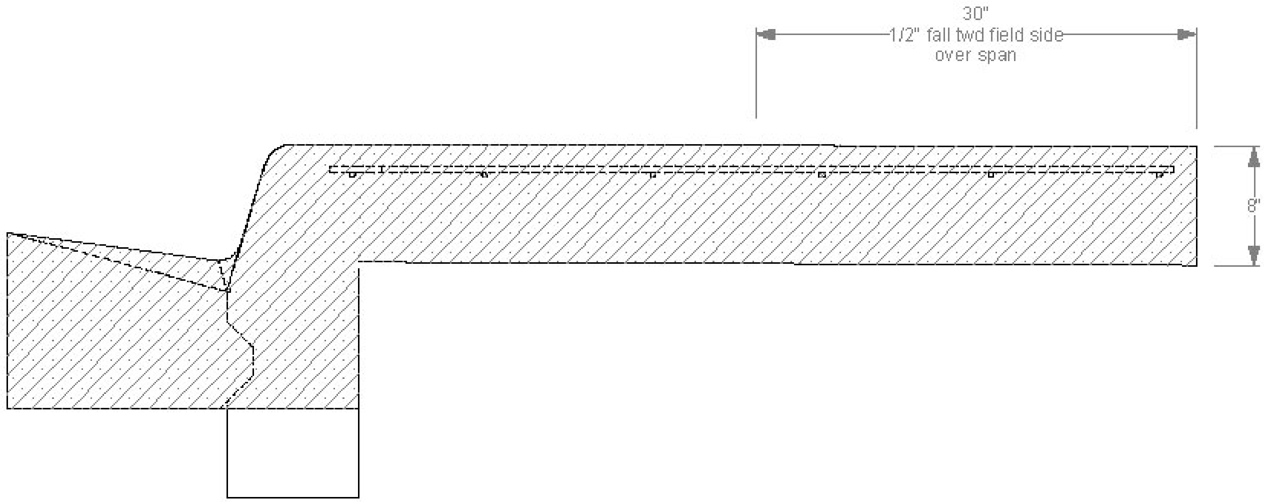


Detail I

Scale 1 : 30

5a. All concrete is 3400 PSI.

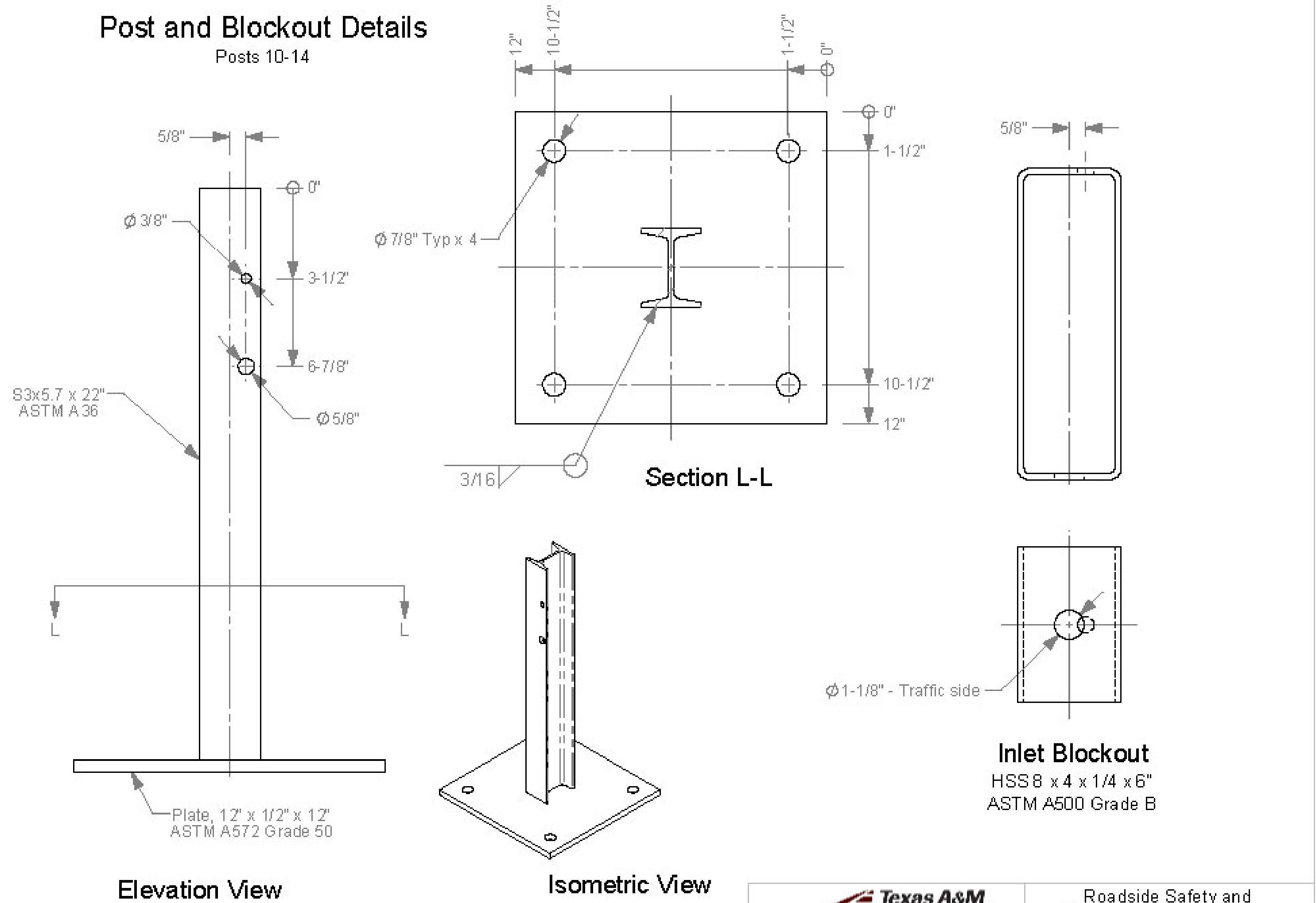
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #611971-1 Curb Inlet		2021-04-19
Drawn by GES/WS	Scale 1:100	Sheet 5 of 9 Concrete



Section J-J

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #611971-1 Curb Inlet		2021-04-19
Drawn by GES/WS	Scale 1:10	Sheet 6 of 9 Section View J-J

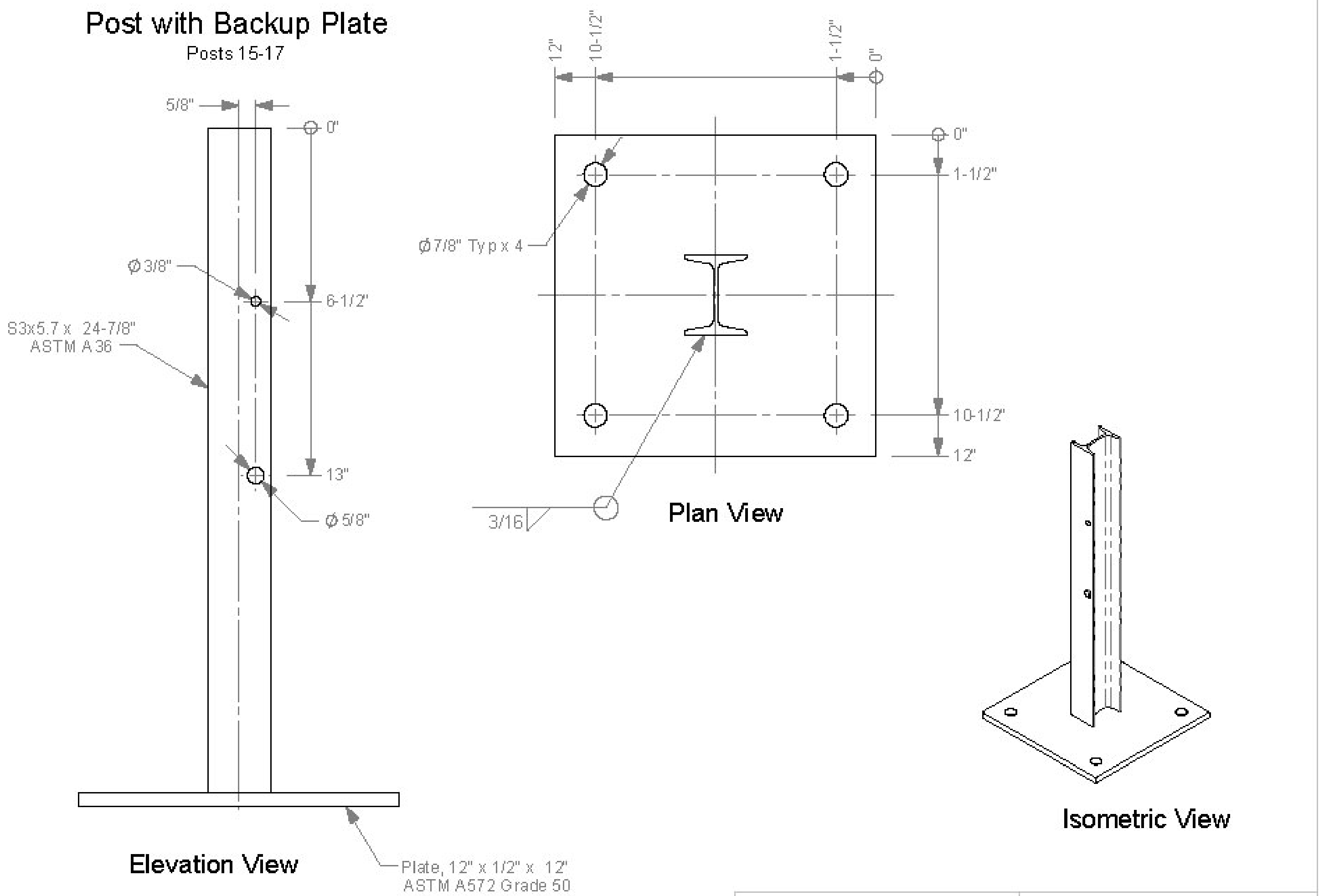
Q:\Accreditation-17025-2017\EIR-000 Project Files\611971 - Florida DOT - Kovar-Sheikh-Dobrovolny\-01 (Special Baseplate Posts)\-01-1 (2-11)\Drafting, 611971-1\2021-03-23\611971-1 Drawing



7a. All welding must be performed by certified welders using industry standard practices.
7b. Galvanize all components after fabrication is complete.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #611971-1 Curb Inlet		2021-04-19
Drawn by GES/WS	Scale 1:5	Sheet 7 of 9 Post and Blockout Details

Q:\Accreditation-17025-2017\EIR-000 Project Files\611971 - Florida DOT - Kovar-Sheikh-Dobrovolny\-01 (Special Baseplate Posts)\-01-1 (2-11)\Drafting, 611971-1\2021-03-23\611971-1 Drawing



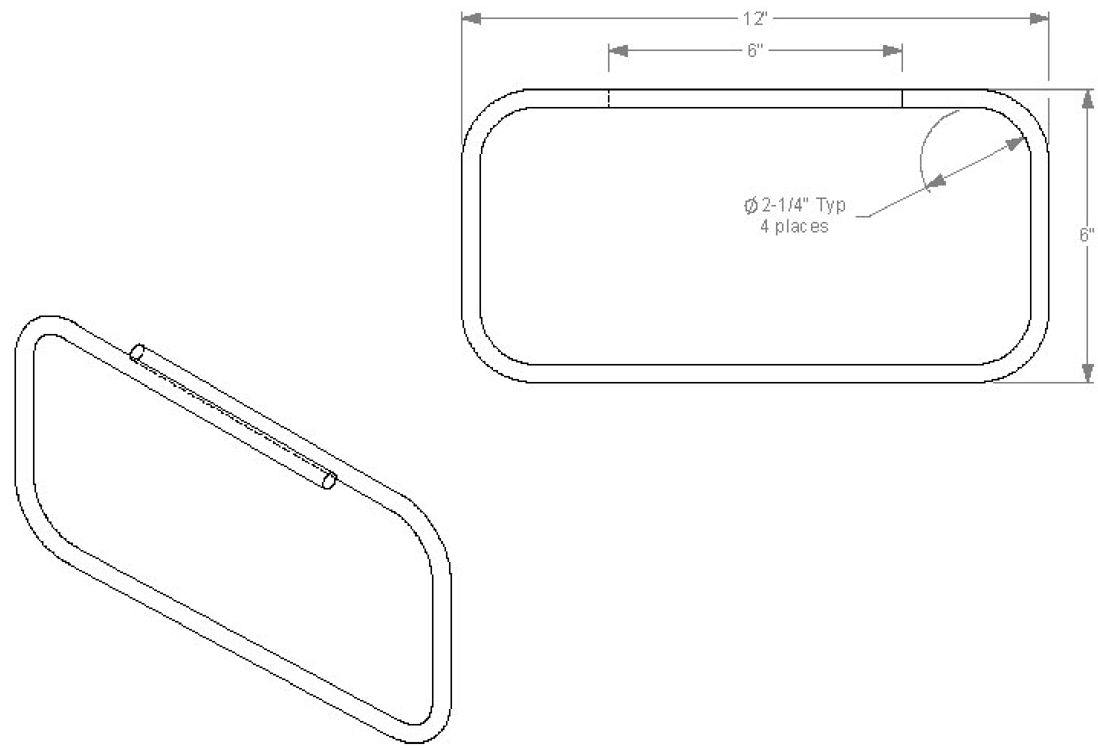
8a. All welding must be performed by certified welders using industry standard practices.
8b. Galvanize all components after fabrication is complete.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #611971-1 Curb Inlet		2021-04-19
Drawn by GES/WS	Scale 1:5	Sheet 8 of 9 Post with Backup Plate

Q:\Accreditation-17025-2017\EIR-000 Project Files\611971 - Florida DOT - Kovar-Sheikh-Dobrovolny\-01 (Special Baseplate Posts)\-01-1 (2-11)\Drafting, 611971-1\2021-03-23\611971-1 Drawing

Rectangle Stirrup

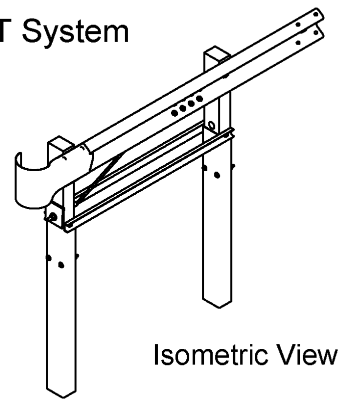
#3 Grade 60

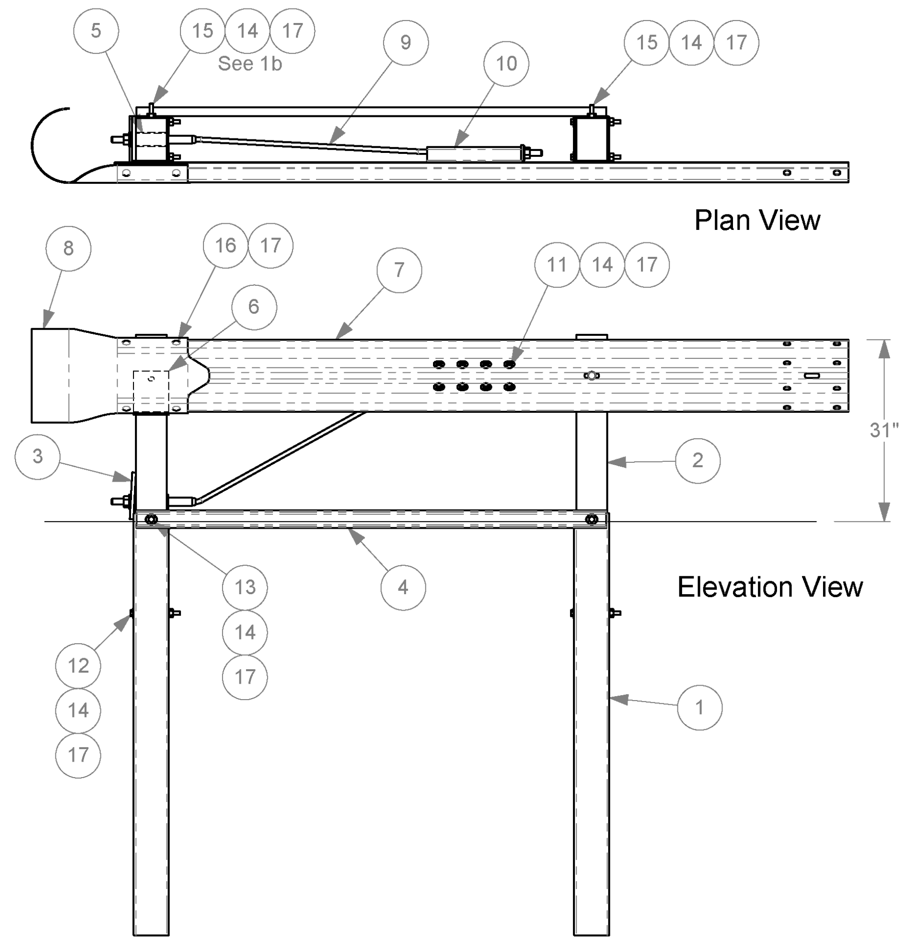


Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #611971-1 Curb Inlet		2021-04-19
Drawn by GES/WS	Scale 1:3	Sheet 9 of 9 Rectangle Stirrup

Q:\Accreditation-17025-2017\EIR-000 Project Files\611971 - Florida DOT - Kovar-Sheikh-Dobrovolny\-01 (Special Baseplate Posts)\-01-1 (2-11)\Drafting, 611971-1\2021-03-23\611971-1 Drawing

DAT System


Isometric View



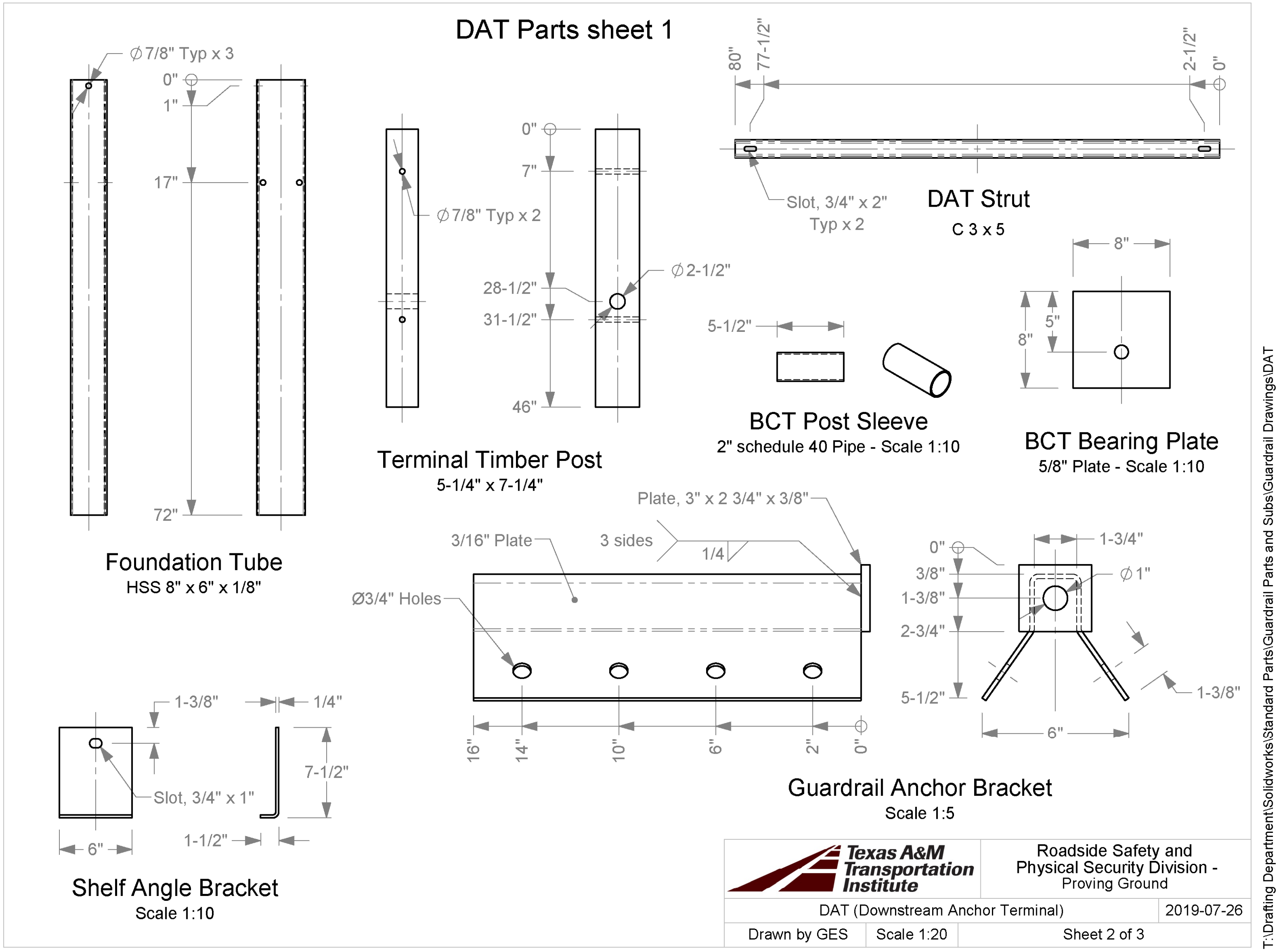
#	Part Name	Qty.
1	Foundation Tube	2
2	Terminal Timber Post	2
3	BCT Bearing Plate	1
4	DAT Strut	2
5	BCT Post Sleeve	1
6	Shelf Angle Bracket	1
7	DAT Terminal Rail	1
8	W-beam End Section	1
9	Anchor Cable Assembly	1
10	Guardrail Anchor Bracket	1
11	Bolt, 5/8 x 2" hex	8
12	Bolt, 5/8 x 8" hex	4
13	Bolt, 5/8 x 10" hex	2
14	Washer, 5/8 F844	16
15	10" Guardrail Bolt	2
16	1-1/4" Guardrail Bolt	4
17	Recessed Guardrail Nut	20

1a. All bolts are ASTM A307.

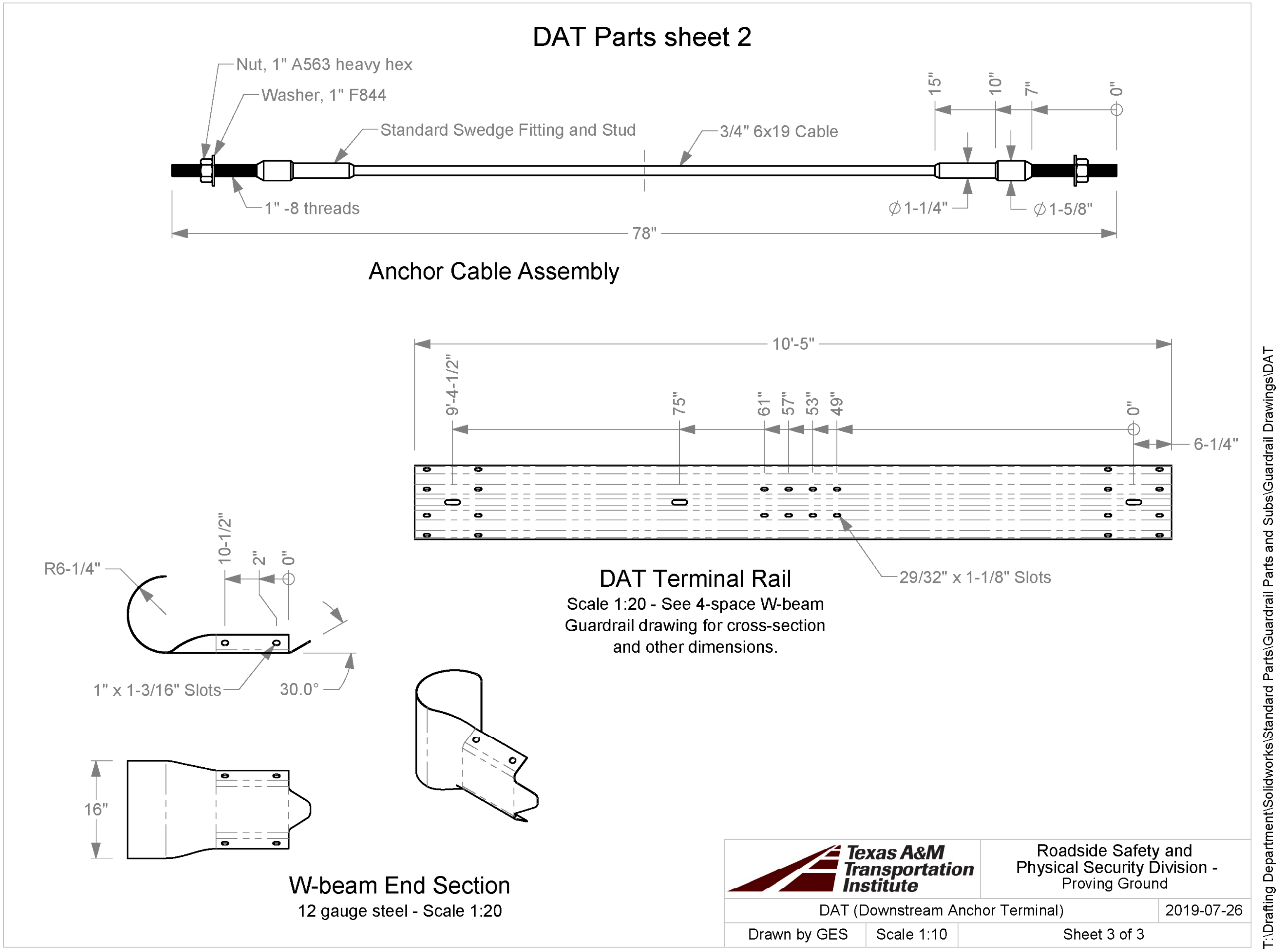
1b. Hardware secures Shelf Angle Bracket to Post. Rail is supported by Shelf Angle Bracket and does not attach directly to Post.

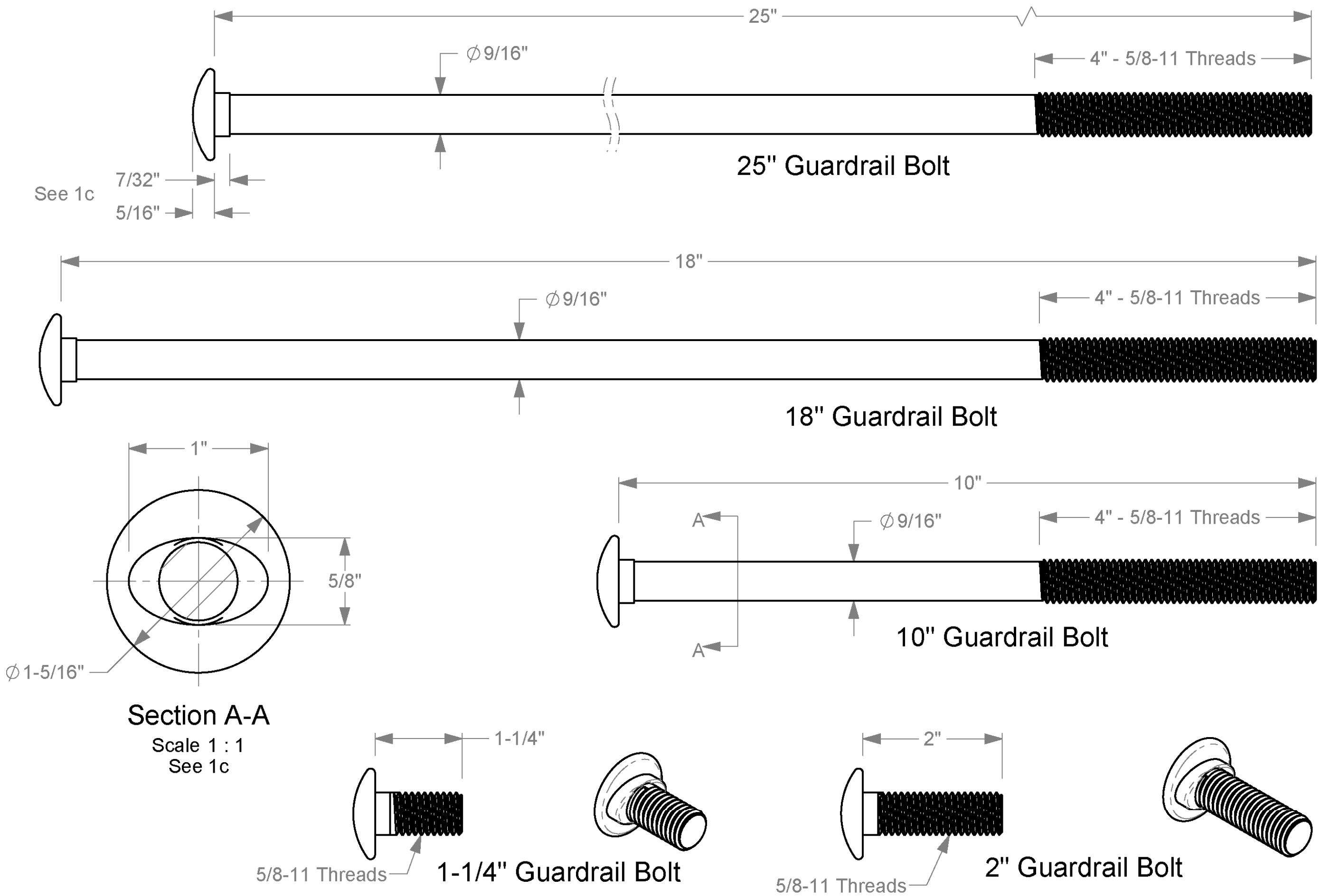
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
DAT (Downstream Anchor Terminal)		2019-07-26
Drawn by GES	Scale 1:25	Sheet 1 of 3

T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Parts and Subs\Guardrail Drawings\DAT



DAT Parts sheet 1
Ø7/8" Typ x 3
0"
1"
17"
72"
Foundation Tube
HSS 8" x 6" x 1/8"
0"
7"
Ø7/8" Typ x 2
Ø2-1/2"
28-1/2"
31-1/2"
46"
Terminal Timber Post
5-1/4" x 7-1/4"
80"
77-1/2"
2-1/2"
0"
Slot, 3/4" x 2"
Typ x 2
DAT Strut
C 3 x 5
5-1/2"
BCT Post Sleeve
2" schedule 40 Pipe - Scale 1:10
8"
5"
8"
BCT Bearing Plate
5/8" Plate - Scale 1:10
Plate, 3" x 2 3/4" x 3/8"
3/16" Plate
3 sides
1/4
Ø3/4" Holes
16"
14"
10"
6"
2"
0"
0"
3/8"
1-3/8"
2-3/4"
5-1/2"
1-3/4"
Ø1"
1-3/8"
6"
Guardrail Anchor Bracket
Scale 1:5
1-3/8"
1/4"
7-1/2"
Slot, 3/4" x 1"
6"
1-1/2"
Shelf Angle Bracket
Scale 1:10
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
DAT (Downstream Anchor Terminal)
2019-07-26
Drawn by GES
Scale 1:20
Sheet 2 of 3
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\DAT


DAT Parts sheet 2
Nut, 1" A563 heavy hex
Washer, 1" F844
Standard Swedge Fitting and Stud
3/4" 6x19 Cable
15"
10"
7"
0"
1" -8 threads
∅1-1/4"
∅1-5/8"
78"
Anchor Cable Assembly
10'-5"
9'-4-1/2"
75"
61"
57"
53"
49"
0"
6-1/4"
29/32" x 1-1/8" Slots
DAT Terminal Rail
Scale 1:20 - See 4-space W-beam Guardrail drawing for cross-section and other dimensions.
R6-1/4"
10-1/2"
2"
0"
1" x 1-3/16" Slots
30.0°
16"
W-beam End Section
12 gauge steel - Scale 1:20
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
DAT (Downstream Anchor Terminal)
2019-07-26
Drawn by GES
Scale 1:10
Sheet 3 of 3
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\DAT

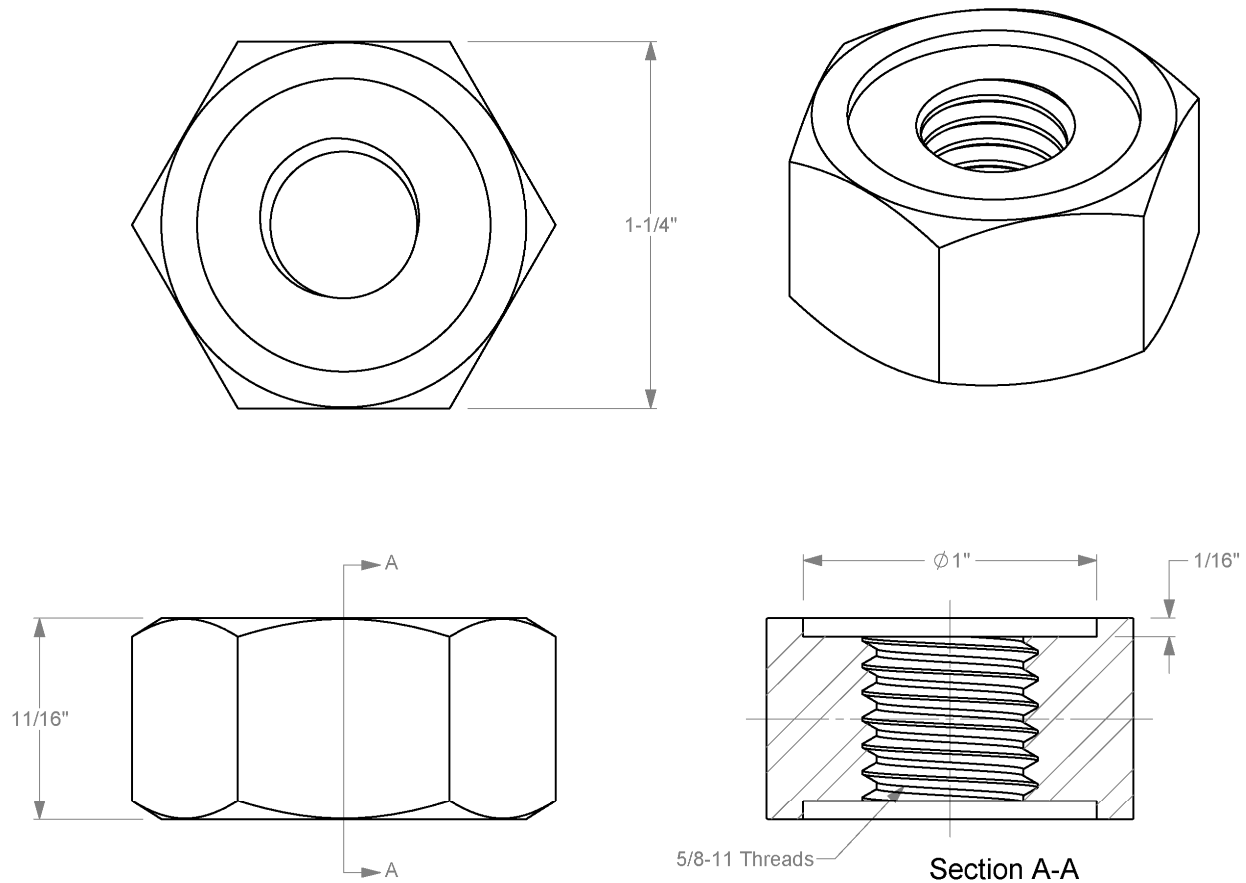


1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all sizes.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Guardrail Bolt		2019-06-27
Drawn by GES	Scale 1:2	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Guardrail Bolt

Recessed Guardrail Nut



1a. Material is ASTM A 563 Grade A.

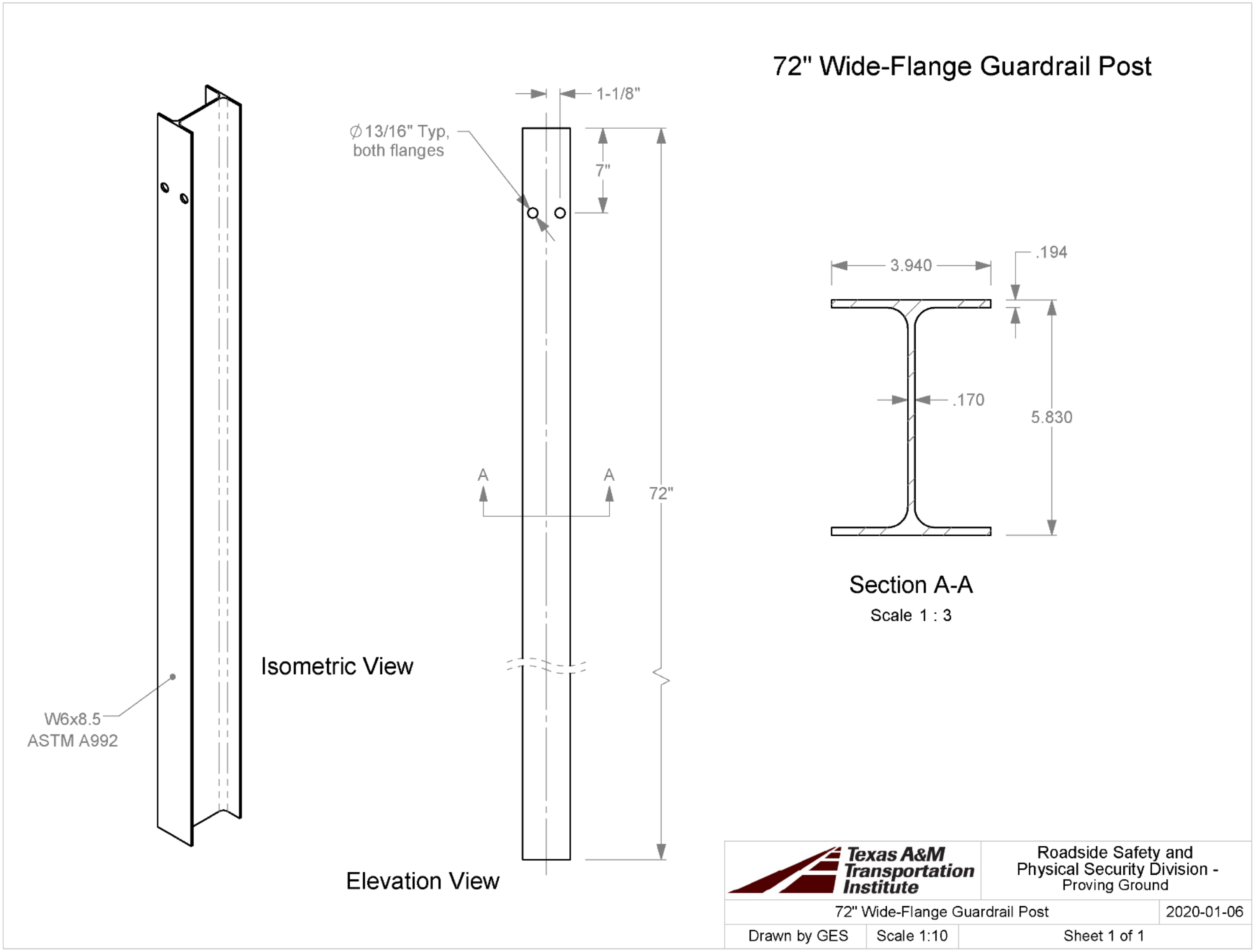
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Recessed Guardrail Nut | 2019-06-27

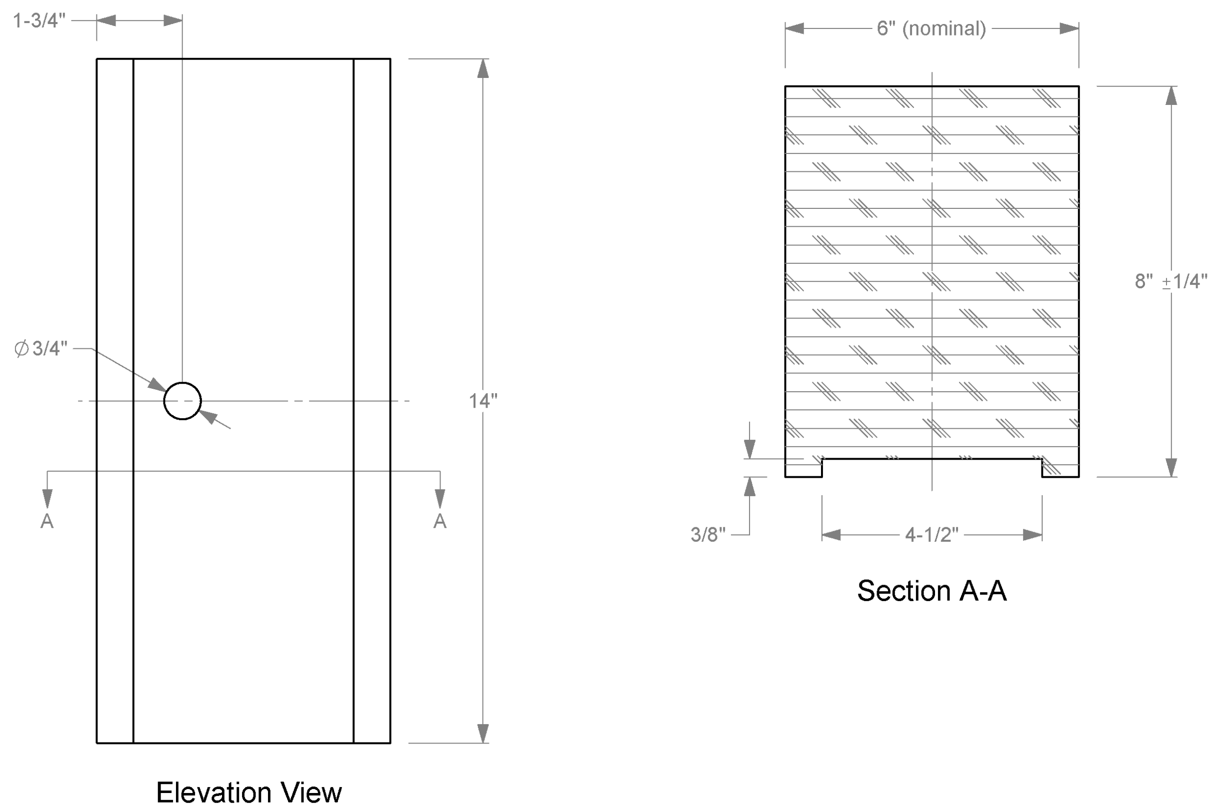
Drawn by GES | Scale 2:1 | Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Nut, Recessed Guardrail



T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, 72" Wide Flange Guardrail

Timber Blockout for W-section Post

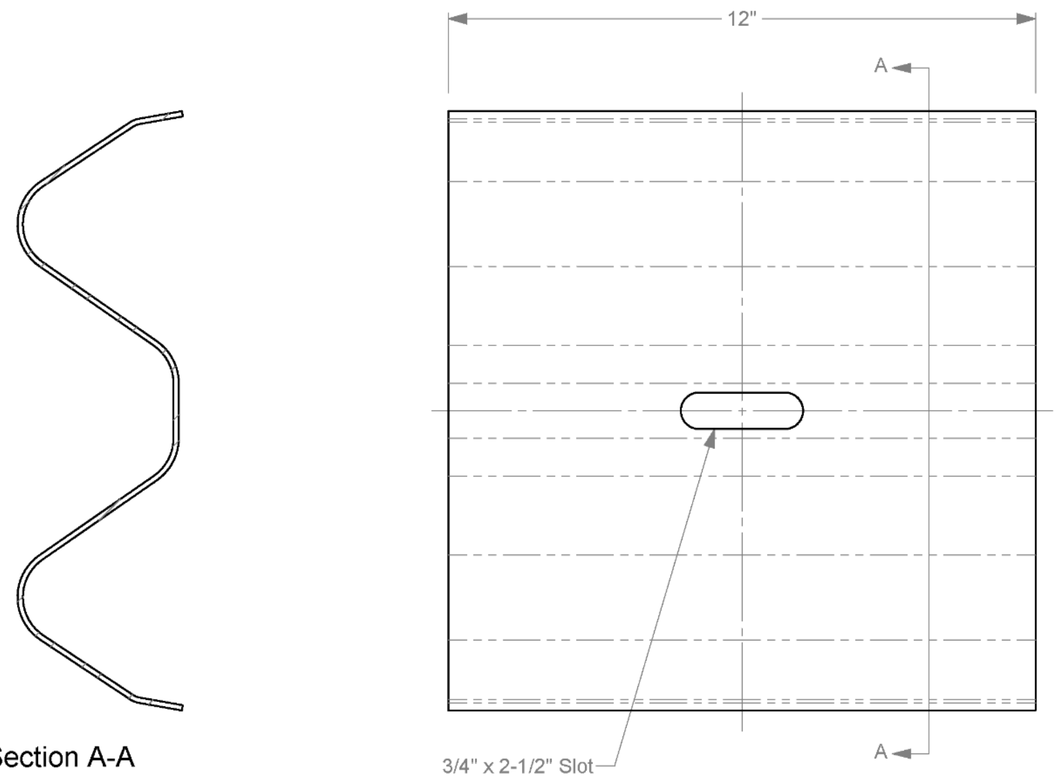


1a. Timber blockouts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Timber Blockout, for W-section Post			2019-07-03
Drawn by GES	Scale 1:3	Sheet 1 of 1	

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Timber Blockout for W-section Post

W-Beam Back-up Plate



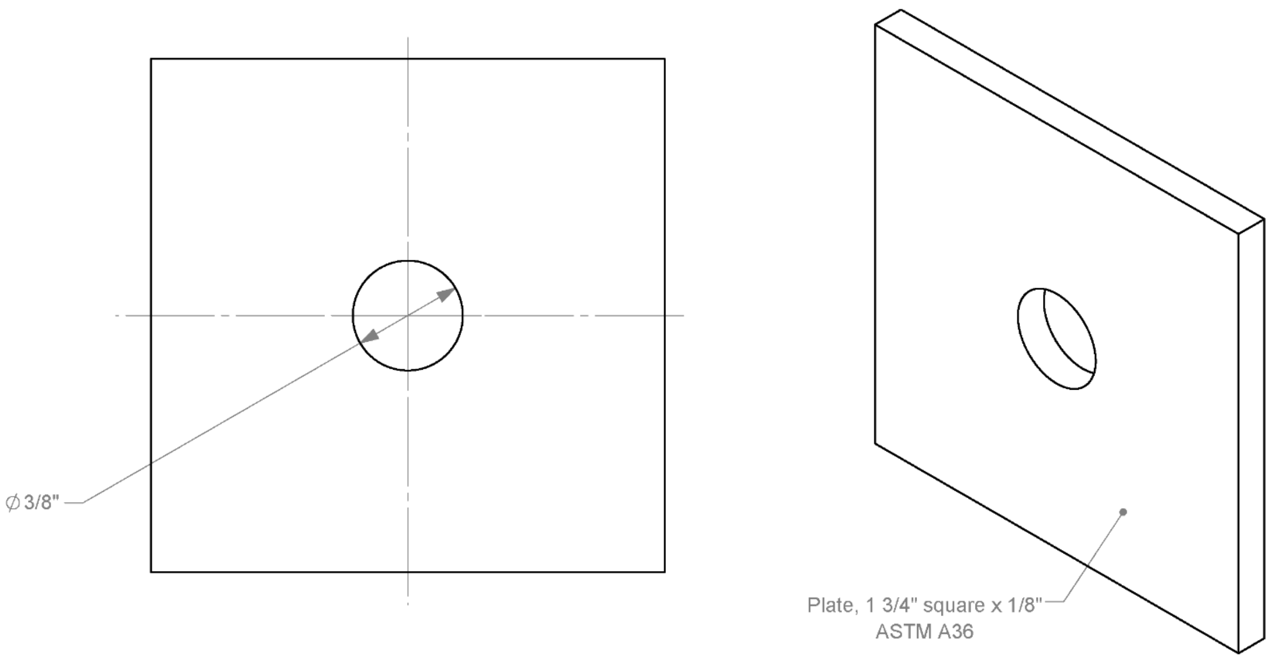
Section A-A

1a. Back-up Plate is made of 12 gauge material. See W-beam Guardrail drawing for all dimensions and material specs not shown here.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
W-beam Back-up Plate			2020-04-29
Drawn by GES	Scale 1:3	Sheet 1 of 1	

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\W- and Thrie-beam\W-Beam Back-up Plate

Square Guardrail Washer



Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Square Guardrail Washer			2020-04-29
Drawn by GES	Scale 2:1	Sheet 1 of 1	

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Square Guardrail Washer

APPENDIX E. SUPPORTING CERTIFICATION DOCUMENTS

Metals 2 Go

MATERIAL TEST REPORT COVER SHEET

224 N HEWITT DR
HEWITT TX 76643
254-235-7700
FAX 254-235-7703
MTR@METALS2GO.COM

MACK MANUFACTURING & MACHINE				
PO #	36110		EXPECTED DELIVERY	5/22/20
TICKET #	199250			

**LAND 15
NUCOR STEEL - BERKELEY

CERTIFIED MILL TEST REPORT

11/15/19 12:51:58
100% EAF MELTED AND MANUFACTURED IN THE USA
Structural sections produced by Nucor-Berkeley are cast and hot rolled to a fully killed and fine grain practice.
Mercury has not been used in the direct manufacturing of this material.

Customer #.: 472 - 5

B.O.L. #...: 1446846

MOS: T

SPECIFICATIONS: Tested in accordance with ASTM specification A6/A6M-19 and A370. Quality Manual Rev #12 (8-27-19).
AASHTO : m270-345M270-50-19
ASME : SA-36 13
ASTM : A992-11(15:/A36-19/A529-19-50/A5725018T1/A7093618/A7095018
CSA : G40.21-44w/G40.2150WM

Description / Part #	Heat# / Grade(s) / Test/Heat JW	Yield/ Tensile Ratio	Yield (PSI) (MPa)	Tensile (PSI) (MPa)	Elong %	C / Cr / ******	Mn / Mo / Ti	P / Sn / ******	S / B / ******	Si / V / N	Cu / Nb / ******	Ni / ****** / CI	CE1 / CE2 / Pcm
S3X5.7	2901385	.84	56300	67400	27.00	.07	.87	.012	.024	.24	.11	.04	.24
040' 00.00"	A992-11(15		388	465		.05	.01	.0060	.0002	.004	.013		.2838
S75X8.5		.84	55700	66300	26.00		.001			.0044		3.21	.1357
012.1920m			384	457	35 Pc(s)		7,980 lbs	Customer PO: 4500338051				Inv#:	0
S3X5.7	1901380	.82	55600	67600	26.00	.07	.83	.009	.022	.23	.09	.04	.23
040' 00.00"	A992-11(15		383	466		.04	.01	.0043	.0002	.003	.014		.2666
S75X8.5		.83	55700	67400	26.00		.001			.0057		2.79	.1263
012.1920m			384	465	35 Pc(s)		7,980 lbs	Customer PO: 4500338051				Inv#:	0
S5x10	2913193	.83	55100	66400	25.00	.07	.84	.008	.034	.25	.07	.03	.23
040' 00.00"	A992-11(15		380	458		.03	.01	.0057	.0002	.004	.027		.2738
S130X15		.83	55100	66300	24.00		.001			.0052		2.37	.1288
012.1920m			380	457	32 Pc(s)		12,800 lbs	Customer PO: 4500339141				Inv#:	0

Elongation based on 8" (20.32cm) gauge length. 'No Weld Repair' was performed.
CI = 26.01Cu+3.88Ni+1.20Cr+1.49Si+17.28P-(7.29Cu*Ni)-(9.10Ni*P)-33.39(Cu*Cu)
Pcm = C+(Si/30)+(Mn/20)+(Cu/20)+(Ni/60)+(Cr/20)+(Mo/15)+(V/10)+5B
CE1= C+(Mn/6)+((Cr+Mo+V)/5)+((Ni+Cu)/15)

"All mechanical testing is performed by the Quality testing lab, which is independent of the production departments"
CE2 = C+((Mn+Si)/6)+((Cr+Mo+V+Cb)/5)+((Ni+Cu)/15)

I hereby certify that the contents of this report are accurate and correct. All test results and operations performed by the material manufacturer are in compliance with material specifications, and when designated by the Purchaser, meet applicable specifications.

Bruce A. Work
Metallurgist/
Quality Control

TR No. 61971-01

77

2023-10-27

NUCOR®

Mill Certification

05/19/2020

MTR#:416498-9
Lot #:110001032960
8812 HWY 79 W
Jewett, TX 75846 US
903-626-4461
Fax: 903-626-6290

Sold To: MJ LATHERN CO INC
DBA METALS 2 GO
PO BOX 20425
WACO, TX 76702 US

Ship To: MJ LATHERN CO INC
224 N HEWITT DR
HEWITT, TX 76643 US

Customer PO	43185	Sales Order #	11016818 - 17.1
Product Group	Hot Roll - Merchant Bar Quality	Product #	3017373
Grade	Nucor Multigrade	Lot #	110001032960
Size	0.5" x 12"	Heat #	1100010329
BOL #	BOL-499803	Load #	416498
Description	Hot Roll - Merchant Bar Quality UM Plate 1/2" x 12" Nucor Multigrade 20' 0" [240"] 2001-6000 lbs	Customer Part #	
Production Date	03/27/2020	Qty Shipped LBS	4900
Product Country Of Origin	United States	Qty Shipped EA	12
Original Item Description		Original Item Number	

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.

Melt Country of Origin : United States | Melting Date: 03/18/2020

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Ni (%)	Cr (%)	Mo (%)	Cu (%)	Ti (%)	V (%)	Nb (%)
0.12	0.84	0.017	0.018	0.206	0.14	0.21	0.06	0.25	0.000	0.055	0.002
Sn (%)											
0.011											

ASTM A529 S78.2 CE (%) : 0.39

Other Test Results

Yield (PSI) : 60000	Yield (PSI) : 60700	Tensile (PSI) : 76700
Tensile (PSI) : 77000	Elongation in 8" (%) : 22.0	Elongation in 8" (%) : 22.0

Comments:

NUCOR MULTIGRADE MEETS THE REQUIREMENTS OF: ASTM A36/A36M-14; A529/529M-05(2009) GR50(345); A572/572M-07 GR50(345); A709/709M-10 GR36(250) & GR50(345); CSA G40.21-04 GR44W(300W)& GR50W(350W); AASHTO M270/M270M-10 GR36(270) & GR50(345); ASME SA36/SA36M-07; MEETS REPORTING REQUIREMENTS OF EN10204 SEC 3.1

1. All manufacturing processes of the steel, including melting, casting & hot rolling, have been performed in U.S.A
2. Mercury in any form has not been used in the production or testing of this product.
3. Welding or weld repair was not performed on this material.
4. This material conforms to the specifications described on this document and may not be reproduced, except in full, without written approval of Nucor Corporation.
5. Results reported ASTM E45 (Inclusion content) and ASTM E381 (Macro-etch) are provided as interpretation of ASTM procedures.

Reddy Vantari, Chief Metallurgist

Metals 2 Go

MATERIAL TEST REPORT COVER SHEET

224 N HEWITT DR
HEWITT TX 76643
254-235-7700
FAX 254-235-7703
MTR@METALS2GO.COM

MACK MANUFACTURING & MACHINE					
PO #	36145			EXPECTED DELIVERY	5/22/20
TICKET #	199351				

GERDAU

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

CERTIFIED MATERIAL TEST REPORT

GRADE GGMULTI	SHAPE / SIZE Flat Bar / 1/4 X 10	DOCUMENT ID: 0000314213	
LENGTH 20'00"	WEIGHT 3,913 LB	HEAT / BATCH **55066182**/03	
SALES ORDER 8686646/000010	CUSTOMER MATERIAL Nº 000000000108100020		
CUSTOMER PURCHASE ORDER NUMBER 4500344610	BILL OF LADING 1323-0000155352	DATE 04/07/2020	

SPECIFICATION / DATE or REVISION
ASTM A529-14, A572-15
ASTM A6-17,A36-14, ASME SA-36
ASTM A709-17, AASHTO M270-15
CSA G40.20-13/G40.21-13

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %
0.13	0.94	0.013	0.035	0.24	0.36	0.16	0.06	0.032	0.008	0.002	0.008

MECHANICAL PROPERTIES

YS 0.2% PSI	UTS PSI	YS MPa	UTS MPa	G/L Inch	Elong. %
59400	76900	410	530	8.000	23.90
57200	77300	394	533	8.000	24.30

COMMENTS / NOTES

This grade meets the requirements for the following grades:
ASTM Grades: A36; A529-50; A572-50; A709-36; A709-50
CSA Grades: 44W; 50W
AASHTO Grades: M270-36; M270-50
ASME Grades: SA36

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

Certified Analysis

Trinity Highway Products LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296

Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525
ADDISON, TX 75001

Project: FDOT

Order Number: 1337314
Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: FDOT
BOL Number: 115299
Ship Date:
Document #: 1
Shipped To: TX
Use State: CA

As of: 4/5/21

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
60	3245G	5/16" HEX NUT A563	A563-3245			P39250 R73084-01													4
30	3300G	WASHER,FLAT,5/8 R,TY	F844-3300			P39556 R75034													4
60	3319G	1/8"X1.75"X1.75" WSHR PL	HW			P35672													
60	4303G	1/2" HEX NUT A563 GR A	FAST			P38839 R71717													4
30	4308G	1/2"X1.5" HEX BOLT A307	HW			P35642													
30	6267G	5/16"X2.375"HXBLT A307	HW			42162													

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

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

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

Certified Analysis

Trinity Highway Products LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296

Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525

ADDISON, TX 75001

Project: FDOT

Order Number: 1337314 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: FDOT
BOL Number: 115299 Ship Date:
Document #: 1
Shipped To: TX
Use State: CA

As of: 4/5/21

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

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329, UNLESS OTHERWISE STATED.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB .

State of Ohio, County of Allen. Sworn and subscribed before me this 5th day of April, 2021 .

Notary Public:
Commission Expires: / /

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

This Memorandum is an acknowledgement that a Bill of Lading has been issued and is not the original Bill of Lading, nor a copy or duplicate, covering the property named herein, and is intended solely for filing or record.

Shipper's No. 55-115299

Carrier: Trinity Highway Products, LLC 3

RECEIVED, subject to the classifications and tariffs in effect on the date of receipt by the carrier of the property described in the Original Bill of Lading, at Lima OH 4/5/2021, 20, from

the property described below, in apparent good order, except as noted (contents and condition of contents of packages unknown) marked, consigned and destined as shown below, which said company (the word company being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its own railroad, water line, highway route or routes, or within the territory of its highway operations, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the conditions not prohibited by law, whether printed or written, herein contained, including the conditions on back hereof, which are hereby agreed to by the shipper and accepted for himself and his assigns.

S/O No. 1337314

Consigned to: SAMPLES. TESTING MATERIALS Cust. P.O. FDOT Load No. 43-1

Destination: TTI BLDG 7090

3100 STATE HWY 47 Total Weight: 21.33

City: BRYAN State: TX Zip: 77807

Ship: 4/5/2021

Arrive: 4/5/21 5:00:00PM

Contact: GARY GERKE Phone: 936-825-4661 606177

Delivering Carrier: UPS Vehicle or Car Initial: ____ No. ____

Subject to Section 7 of Conditions of applicable Bill of Lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.
TRINITY HIGHWAY PRODUCTS, LLC
Trinity Highway Products, LLC
(Signature of Consignor)

If charges are to be prepaid, write or stamp here, "To be Prepaid."
TO BE PREPAID

Received $ ____ to apply in prepayment of the charges on the property described hereon.

Agent or Cashier

Per ____ (The signature here acknowledges only the amount prepaid.)

Charges advanced:

Collect On Delivery: $ ____ and remit to: 1 Box @ 17# Street ____ City ____ State ____

C.O.D. charge to be paid by: Shipper ☐ Consignee ☐

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
		Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy No. OMS-LG-002			
		Project Info: FDOT			
		LD Comments:			
	60	3245G 5/16" HEX NUT A563			
	30	3300G WASHER,FLAT,5/8 R,TY B,G			
	60	3319G 1/8"X1.75"X1.75" WSHR PL			
	60	4303G 1/2" HEX NUT A563 GR A			
	30	4308G 1/2"X1.5" HEX BOLT A307			
	30	6267G 5/16"X2.375"HXBLT A307 FT			

9/6.07
1Z4108842035059274A

NMFC ITEM # 105469
CLASS 50

SPECIAL INSTRUCTIONS: 55-115299

SHIPPER LOAD - CONSIGNEE UNLOAD

Total Weight 2

*If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is "carrier's or shipper's weight."
NOTE - Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property.
The agreed or declared value of the property is hereby specifically stated by the shipper to be not exceeding ____ per ____

ORIGIN: SHIPPER OR AGENT — I hereby authorize this shipment and make the declaration of values (if any) and agree to the contract terms and conditions hereof. SIGN HERE [signature] DATE 4-5-21

AGENT OR DRIVER — This shipment received subject to exceptions as noted and according to the terms and conditions hereof. (SIGN HERE) ____ DATE ____

DESTINATION: CONSIGNEE OR AGENT — Received the above described property in good condition except as noted on the back hereof and agree to the foregoing contract terms and conditions. SIGN HERE ____ DATE / / TIME A.M. P.M.

DRIVER ____ NO ____

Permanent post-office address of shipper,

TRI 609-RF (R 10/93) (This Bill of Lading is to be signed by the shipper and agent of the carrier issuing same.) CARRIER COPY

This Memorandum is an acknowledgement that a Bill of Lading has been issued and is not the original Bill of Lading, nor a copy or duplicate, covering the property named herein, and is intended solely for filing or record.

55-115299

Carrier: Trinity Highway Products, LLC 3

Shipper's No.

S/O No. 1337314

RECEIVED, subject to the classifications and tariffs in effect on the date of receipt by the carrier of the property described in the Original Bill of Lading, at Lima, OH 4/5/2021 20, from

the property described below, in apparent good order, except as noted (contents and condition of contents of packages unknown) marked, consigned and destined as shown below, which said company (the word company being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its own railroad, water line, highway route or routes, or within the territory of its highway operations, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the conditions not prohibited by law, whether printed or written, herein contained, including the conditions on back hereof, which are hereby agreed to by the shipper and accepted for himself and his assigns.

Subject to Section 7 of Conditions of applicable Bill of Lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges.
TRINITY HIGHWAY PRODUCTS, LLC
Trinity Highway Products, LLC
(Signature of Consignor)

If charges are to be prepaid, write or stamp here, "To be Prepaid."
TO BE PREPAID

Received $ ______ to apply in prepayment of the charges on the property described hereon.

Agent or Cashier

Per ______
(The signature here acknowledges only the amount prepaid.)
Charges advanced:

Consigned to: SAMPLES, TESTING MATERIALS　Cust. P.O. FDOT　Load No.: 43-1

Destination: TTI　BLDG 7090

3100 STATE HWY 47　Total Weight: 21.33

City: BRYAN　State: TX　Zip: 77807

Ship: 4/5/2021

Arrive: 4/5/21 5:00:00PM

Contact: GARY GERKE　Phone: 936-825-4661　606177

Delivering Carrier: UPS　Vehicle or Car Initial: ______ No. ______

Collect On Delivery:
$ ______ and remit to: ______
1 Box @ 17# ______ Street ______ City ______ State

C.O.D. charge to be paid by Shipper ☐ Consignee ☐

No. Pkgs.	Piece Count	Description of Articles	*Wt.	Class or Rate	✓ Col.
		Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy No. QMS-LG-002			
		Project Info: FDOT			
		LD Comments:			
	60	3245G 5/16" HEX NUT A563			
	30	3300G WASHER,FLAT,5/8 R.TY B,G			
	60	3319G 1/8"X1.75"X1.75" WSHR PL			
	60	4303G 1/2" HEX NUT A563 GR A			
	30	4308G 1/2"X1.5" HEX BOLT A307			
	30	6267G 5/16"X2.375"HXBLT A307 FT			

NMFC ITEM # 105460
CLASS 50

SPECIAL INSTRUCTIONS:
SHIPPER LOAD - CONSIGNEE UNLOAD

55-115299

Total Weight 3

*If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is "carrier's or shipper's weight."
NOTE - Where the rate is dependent on value, shippers are required to state specifically in writing the agreed or declared value of the property.
The agreed or declared value of the property is hereby specifically stated by the shipper to be not exceeding ______ per ______

ORIGIN
SHIPPER OR AGENT — I hereby authorize this shipment and make the declaration of values (if any) and agree to the contract terms and conditions hereof.
SIGN HERE [signature]　DATE 4-5-21
AGENT OR DRIVER — This shipment received subject to exceptions as noted and according to the terms and conditions hereof.
(SIGN HERE)　DATE

DESTINATION
CONSIGNEE OR AGENT — Received the above described property in good condition except as noted on the back hereof and agree to the foregoing contract terms and conditions.
SIGN HERE　DATE / /　TIME A.M. P.M.
DRIVER　NO

Permanent post-office address of shipper,

TRI 609-RF (R 10/93)　(This Bill of Lading is to be signed by the shipper and agent of the carrier issuing same.)　CONSIGNEE/CUSTOMER COPY

CERTIFIED MILL TEST REPORT 12/22/20 22:13:31

100% EAF MELTED AND MANUFACTURED IN THE USA

Structural sections produced by Nucor-Berkeley are cast and hot rolled to a fully killed and fine grain practice. Mercury not intentionally added at any point during manufacturing.

Customer #.: 472 - 14

B.O.L. #...: 1523690

MOS: T

SPECIFICATIONS: Tested in accordance with ASTM specification A6/A6M-19 and A370. Tested in accordance with EN10204-2004-3.1. Quality Manual Rev #14 (9-23-20).

AASHTO : m270-345M270-50-19
ASME : SA-36 13
ASTM : A992-11(15:/A36-19/A529-19-50/A5725018T1/A7093618/A7095018
CSA : G40.21-44w/G40.21-50w/G40.2150WM

Description Part #	Heat# Grade(s) Test/Heat JW	Yield/ Tensile Ratio	Yield (PSI) (MPa)	Tensile (PSI) (MPa)	Elong %	C Cr ******	Mn Mo Ti	P Sn ******	S B ******	Si V N	Cu Nb ******	Ni ****** CI	CE1 CE2 Pcm
C10X30	2012322	.79	53500	67900	26.00	.07	1.03	.008	.018	.21	.10	.03	.26
040' 00.00"	A992-11(15		369	468		.04	.01	.0042	.0002	.002	.029		.2996
C250X45		.78	53100	67900	26.00		.001			.0053		2.84	.1348
012.1920m			366	468	16 Pc(s) 19,200 lbs	Customer PO: 4500358720 BoL#: 1523690							
2510300040													
S3X5.7	2013831	.81	56200	69000	28.00	.07	.81	.009	.015	.21	.08	.03	.22
020' 00.00"	A992-11(15		387	476		.04	.01	.0045	.0002	.002	.014		.2633
S75X8.5		.81	55900	68800	29.00		.001			.0055		2.53	.1274
006.0960m			385	474	140 Pc(s) 15,960 lbs	Customer PO: 4500358742 BoL#: 1523690							
35357020													
W10x12	2017578	.84	59600	71300	30.00	.07	.82	.006	.022	.22	.13	.05	.23
030' 00.00"	A992-11(15		411	492		.05	.01	.0048	.0002	.002	.014		.2693
W250X17.9		.83	59000	71000	28.00		.001			.0053		3.42	.1287
009.1440m			407	490	24 Pc(s) 8,640 lbs	Customer PO: 4500358782 BoL#: 1523690							
3710120030													

Elongation based on 8" (20.32cm) gauge length. 'No Weld Repair' was performed.
CI = 26.01Cu+3.88Ni+1.20Cr+1.49Si+17.28P-(7.29Cu*Ni)-(9.10Ni*P)-33.39(Cu*Cu)
Pcm = C+(Si/30)+(Mn/20)+(Cu/20)+(Ni/60)+(Cr/20)+(Mo/15)+(V/10)+5B
CE1= C+(Mn/6)+((Cr+Mo+V)/5)+((Ni+Cu)/15)

"All mechanical testing is performed by the Quality testing lab, which is independent of the production departments"
CE2 = C+((Mn+Si)/6)+((Cr+Mo+V+Cb)/5)+((Ni+Cu)/15)

Nucor certifies that the contents of this report are accurate and correct. All test results and operations performed by the material manufacturer are in compliance with material specifications, and when designated by the Purchaser, meet applicable specifications.

Dmitri Nassyrov
Metallurgist/
Quality Control

611971-01-1

3 Heat(s) for this MTR.

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

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

Rolando A Davila

Quality Assurance Manager

HEAT NO.:3099172 SECTION: REBAR 13MM (#4) 20'0" 420/60 GRADE: ASTM A615-20 Gr 420/60 ROLL DATE: 08/19/2020 MELT DATE: 08/11/2020 Cert. No.: 83205565 / 099172A130	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 83205565 BOL#: 73766378 CUST PO#: 861736 CUST P/N: DLVRY LBS / HEAT: 48202.000 LB DLVRY PCS / HEAT: 3608 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.44%	Bend Test Diameter	1.750IN		
Mn	0.73%				
P	0.011%				
S	0.052%				
Si	0.19%				
Cu	0.38%				
Cr	0.21%				
Ni	0.21%				
Mo	0.050%				
V	0.000%				
Cb	0.002%				
Sn	0.013%				
Al	0.002%				
Yield Strength test 1	66.7ksi				
Tensile Strength test 1	104.8ksi				
Elongation test 1	14%				
Elongation Gage Lgth test 1	8IN				
Tensile to Yield ratio test1	1.57				
Bend Test 1	Passed				

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

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

REMARKS :

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

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

Rolando A Davila
Quality Assurance Manager

HEAT NO.:3099430 SECTION: REBAR 19MM (#6) 40'0" 420/60 GRADE: ASTM A615-20 Gr 420/60 ROLL DATE: 08/22/2020 MELT DATE: 08/22/2020 Cert. No.: 83194931 / 099430A307	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 83194931 BOL#: 73751576 CUST PO#: 860612 CUST P/N: DLVRY LBS / HEAT: 23793.000 LB DLVRY PCS / HEAT: 396 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.46%	Bend Test Diameter	3.750IN		
Mn	0.83%				
P	0.010%				
S	0.045%				
Si	0.18%				
Cu	0.29%				
Cr	0.11%				
Ni	0.15%				
Mo	0.067%				
V	0.000%				
Cb	0.002%				
Sn	0.012%				
Al	0.001%				
Yield Strength test 1	64.0ksi				
Tensile Strength test 1	102.7ksi				
Elongation test 1	16%				
Elongation Gage Lgth test 1	8IN				
Tensile to Yield ratio test1	1.60				
Bend Test 1	Passed				

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

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

REMARKS :

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT
For additional copies call
830-372-8771

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

Rolando A Davila
Quality Assurance Manager

HEAT NO.:3097746 SECTION: REBAR 13MM (#4) 40'0" 420/60 GRADE: ASTM A615-20 Gr 420/60 ROLL DATE: 06/23/2020 MELT DATE: 06/15/2020 Cert. No.: 83198572 / 097746A371	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 83198572 BOL#: 73755909 CUST PO#: 861111 CUST P/N: DLVRY LBS / HEAT: 19881.000 LB DLVRY PCS / HEAT: 744 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.44%	Bend Test Diameter	1.750IN		
Mn	0.82%				
P	0.014%				
S	0.051%				
Si	0.20%				
Cu	0.30%				
Cr	0.11%				
Ni	0.16%				
Mo	0.047%				
V	0.000%				
Cb	0.000%				
Sn	0.010%				
Al	0.001%				
Yield Strength test 1	64.9ksi				
Tensile Strength test 1	104.3ksi				
Elongation test 1	14%				
Elongation Gage Lgth test 1	8IN				
Tensile to Yield ratio test1	1.61				
Bend Test 1	Passed				

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

REMARKS :

APPENDIX F. SOIL PROPERTIES

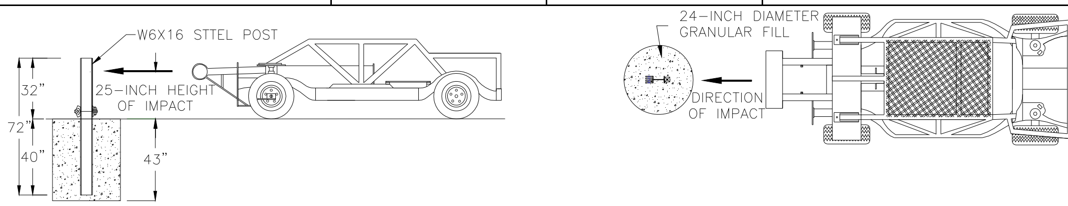
Table F.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.

Dynamic Test Setup

Post-Test Photo of post

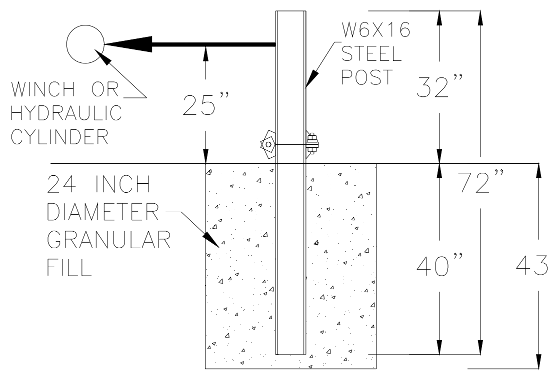
Static Load Test

Post-Test Photo



Dynamic Test Installation Details

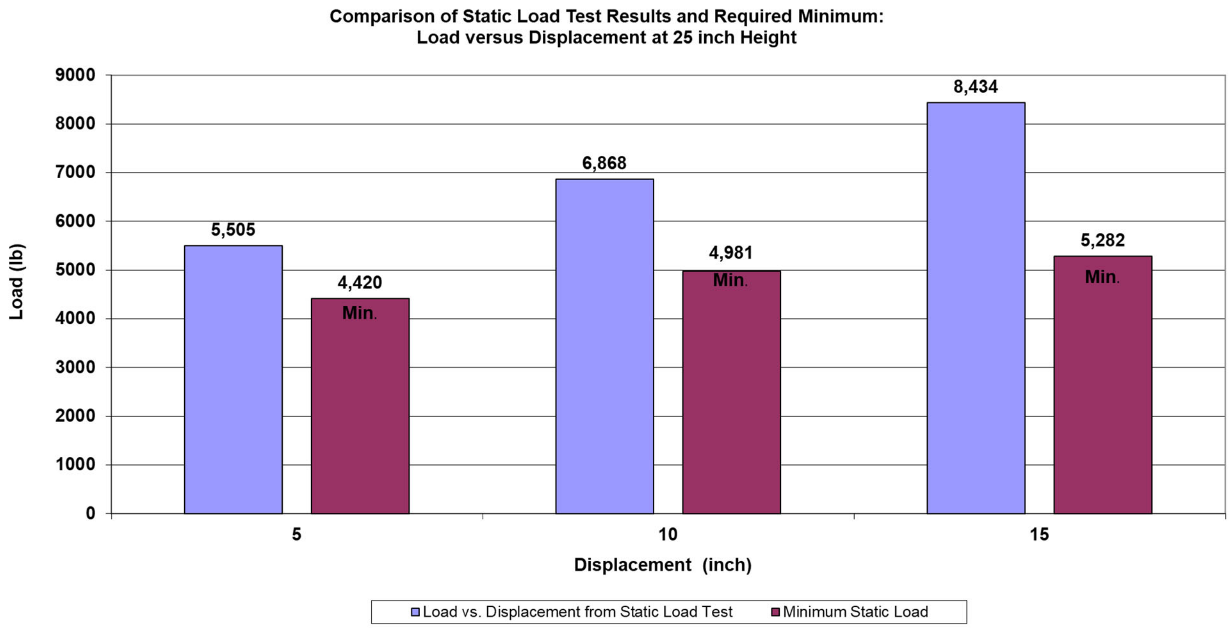
Comparison of Load vs. Displacement



Static Load Test Installation Details

Date	2020-02-02
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147 Grade D or Type D Crushed Concrete Road Base
Description of Fill Placement Procedure	12-inch lifts tamped with a pneumatic compactor for 20 sec
Bogie Weight	2020 lb
Impact Velocity	19.2 mph

Table F.2. Test Day Static Soil Strength Documentation for Test No. 611971-01-1.



Date	2021-04-22 – Test No. 611971-01-1
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Crushed Concrete
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO M147 Type D, Grade 1 crushed concrete
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

APPENDIX G. *MASH* TEST 2-11 (CRASH TEST NO. 611971-01-1)

G.1. VEHICLE PROPERTIES AND INFORMATION

Table G.1. Vehicle Properties for Test No. 611971-01-1.

Date: 2021-04-22 Test No.: 611971-01-1 VIN No.: 1C6RR6GT1FS607495

Year: 2015 Make: RAM Model: 1500

Tire Size: 265/70 R 17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 128203

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

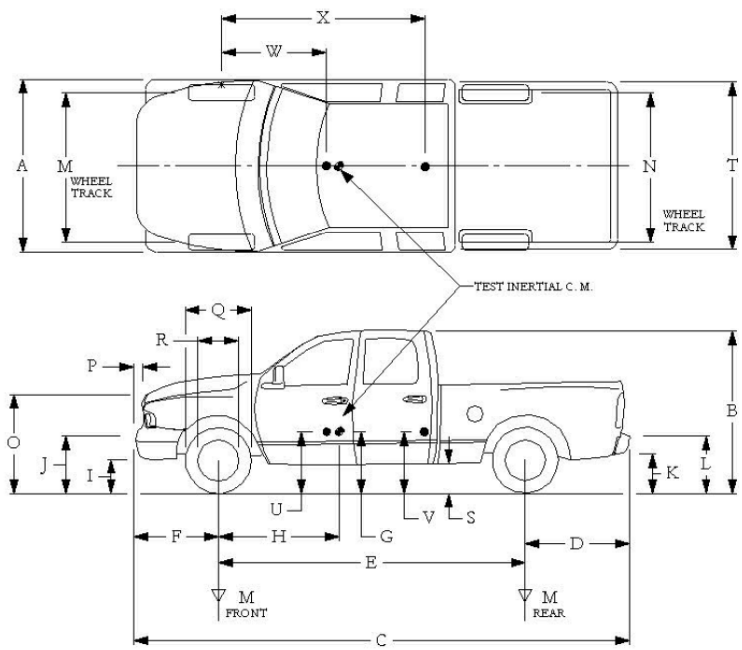
NOTES: None

Engine Type: V-8
Engine CID: 5.7 L

Transmission Type:
☑ Auto or ☐ Manual
☐ FWD ☑ RWD ☐ 4WD

Optional Equipment:
None

Dummy Data:
Type: NONE
Mass: 0 lb
Seat Position:



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.25	L	30.00	Q	30.50	V	30.25
C	227.50	H	61.73	M	68.50	R	18.00	W	61.70
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	12.50
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	22.50

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; (M+N)/2=67 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2933	2821	2821
Back	3900	M_{rear}	2129	2211	2211
Total	6700	M_{Total}	5062	5032	5032

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:
lb LF: 1408 RF: 1413 LR: 1115 RR: 1096

Table G.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 611971-01-1.

Date: 2021-04-22 Test No.: 611971-01-1 VIN: 1C6RR6GT1FS607495

Year: 2015 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 128203

Engine: 5.7 L V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 130 (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70 R 17

Measured Vehicle Weights: (lb)								
LF:	1408		RF:	1413		Front Axle:	2821	
LR:	1115		RR:	1096		Rear Axle:	2211	
Left:	2523		Right:	2509		Total:	5032	
							5000 ±110 lb allowed	
Wheel Base:	140.50	inches	Track: F:	68.50	inches	R:	68.00	inches
	148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed				
Center of Gravity, SAE J874 Suspension Method								
X:	61.73	inches	Rear of Front Axle	(63 ±4 inches allowed)				
Y:	-0.09	inches	Left -	Right +	of Vehicle Centerline			
Z:	28.25	inches	Above Ground	(minumum 28.0 inches allowed)				

Hood Height: 46.00 inches
43 ±4 inches allowed

Front Bumper Height: 27.00 inches

Front Overhang: 40.00 inches
39 ±3 inches allowed

Rear Bumper Height: 30.00 inches

Overall Length: 227.50 inches
237 ±13 inches allowed

Table G.3. Exterior Crush Measurements for Test No. 611971-01-1.

Date:	2021-04-22	Test No.:	611971-01-1	VIN No.:	1C6RR6GT1FS607495
Year:	2015	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bmp ht	14	6	24	-	-	-	-	-	-	-24
2	Side plane at bmp ht	14	8	48	-	-	-	-	-	-	74
	Measurements recorded										
	☑ **inches** **or** ☐ **mm**										

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

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

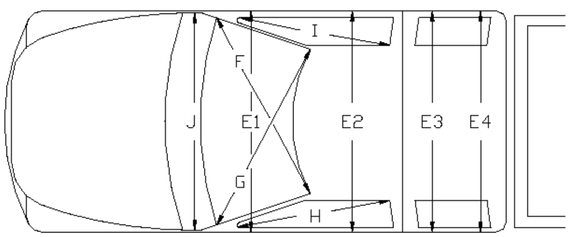
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

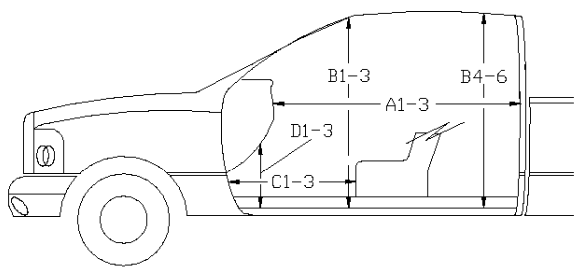
***Measure and document on the vehicle diagram the location of the maximum crush.

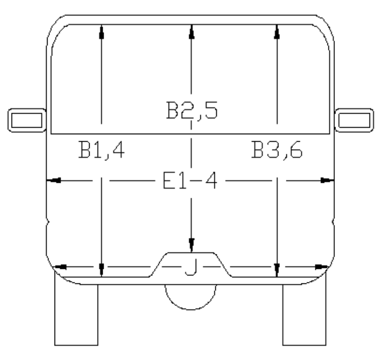
Note: Use as many lines/columns as necessary to describe each damage profile.

Table G.4. Occupant Compartment Measurements for Test No. 611971-01-1.

Date:	2021-04-22	Test No.:	611971-01-1	VIN No.:	1C6RR6GT1FS607495
Year:	2015	Make:	RAM	Model:	1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	11.50	0.00
E1	58.50	58.50	0.00
E2	63.50	63.50	0.00
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	25.00	0.00

G.2. SEQUENTIAL PHOTOGRAPHS

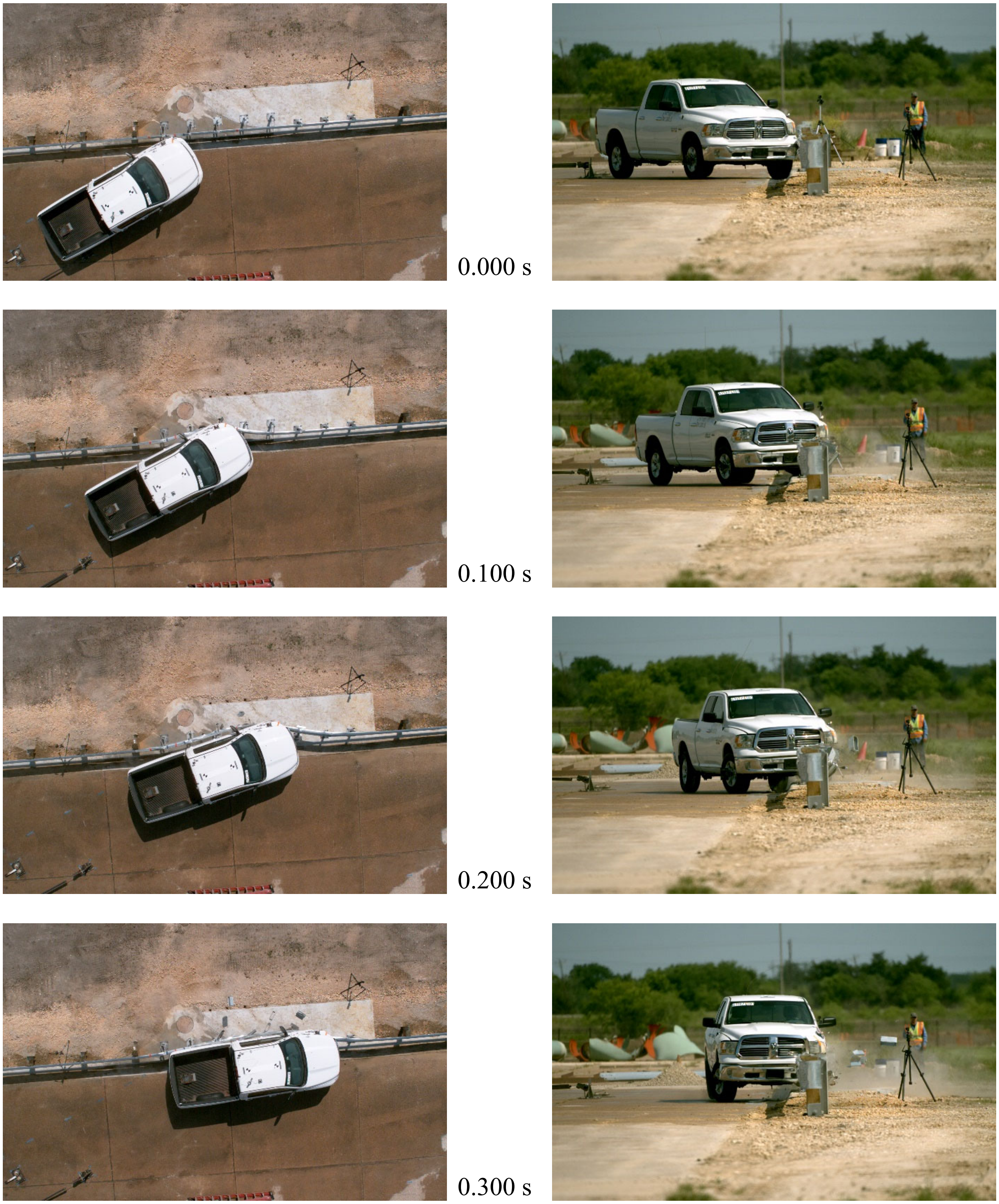
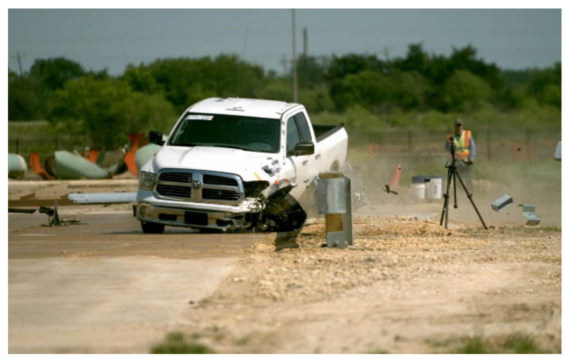


Figure G.1. Sequential Photographs for Test No. 611971-01-1 (Overhead and Frontal Views).

0.400 s

0.500 s

0.600 s



0.700 s

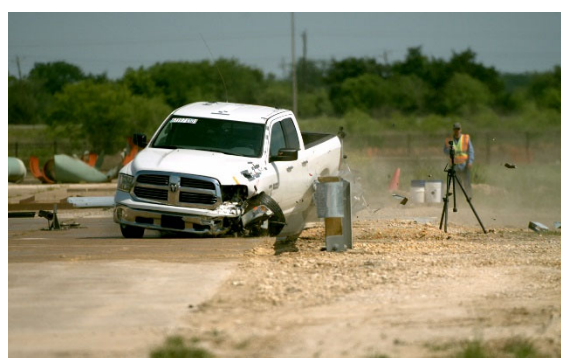


Figure G.1. Sequential Photographs for Test No. 611971-01-1 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

0.200 s

0.300 s

0.400 s

0.500 s

0.600 s

0.700 s

Figure G.2. Sequential Photographs for Test No. 611971-01-1 (Rear View).

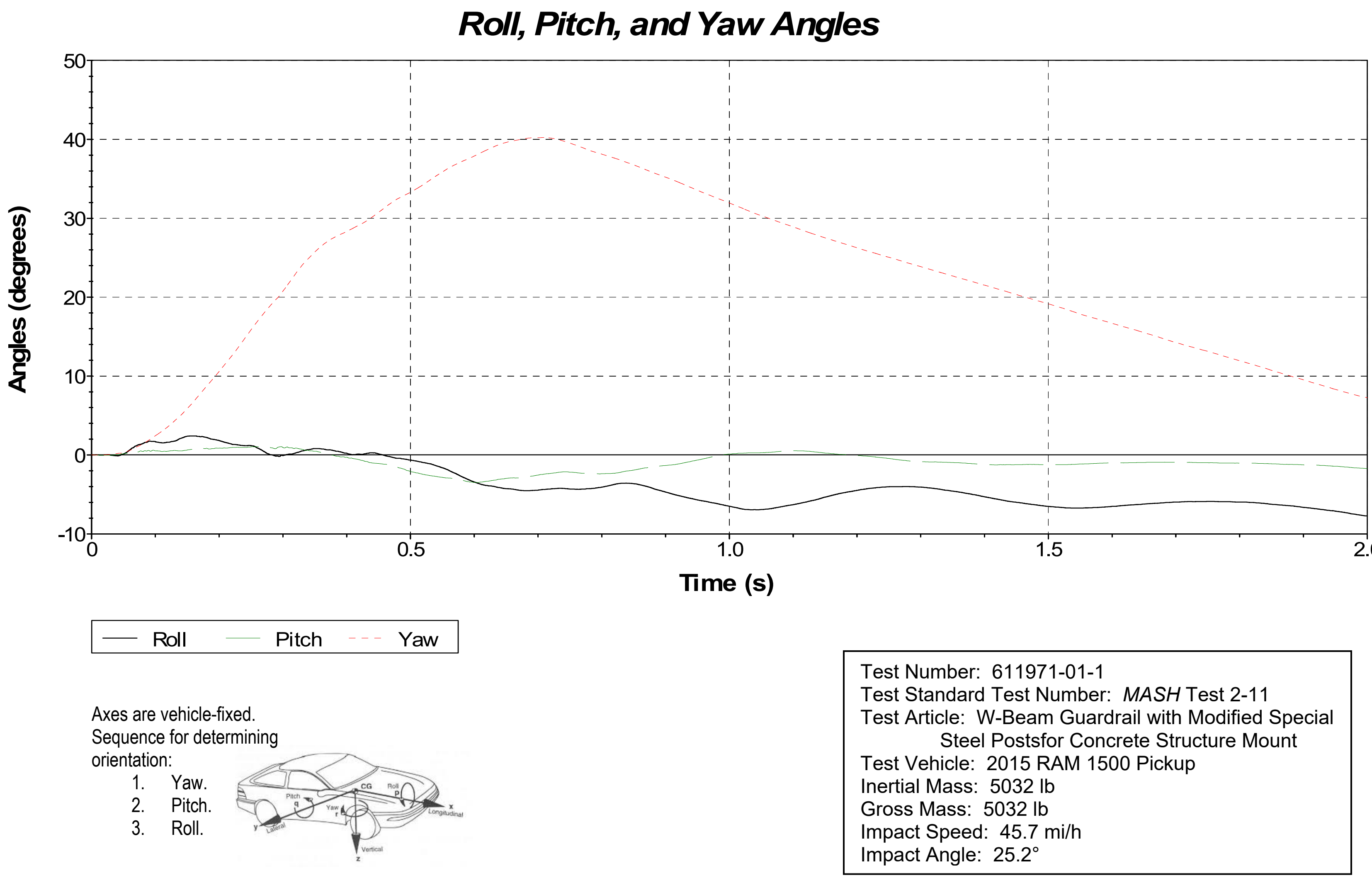


Figure G.3. Vehicle Angular Displacements for Test No. 611971-01-1.

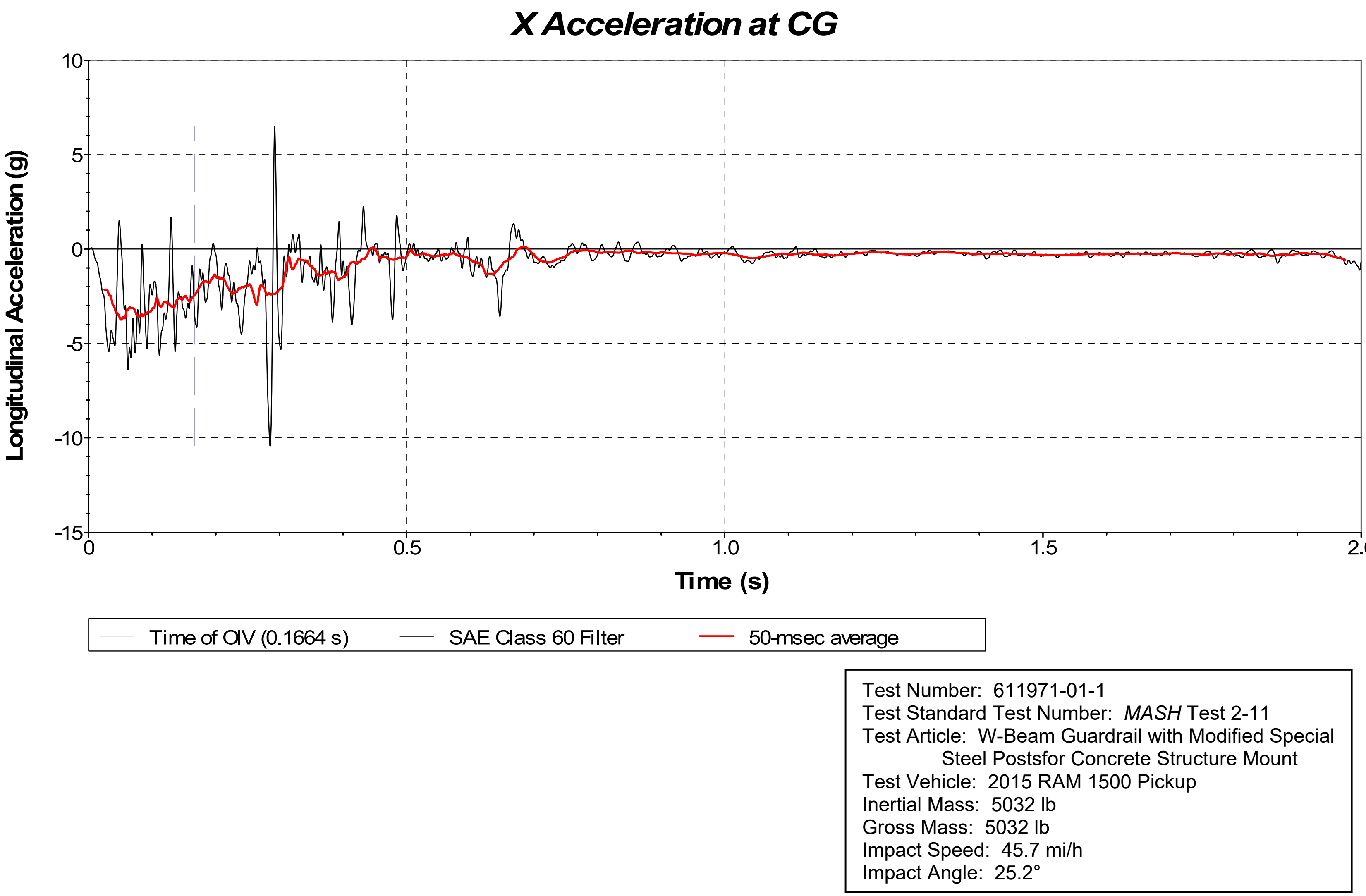
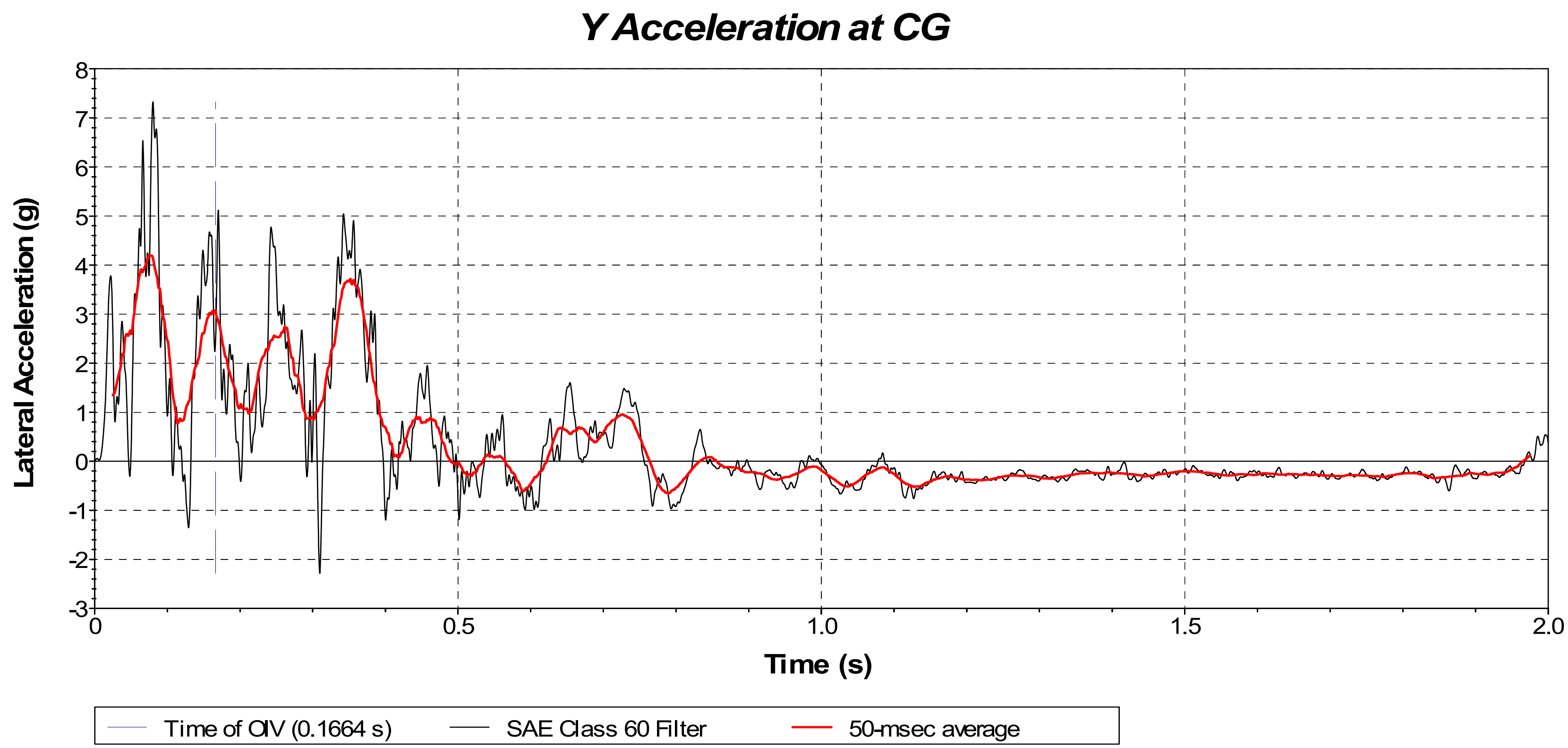


Figure G.4. Vehicle Longitudinal Accelerometer Trace for Test No. 611971-01-1 (Accelerometer Located at Center of Gravity).



Test Number: 611971-01-1
Test Standard Test Number: *MASH* Test 2-11
Test Article: W-Beam Guardrail with Modified Special Steel Postsfor Concrete Structure Mount
Test Vehicle: 2015 RAM 1500 Pickup
Inertial Mass: 5032 lb
Gross Mass: 5032 lb
Impact Speed: 45.7 mi/h
Impact Angle: 25.2°

Figure G.5. Vehicle Lateral Accelerometer Trace for Test No. 611971-01-1 (Accelerometer Located at Center of Gravity).

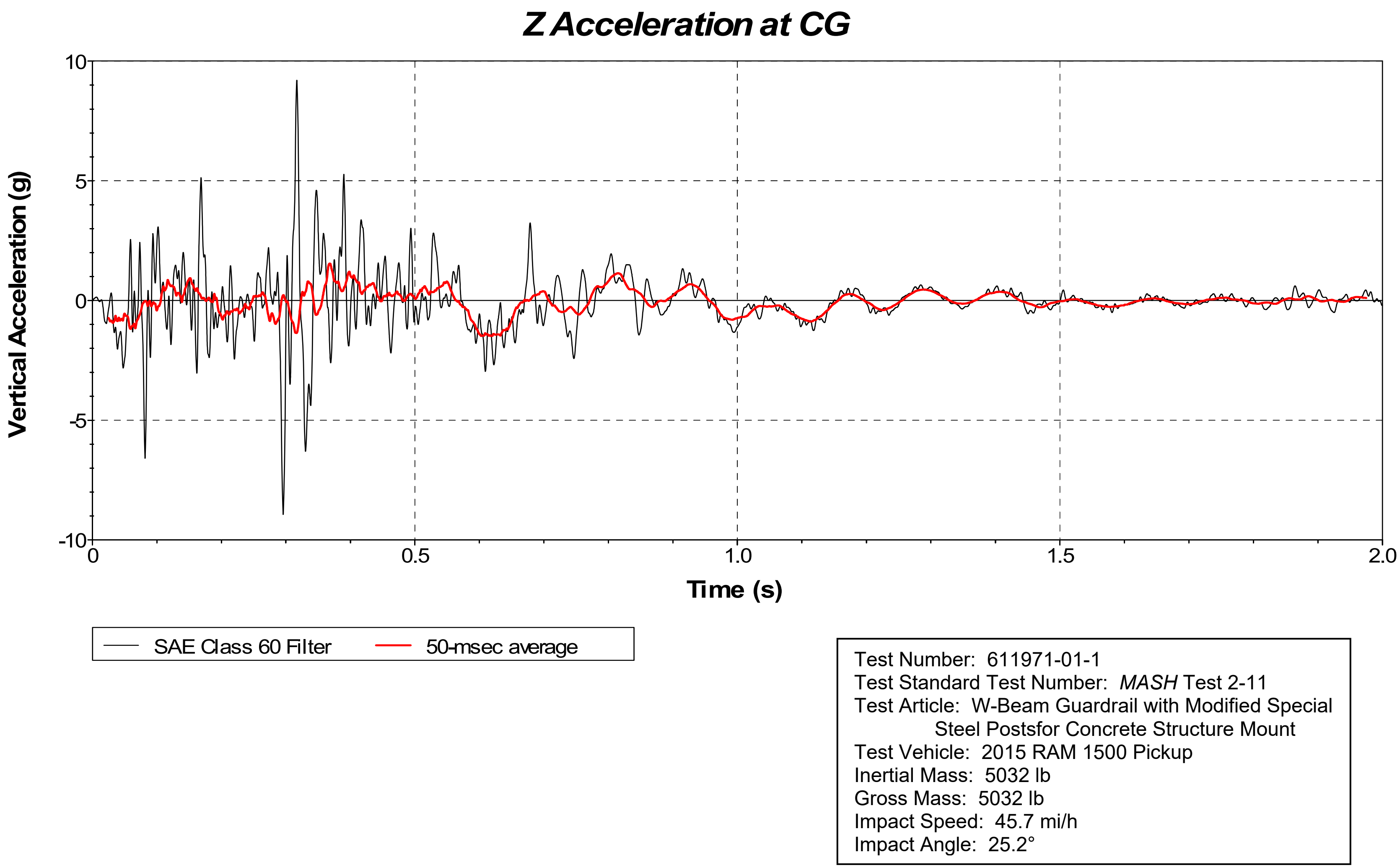


Figure G.6. Vehicle Vertical Accelerometer Trace for Test No. 611971-01-1 (Accelerometer Located at Center of Gravity).