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APPROACH GUARDRAIL TRANSITION TO THE HAWAII CONCRETE POST AND BEAM BRIDGE RAIL

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16. Abstract

The Hawaii Department of Transportation (HDOT) has utilized bridge railings similar to the Hawaii Modified Natchez Trace Bridge Rail and its associated approach guardrail transition (AGT) to safely redirect vehicles on or near bridges. However, the crashworthiness of the bridge railing and AGT had not been evaluated under current impact safety standards, the *Manual for Assessing Safety Hardware* (MASH). As part of a previous phase of this project, crash testing of the Hawaii Modified Natchez Trace Bridge Rail resulted in excessive occupant compartment deformations that failed to satisfy the safety performance criteria of MASH Test Level 3 (TL-3). Subsequently, the railing was redesigned with a vertical face and renamed the Hawaii Concrete Post and Beam Bridge Railing. This new railing was crash tested in accordance with MASH test designation nos. 3-10 and 3-11 and passed MASH TL-3 safety criteria.

Documented herein, HDOT's AGT to open concrete bridge rail was redesigned to ensure crashworthiness to MASH TL-3. The geometry of the bridge rail end post was modified such that its cross section gradually transitioned from a solid, vertical-faced parapet to a cross section matching that of the Hawaii Concrete Post and Beam Bridge Rail. Additionally, the length of the bridge rail end post was shortened to optimize installation costs. Finally, the post and rail components of the AGT were modified to match the configuration of another AGT to concrete parapet that had already passed MASH TL-3 crash testing. Since all of the components of this AGT configuration had already been shown to be MASH TL-3 crashworthy, this new AGT to the Hawaii Concrete Post and Beam Bridge Rail was also determined to be MASH TL-3 compliant.

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

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

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1 INTRODUCTION

1.1 Background

Previously, the Hawaii Department of Transportation (HDOT) utilized concrete bridge railings and their associated approach guardrail transitions (AGT) to safely redirect errant vehicles on or near bridges. However, the crashworthiness of these barrier systems had not been evaluated under the current impact safety standards. Thus, HDOT desired to evaluate their bridge railings and AGTs in accordance with the American Association of State Highway and Transportation Officials' (AASHTO) *Manual for Assessing Safety Hardware* (MASH) [1].

One concrete bridge rail commonly used by HDOT was the Hawaii Modified Natchez Trace Bridge Rail. The original Natchez Trace Bridge Railing [2] was developed and crash tested to Performance Level 1 (PL-1) criteria of the *AASHTO Guide Specifications for Bridge Railings* [3]. The Natchez Trace Bridge Rail was an open concrete bridge rail positioned atop a 10-in. tall curb, as shown in Figure 1. The railing incorporated a 13-in. tall by 12-in. wide concrete rail supported by 9-in. x 18-in. concrete posts spaced 7 ft – 6¾ in. apart. The face of the curb extended approximately 4½ in. out from the face of the concrete railing. A similar railing configuration with only minor reinforcement changes was later shown to be crashworthy to NCHRP Report 350 Test Level 3 (TL-3) safety criteria [4-5].

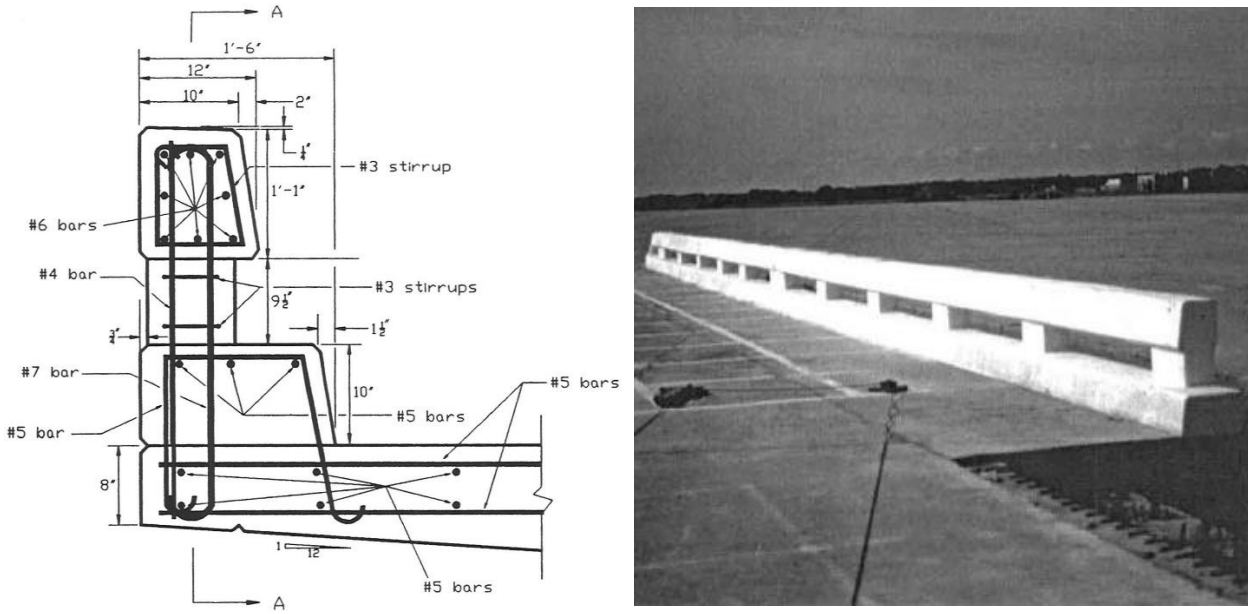


Figure 1. Natchez Trace Bridge Rail Design Details [2]

HDOT modified this original design to create the Hawaii Modified Natchez Trace Bridge Rail. As shown in Figure 2, the HDOT version was taller, wider, and was equipped with a steel tube pedestrian handrail on the back side of the rail. Additionally, the lateral offset between the lower curb and the upper rail was eliminated, which gave the front face of the Hawaii-Modified Natchez Trace Bridge Rail a profile similar to single slope parapets.

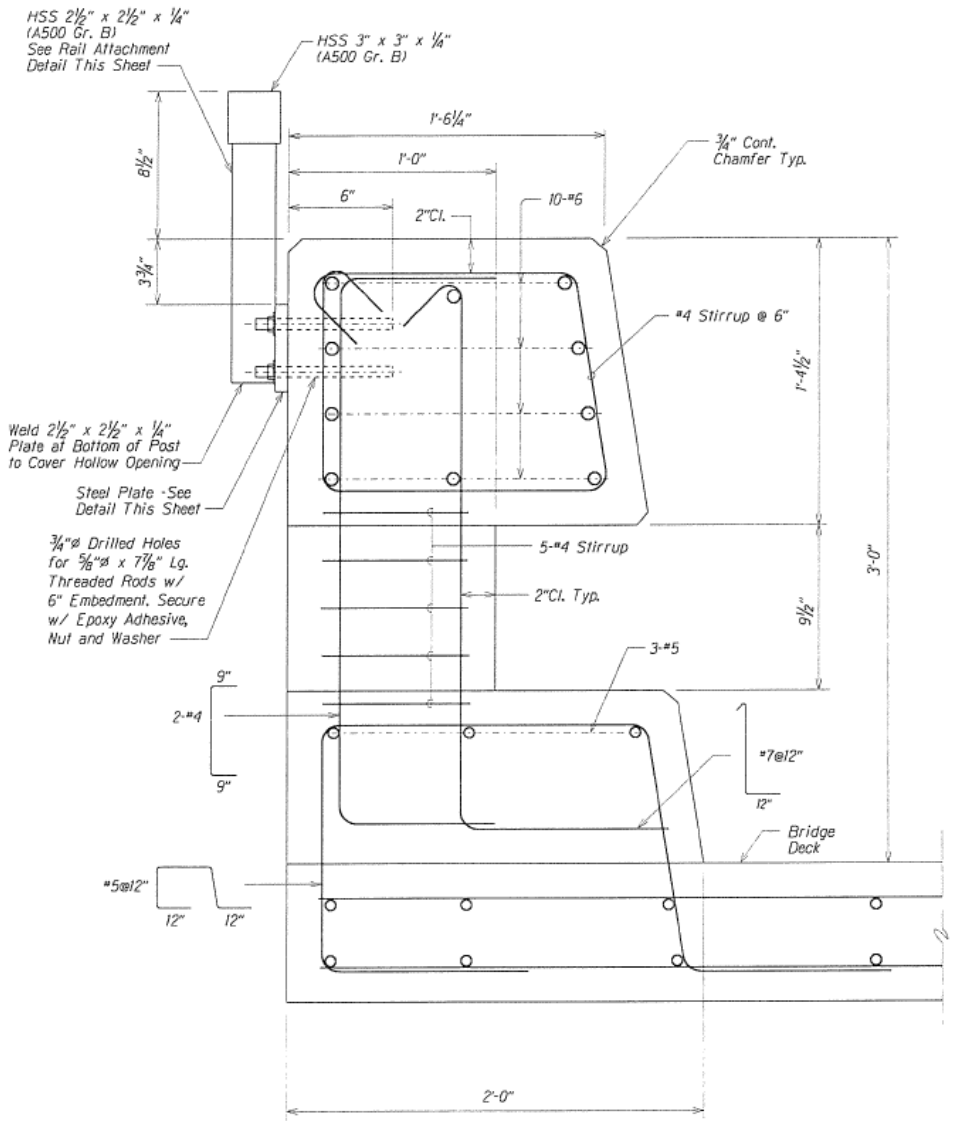


Figure 2. Hawaii Modified Natchez Trace Bridge Rail Design Details

As part of a previous phase of this project, MASH crash testing was conducted on the Hawaii Modified Natchez Trace Bridge Rail. Test no. HNTRB-1 resulted in occupant compartment deformations that exceeded the safety limits of MASH TL-3 [6]. Subsequently, the railing was redesigned with a vertical face and renamed the Hawaii Concrete Post and Beam Bridge Railing. This new railing configuration, shown in Figure 3, was crash tested in accordance with MASH test designation nos. 3-10 and 3-11 and passed MASH TL-3 safety criteria [7]. As the Hawaii Concrete Post and Beam Bridge Railing passed MASH TL-3, HDOT desired to evaluate the associated AGT to ensure the entire barrier system was crashworthy to MASH TL-3.

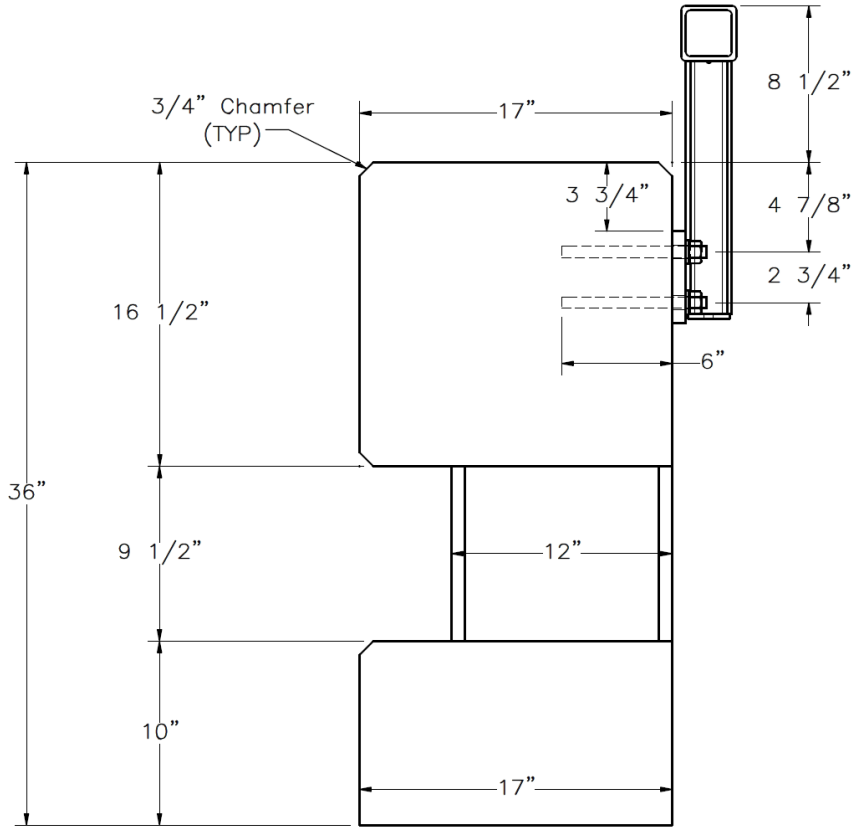


Figure 3. Hawaii Concrete Post and Beam Bridge Rail [7]

1.2 Objective

The objective of this project was to evaluate the HDOT thrie-beam AGT to the Hawaii Concrete Post and Beam Bridge Rail to MASH TL-3 safety performance criteria. Due to the change in geometry of the bridge rail, modifications to the bridge rail end post were necessary to create a smooth transition to the new bridge railing and prevent vehicle snag. Additionally, modifications to the AGT were desired to reflect the configuration of other MASH TL-3 AGTs previously developed for HDOT.

1.3 Scope

The project began with a review of the existing AGT to the Hawaii Modified Natchez Trace Bridge Rail as well as a review of other AGTs developed for HDOT that had previously passed MASH TL-3 safety criteria. Next, the AGT was modified to reflect the configuration of other MASH crashworthy HDOT AGTs, and the associated bridge rail end post was modified to match the new Hawaii Concrete Post and Beam Bridge Rail. Finally, the new AGT configuration was evaluated to MASH TL-3 safety criteria.

2 DESIGN MODIFICATIONS

HDOT's standard plans for approach guardrail installations adjacent to the Hawaii Modified Natchez Trace Bridge Rail consisted of a W-to-thrie beam upstream stiffness transition, a nested thrie beam AGT, and a specialized concrete end post that transitioned from a vertical shaped parapet to a single-sloped shape that matched the cross section of the bridge rail, as shown in Figure 4. As described previously, the shape of HDOT's concrete post and beam bridge rail was changed as part of the MASH evaluation of the bridge rail. Thus, the shape of the bridge rail end post had to be adjusted to match the new Hawaii Concrete Post and Beam Bridge Rail. Additionally, components of the AGT were modified to improve its safety performance and to match a previously MASH tested AGT.

The HDOT AGT shown in Figure 4 was similar to another HDOT AGT that was previously crash tested and passed MASH TL-3 criteria [8]. This previously tested HDOT AGT was developed for use with vertical shaped, concrete bridge rails and used a Type D2 End Post between the guardrail segments and the bridge rail, as shown in Figures 5 and 6. Both HDOT AGT configurations utilized the same number of posts and the same guardrail segments, including the asymmetric W-to-thrie transition segment as part of the MASH TL-3 crashworthy MGS upstream stiffness transition [9]. Additionally, both AGT configurations had a 6-in. tall curb located below the nested thrie beam and positioned with the face of the curb in line with the face of the guardrail.

There were two notable differences between the AGT configurations. First, the four transition posts located in the nested thrie beam region of the AGT were different sizes. Although the AGTs used the same length and spacing for the posts, the AGT for the post and beam bridge rail shown in Figure 4 called for W6x9 posts, while the previously MASH tested AGT used W6x15 posts. To promote consistency among AGT installations, HDOT elected to change these four transition posts to W6x15 posts.

The second difference between the AGTs was the shapes of the bridge rail end posts at the attachment location of the thrie beam terminal connector. The previously tested Type D2 End Post had a 4-in. lateral recess, which resulted in the face of the guardrail being in line with the face of the bridge rail end post. This recess was not present on the end post details for the post and beam bridge rail. This may not be a safety performance concern, but it does create issues with the lateral position of the curb, which was supposed to be in line with the face of the guardrail, as shown in Figure 7. To avoid curb-to-end post alignment issues and to promote consistency among AGT installations, HDOT decided to add the 4-in. lateral recess to the upstream end of the concrete end post for the post and beam bridge railing.

The bridge rail end post shown in Figure 4 had been designed with a shape transition such that the downstream end matched the cross section of the Hawaii Modified Natchez Trace Bridge Rail. However, as discussed previously, the newly developed Hawaii Concrete Post and Beam Bridge Rail had a vertical front profile instead of a sloped front profile. Accordingly, the bridge rail end post was redesigned to maintain a vertical front profile throughout its length. A 9½-in. tall by 5-in. deep (lateral) recess was placed at the downstream end of the end post to match the lateral post setback of the Hawaii Concrete Post and Beam Bridge Rail, shown previously in Figure 3. A 10:1 taper was used to transition from this 5-in. recess to the continuous vertical face in the middle of the end post. The new shape of the bridge rail end post is shown in Figure 8.

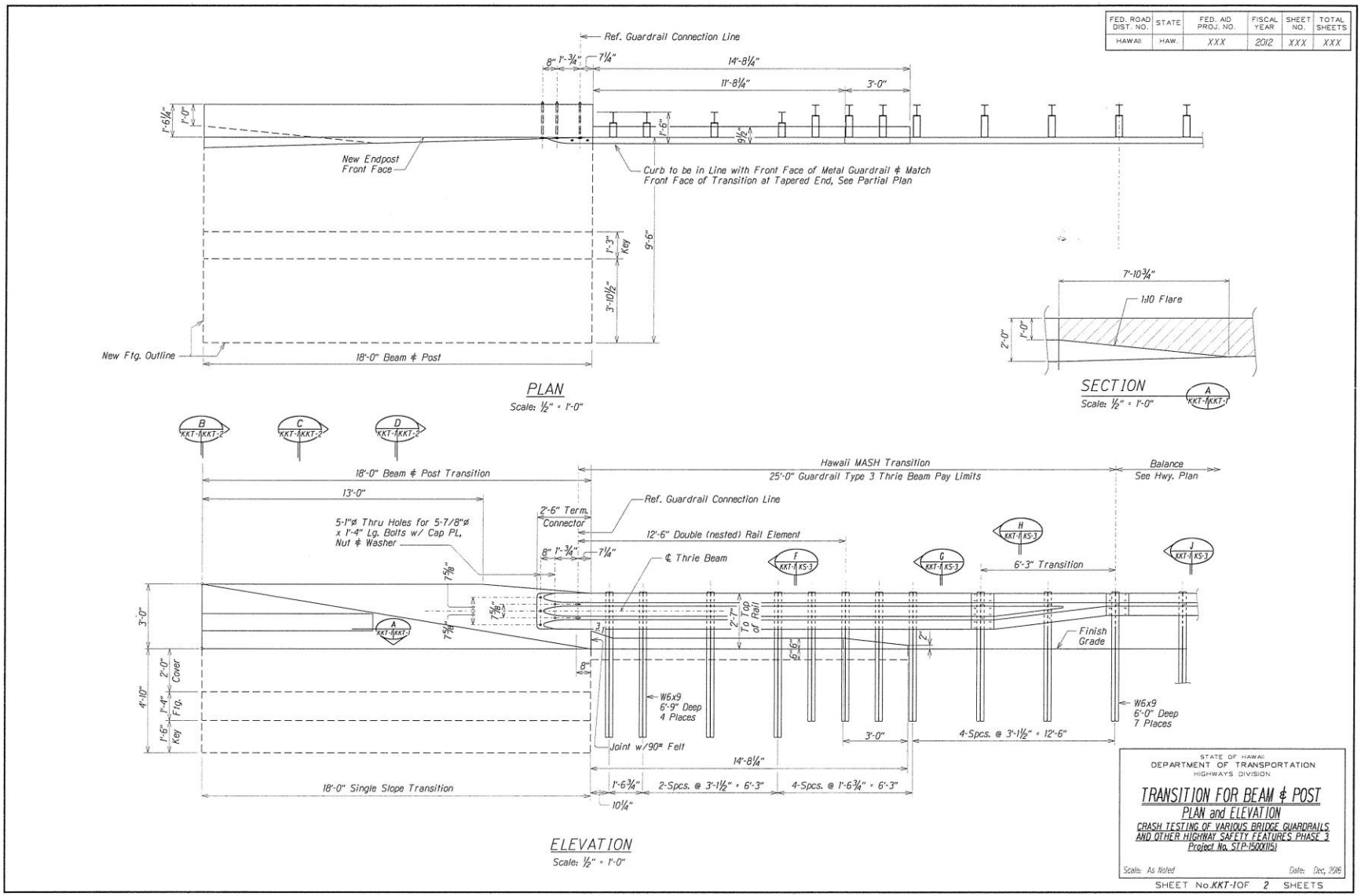


Figure 4. Original HDOT Details for AGT to Hawaii Modified Natchez Trace Bridge Rail

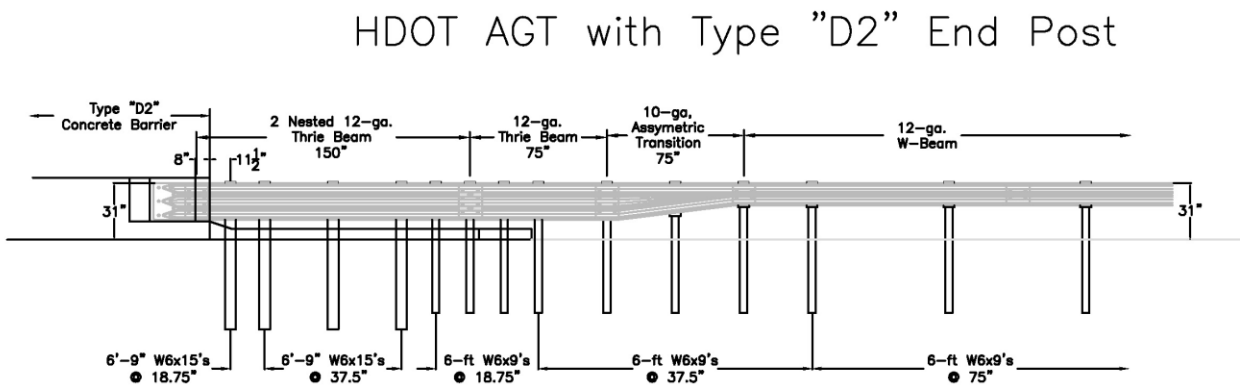


Figure 5. Details, MASH TL-3 Crashworthy HDOT AGT to Concrete End Post

Figure 6. Test Installation Photograph, HDOT AGT to Concrete End Post

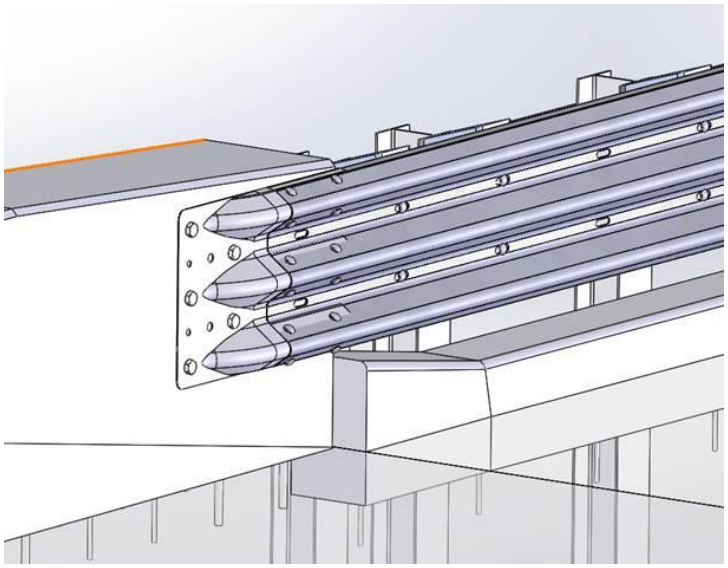


Figure 7. Curb and Concrete End Post Alignment Issues

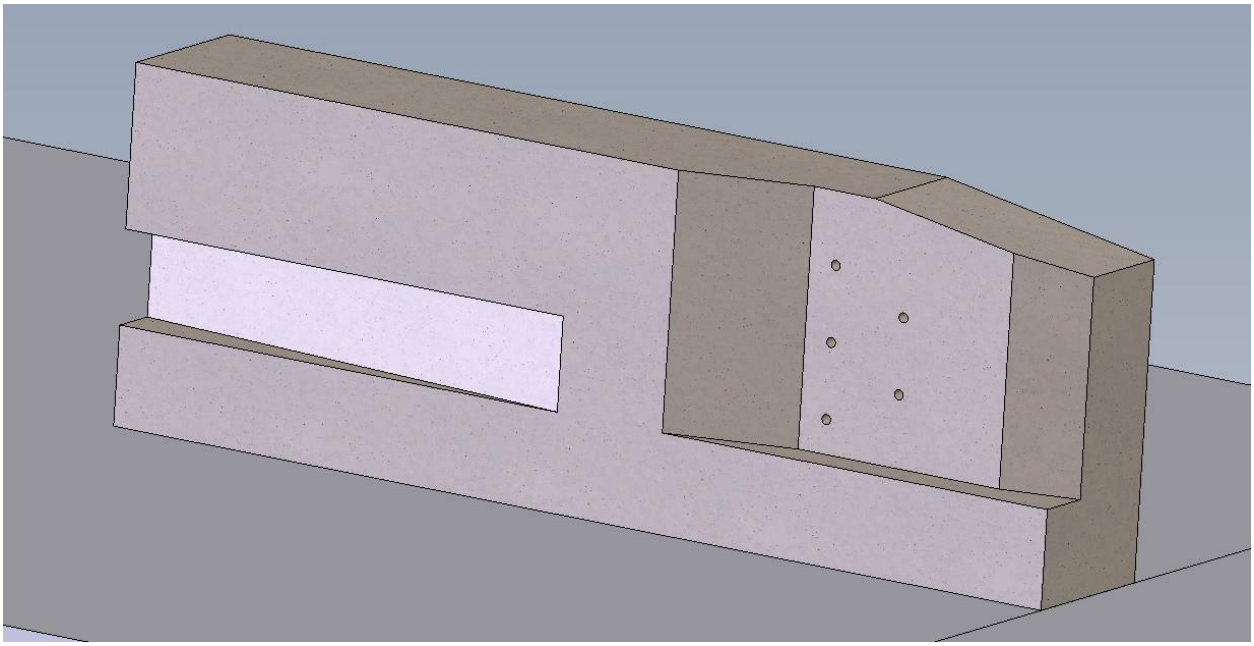


Figure 8. Concrete End Post for Hawaii Concrete Post and Beam Bridge Rail

Finally, there was a minor modification to the curb where the height of the curb was raised to match the height to the recess on the upstream end of the concrete end post. The previously tested AGT configuration utilized a 3:1 slope to transition from a 6 in. height to a 10 in. height [8]. The same curb height transition was later found to contribute to wheel snag during MASH crash testing of the AGT to the Hawaii Modified Delaware Retrofit Thrie Beam Bridge Rail. Subsequently, the slope of the curb's height transition was reduced to 6:1 [10]. A comparison of these curb height transition slopes is shown in Figure 9. To promote consistency among AGT installations, HDOT opted to incorporate the 6:1 curb height transition slope into all of their AGT details.

3:1 Curb Slope –Test Installation for Test No. HWTT-1 [8]

6:1 Curb Slope – Test Installation for Test No. HMDT-4 [10]

Figure 9. Comparison of Curb Height Transition Slopes

3 DESIGN DETAILS

The complete barrier transition from standard W-beam guardrail (the Midwest Guardrail System) to the Hawaii Concrete Post and Beam Bridge Rail was comprised of multiple regions, including an upstream W-to-thrie beam stiffness transition, a thrie beam approach guardrail transition, and a bridge rail end post. The layout of these barrier regions is depicted in Figure 10. The absence of any one of these barrier regions would result in an incomplete AGT and would negatively affect the safety performance of the barrier system.

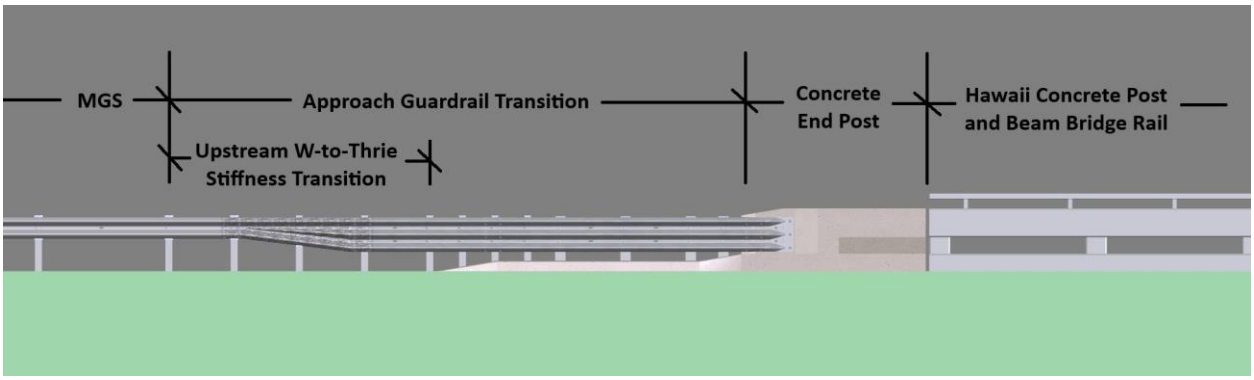


Figure 10. Transition Layout from MGS to Hawaii Concrete Post and Beam Bridge Rail

Going from upstream to downstream, the approach guardrail transition, including the W-to-thrie stiffness transition, consisted of a 6.25-ft long, asymmetric, 10-ga. W-to-thrie beam transition segment, 6.25 ft of 12-ga. thrie beam, 12.5 ft of nested 12-ga thrie beam, and a 10-ga. thrie beam terminal connector. All guardrail segments had a nominal top height of 31 in. The four transition posts at the downstream end of the AGT were 6.5-ft long W6x15 posts with 8-in. deep blockouts, while the remaining posts were 6-ft long W6x9 posts with 12-in. deep blockouts. Post spacings varied between 37½ in. and 18¾ in. depending on the location within the AGT. Additionally, a 6-in. tall curb was located below the nested thrie beam guardrail with the face of the curb in line with the face of the guardrail. Note, the upstream end of the curb was terminated prior to the W-to-thrie transition segment, and the height of the curb increased to 10 in. on the downstream end of the curb to match the height of the lateral recess in the bridge rail end post.

Both the upstream W-to-thrie stiffness transition and HDOT's AGT to a vertical shaped concrete end post were previously developed and successfully crash tested to MASH TL-3. Discussion and implementation guidance for this AGT can be found in a previous crash testing report [8]. CAD details for the test installation used to evaluate the AGT are provided in Appendix A.

The Hawaii Concrete Post and Beam Bridge Rail was a 36-in. tall by 17-in. wide open concrete bridge rail. The upper rail was supported by 9½-in. tall, 12-in. square posts, which sat upon a 10-in. tall lower curb. The posts were offset 5 in. laterally from the face of the bridge rail. A steel tube pedestrian handrail was attached to the back side of the rail. The Hawaii Concrete Post and Beam Bridge Rail was also previously developed and successfully crash tested to MASH TL-3 criteria [7]. CAD details for the bridge rail test installation are provided in Appendix B.

The new and unique component within the AGT to the Hawaii Concrete Post and Beam Bridge Rail was the new bridge rail end post. Details for the new bridge rail end post are shown in Figures 11 through 18.The end post was a concrete parapet with a height of 36 in. and a width of 17 in., which matched the dimensions of the bridge rail. The upstream end of the bridge rail end post included a 4-in. lateral recess for the attachment of the thrie beam terminal connector. This recess allowed the face of the guardrail to be in line with the face of the end post and bridge rail. The upstream end also had a 6:1 vertical taper as the height of the end post increased from 32 in. to 36 in.

The downstream end of the bridge rail end post needed to match that of the Hawaii Concrete Post and Beam Bridge Rail to avoid vehicle snag concerns. Thus, a 9½-in. tall by 5-in. deep (lateral) recess was placed on the downstream end. The transition between the continuous, vertical mid-section and the downstream end with the recess was achieved using a 10:1 lateral slope to mitigate vehicle snag and instability concerns for reverse direction impacts.

The length of the bridge rail end post should be a minimum of 106 in., which provides a 12-in. length of continuous, vertical barrier face between the upstream and downstream recesses/shape transitions. If a longer end post is desired due to site requirements or the size of the supporting foundation structure, this middle section with a continuous vertical face should be elongated to meet the desired parapet length.

Reinforcement details for the bridge rail end post were taken from the previously MASH tested Type D2 end post [8]. The bridge rail end post contained six longitudinal no. 6 bars and six longitudinal no. 4 bars placed as shown in Figures 12 through 14. Note, a number of the longitudinal bars had to be bent to follow the shape of the recesses within the end post, as detailed in Figures 16 and 17.

The front side of the end post contained no. 6 vertical bars spaced at 6 in. on-center near the upstream end and at 9 in. on-center within the middle and downstream sections. Additional no. 6 bars with the same spacings were placed in the lower-front portion of the end post to anchor the parapet below the recesses. The back side of the end post contained no. 4 vertical bars spaced at 12 in. on-center. The lateral lengths at the top of the vertical bars will vary depending on the individual bar locations within the end post and its recesses.

Note, the vertical bars labeled e1 through e4 in Figures 12 through 15 are depicted as extending only 8 in. below the base of the end post (ground line). The actual length and shape of the bottom of these bars will be dependent on the size and shape of the supporting foundation structure to which the end post is anchored. All vertical rebar should be properly anchored/embedded within the foundation structure, including any bends and/or hooks, to ensure these bars can develop their full tensile load. Epoxy anchorage may also be used to anchor these vertical bars by following all manufacturer guidelines to fully develop the bars.

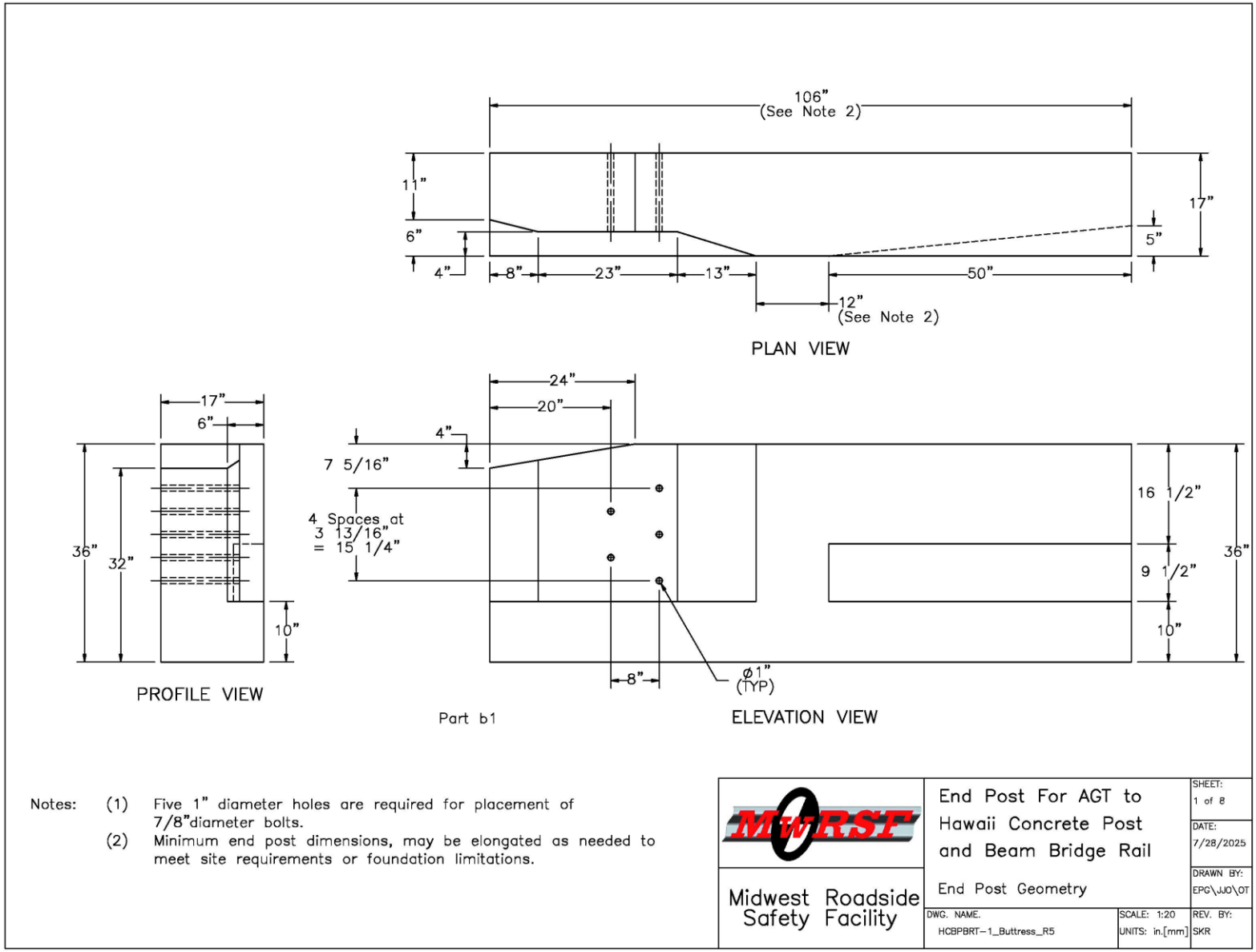


Figure 11. Bridge Rail End Post, Geometry Details

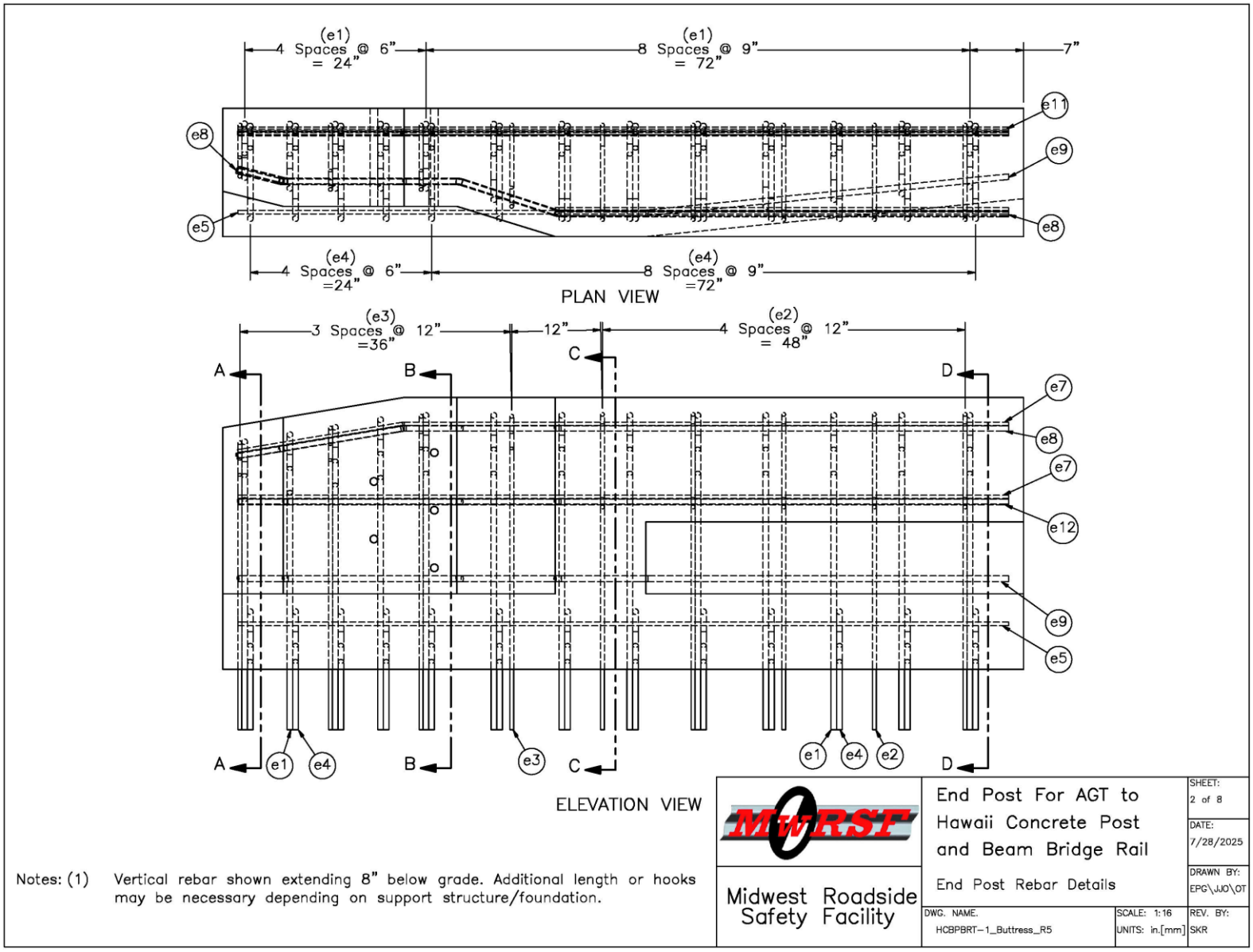


Figure 12. Bridge Rail End Post, Reinforcement Details

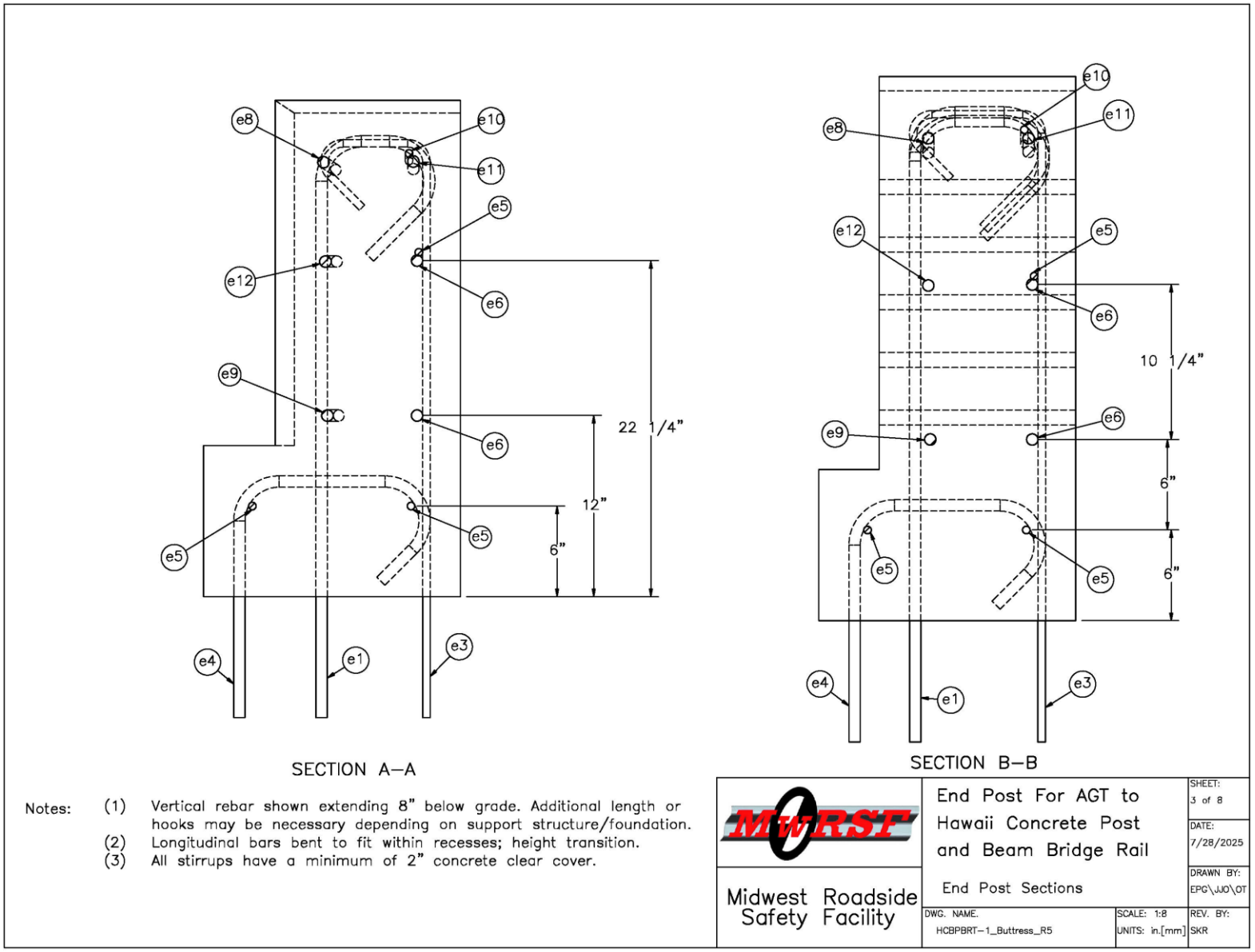


Figure 13. Bridge Rail End Post, Cross Section Details

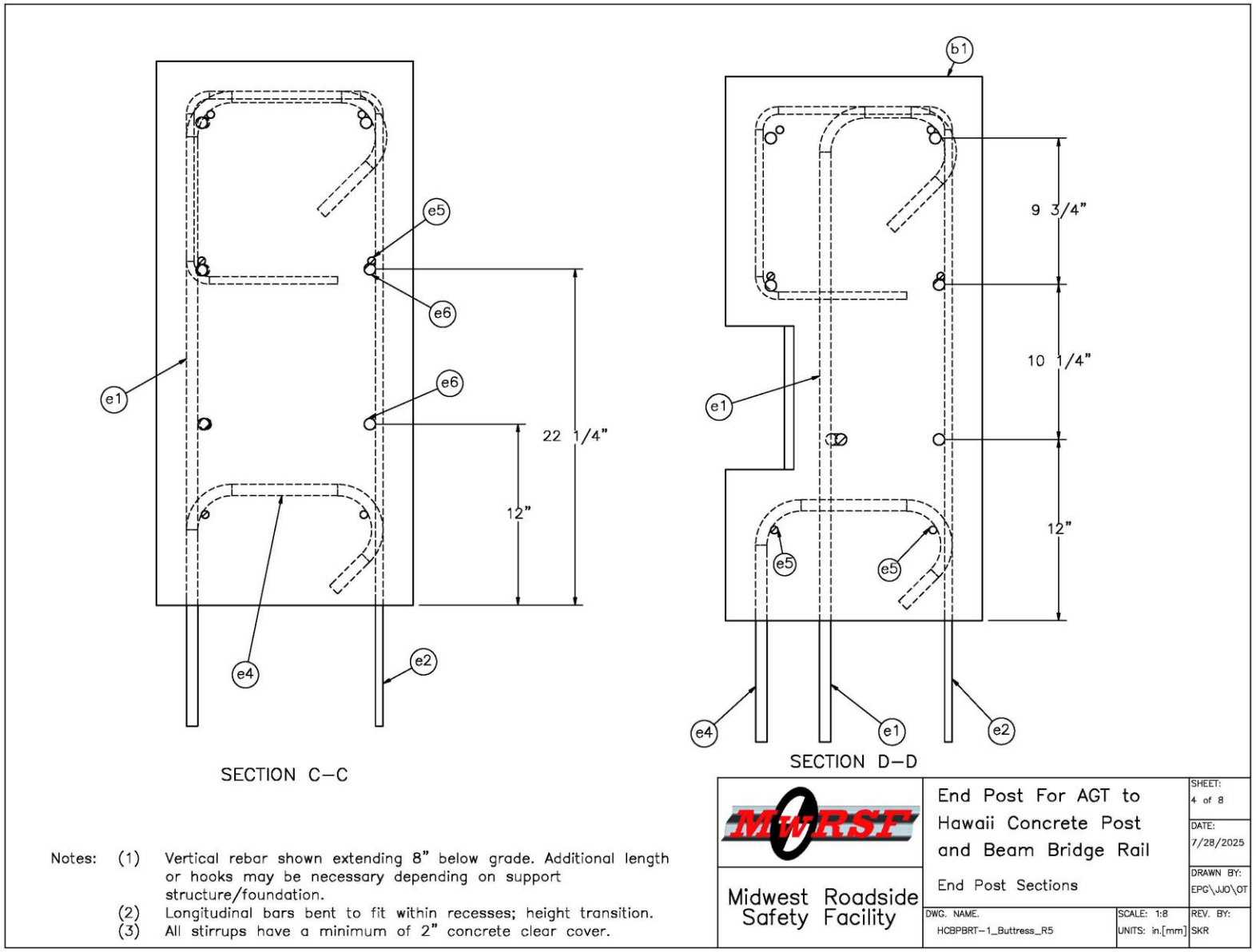


Figure 14. Bridge Rail End Post, Cross Section Details

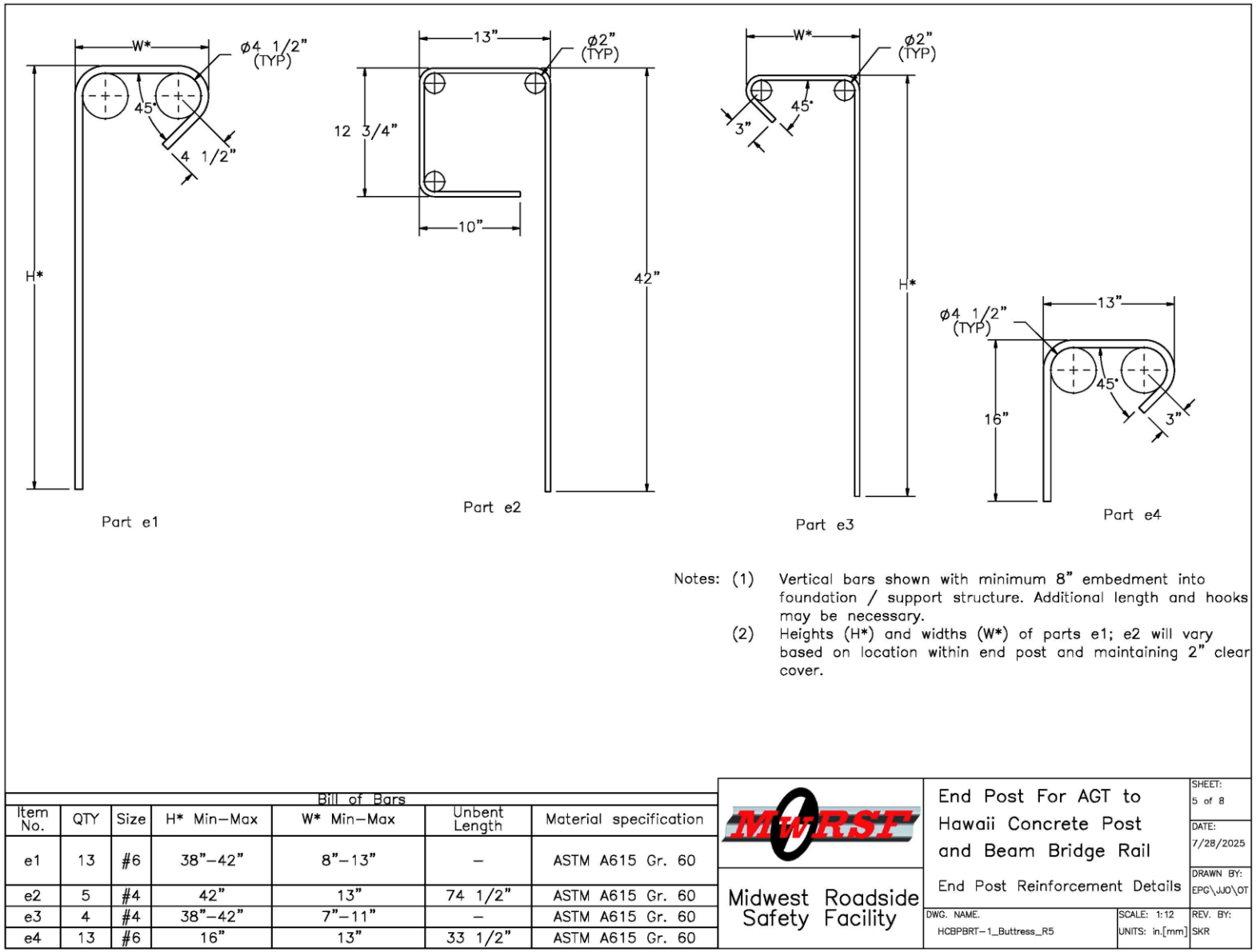
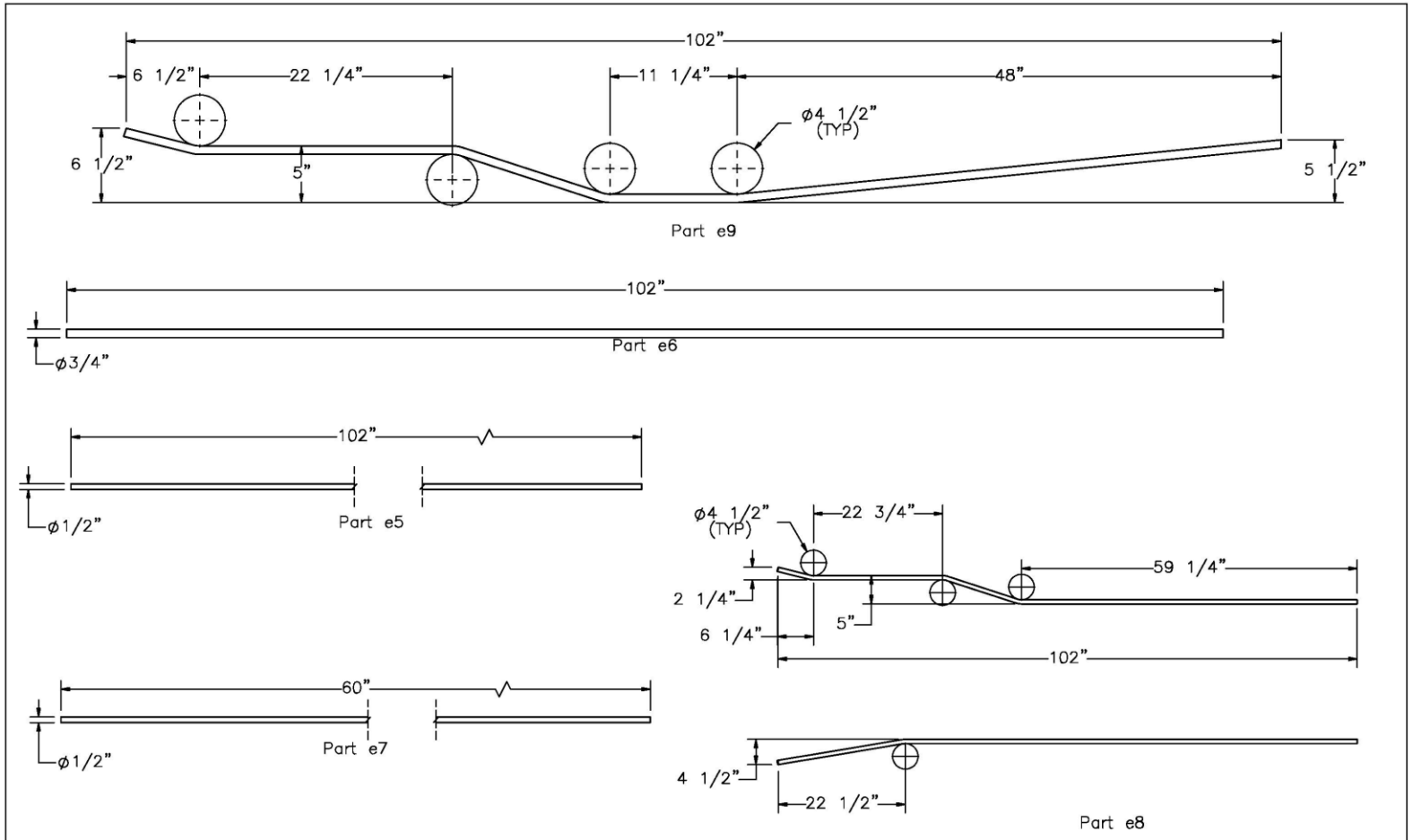


Figure 15. Bridge Rail End Post, Transverse Rebar Details



Bill of Bars

Part No.	Bar No.	QTY	Unbent Length	Material Specification
e5	#4	3	102"	ASTM A615 Gr. 60
e6	#6	2	102"	ASTM A615 Gr. 60
e7	#4	2	60"	ASTM A615 Gr. 60
e8	#6	1	103 1/2"	ASTM A615 Gr. 60
e9	#6	1	103"	ASTM A615 Gr. 60

MwRSF

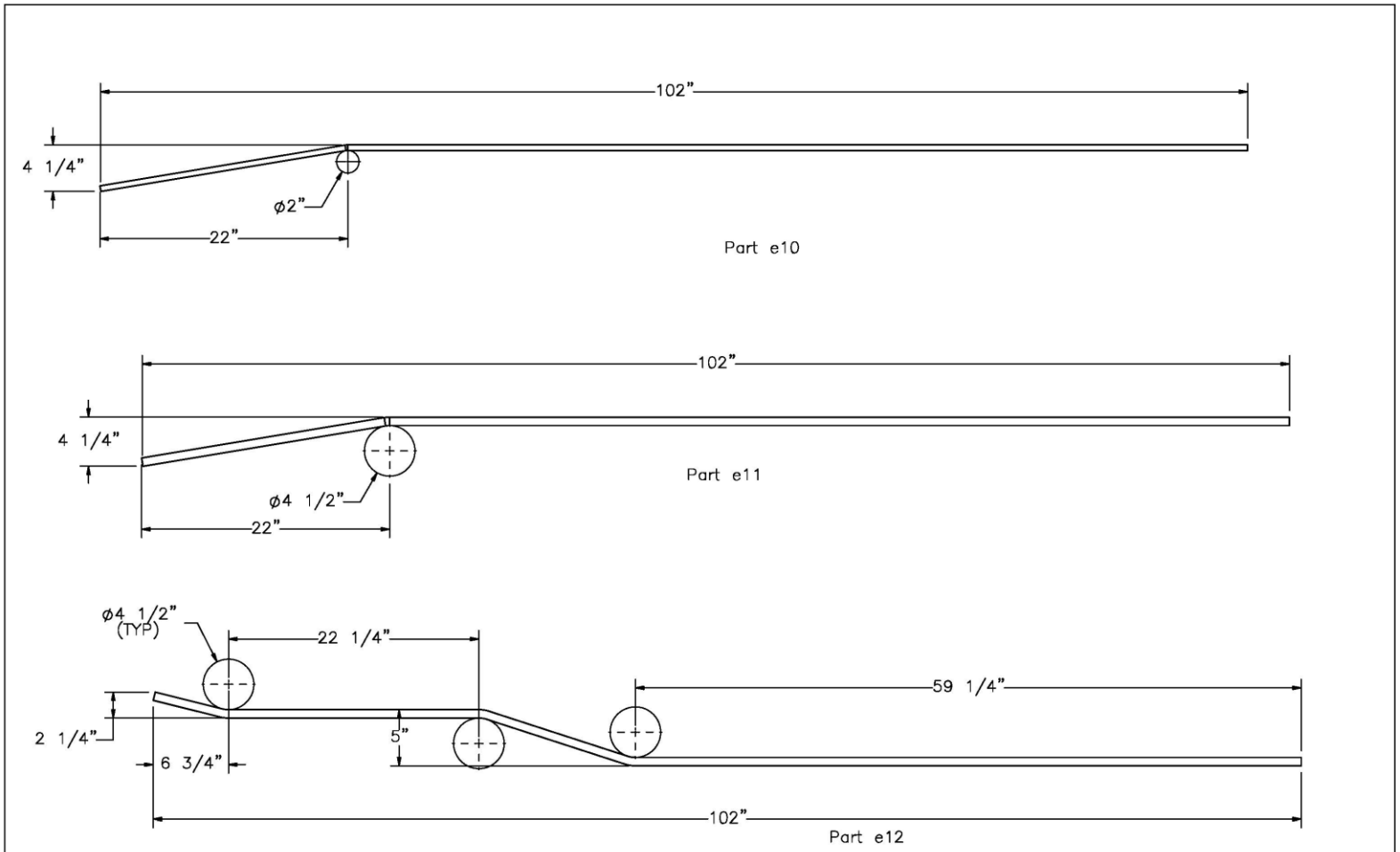
Midwest Roadside Safety Facility

End Post For AGT to Hawaii Concrete Post and Beam Bridge Rail

End Post Reinforcement Details

SHEET: 6 of 8
DATE: 7/28/2025
DRAWN BY: EPG\JJO\OT
REV. BY: SKR
DWG. NAME. HCBPBRT-1_Buttress_R5
SCALE: 1:12
UNITS: in.[mm]

Figure 16. Bridge Rail End Post, Longitudinal Rebar Details



Bill of Bars

Part No.	Bar No.	QTY	Unbent Length	Material Specification
e10	#4	1	102 1/2"	ASTM A615 Gr. 60
e11	#6	1	102 1/2"	ASTM A615 Gr. 60
e12	#6	1	103"	ASTM A615 Gr. 60

MwRSF

Midwest Roadside Safety Facility

End Post For AGT to Hawaii Concrete Post and Beam Bridge Rail

End Post Reinforcement Details

SHEET: 7 of 8
DATE: 7/28/2025
DRAWN BY: EPG\JJO\OT
REV. BY: SKR
DWG. NAME. HCBPBRT-1_Buttress_R5
SCALE: 1:12
UNITS: in.[mm]

Figure 17. Bridge Rail End Post, Longitudinal Rebar Details

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
b1	1	Reinforced Concrete	Min. f'c = 4,000 psi [27.6 MPa] NE Mix 47BD		–
e1	13	#6 Rebar, 60" Total Unbent Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
e2	5	#4 Rebar, 74 1/2" Total Unbent Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
e3	4	#4 Rebar, 57 1/4" Total Unbent Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
e4	13	#6 Rebar, 33 1/2" Total Unbent Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
e5	3	#4 Rebar, 102" Total Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
e6	2	#6 Rebar, 102" Total Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
e7	2	#4 Rebar, 60" Total Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
e8	1	#6 Rebar, 103 1/2" Total Unbent Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
e9	1	#6 Rebar, 103" Total Unbent Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
e10	1	#4 Rebar, 102 1/2" Total Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
e11	1	#6 Rebar, 102 1/2" Total Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
e12	1	#6 Rebar, 103" Total Unbent Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–

MwRSF

Midwest Roadside Safety Facility

End Post For AGT to Hawaii Concrete Post and Beam Bridge Rail

Bill of Materials

SHEET: 8 of 8

DATE: 7/28/2025

DRAWN BY: EPG\JJO\OT

DWG. NAME. HCBPBRT-1_Buttress_R5

SCALE: None

UNITS: in.[mm]

REV. BY: SKR

Figure 18. Bridge Rail End Post, Bill of Materials

4 MASH EVALUATION

The approach guardrail transition to the Hawaii Concrete Post and Beam Bridge Rail consisted of both a thrie beam AGT, and a concrete end post, as shown in Figure 19. The AGT, including the upstream stiffness transition, included a 6.25-ft long, asymmetric, 10-ga. W-to-thrie beam transition segment, 6.25 ft of 12-ga. thrie beam, 12.5 ft of nested 12-ga thrie beam, and a 10-ga. thrie beam terminal connector. The guardrail segments had a nominal top height of 31 in. and were supported by four W6x15 transition posts and eight standard w6x9 guardrail posts. A 6-in. tall curb was located below the thrie beam guardrail and positioned with the front face of the curb in line with the front face of the guardrail. Further details on the AGT components can be found in the crash testing report [8] and the CAD details provided in Appendix A.

The bridge rail end post was 36 in. tall by 17 in. wide and had a minimum length of 106 in. Note, if desired, the length of the bridge rail end post may be increased by extending the middle section of the end post between the two recesses. A 4-in. deep recess was located on the upstream end of the bridge rail end post, which results in the face of the guardrail being in line with the face of the end post. The recess was terminated with a 13-in. long tapered section to create a continuous, vertical front face 44 in. from the upstream end. The upstream end also had a 6:1 vertical slope to bring its height from 32 in. at the upstream end to 36 in. The downstream end of the bridge rail end post included a 9½-in. tall by 5-in. deep (lateral) recess, which resulted in the cross section matching the shape of the Hawaii Concrete Post and Beam Bridge Rail. Details for the concrete end post can be found in Chapter 3, while CAD drawings for the bridge rail are provided in Appendix B.

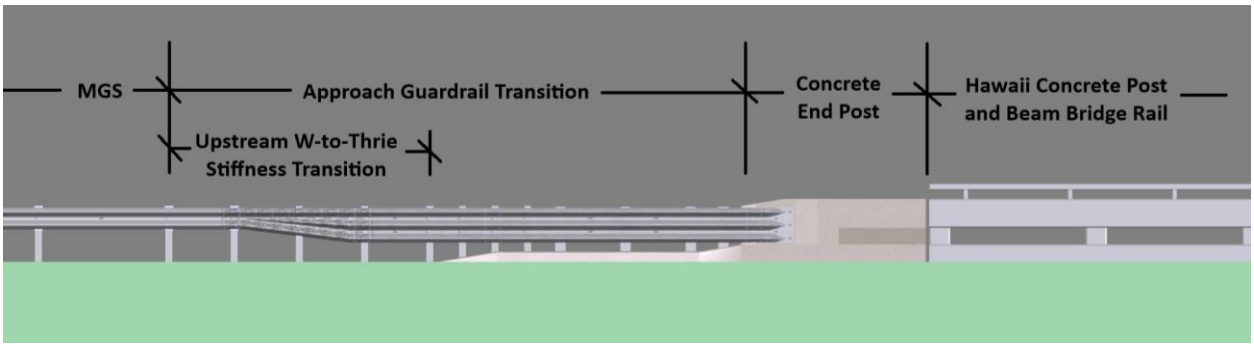


Figure 19. AGT from MGS to Hawaii Concrete Post and Beam Bridge Rail

According to TL-3 of MASH, longitudinal barrier transitions must be subjected to two full-scale vehicle crash tests, MASH test designation no. 3-20 with the 1100C small car and MASH test designation no. 3-21 with the 2270P pickup truck, as summarized in Table 1. However, recent testing has demonstrated that there are multiple critical impact points along most AGTs. The first critical impact point has been identified as near the downstream end of the AGT to maximize snagging on the rigid parapet (concrete end post). The second critical impact point would be near the upstream end of the AGT to maximize snagging and pocketing at the W-to-thrie transition section. Additionally, the size and unique shape of this bridge rail end post warranted consideration for impacts to the end post as well. Thus, the safety performance evaluation of the AGT to the Hawaii Concrete Post and Beam Bridge Railing included impacts to three different regions of the barrier system.

Table 1. MASH TL-3 Crash Test Conditions for Longitudinal Barrier Transitions

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

[1] Evaluation criteria explained in MASH 2016.

Evaluation of the first critical impact point (thrie beam region adjacent to the bridge rail end point) was completed during the previous crash testing of HDOT's AGT to vertical concrete bridge rail when both MASH test designation nos. 3-20 and 3-21 were conducted and satisfied all safety criteria [8]. Nearly all components in this region of the AGT are identical to this previously tested system: guardrail segments, posts, post spacings, blockouts, curb, and the geometry of the upstream end of the bridge rail end post. The only change was the reduction of the slope of the curb height transition adjacent to the end post from 3:1 to 6:1. This minor modification was recommended to mitigate potential wheel snag, as observed in previous crash testing of a similar AGT [10]. Thus, this minor modification to the curb height transition improves the performance of the AGT. Based on the previous crash testing, this region of the AGT was considered MASH TL-3 crashworthy.

The upstream, W-to-thrie stiffness transition was also previously crash tested and passed both MASH test designation nos. 3-20 and 3-21 [9]. This region of the AGT to the Hawaii Concrete Post and Beam Bridge Rail is identical to the as-tested upstream stiffness transition. Thus, the upstream end of the AGT was also considered MASH TL-3 crashworthy.

Evaluation of the middle section and downstream end of the bridge rail end post also relied on comparisons to previous MASH crash testing. The middle section of the end post was a 36-in. tall, vertical concrete barrier. MASH test designation nos. 3-10 and 3-11 were successful on vertical concrete bridge rails with heights of 34 in. and 42 in. Thus, a vertical concrete parapet with a height of 36 in. (between the heights of the MASH tested bridge rails) was considered MASH TL-3 compliant. The downstream end of the bridge rail end post included a recess that transitions the end post shape from a vertical wall to match the cross section of the Hawaii Concrete Post and Beam Bridge Rail. This bridge rail also satisfied all safety criteria for both MASH test designation nos. 3-10 and 3-11, thus, the downstream end of the bridge rail end post was considered MASH TL-3 compliant.

Finally, impacts to the bridge rail end post in the reverse direction (going from bridge rail toward the AGT) were also considered. The recess on the end post's downstream end was given a 10:1 lateral slope to transition between the shape of the bridge rail and a vertical face. The 10:1 lateral slope was based on a previous study that found rigid barrier shape transitions with lateral slopes of 10:1 or flatter did not negatively affect safety performance [13]. Therefore, the bridge rail end post was considered MASH TL-3 crashworthy in the reverse direction.

Based on previous MASH crash testing conducted on similar AGTs and concrete bridge rails, the AGT to the Hawaii Concrete Post and Beam Bridge Rail was deemed crashworthy to MASH TL-3.

5 REFERENCES

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6 APPENDICES

Appendix A. Approach Guardrail Transition Details

The following design details were created for the test installation for test nos. HWTT-1 and HWTT-2, which evaluated HDOT's AGT to a vertical faced bridge rail. The same guardrail and post components should be used in combination with the new concrete end post detailed in Chapter 3 to create a complete AGT to the Hawaii Concrete Post and Beam Bridge Rail. Further details on the steel components for the AGT can be found in the crash testing report [8].

Note: Although test nos. HWTT-1 and HWTT-2 utilized a 3:1 slope, a 6:1 slope should be used to transition the height of the curb adjacent to the concrete end post. This is noted in Figures A-18 and A-19.

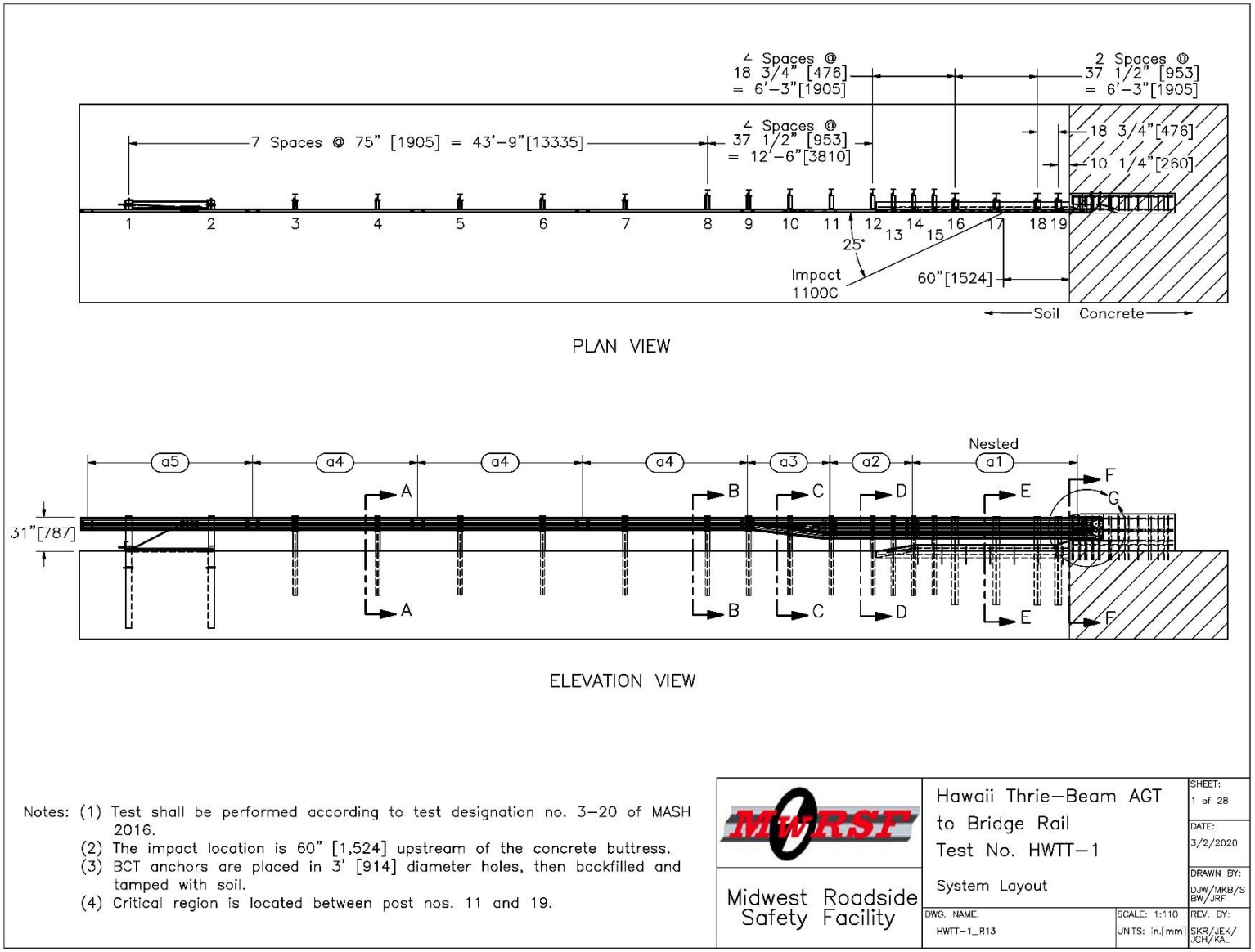


Figure A-1. System Layout, Test No. HWTT-1

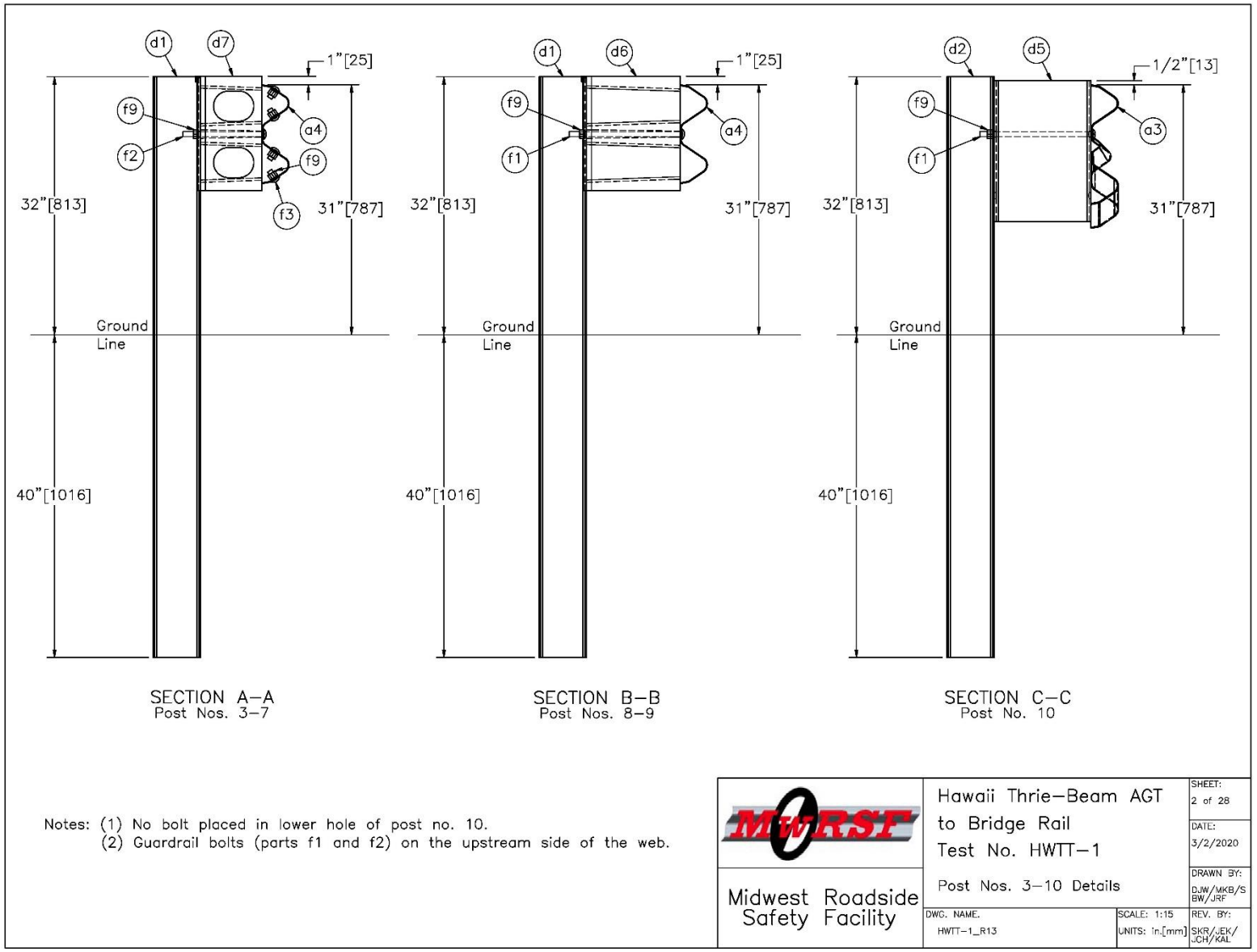


Figure A-2. Post Nos. 3 through 10 Details, Test Nos. HWTT-1 and HWTT-2

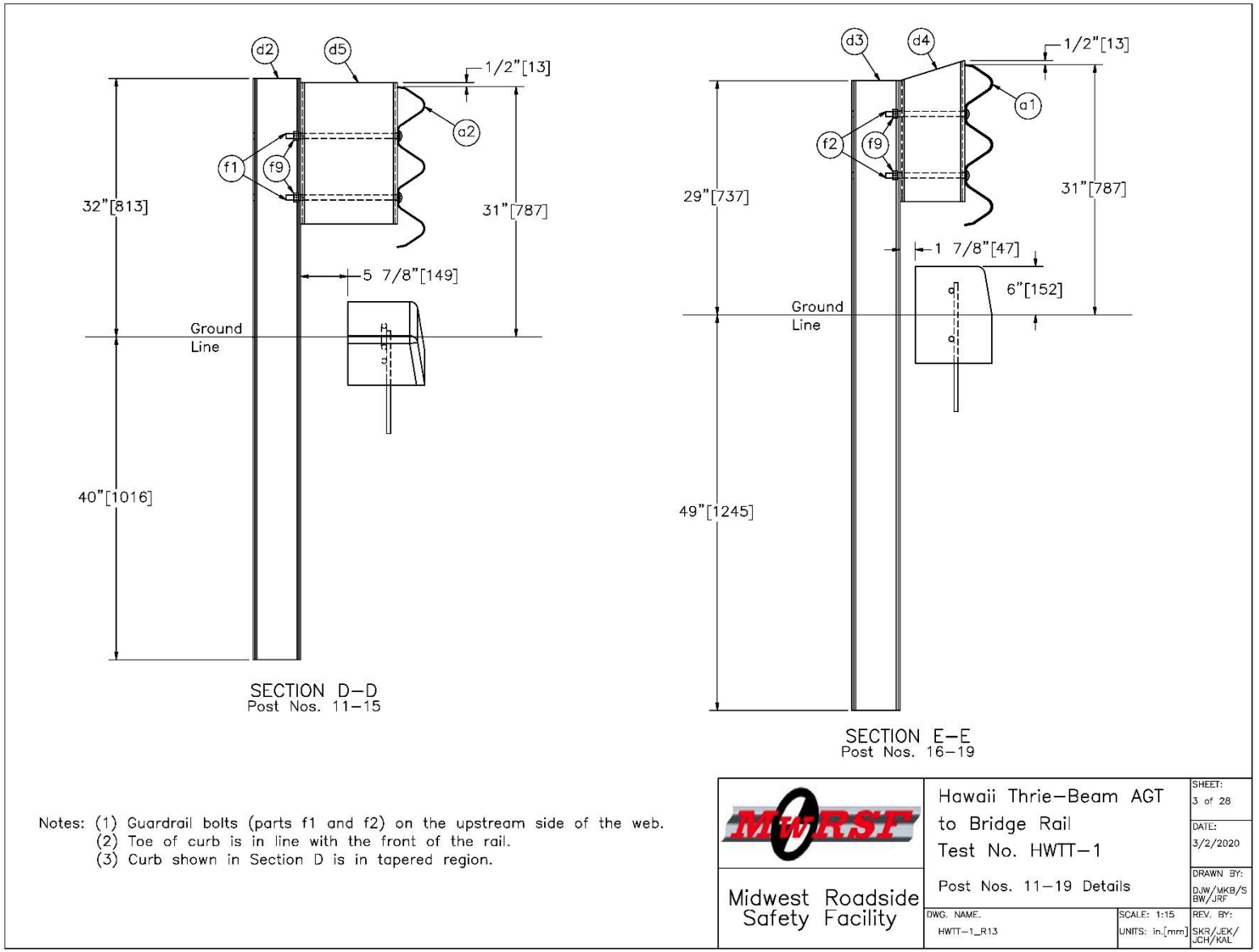


Figure A-3. Post Nos. 11 through 19 Details, Test Nos. HWTT-1 and HWTT-2

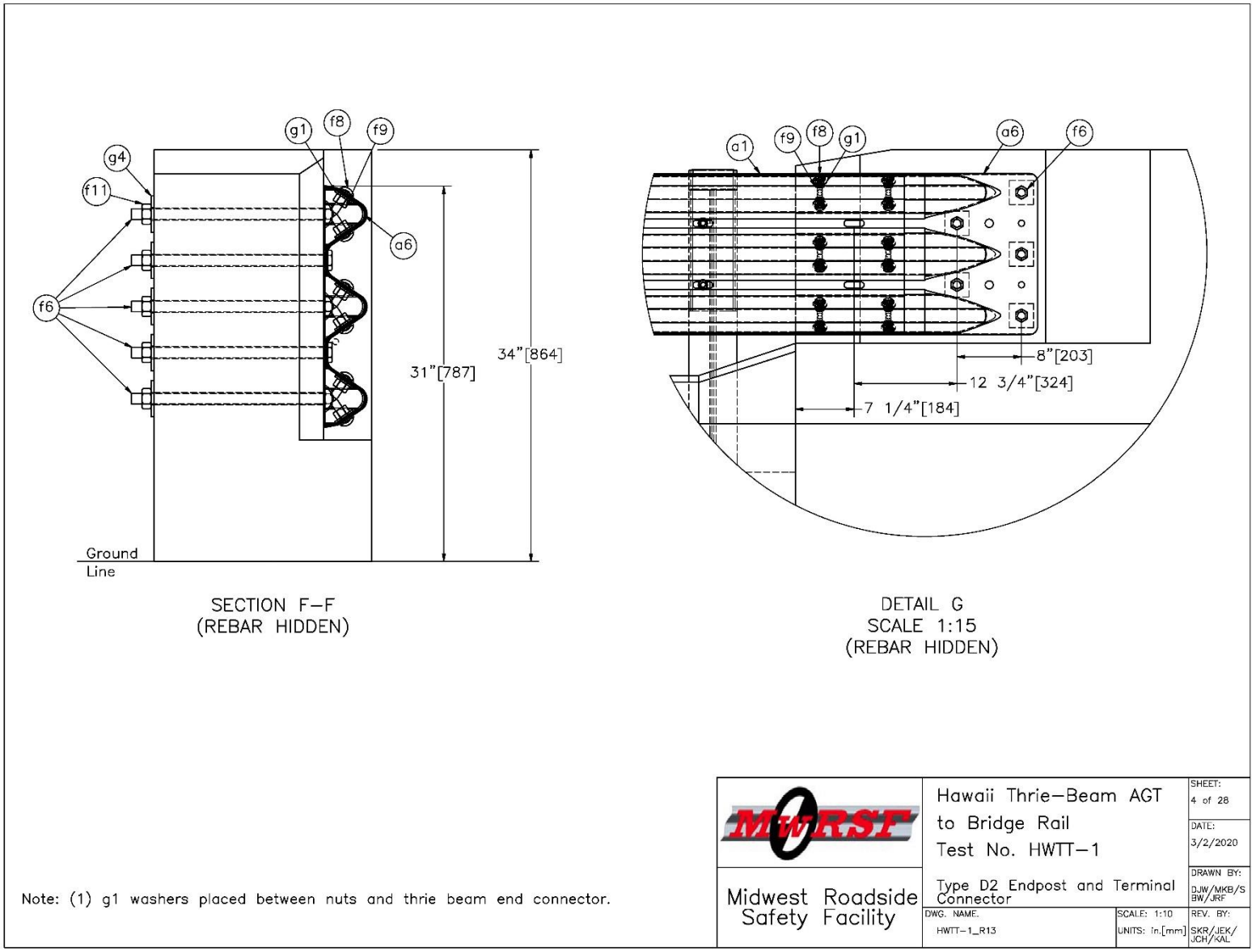


Figure A-4. Type D2 End Post and Terminal Connector, Test Nos. HWTT-1 and HWTT-2

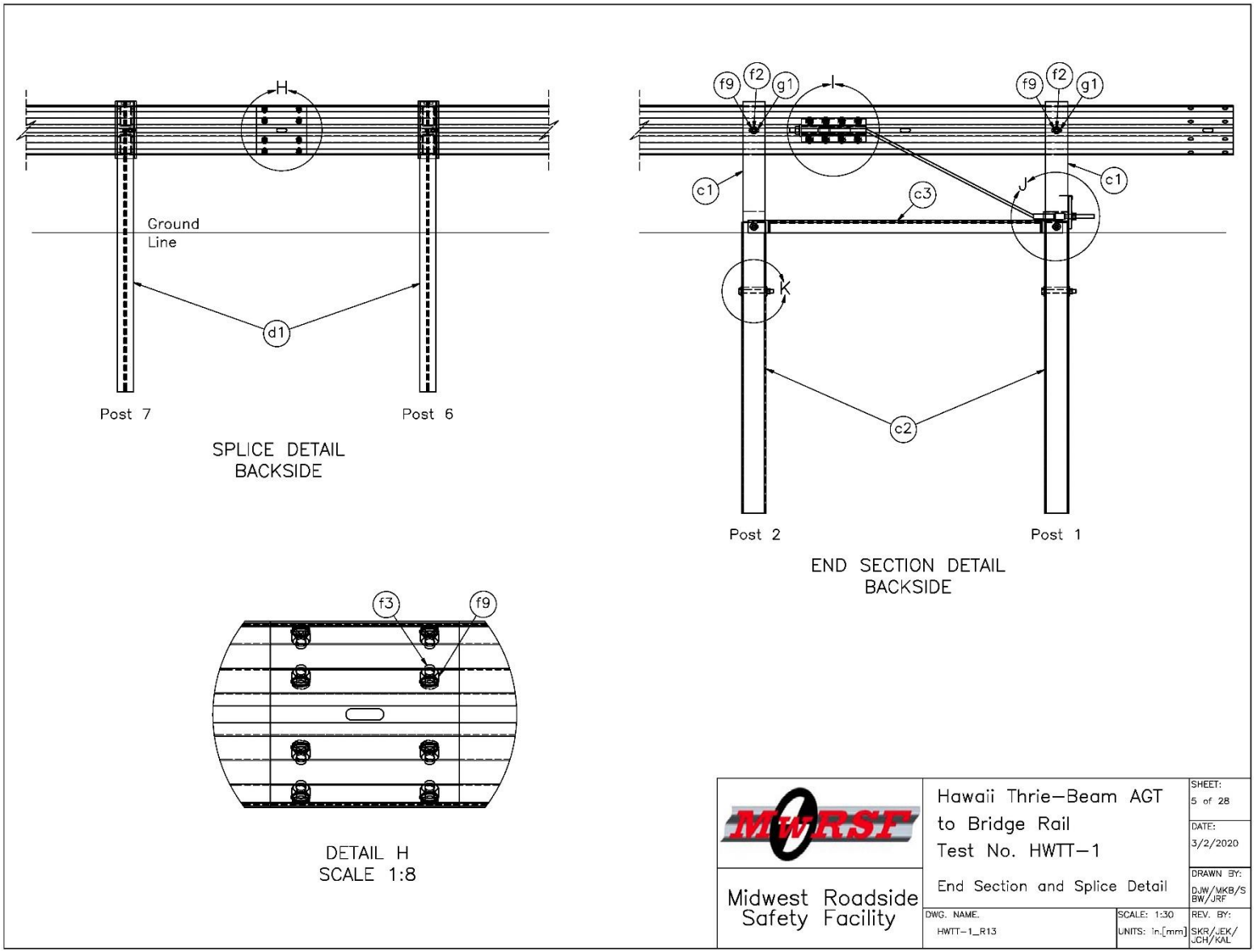


Figure A-5. Guardrail End Section and Splice Detail, Test Nos. HWTT-1 and HWTT-2

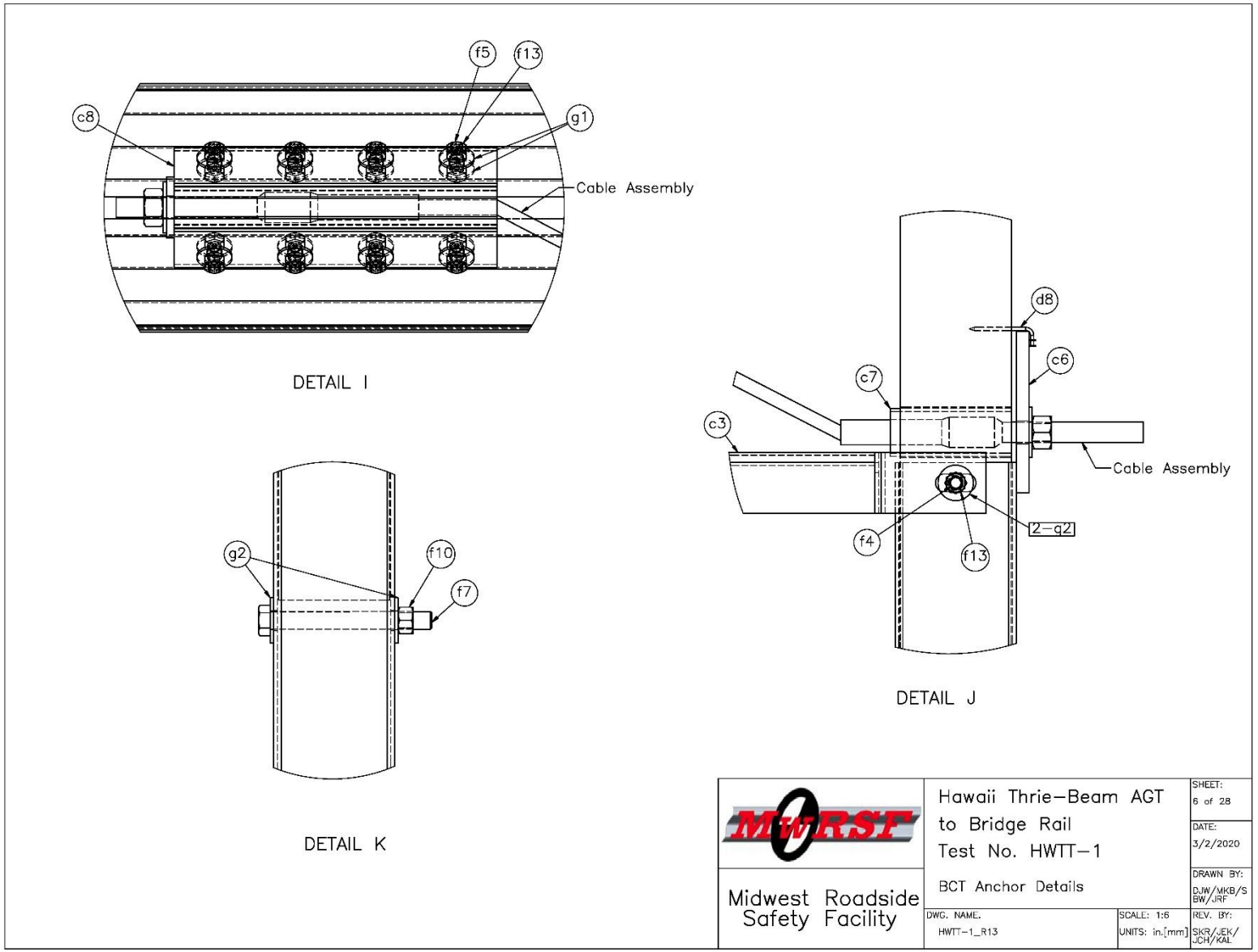


Figure A-6. BCT Anchor Details, Test Nos. HWTT-1 and HWTT-2

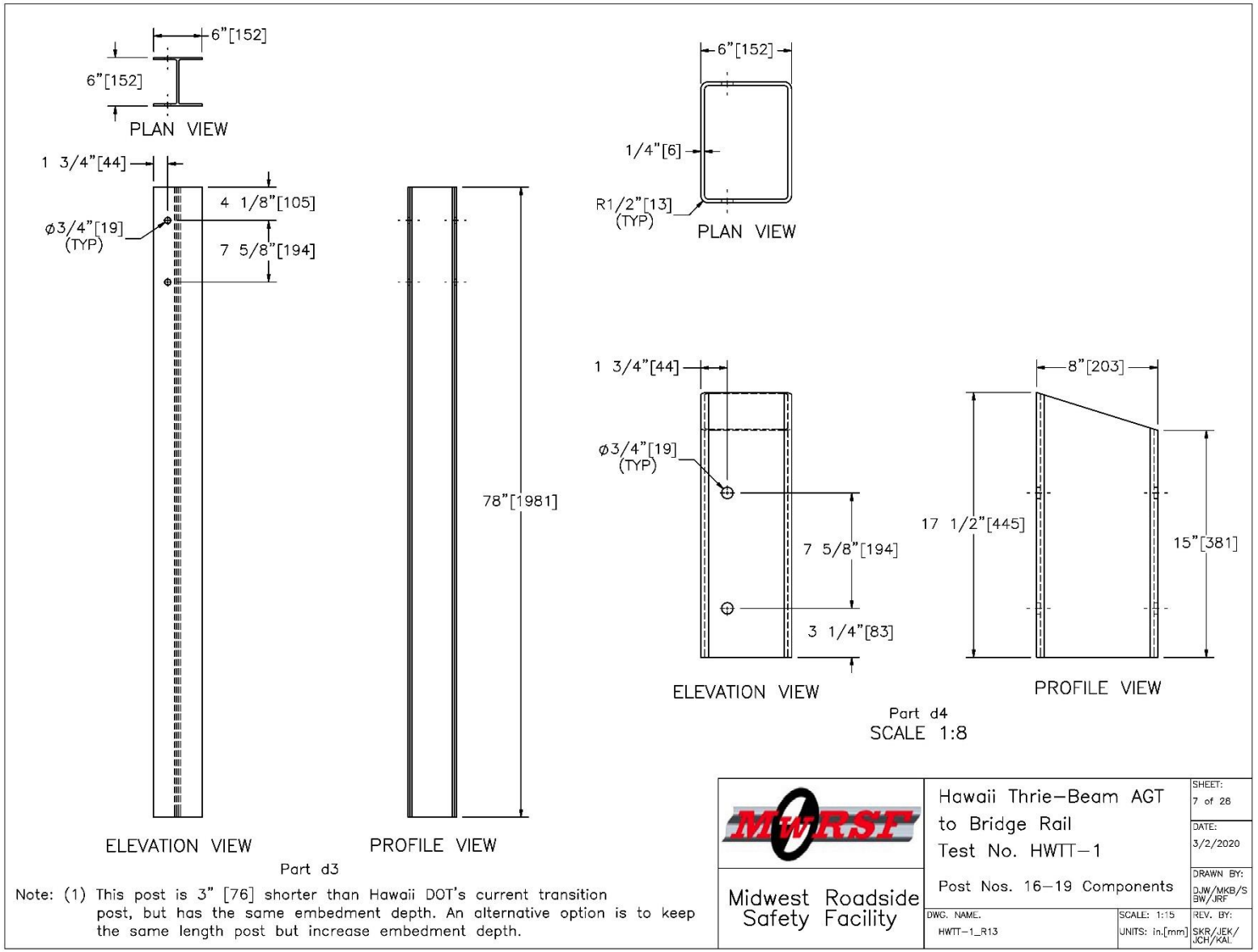


Figure A-7. Post Nos. 16 through 19 Components, Test Nos. HWTT-1 and HWTT-2

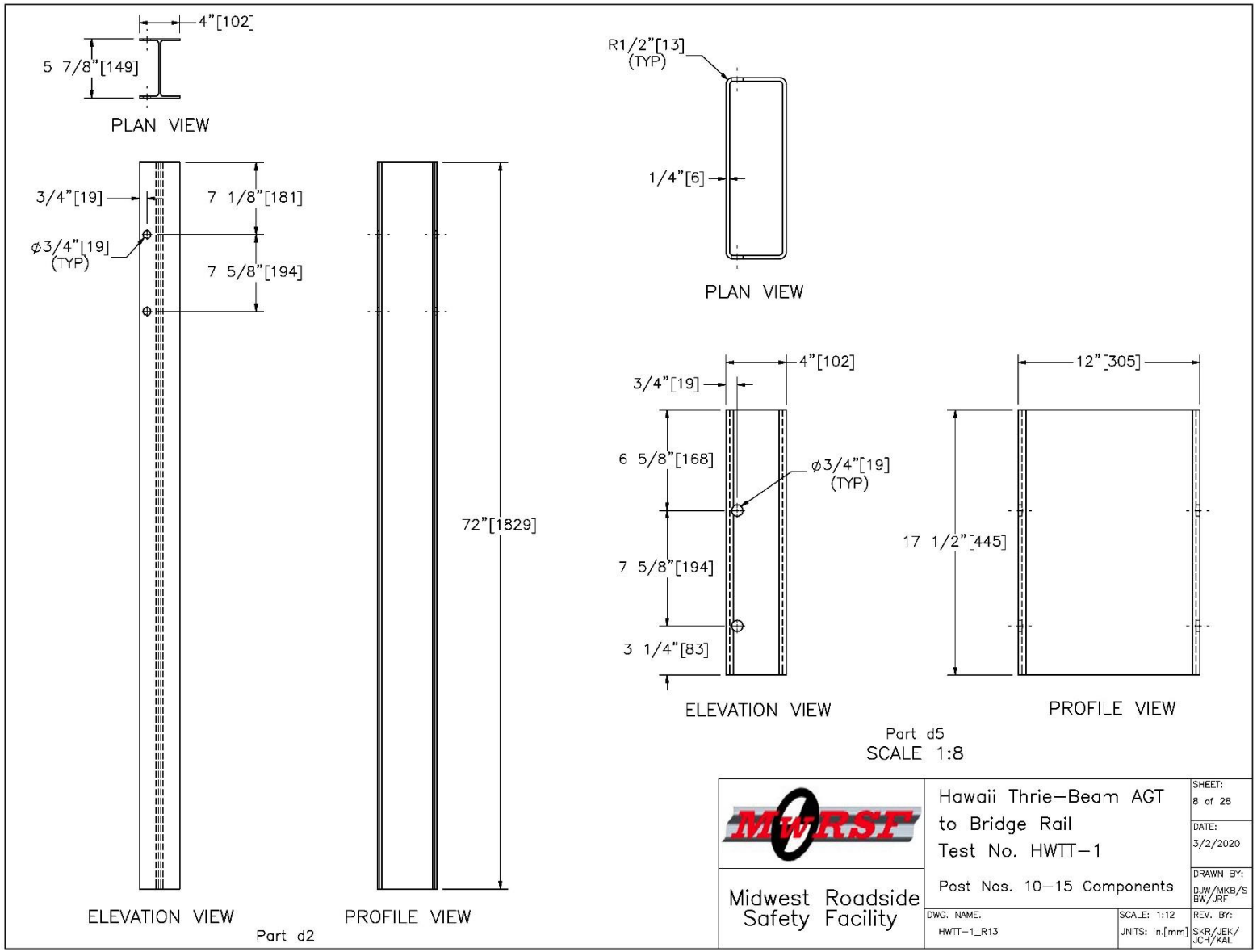


Figure A-8. Post Nos. 10 through 15 Components, Test Nos. HWTT-1 and HWTT-2

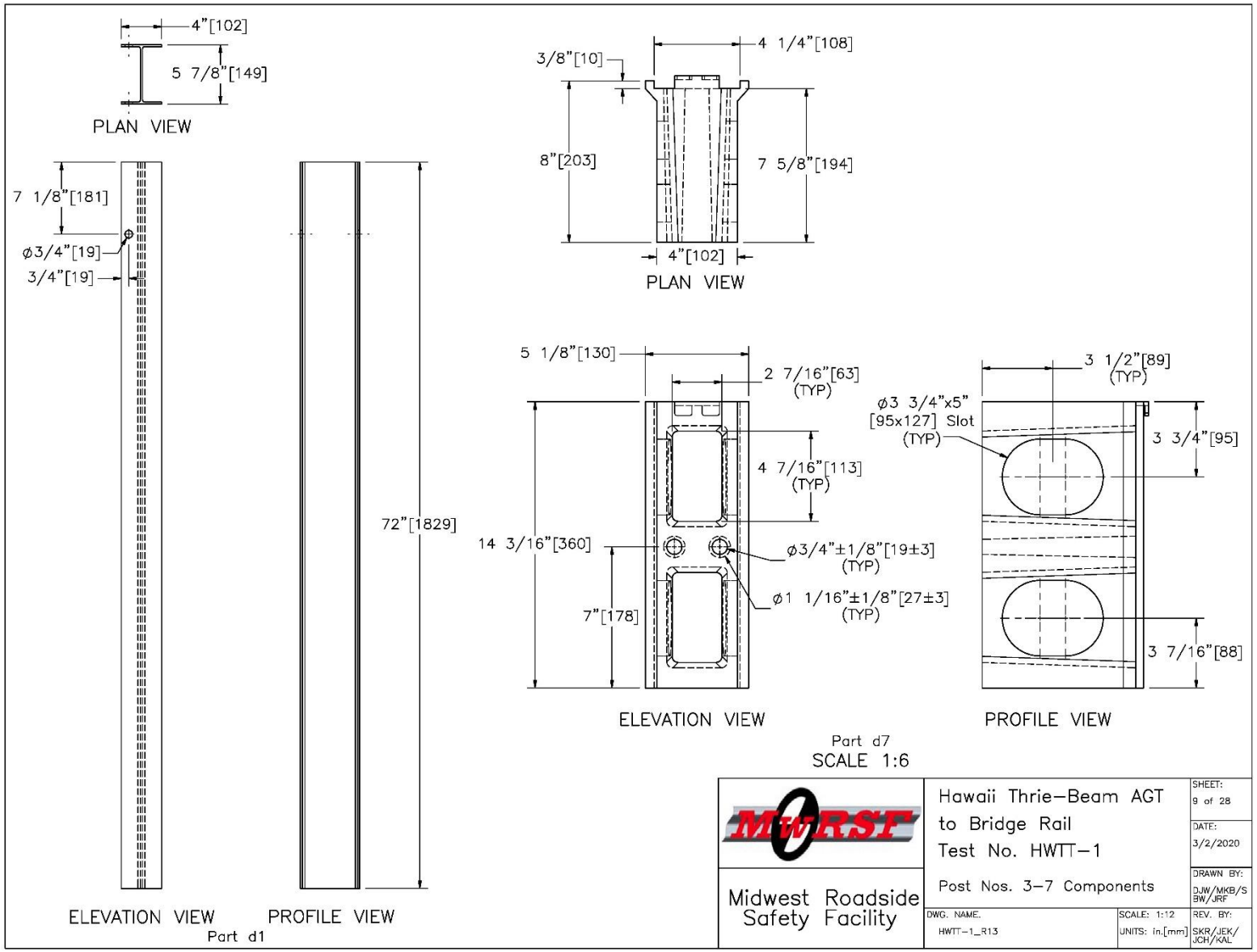


Figure A-9. Post Nos. 3 through 7 Components, Test Nos. HWTT-1 and HWTT-2

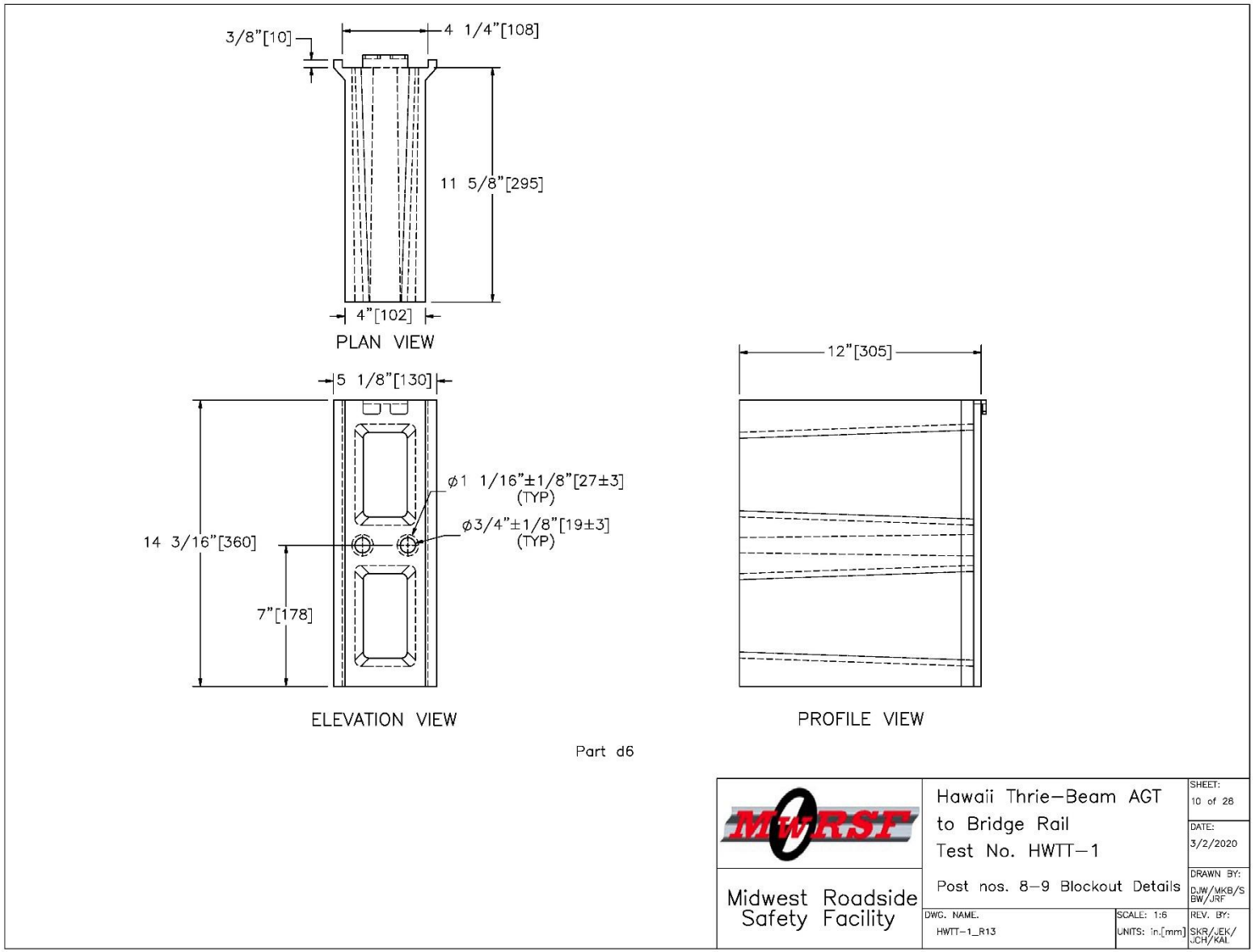


Figure A-10. Post Nos. 8 and 9 Blockout Details, Test Nos. HWTT-1 and HWTT-2

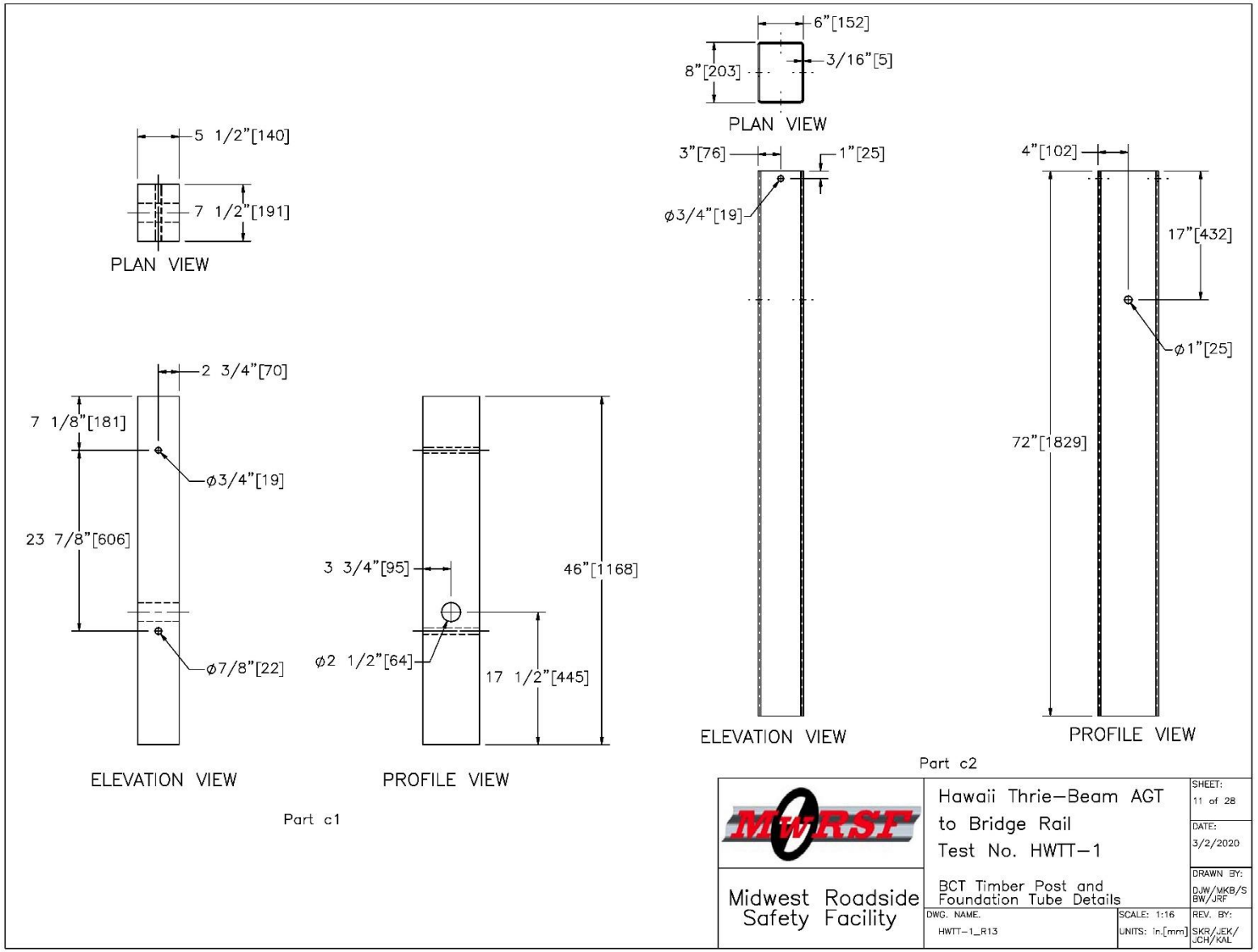


Figure A-11. BCT Timber Post and Foundation Tube Details, Test Nos. HWTT-1 and HWTT-2

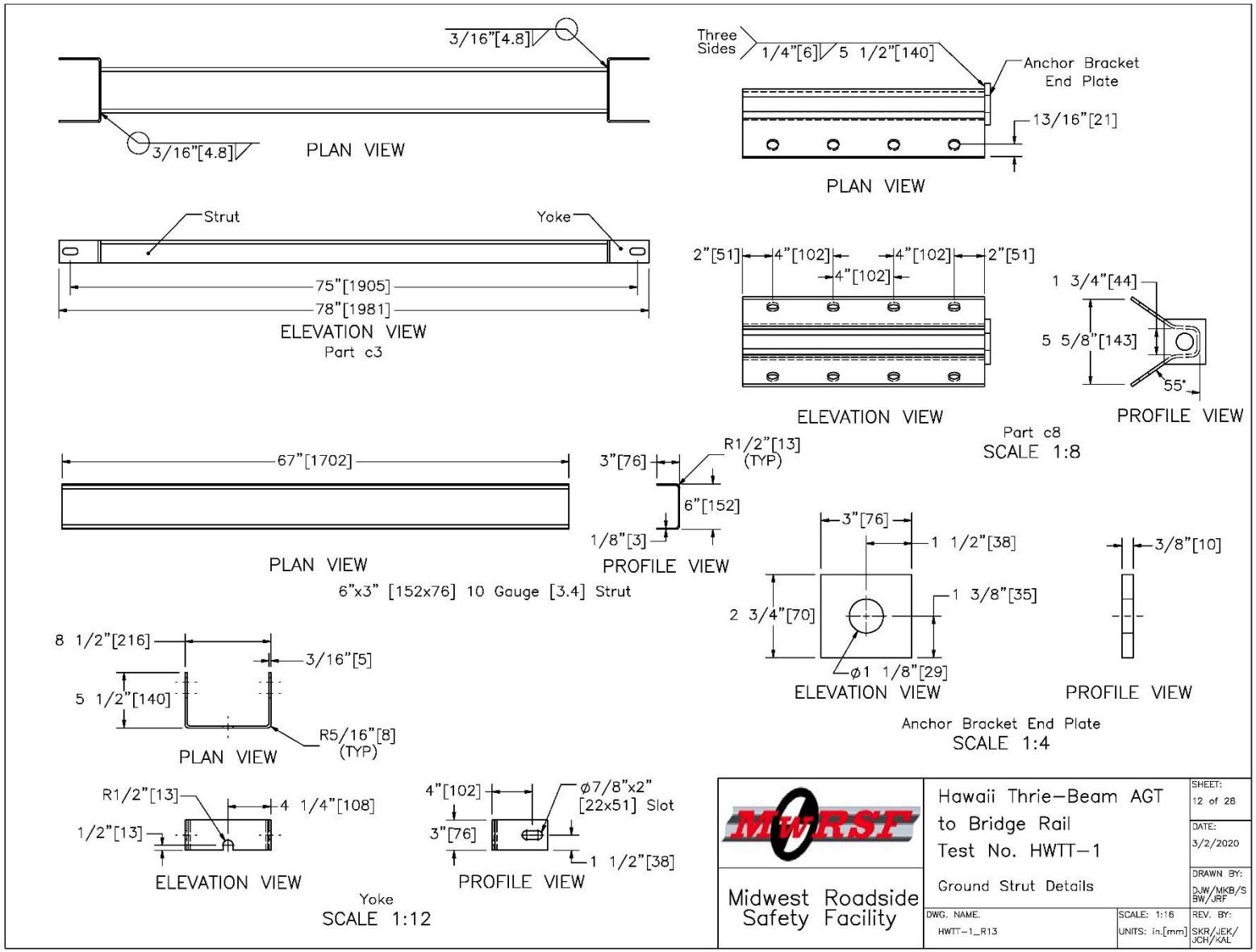
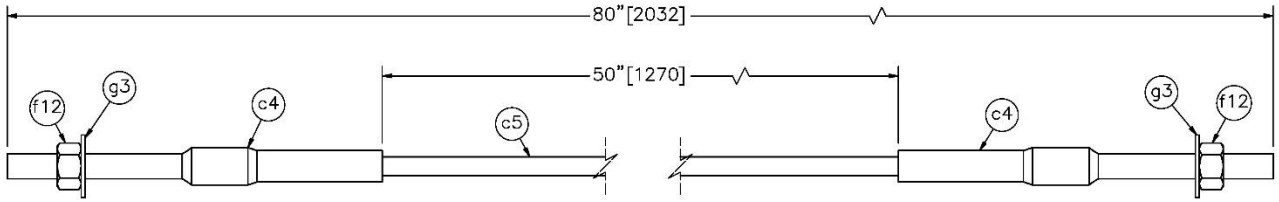


Figure A-12. Ground Strut Details, Test Nos. HWTT-1 and HWTT-2



Cable Assembly

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
–	1	Cable Assembly	–	–	FCA01
c4	2	BCT Anchor Cable End Swaged Fitting	Fitting – ASTM A576 Gr. 1035 Stud – ASTM F568 Class C	Fitting – ASTM A153 Stud – ASTM A153 or B695	–
c5	1	3/4" [19] Dia. 6x19 IWRC IPS Wire Rope	ASTM A741 Type 2	Class A Coating	–
f12	2	1"–8 UNC [M24x3] Heavy Hex Nut	ASTM A563DH or equivalent	ASTM A153 or B695 Class 55 or F2329	FNX24b
g3	2	1" [25] Dia. Plain USS Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC24a

Midwest Roadside Safety Facility

Hawaii Thrie–Beam AGT to Bridge Rail
Test No. HWTT–1
BCT Anchor Cable

SHEET: 13 of 28
DATE: 3/2/2020
DRAWN BY: DJW/MKB/SBW/JRF
REV. BY: SKR/JEK/JCH/KAL
DWG. NAME. HWTT–1_R13
SCALE: 1:6
UNITS: in.[mm]

Figure A-13. BCT Anchor Cable Details, Test Nos. HWTT-1 and HWTT-2

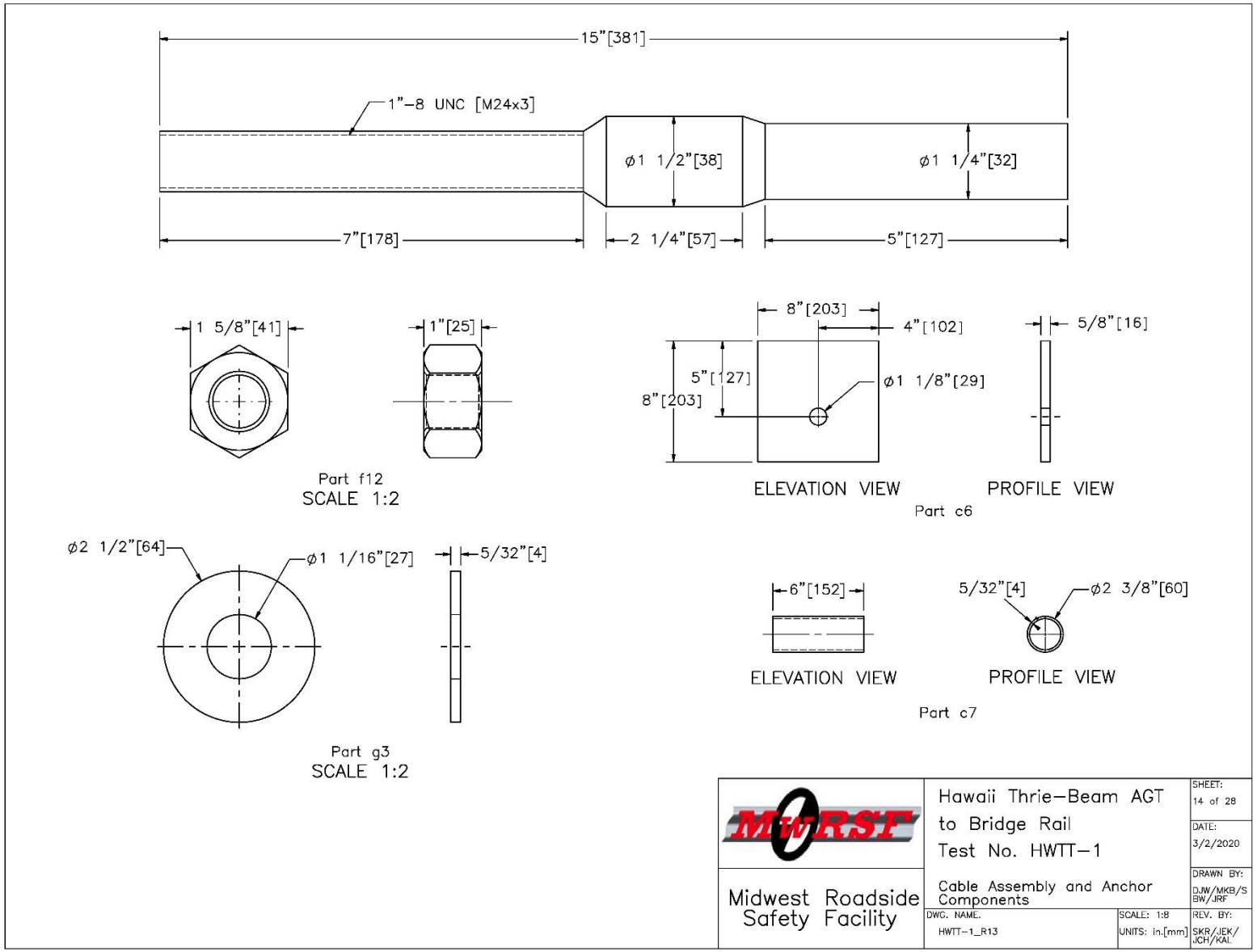


Figure A-14. Cable Assembly and Anchor Components, Test Nos. HWTT-1 and HWTT-2

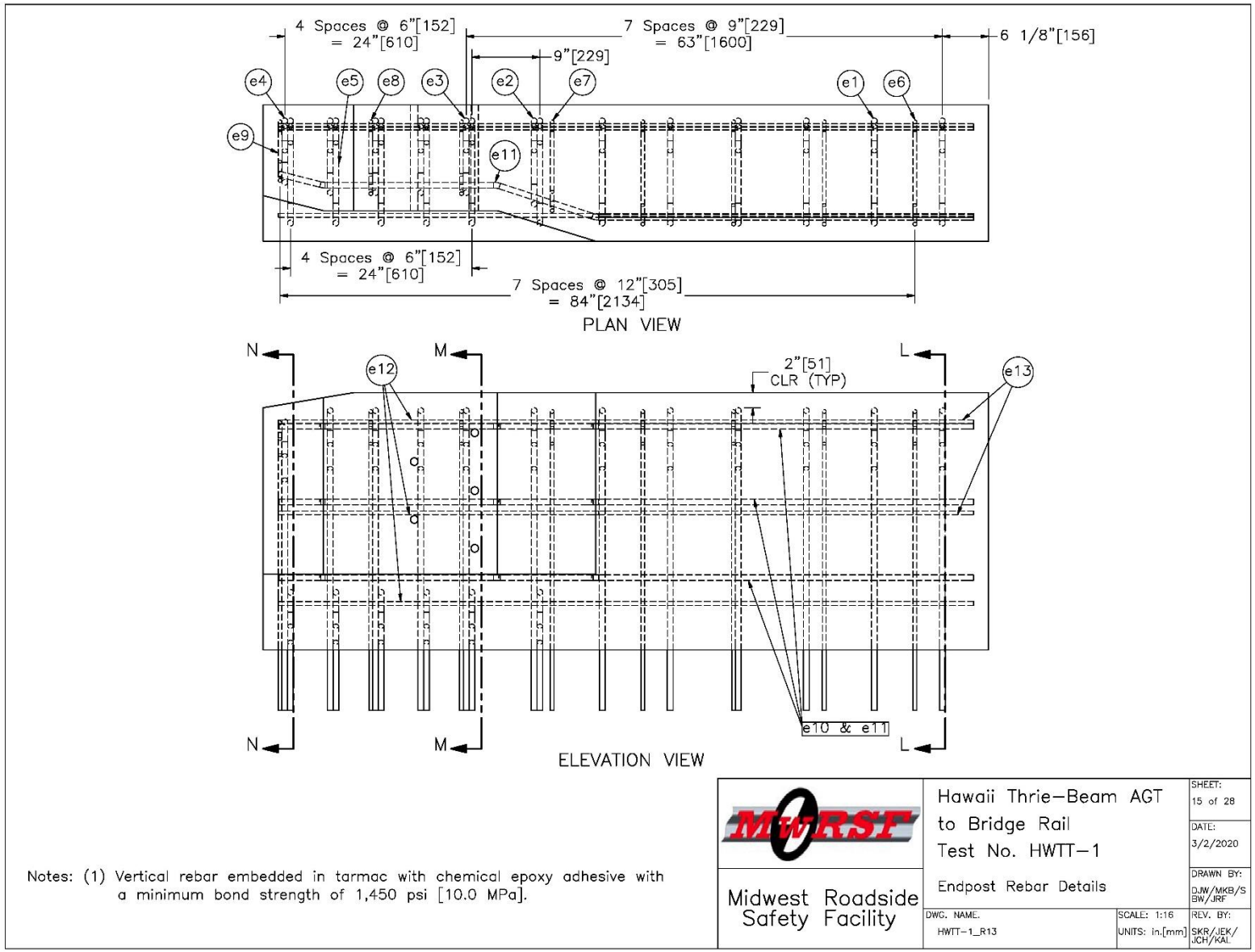


Figure A-15. End Post Rebar Details, Test Nos. HWTT-1 and HWTT-2

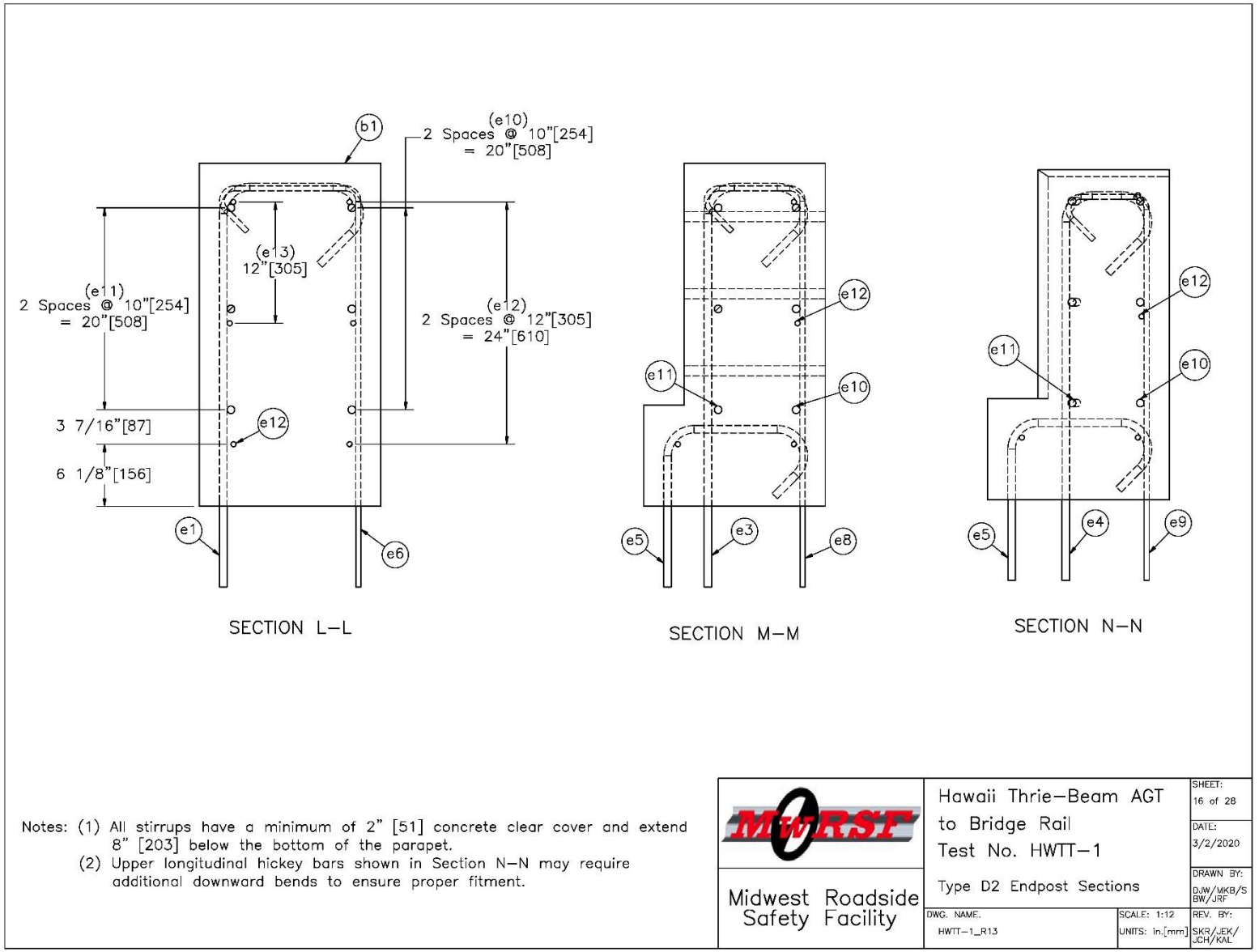


Figure A-16. End Post Sections, Test Nos. HWTT-1 and HWTT-2

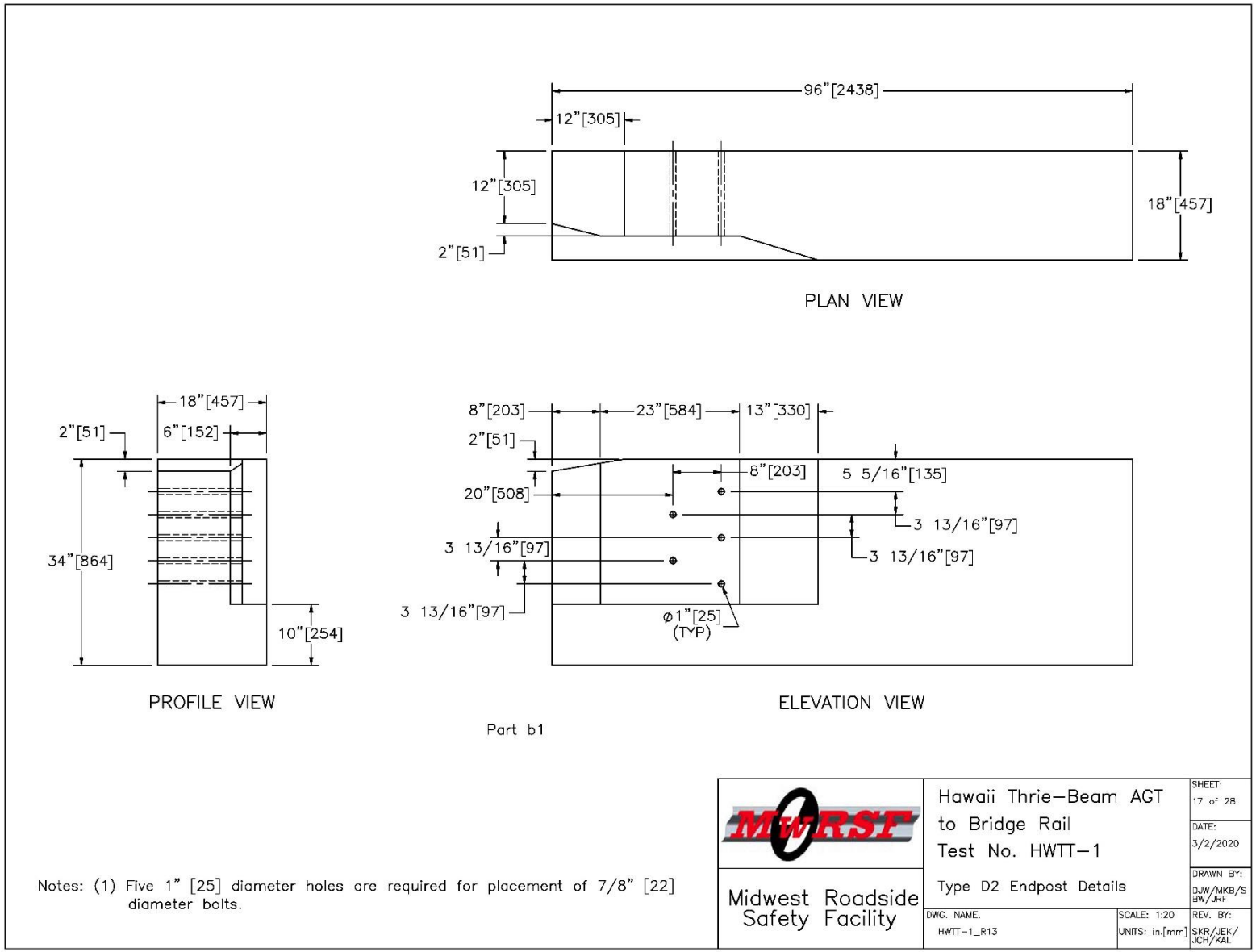


Figure A-17. End Post Details, Test Nos. HWTT-1 and HWTT-2

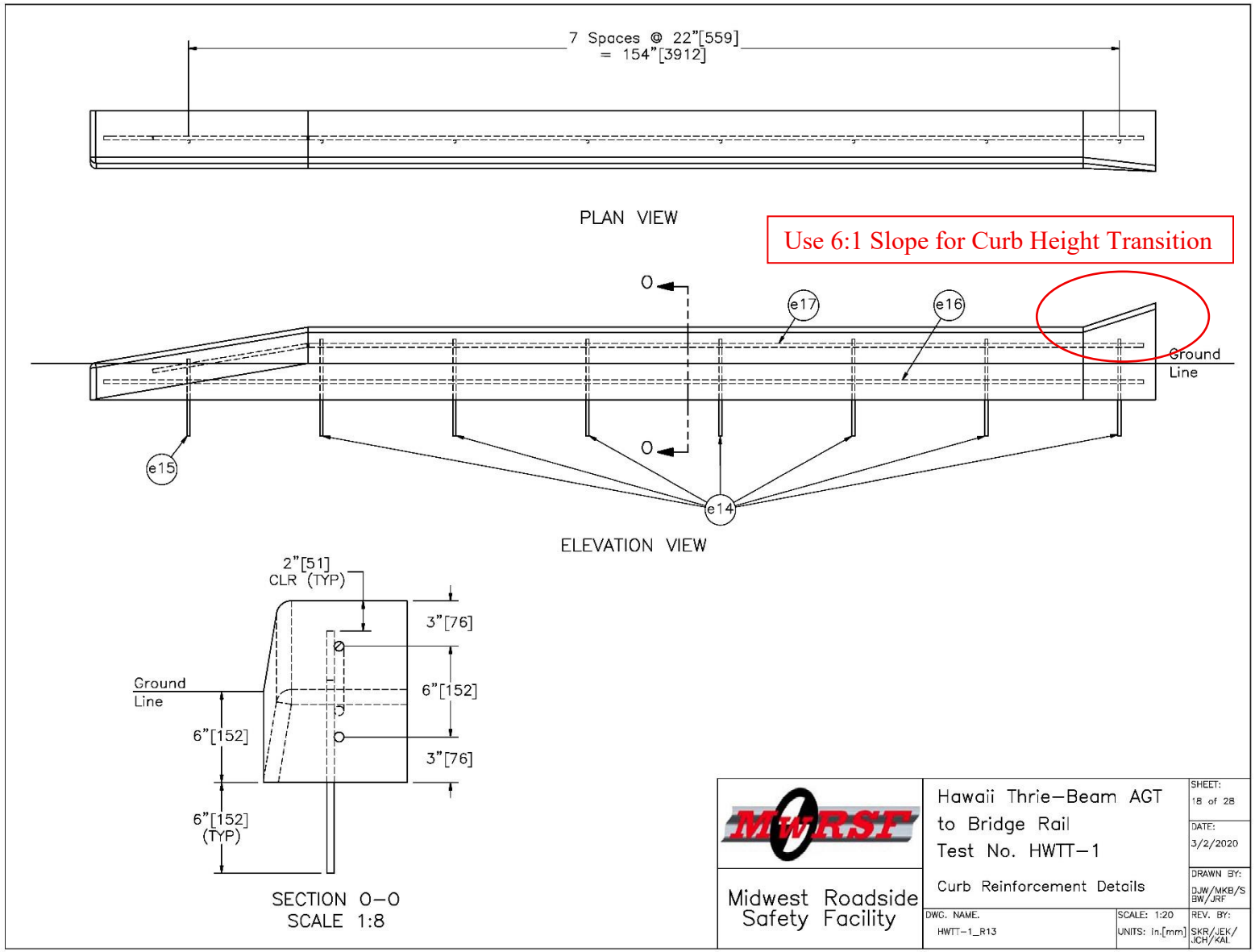


Figure A-18. Curb Reinforcement Details, Test Nos. HWTT-1 and HWTT-2

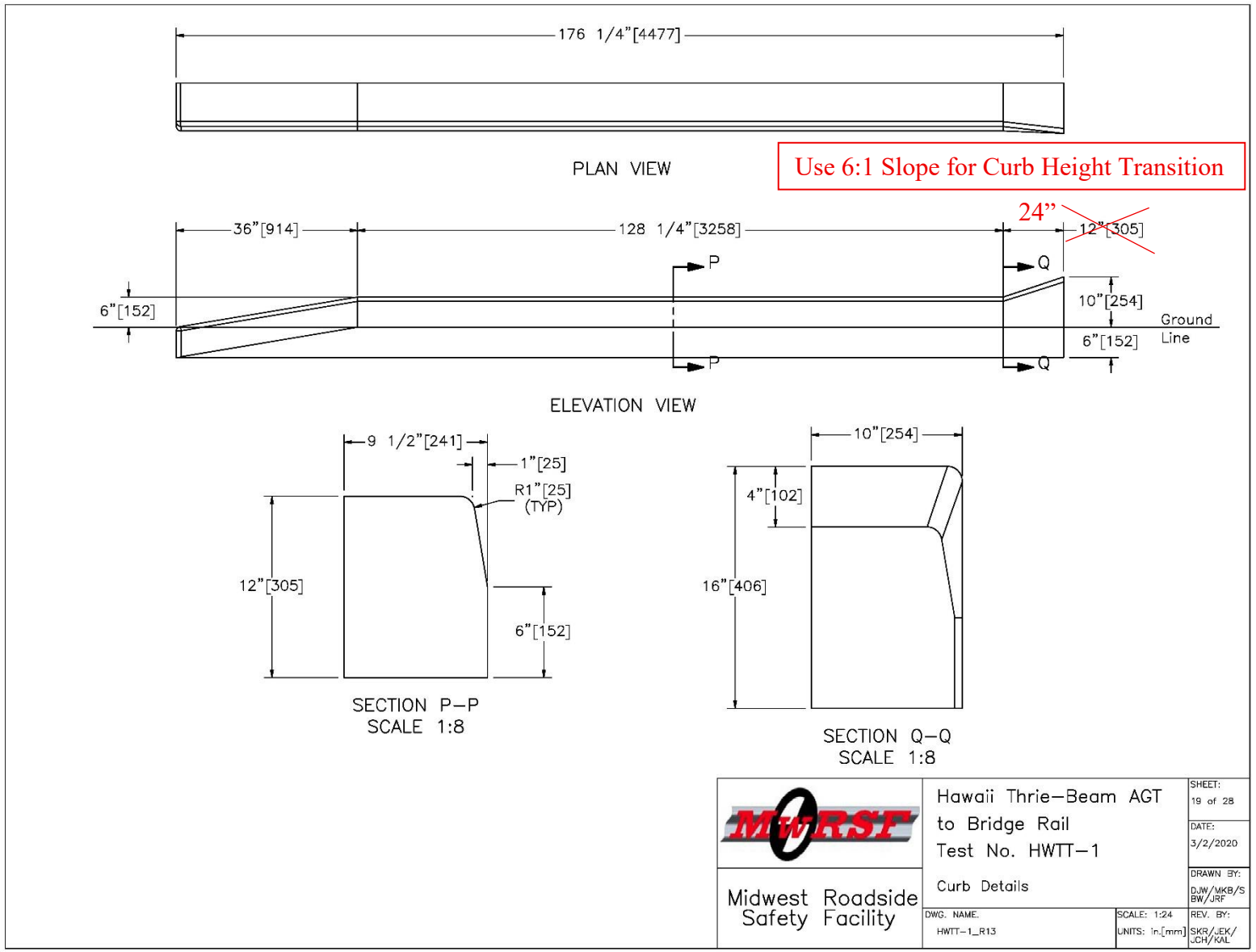
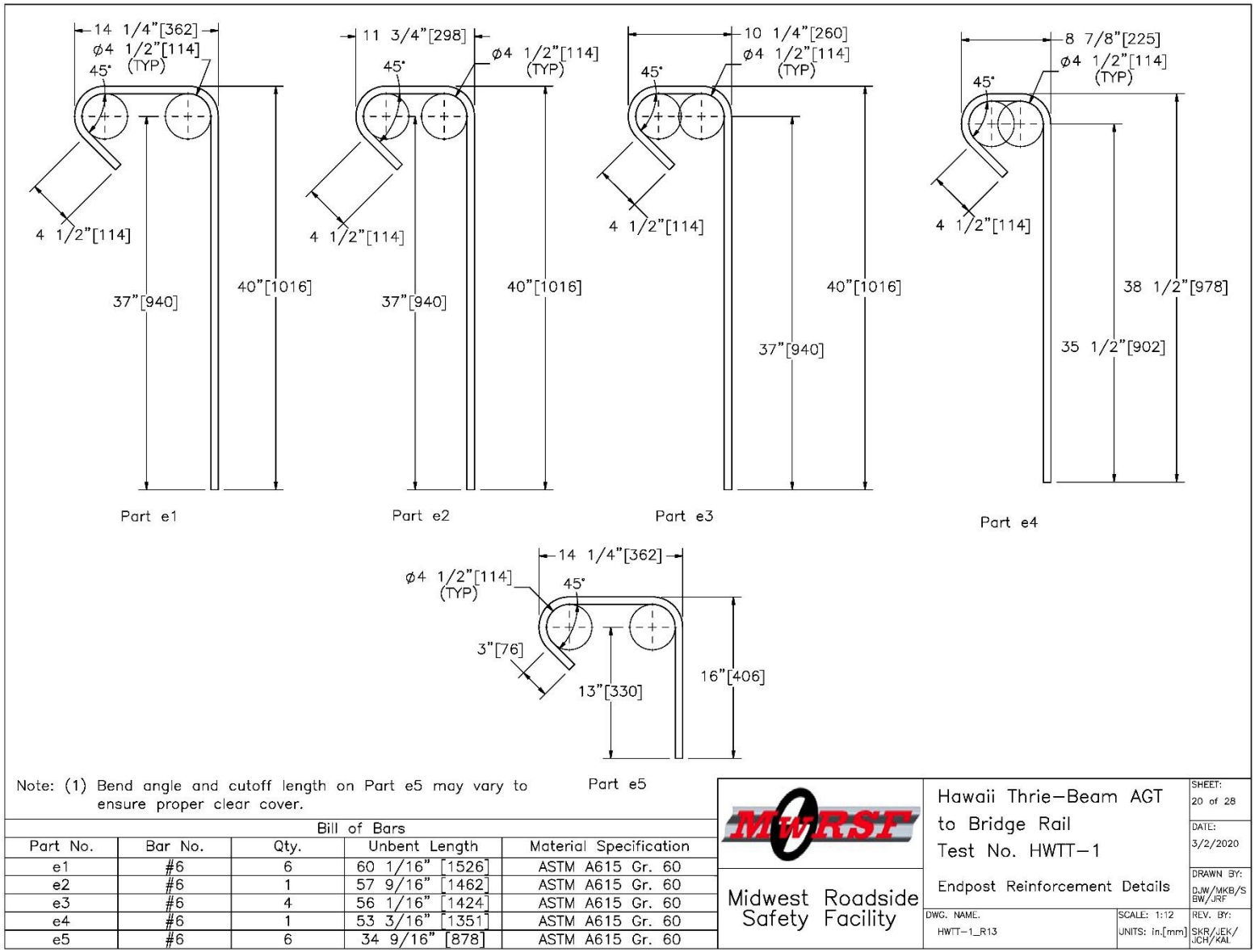


Figure A-19. Curb Details, Test Nos. HWTT-1 and HWTT-2



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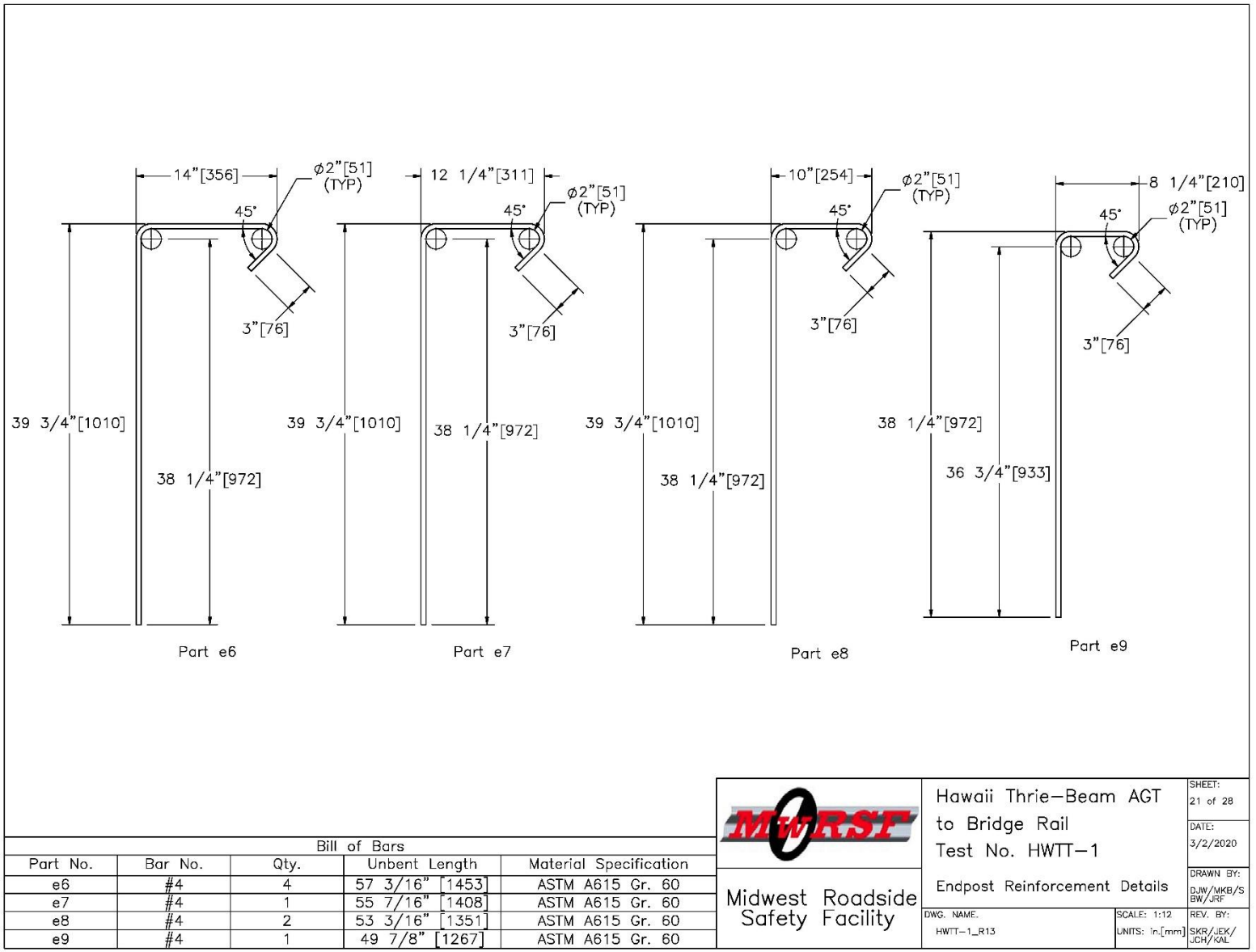


Bill of Bars

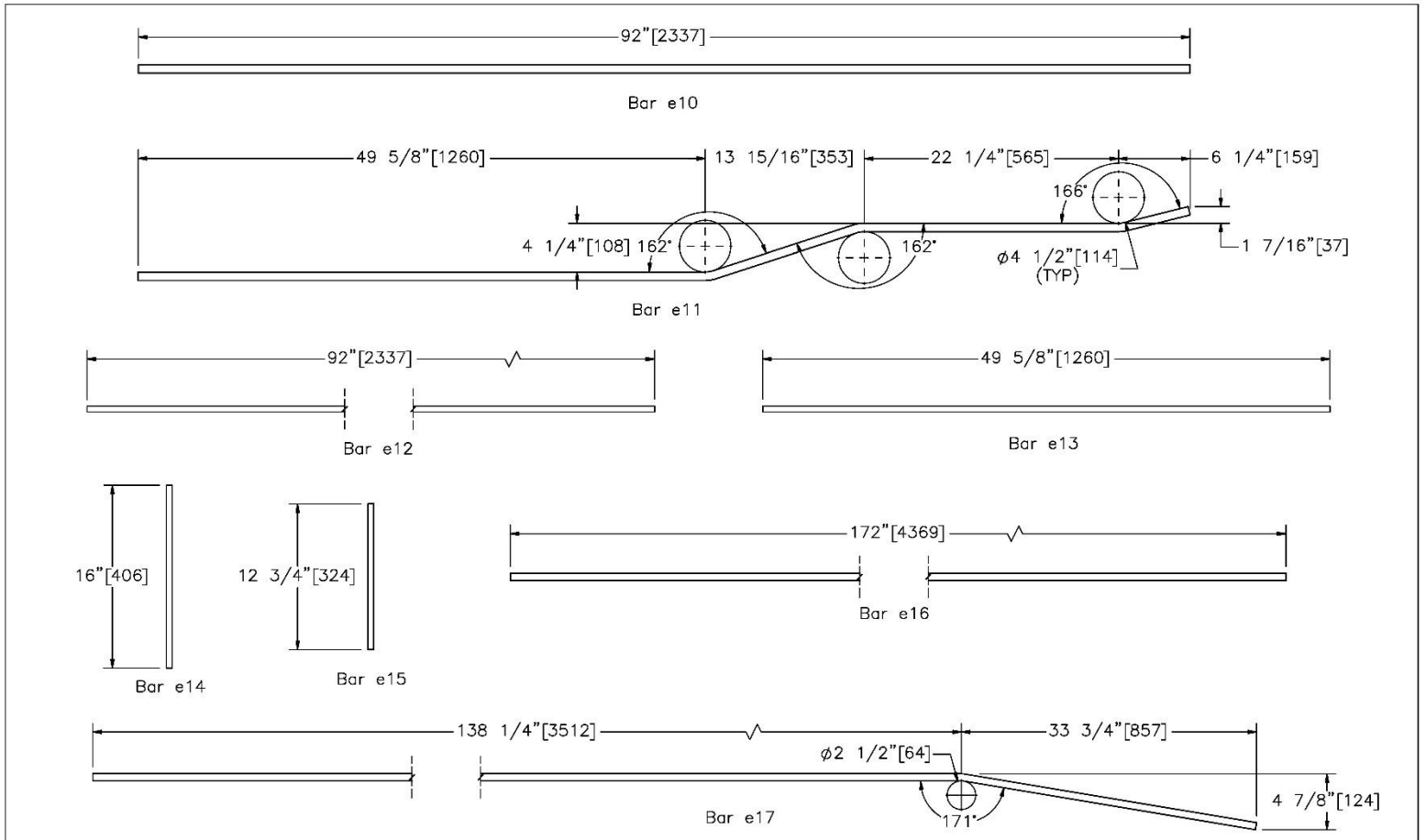
Part No.	Bar No.	Qty.	Unbent Length	Material Specification
e6	#4	4	57 3/16" [1453]	ASTM A615 Gr. 60
e7	#4	1	55 7/16" [1408]	ASTM A615 Gr. 60
e8	#4	2	53 3/16" [1351]	ASTM A615 Gr. 60
e9	#4	1	49 7/8" [1267]	ASTM A615 Gr. 60

Midwest Roadside Safety Facility

Hawaii Thrie-Beam AGT to Bridge Rail
Test No. HWTT-1
Endpost Reinforcement Details

SHEET: 21 of 28
DATE: 3/2/2020
DRAWN BY: DJW/MKB/SBW/JRF
REV. BY: SKR/JEK/JCH/KAL
DWG. NAME. HWTT-1_R13
SCALE: 1:12
UNITS: in.[mm]

Figure A-21. End Post Reinforcement Details, Test Nos. HWTT-1 and HWTT-2



Bill of Bars				
Part No.	Bar No.	Qty.	Unbent Length	Material Specification
e10	#6	3	92" [2337]	ASTM A615 Gr. 60
e11	#6	3	92 7/8" [2359]	ASTM A615 Gr. 60
e12	#4	4	92" [2337]	ASTM A615 Gr. 60
e13	#4	2	49 5/8" [1260]	ASTM A615 Gr. 60
e14	#4	7	16" [406]	ASTM A615 Gr. 60
e15	#4	1	12 3/4" [324]	ASTM A615 Gr. 60
e16	#5	1	172" [4369]	ASTM A615 Gr. 60
e17	#5	1	164 1/4" [4172]	ASTM A615 Gr. 60

Midwest Roadside Safety Facility

Hawaii Thrie-Beam AGT to Bridge Rail
Test No. HWTT-1
Longitudinal Endpost and Curb Reinforcement Details

SHEET: 22 of 28
DATE: 3/2/2020
DRAWN BY: DJW/MKB/S BW/JRF
REV. BY: SKR/JEK/ JCH/KAL
DWG. NAME: HWTT-1_R13
SCALE: 1:12
UNITS: in.[mm]

Figure A-22. Longitudinal End Post and Curb Reinforcement Details, Test Nos. HWTT-1 and HWTT-2

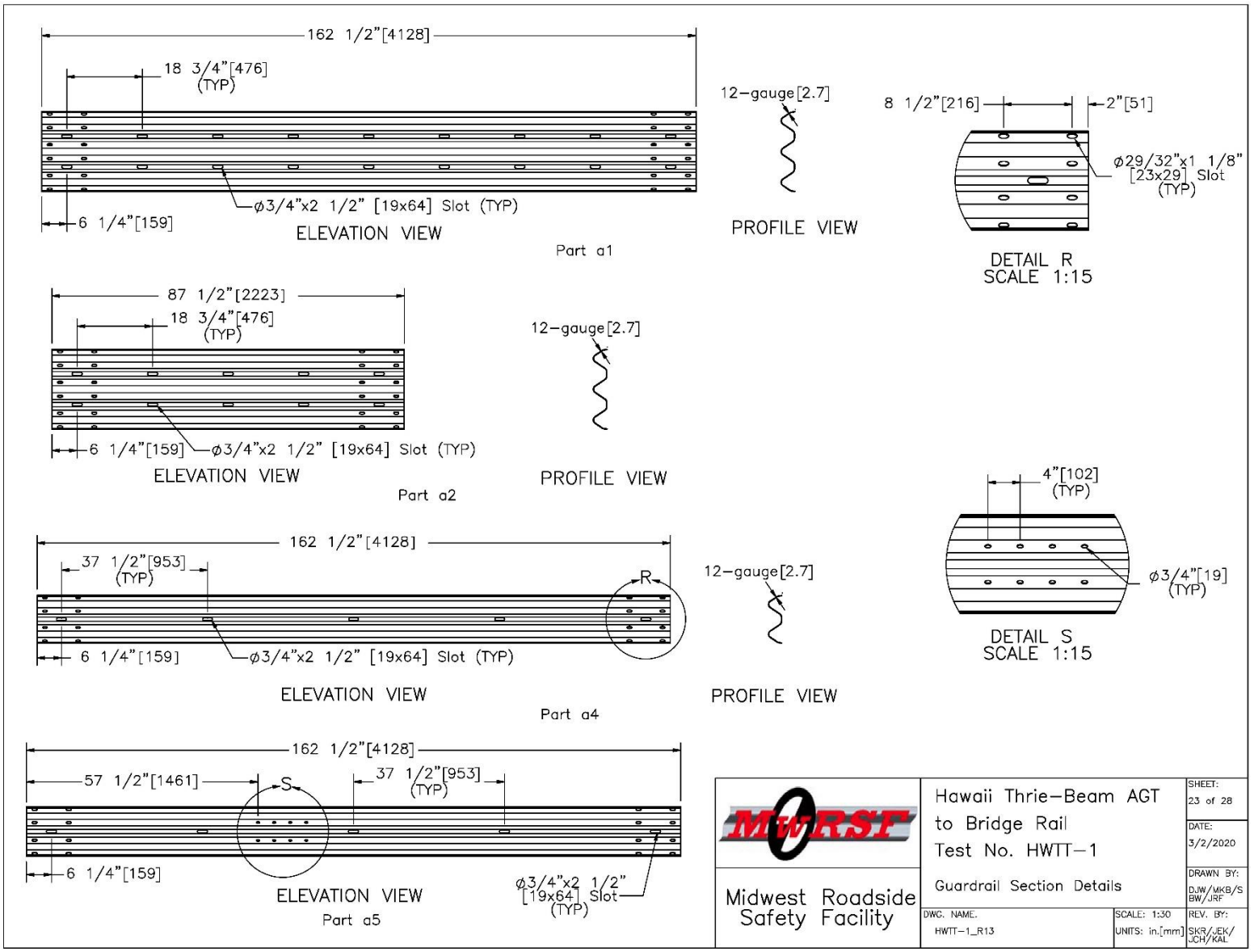


Figure A-23. Guardrail Section Details, Test Nos. HWTT-1 and HWTT-2

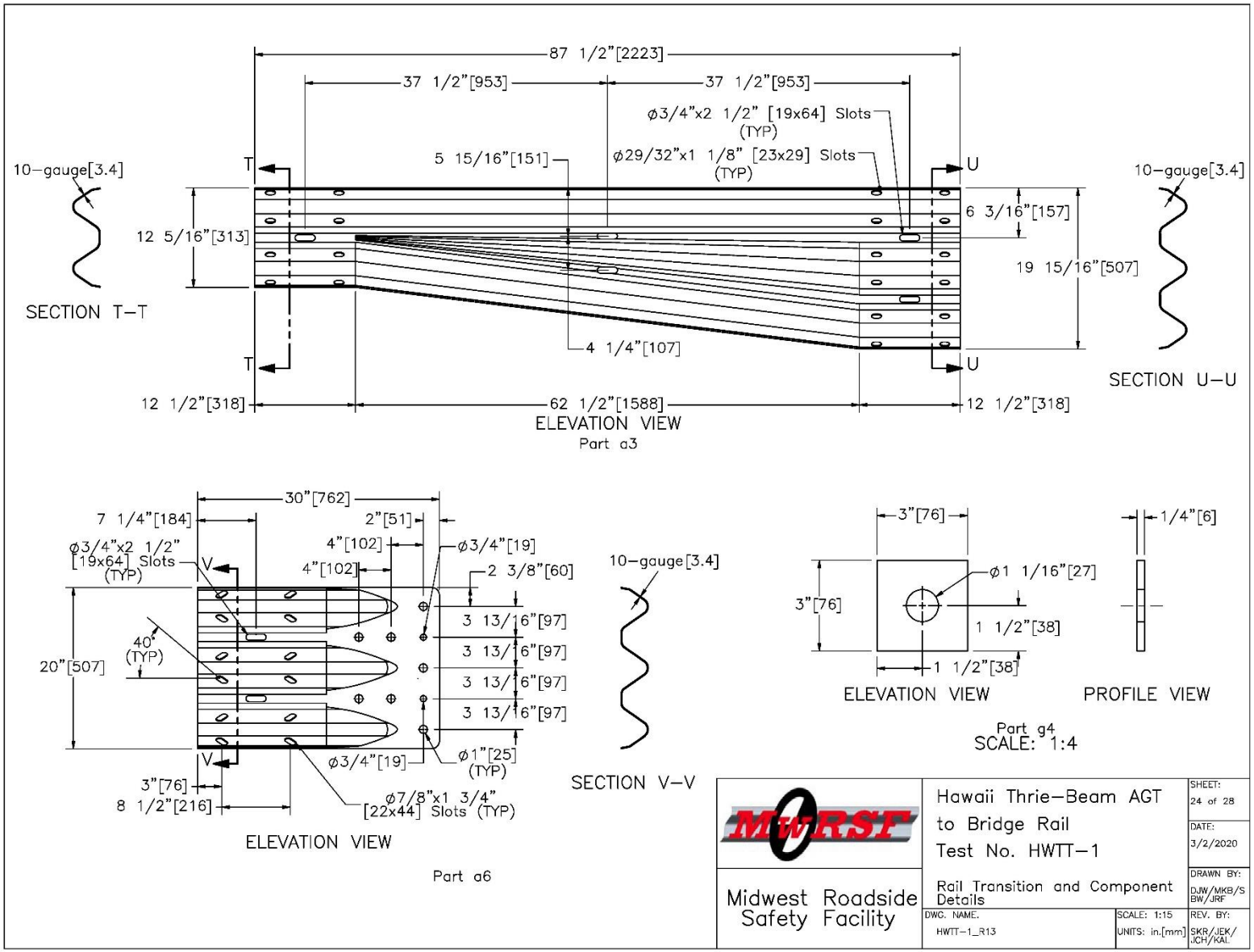


Figure A-24. Asymmetric Transition Rail and Terminal Connector Details, Test Nos. HWTT-1 and HWTT-2

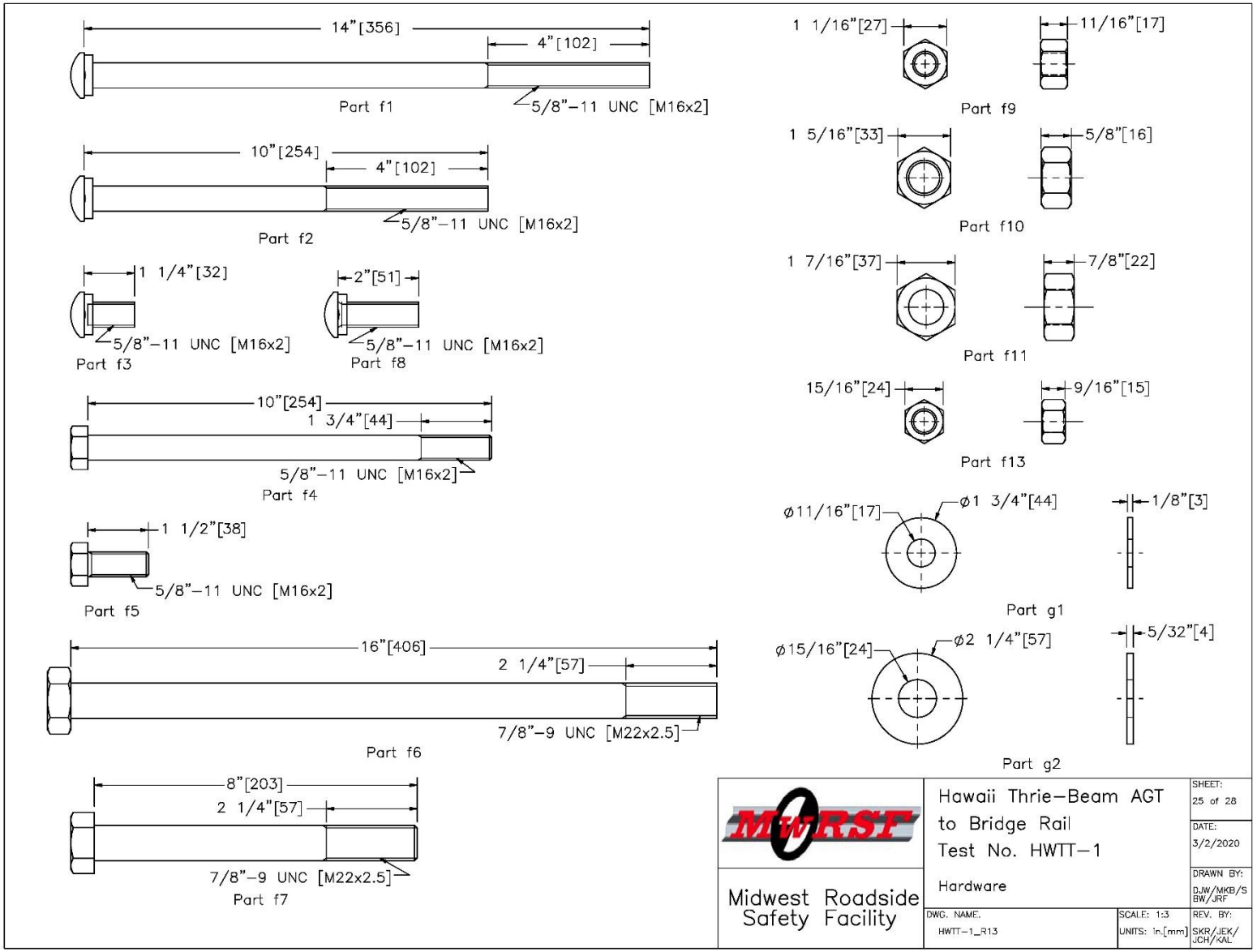


Figure A-25. Hardware, Test Nos. HWTT-1 and HWTT-2

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	2	12'–6" [3,810] 12–gauge [2.7] Thrie Beam Section	AASHTO M180	ASTM A123 or A653	RTM08a
a2	1	6'–3" [1,905] 12–gauge [2.7] Thrie Beam Section	AASHTO M180	ASTM A123 or A653	RTM19a
a3	1	6'–3" [1,905] 10–gauge [3.4] W–Beam to Thrie–Beam Asymmetric Transition Section	AASHTO M180	ASTM A653	RWT02
a4	3	12'–6" [3,810] 12–gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	RWM04a
a5	1	12'–6" [3,810] 12–gauge [2.7] W–Beam MGS End Section	AASHTO M180	ASTM A123 or A653	RWM14a
a6	1	10–gauge [3.4] Thrie Beam Terminal Connector	AASHTO M180 Min. yield strength = 50 ksi [345 MPa] Min. ultimate strength = 70 ksi [483 MPa]	ASTM A123 or A653	RTE01b
b1	1	Reinforced Concrete	Min. f'c = 4,000 psi [27.6 MPa] NE Mix 47BD		–
c1	2	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots +/– 18" [457] from ground on tension face)	–	PDF01
c2	2	72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	ASTM A123	PTE06
c3	1	Ground Strut Assembly	ASTM A36	ASTM A123	PFP02
c4	2	BCT Anchor Cable End Swaged Fitting	Fitting – ASTM A576 Gr. 1035 Stud – ASTM F568 Class C	Fitting – ASTM A153 Stud – ASTM A153 or B695	–
c5	1	3/4" [19] Dia. 6x19 IWRC IPS Wire Rope	ASTM A741 Type 2	Class A Coating	–
c6	1	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	ASTM A123	FPB01
c7	1	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	ASTM A123	FMM02
c8	1	Anchor Bracket Assembly	ASTM A36	ASTM A123	FPA01
d1	7	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1,829] Long Steel Post	ASTM A992	*ASTM A123	PWE06
d2	6	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1,829] Long Steel Post	ASTM A992	*ASTM A123	PWE06
d3	4	W6x15 [W152x22.5], 78" [1,981] Long Steel Post	ASTM A992	*ASTM A123	–
d4	4	17 1/2" [445] Long, 8"x6"x1/4" [203x152x6] Steel Blockout	ASTM A500 Gr. B	*ASTM A123	–
d5	6	17 1/2" [445] Long, 12"x4"x1/4" [305x102x6] Steel Blockout	ASTM A500 Gr. B	*ASTM A123	–

* Component does not need to be galvanized for testing purposes.

Midwest Roadside Safety Facility

Hawaii Thrie–Beam AGT to Bridge Rail
Test No. HWTT–1
Bill of Materials

SHEET: 26 of 28
DATE: 3/2/2020
DRAWN BY: DJW/MKB/SBW/JRF
REV. BY: SKR/JEK/JCH/KAL
DWG. NAME. HWTT–1_R13
SCALE: None
UNITS: In.[mm]

Figure A-26. Bill of Materials, Test Nos. HWTT-1 and HWTT-2

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
d6	2	14 3/16"x12"x5 1/8" [360x305x130] Composite Recycled Blockout	Mondo Polymer MGS14SH or Equivalent	–	–
d7	5	14 3/16"x8"x5 1/8" [360x203x130] Composite Recycled Blockout	Mondo Polymer GB14SH2 or Equivalent	–	–
d8	1	16D Double Head Nail	–	–	–
e1	6	#6 [19] Rebar, 60 1/16" [1526] Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e2	1	#6 [19] Rebar, 57 9/16" [1462] Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e3	4	#6 [19] Rebar, 56 1/16" [1424] Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e4	1	#6 [19] Rebar, 53 3/16" [1351] Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e5	6	#6 [19] Rebar, 34 9/16" [878] Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e6	4	#4 [13] Rebar, 57 3/16" [1453] Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e7	1	#4 [13] Rebar, 55 7/16" [1408] Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e8	2	#4 [13] Rebar, 53 3/16" [1351] Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e9	1	#4 [13] Rebar, 49 7/8" [1267] Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e10	3	#6 [19] Rebar, 92" [2337] Total Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e11	3	#6 [19] Rebar, 92 7/8" [2359] Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e12	4	#4 [13] Rebar, 92" [2337] Total Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e13	2	#4 [13] Rebar, 49 5/8" [1260] Total Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e14	7	#4 [13] Rebar, 16" [406] Total Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e15	1	#4 [13] Rebar, 12 3/4" [324] Total Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e16	1	#5 [16] Rebar, 172" [4369] Total Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
e17	1	#5 [16] Rebar, 164 1/4" [4172] Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–

** Rebar does not need to be epoxy–coated for testing purposes.

Midwest Roadside Safety Facility

Hawaii Thrie–Beam AGT to Bridge Rail
Test No. HWTT–1
Bill of Materials

SHEET: 27 of 28
DATE: 3/2/2020
DRAWN BY: DJW/MKB/SBW/JRF
REV. BY: SKR/JEK/JCH/KAL
DWG. NAME. HWTT–1_R13
SCALE: None
UNITS: in.[mm]

Figure A-27. Bill of Materials, Cont., Test Nos. HWTT-1 and HWTT-2

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
f1	13	5/8"–11 UNC [M16x2], 14" [356] Long Guardrail Bolt	ASTM A307 Gr. A	ASTM A153 or B695 Class 55 or F2329	FBB06
f2	15	5/8"–11 UNC [M16x2], 10" [254] Long Guardrail Bolt	ASTM A307 Gr. A	ASTM A153 or B695 Class 55 or F2329	FBB03
f3	44	5/8"–11 UNC [M16x2], 1 1/4" [32] Long Guardrail Bolt	ASTM A307 Gr. A	ASTM A153 or B695 Class 55 or F2329	FBB01
f4	2	5/8"–11 UNC [M16x2], 10" [254] Long Hex Head Bolt	ASTM A307 Gr. A or equivalent	ASTM A153 or B695 Class 55 or F2329	FBX16a
f5	8	5/8"–11 UNC [M16x2], 1 1/2" [38] Long Hex Head Bolt	ASTM A307 Gr. A or equivalent	ASTM A153 or B695 Class 55 or F2329	FBX16a
f6	5	7/8"–9 UNC [M22x2.5], 16" [406] Long Heavy Hex Head Bolt	ASTM F3125 Gr. A325 or equivalent	ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F2329 or F2833 Gr. 1	FBX22b
f7	2	7/8"–9 UNC [M22x2.5], 8" [203] Long Hex Head Bolt	ASTM A307 Gr. A or equivalent	ASTM A153 or B695 Class 55 or F2329	–
f8	24	5/8"–11 UNC [M16x2], 2" [51] Long Guardrail Bolt	ASTM A307 Gr. A	ASTM A153 or B695 Class 55 or F2329	FBB02
f9	96	5/8"–11 UNC [M16x2] Heavy Hex Nut	ASTM A563A or equivalent	ASTM A153 or B695 Class 55 or F2329	FNX16b
f10	2	7/8"–9 UNC [M22x2.5] Hex Nut	ASTM A563A or equivalent	ASTM A153 or B695 Class 55 or F2329	–
f11	5	7/8"–9 UNC [M22x2.5] Heavy Hex Nut	ASTM A563DH	ASTM A153 or B695 Class 55 or F2329	FNX22b
f12	2	1"–8 UNC [M24x3] Heavy Hex Nut	ASTM A563DH or equivalent	ASTM A153 or B695 Class 55 or F2329	FNX24b
f13	10	5/8"–11 UNC [M16x2] Hex Nut	ASTM A563A or equivalent	ASTM A153 or B695 Class 55 or F2329	FNX16a
g1	46	5/8" [16] Dia. Plain USS Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC16a
g2	4	7/8" [22] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–
g3	2	1" [25] Dia. Plain USS Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC24a
g4	5	3"x3"x1/4" [76x76x6] or 3 1/2"x3 1/2"x1/4" [89x89x6] Square Washer Plate	ASTM A572 Gr. 50	ASTM A123	–
–	–	Epoxy Adhesive	Hilti HIT RE–500 V3	–	–

Midwest Roadside Safety Facility

Hawaii Thrie–Beam AGT to Bridge Rail
Test No. HWTT–1
Bill of Materials

SHEET: 28 of 28
DATE: 3/2/2020
DRAWN BY: DJW/MKB/SBW/JRF
REV. BY: SKR/JEK/JCH/KAL
DWG. NAME. HWTT–1_R13
SCALE: None
UNITS: in.[mm]

Figure A-28. Bill of Materials, Cont., Test Nos. HWTT-1 and HWTT-2

Appendix B. Hawaii Concrete Post and Beam Bridge Rail Details

The following design details were created for the test installation of test nos. HNTBR-2 and HNTBR-3, which evaluated the Hawaii Concrete Post and Beam Bridge Rail. CAD details are included herein as a reference for the bridge railing that would be located at the downstream end of the AGT and concrete end post discussed in this report. Further details on the bridge railing can be found in the crash testing report [7].

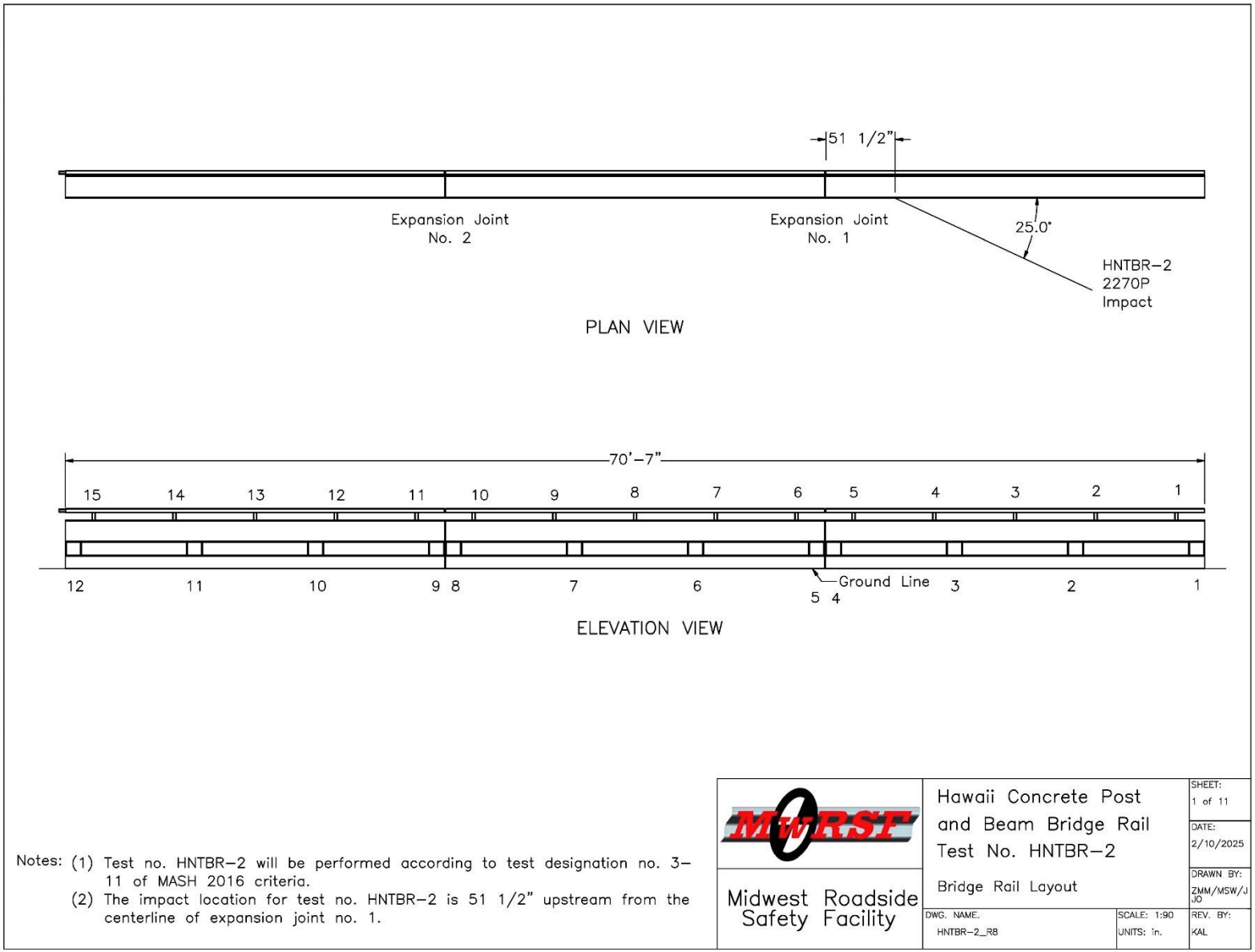


Figure B-1. Test Installation Layout, Test No. HNTBR-2

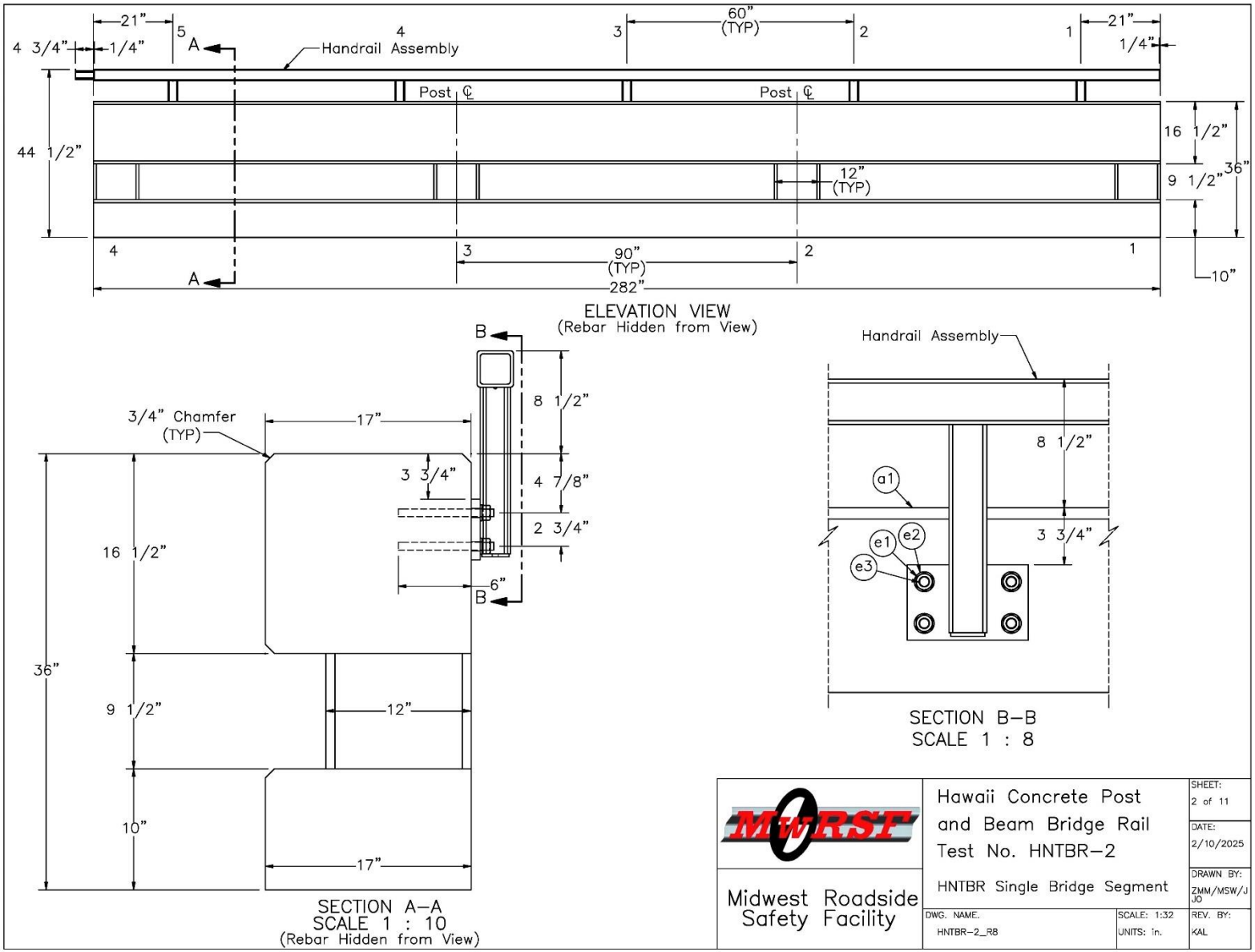


Figure B-2. Bridge Rail Layout, Test Nos. HNTBR-2 and HNTBR-3

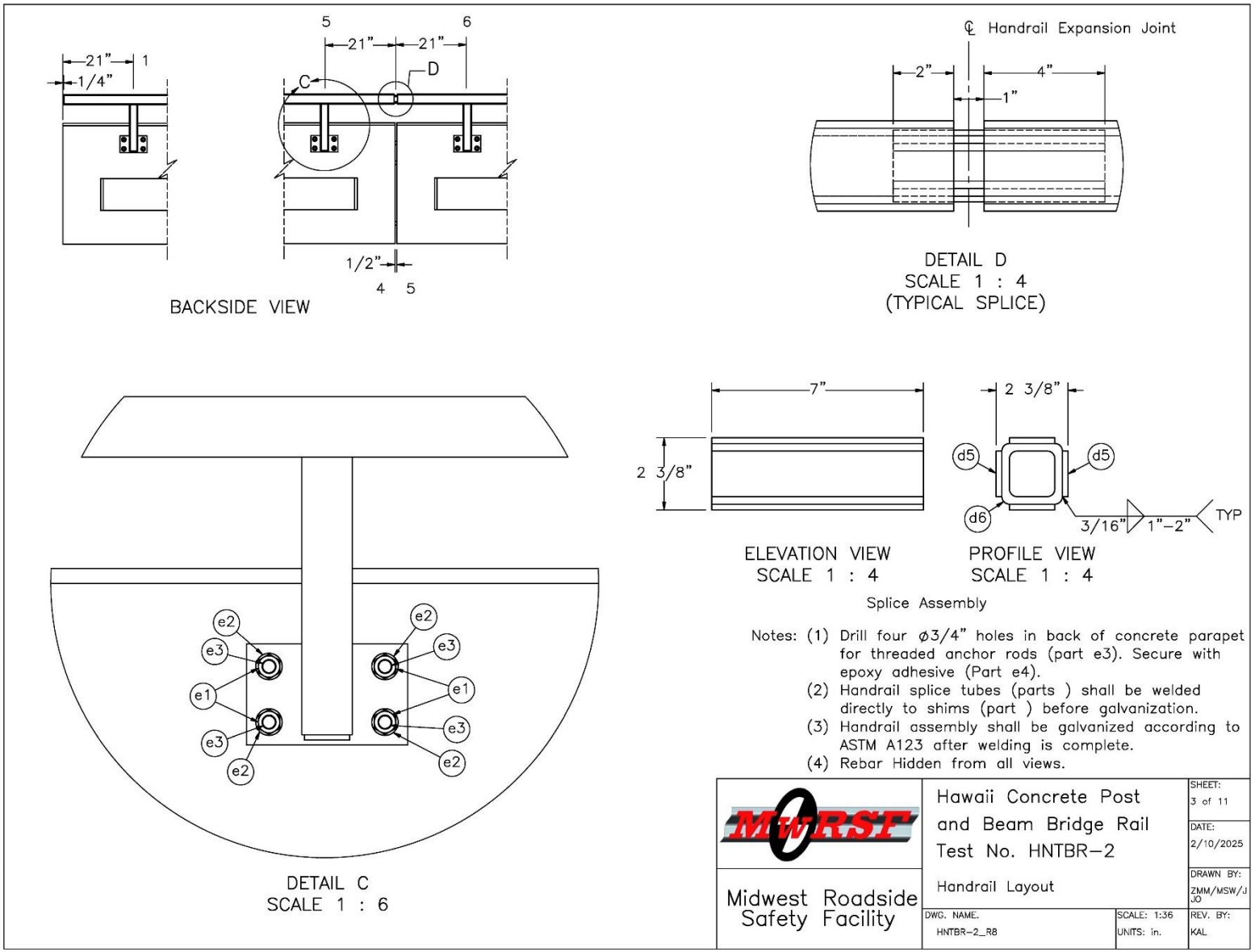
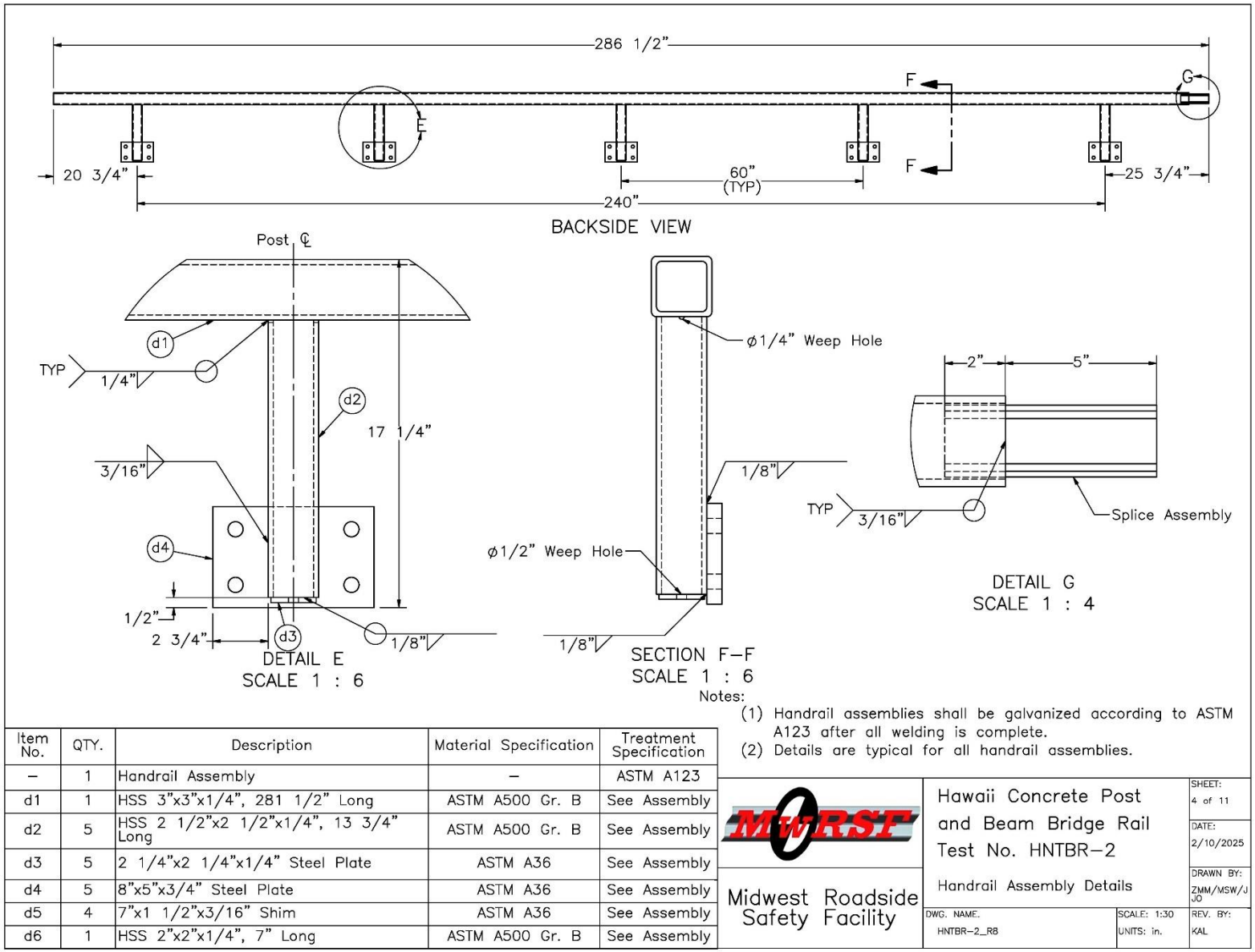


Figure B-3. Handrail Detail, Test Nos. HNTBR-2 and HNTBR-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Handrail Assembly	–	ASTM A123
d1	1	HSS 3"x3"x1/4", 281 1/2" Long	ASTM A500 Gr. B	See Assembly
d2	5	HSS 2 1/2"x2 1/2"x1/4", 13 3/4" Long	ASTM A500 Gr. B	See Assembly
d3	5	2 1/4"x2 1/4"x1/4" Steel Plate	ASTM A36	See Assembly
d4	5	8"x5"x3/4" Steel Plate	ASTM A36	See Assembly
d5	4	7"x1 1/2"x3/16" Shim	ASTM A36	See Assembly
d6	1	HSS 2"x2"x1/4", 7" Long	ASTM A500 Gr. B	See Assembly

Figure B-4. Handrail Detail, Test Nos. HNTBR-2 and HNTBR-3

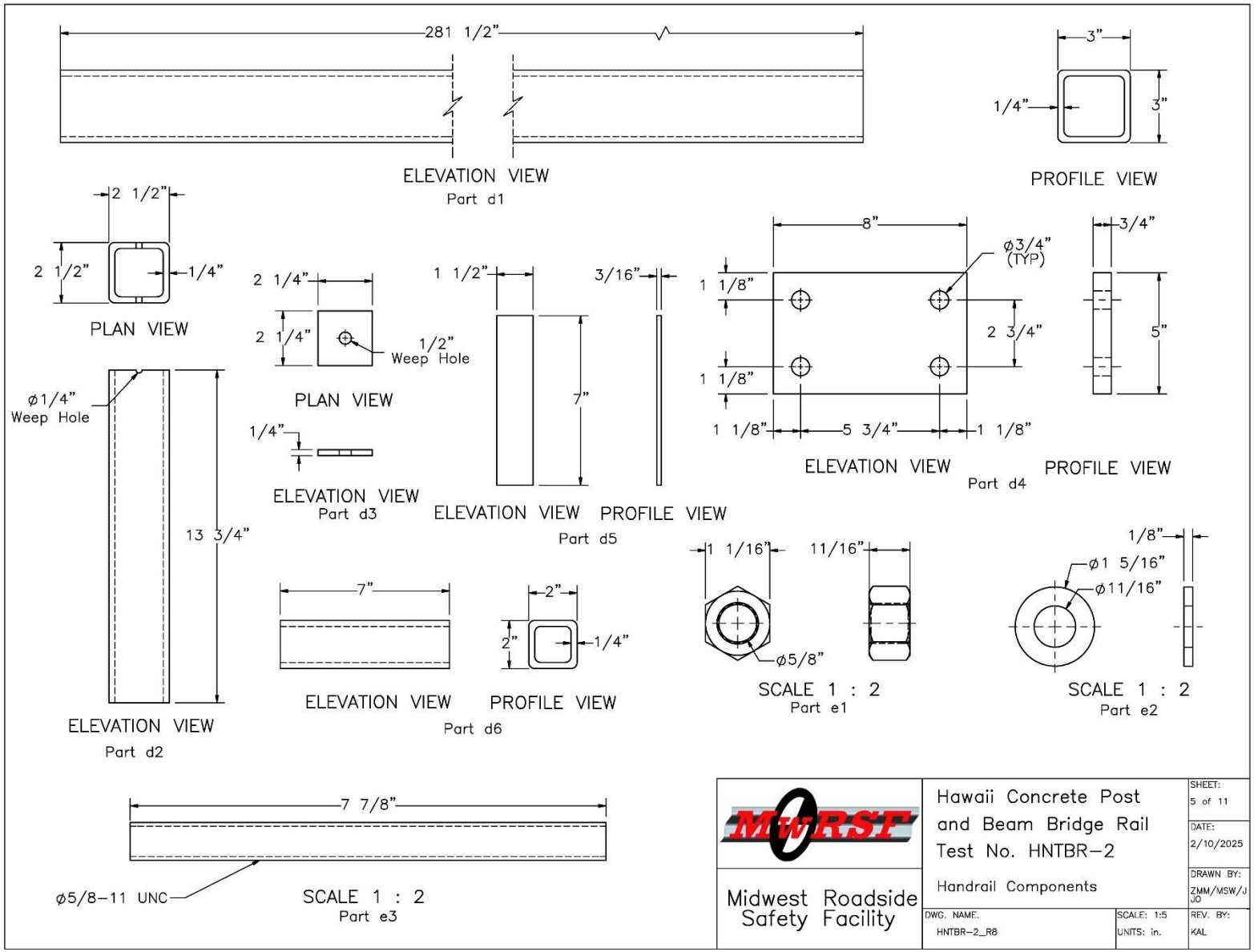


Figure B-5. Handrail Assembly Components, Test Nos. HNTBR-2 and HNTBR-3

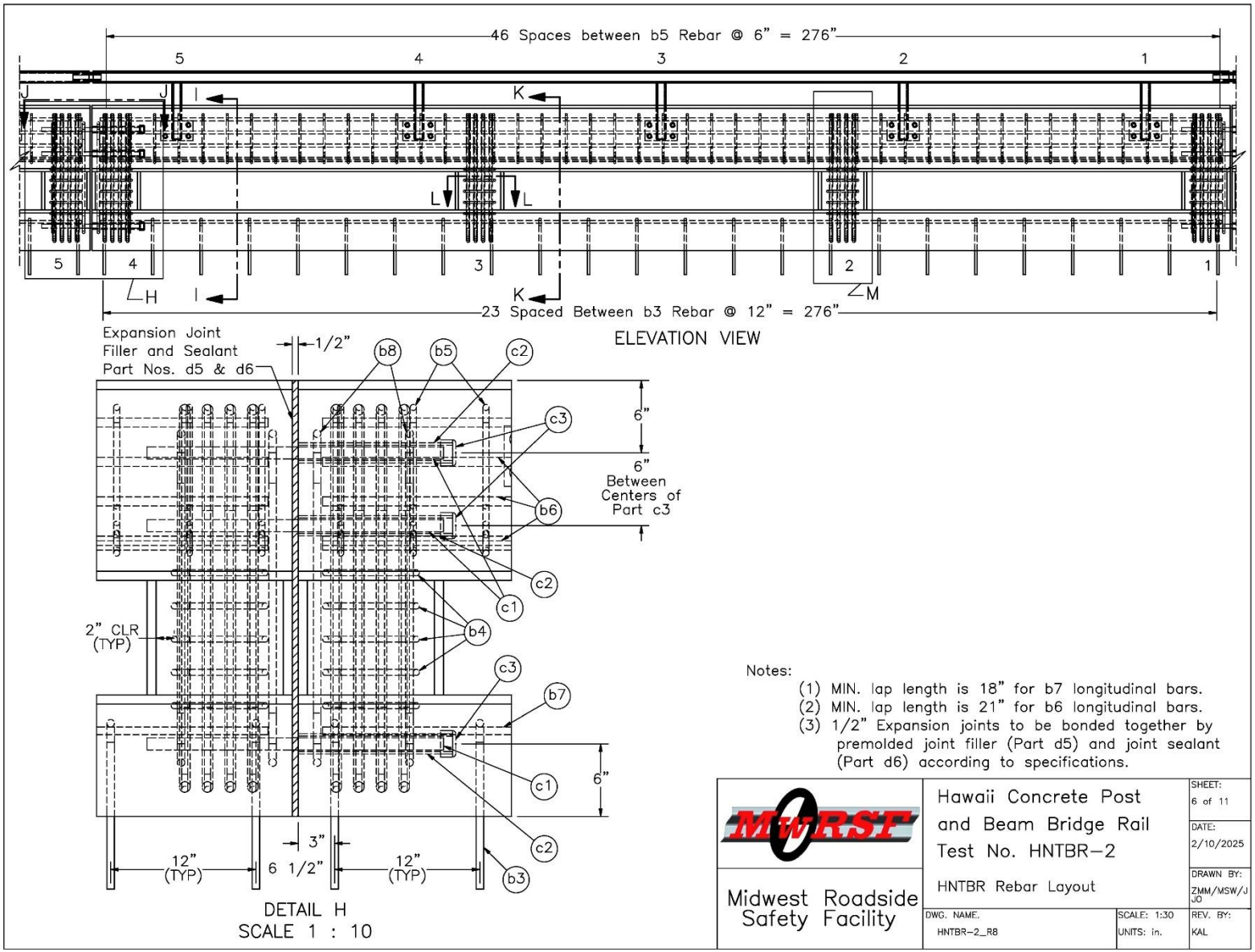


Figure B-6. Rails Rebar Detail, Test Nos. HNTBR-2 and HNTBR-3

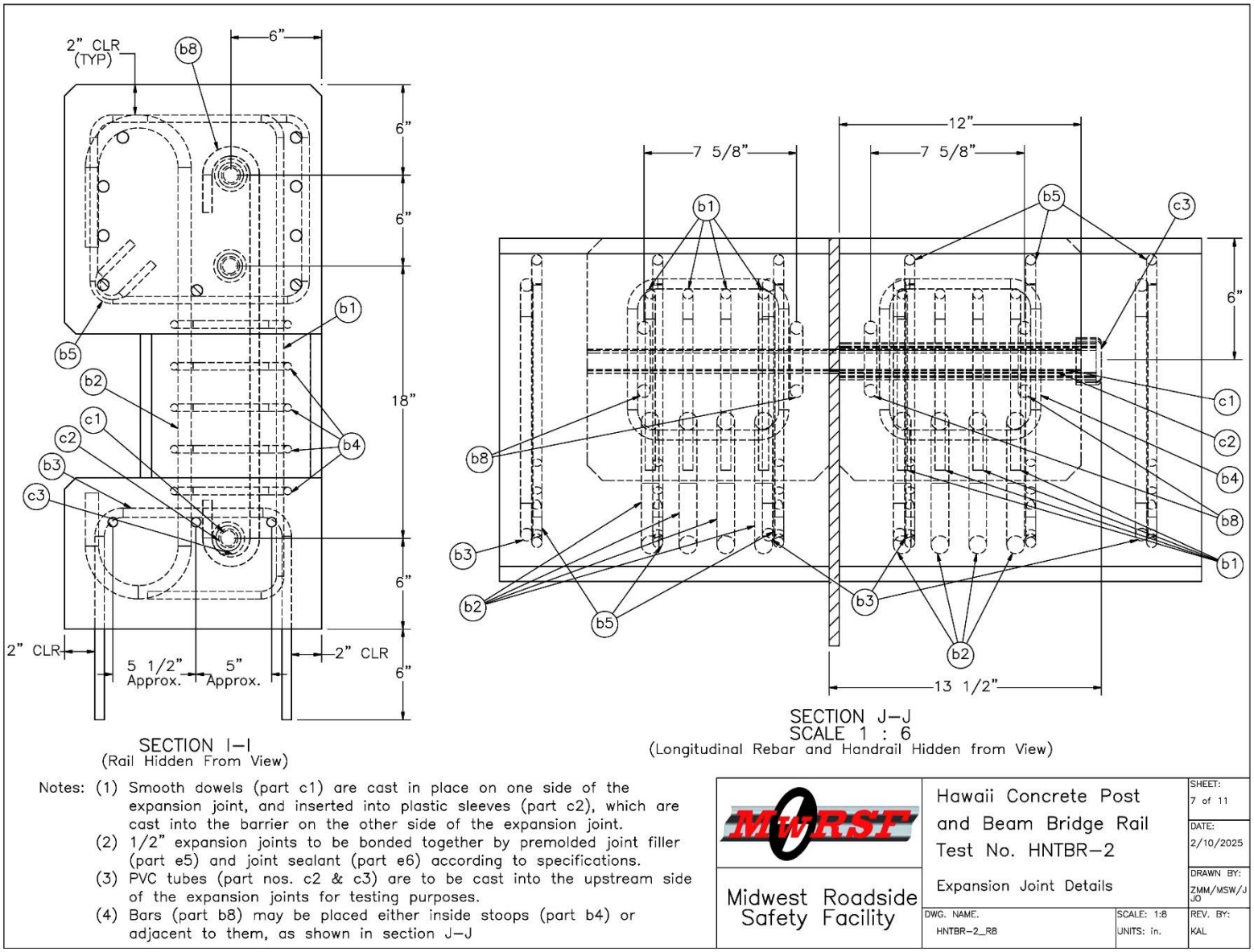


Figure B-7. Post-Rail Rebar Arrangement, Test Nos. HNTBR-2 and HNTBR-3

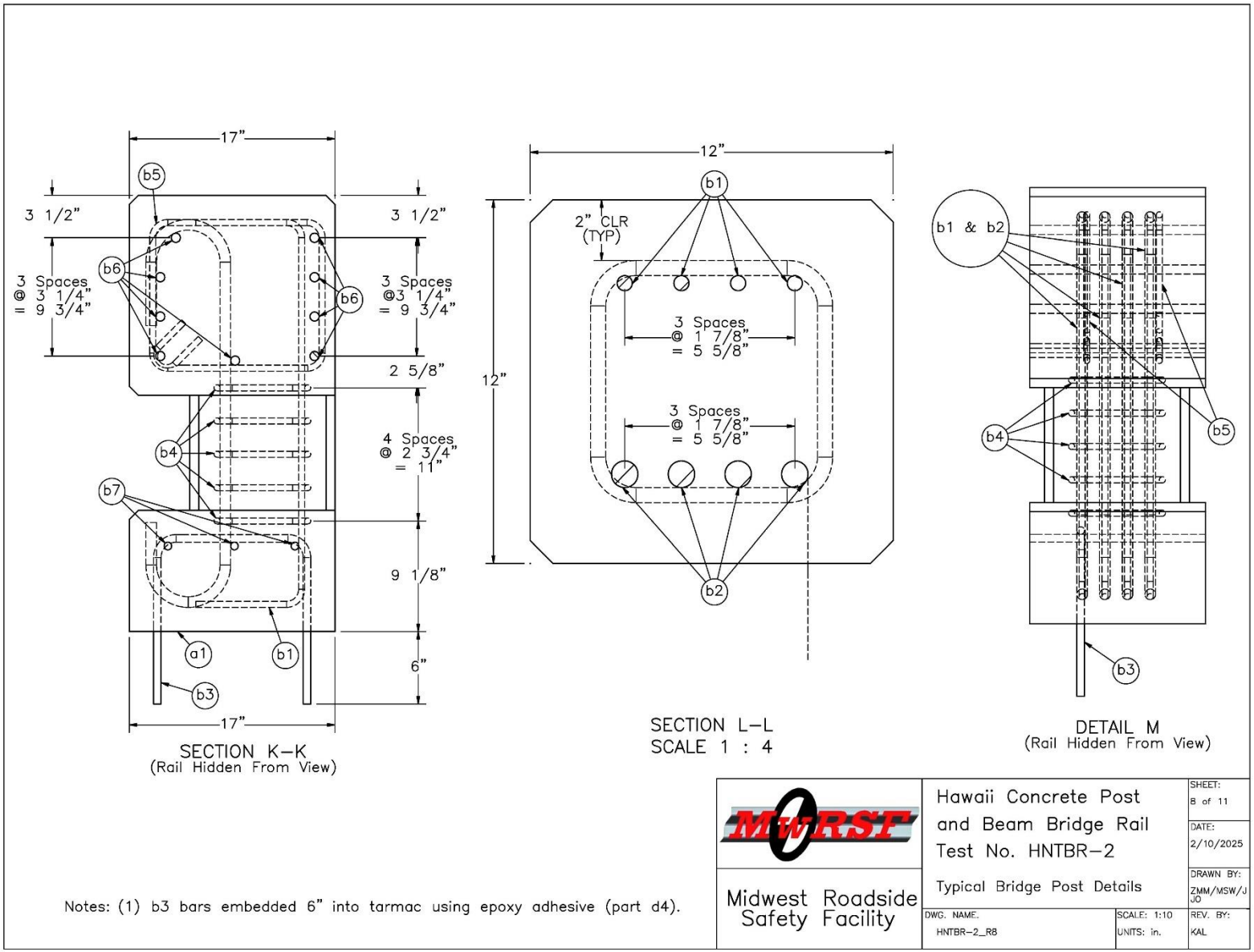
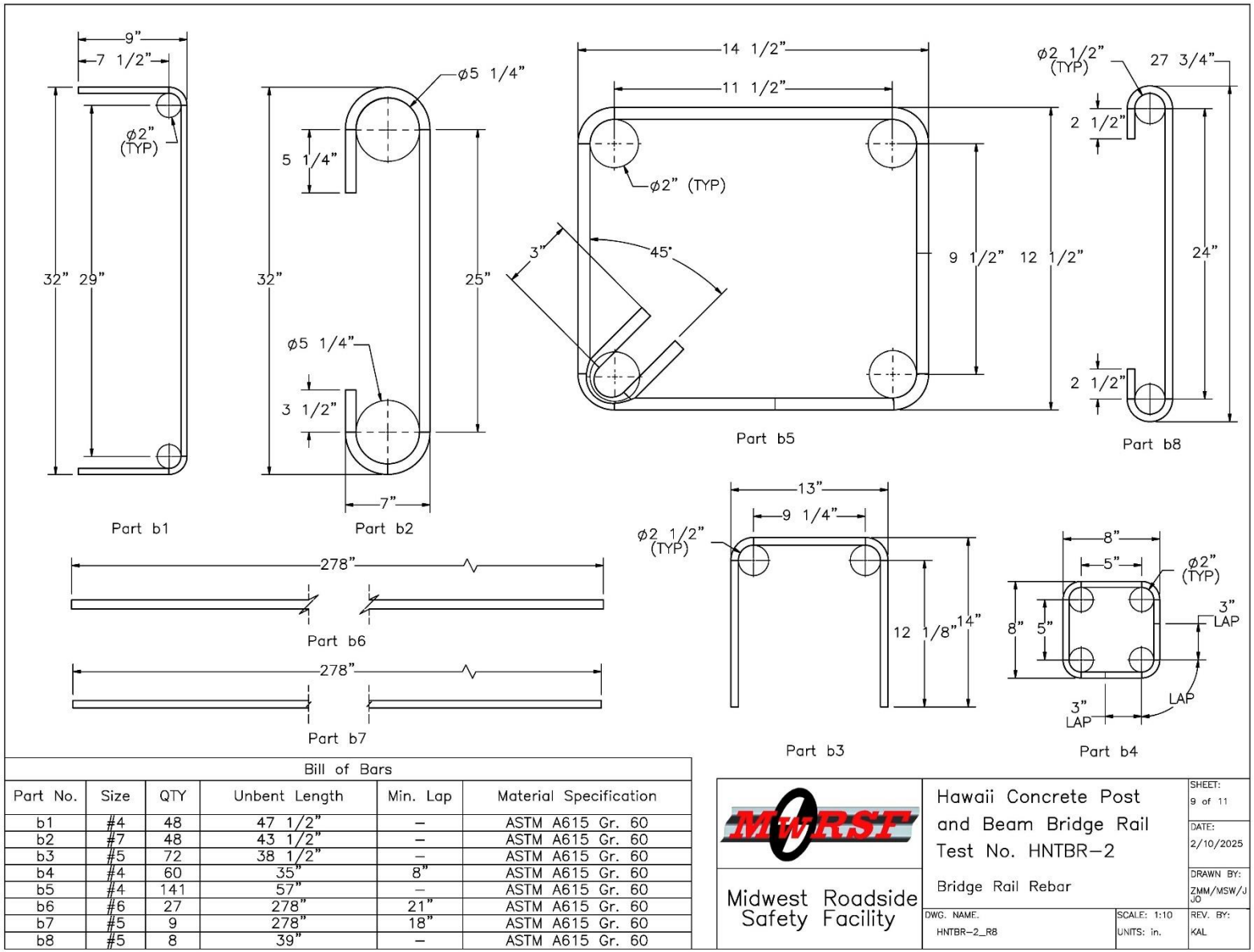


Figure B-8. Post-Rail Rebar Arrangement, Test Nos. HNTBR-2 and HNTBR-3



Bill of Bars

Part No.	Size	QTY	Unbent Length	Min. Lap	Material Specification
b1	#4	48	47 1/2"	–	ASTM A615 Gr. 60
b2	#7	48	43 1/2"	–	ASTM A615 Gr. 60
b3	#5	72	38 1/2"	–	ASTM A615 Gr. 60
b4	#4	60	35"	8"	ASTM A615 Gr. 60
b5	#4	141	57"	–	ASTM A615 Gr. 60
b6	#6	27	278"	21"	ASTM A615 Gr. 60
b7	#5	9	278"	18"	ASTM A615 Gr. 60
b8	#5	8	39"	–	ASTM A615 Gr. 60

Midwest Roadside Safety Facility

Hawaii Concrete Post and Beam Bridge Rail
Test No. HNTBR–2
Bridge Rail Rebar

DWG. NAME. HNTBR–2_R8
SCALE: 1:10
UNITS: in.
SHEET: 9 of 11
DATE: 2/10/2025
DRAWN BY: ZMM/MSW/JO
REV. BY: KAL

Figure B-9. Rebar Details, Test Nos. HNTBR-2 and HNTBR-3

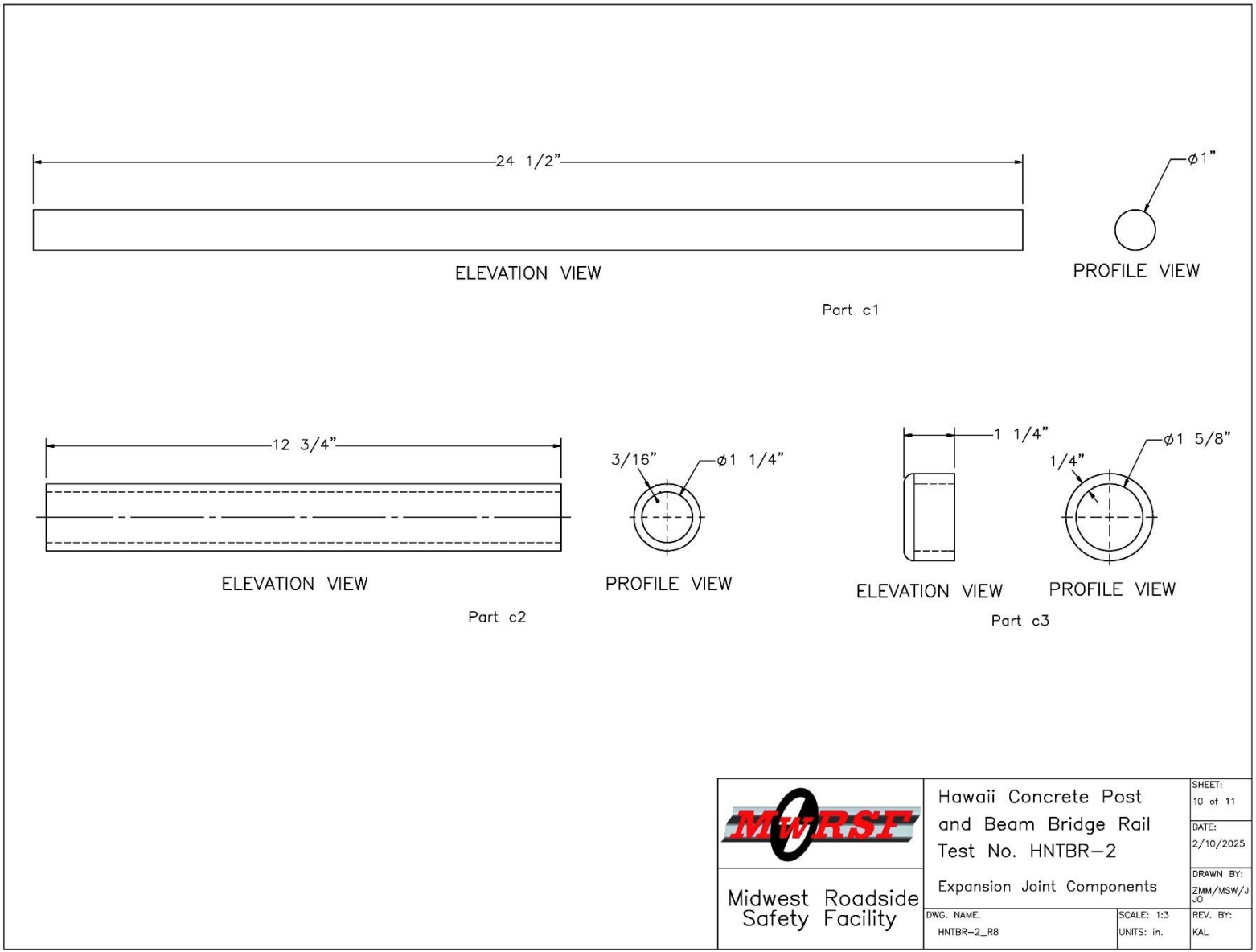


Figure B-10. Pipe Details, Test Nos. HNTBR-2 and HNTBR-3

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	3	Concrete*	Min. f'c = 4,000 psi	–	–
b1	48	#4 Rebar, 47 1/2" Total Unbent Length	ASTM A615 Gr. 60	**Epxoy–Coated (ASTM A775 or A934)	–
b2	48	#7 Rebar, 43 1/2"" Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
b3	72	#5 Rebar, 38 1/2" Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
b4	60	#4 Rebar, 35" Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
b5	141	#4 Rebar, 57" Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
b6	27	#6 Rebar, 278" Total Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
b7	9	#5 Rebar, 278" Total Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
b8	8	#5 Rebar, 39" Total Unbent Length	ASTM A615 Gr. 60	**Epoxy Coated (ASTM A775 or A934)	–
c1	6	#8 Smooth Rebar, 24 1/2" Long	ASTM A615 Gr. 60	**Epoxy Coated (ASTM A775 or A934)	–
c2	6	1 1/4" Dia. PVC Pipe	Schedule 80 PVC Gr. 12454	–	–
c3	6	1 1/4" Dia. PVC End Cap	Schedule 80 PVC Gr. 12454	–	–
d1	3	HSS 3"x3"x1/4", 281 1/2" Long	ASTM A500 Gr. B	See Assembly	–
d2	15	HSS 2 1/2"x2 1/2"x1/4", 13 3/4" Long	ASTM A500 Gr. B	See Assembly	–
d3	15	2 1/4"x2 1/4"x1/4" Steel Plate	ASTM A36	See Assembly	–
d4	15	8"x5"x3/4" Steel Plate	ASTM A36	See Assembly	–
d5	12	7"x1 1/2"x3/16" Shim	ASTM A36	See Assembly	–
d6	3	HSS 2"x2"x1/4", 7" Long	ASTM A500 Gr. B	See Assembly	–
e1	60	5/8"–11 UNC Heavy Hex Nut	ASTM A563–15 Grade DH	ASTM F2329	FNX18b
e2	60	5/8" Dia. Hardened Washer	ASTM F436	ASTM F2329	FWC18b
e3	60	5/8"–11 UNC, 7 7/8" Long Threaded Rod	ASTM F1554–15 Gr. 105	ASTM F2329	–
e4	–	Epoxy Adhesive	Hilti HIT RE–500 V3	–	–
e5	–	Joint Filler	AASHTO M33, M153, or M213	–	–
e6	–	Expansion Joint Sealant	AASHTO M173, M282, M301, ASTM D3581, or ASTM D5893	–	–

* NE Mix 47B15/1PF4000HW was used for testing purposes.
** Rebar does not need to be epoxy–coated for testing purposes.

MwRSF

Midwest Roadside Safety Facility

Hawaii Concrete Post and Beam Bridge Rail Test No. HNTBR–2

HNTBR BOM

SHEET: 11 of 11
DATE: 2/10/2025
DRAWN BY: ZMM/MSW/JO
DWG. NAME. HNTBR–2_R8
SCALE: 1:192
UNITS: in.
REV. BY: KAL

Figure B-11. Bill of Materials, Test Nos. HNTBR-2 and HNTBR-3

END OF DOCUMENT