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TECHNICAL MEMORANDUM

Project Name: **T4541 MASH Implementation Technical Support for Washington State I-90 Snoqualmie Pass Scupper Barrier, TTI Project No. 618141**

Sponsor: **Washington Department of Transportation (WSDOT)**

Subject: **Phase 2 - Full Scale Crash Testing of I-90 Scupper Barrier, & Recommended Phase 3 Design**

DATE: **September 17, 2024**

FROM: **William Williams, P.E.**, Associate Research Engineer
Phone: 979-317-2707
Email: w-williams@tti.tamu.edu

PROBLEM STATEMENT AND BACKGROUND

Initially, WSDOT desired a crashworthy barrier gap design for the Interstate-90 (I-90) roadway location through Snoqualmie Pass in Washington State. Texas A&M Transportation Institute received a packet of information entitled "Barrier Gap- Data Package" from John Donahue (Washington DOT Design and Policy Manager). This package contained drawings and details on a proposed barrier gap to be used for this project along with information on the current barrier type used for the roadway. After the initial investigation of the barrier gap proposal, it was determined that a barrier with a large scupper design would be more likely to be found MASH compliant through crash testing. The purpose of this technical memo is to provide details of the crash tested design, report the results of a successful MASH Test 3-10 crash test and failed MASH Test 3-11 crash test. In addition, material testing of failed components is also reported herein, as well as recommendations and details for a new barrier design with improved loops in the scupper barriers are also provided.

OBJECTIVE

The objective of this project was to develop a new barrier design to be used on Interstate 90 (I-90) Snoqualmie Pass in Washington State. This new design developed for this project was a scupper barrier that crash tested to MASH Test Level 3 Specifications as part this Phase 2 project.

BENEFITS

The main benefit of this project will be to have a scupper barrier design option that ultimately meets the performance requirements of MASH Test Level 3 Specifications that can be used on the I-90 Snoqualmie Pass roadway.

PRODUCTS

A scupper barrier gap design that is best suited to meet the drainage needs while meeting the performance requirements of MASH Test Level 3. Provide full test installation details of the new design to WSDOT for full scale crash testing in a separate phase of the project (Phase 3).

WORK PLAN

From a previous project (Phase 1), TTI designed and developed engineering drawings of the new scupper barrier. Several concepts were considered for a barrier gap design. After review of a few concepts, the project team selected a concrete barrier with a scupper opening at the base of the barrier gap. The ends of the barrier gap opening were tapered to improve the performance with the small car. The final barrier gap details developed, constructed, and crash tested for this Phase 2 project are provided in Figures 1 to 8 shown below.

For Phase 2, the barriers designed and developed from Phase 1 was constructed and full-scale crash tested. The work plan for this Phase 2 is provided as follows:

1.) **Task 1 – Computer Simulations and Analyses** – The TTI research team will perform computer simulations on the scupper barrier details developed in Phase 1. The TTI research team will perform LS-DYNA computer simulations to determine the critical impact points (CIP's) for both MASH Tests 3-10 and 3-11 planned for Task 3 of this project. The TTI research team will use the computer simulations to determine vehicle performance for both MASH Test 3-10 and MASH Test 3-11. Full computer modeling of the barrier system to consider any possible material yielding or failure is outside the scope of this task.

2.) **Task 2 – Construction of Full-Scale Test Installation** – As part of this task, the TTI research team will construct full-scale test installation using the Details developed for this project in Phase 1.

3.) **Task 3 – Full Scale Crash Testing –** As part of this task, the TTI research team will perform two full-scale crash tests, MASH Test 3-10 and MASH Test 3-11. Once the crash tests have been performed, the TTI research team will prepare and submit a test report that documents information about the test article including all drawings, details, and material specifications used to construct the test article. All information obtained from the full-scale testing will also be included in the test report. In addition, demolition of the test article after the testing is performed and the installation is no longer needed is included in this task.

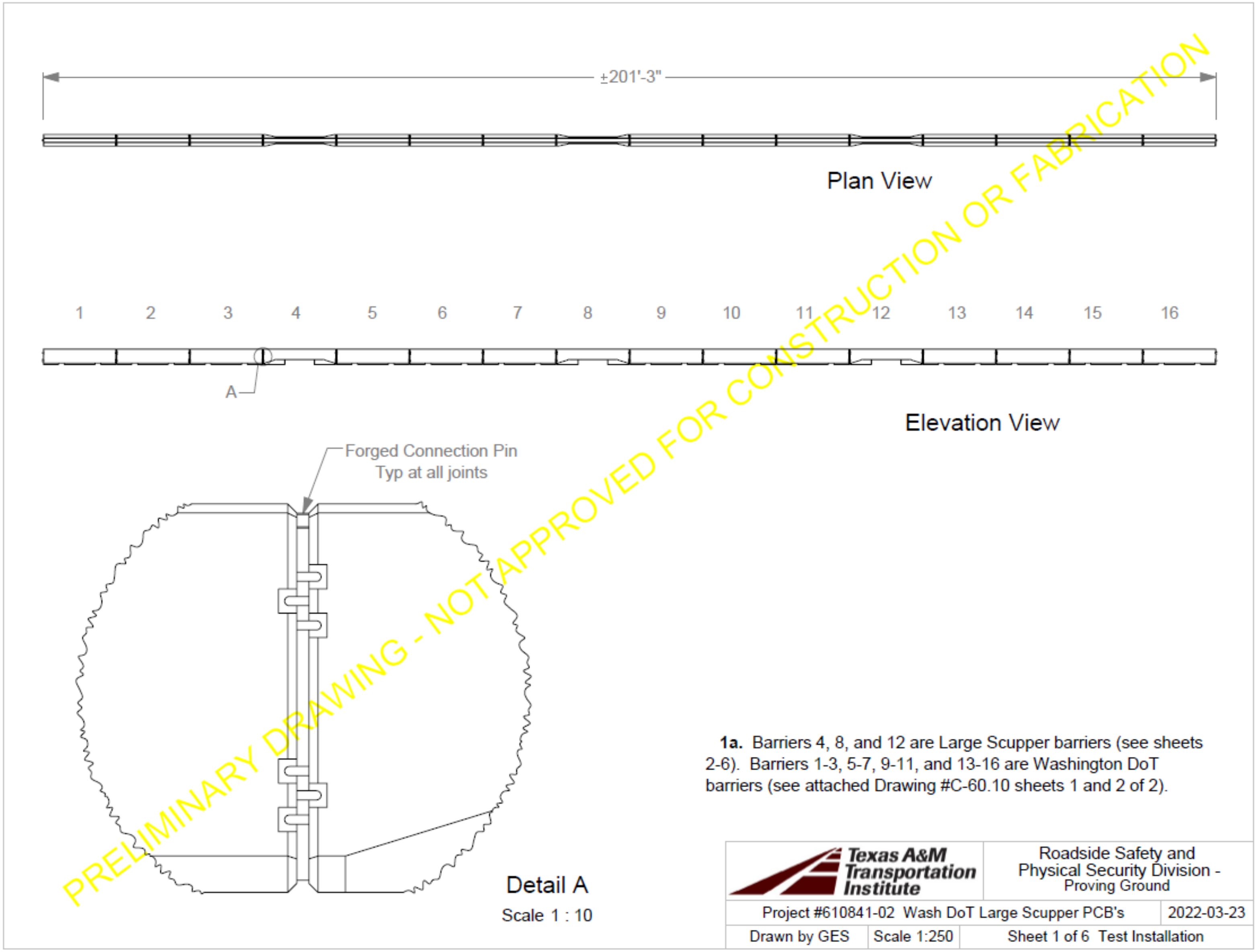


Figure 1 – Layout of Barrier Gap Test Installation.

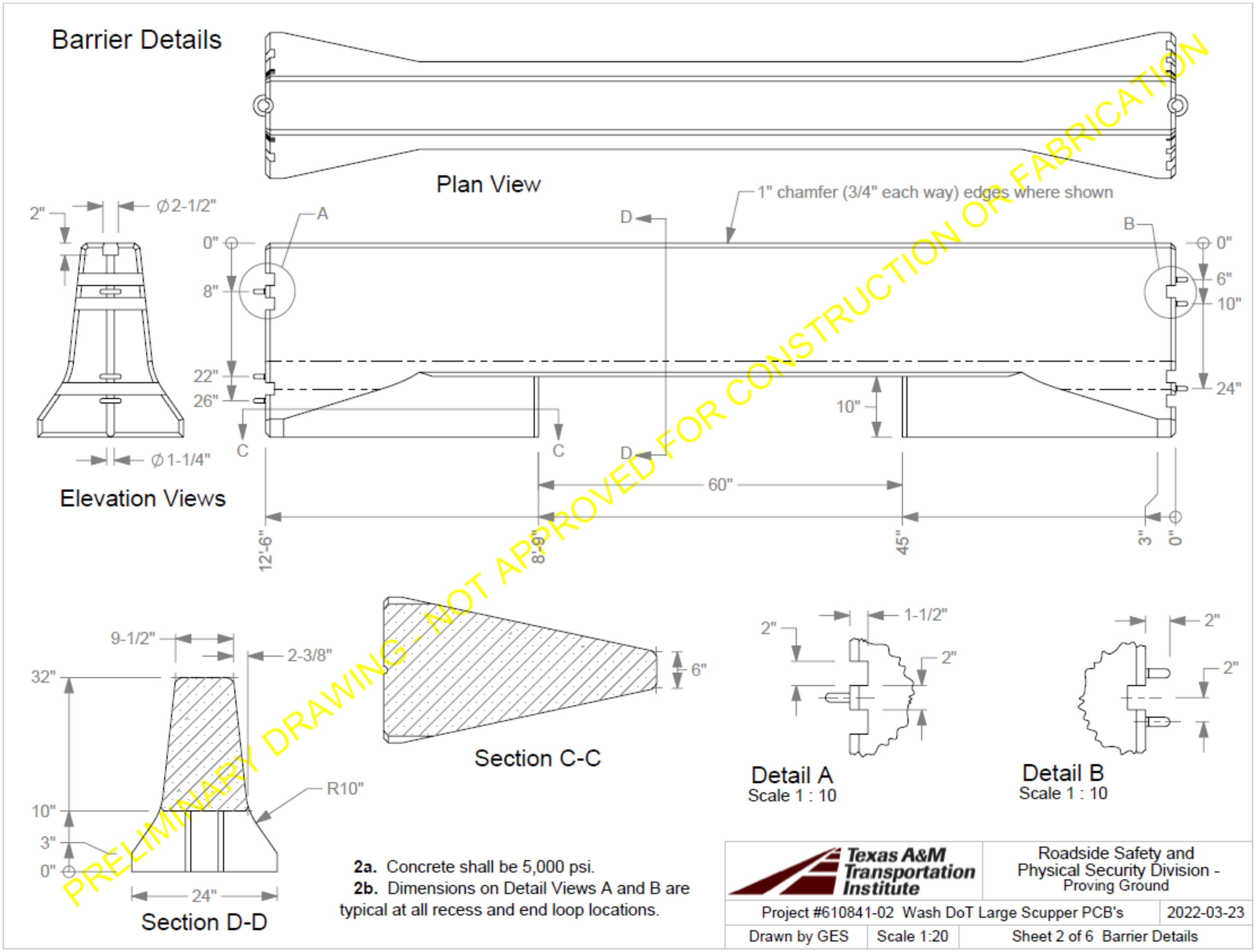
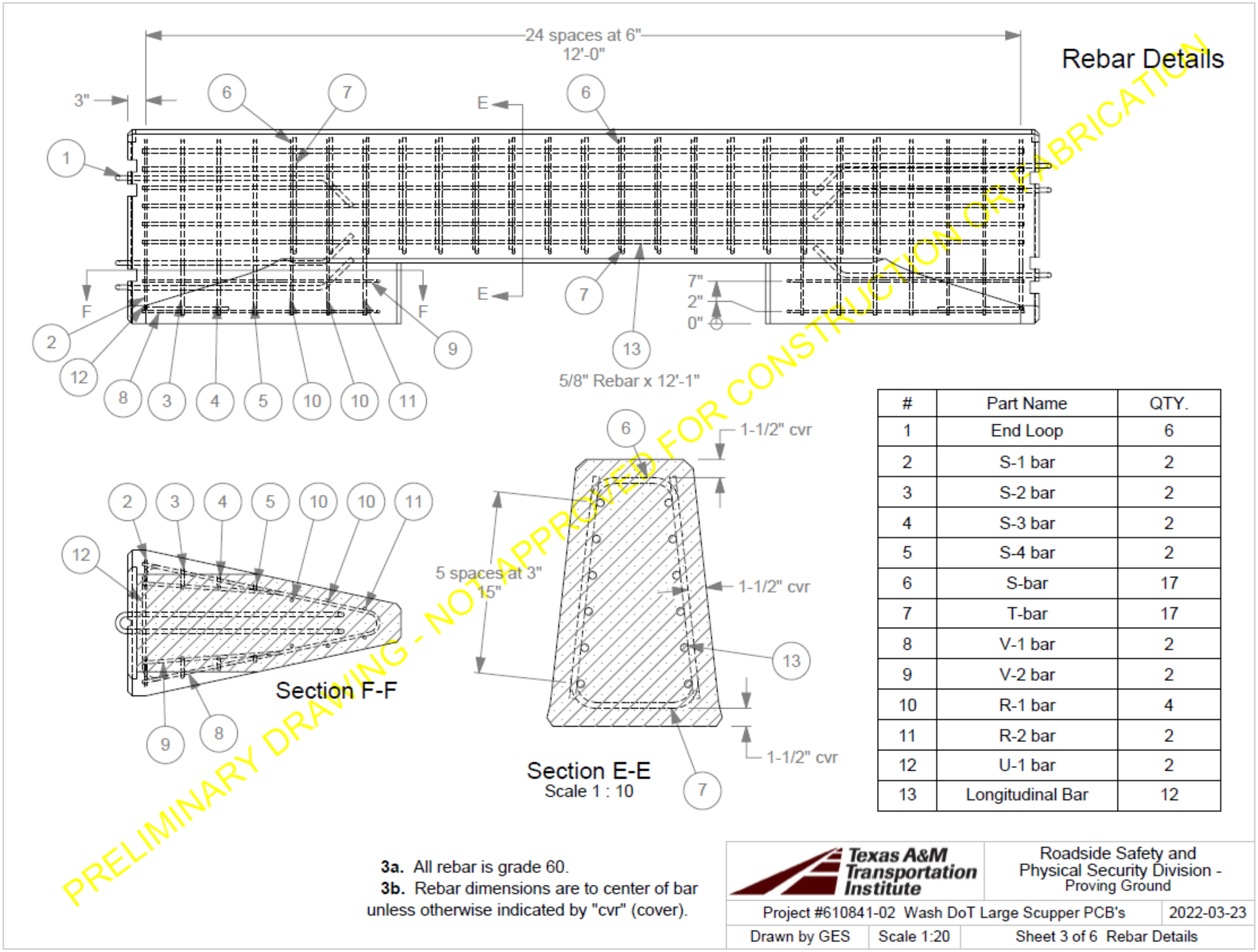


Figure 2 – Barrier Details.



#	Part Name	QTY.
1	End Loop	6
2	S-1 bar	2
3	S-2 bar	2
4	S-3 bar	2
5	S-4 bar	2
6	S-bar	17
7	T-bar	17
8	V-1 bar	2
9	V-2 bar	2
10	R-1 bar	4
11	R-2 bar	2
12	U-1 bar	2
13	Longitudinal Bar	12

Figure 3 – Reinforcement Details.

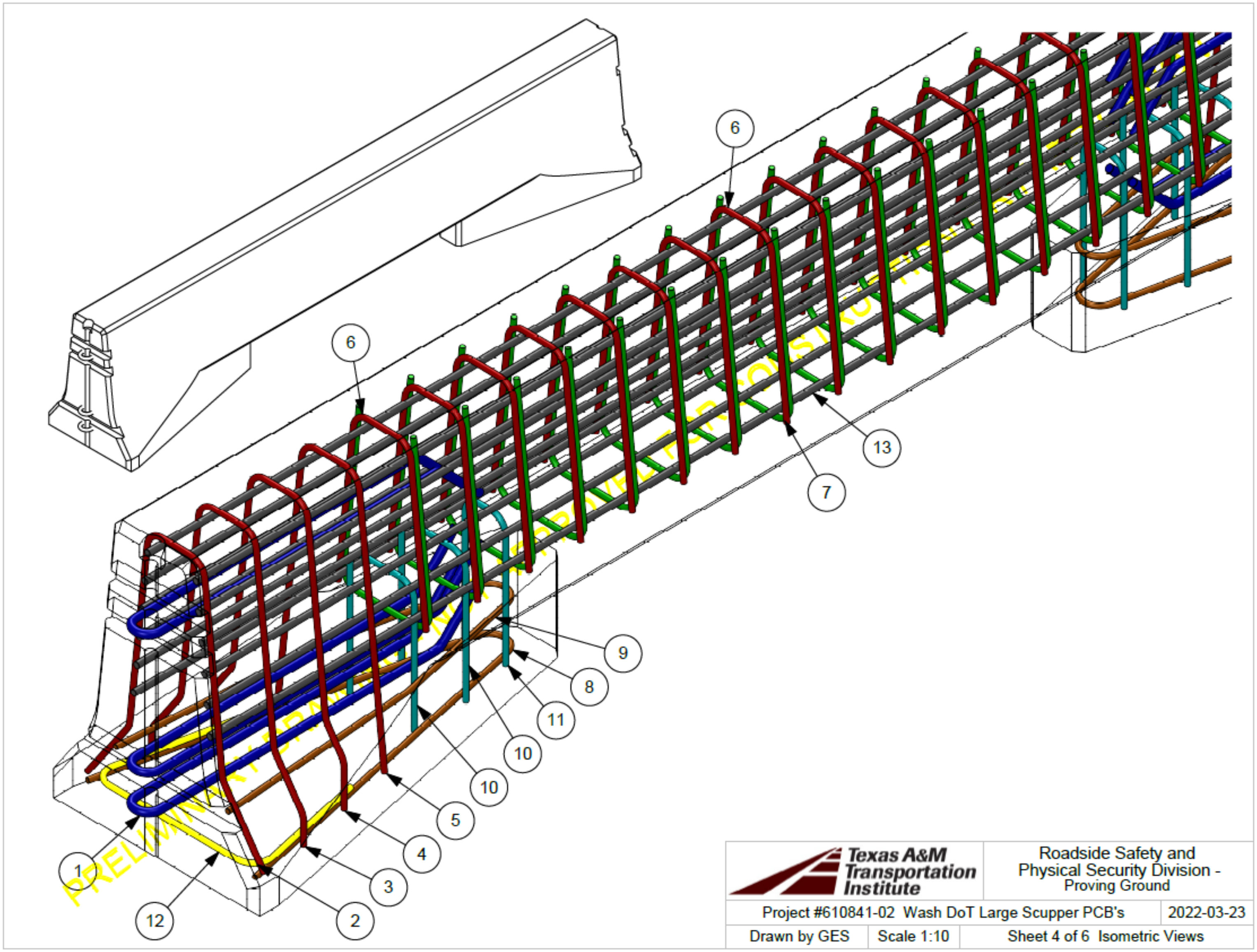


Figure 4 – Isometric View of Barrier Gap Design.

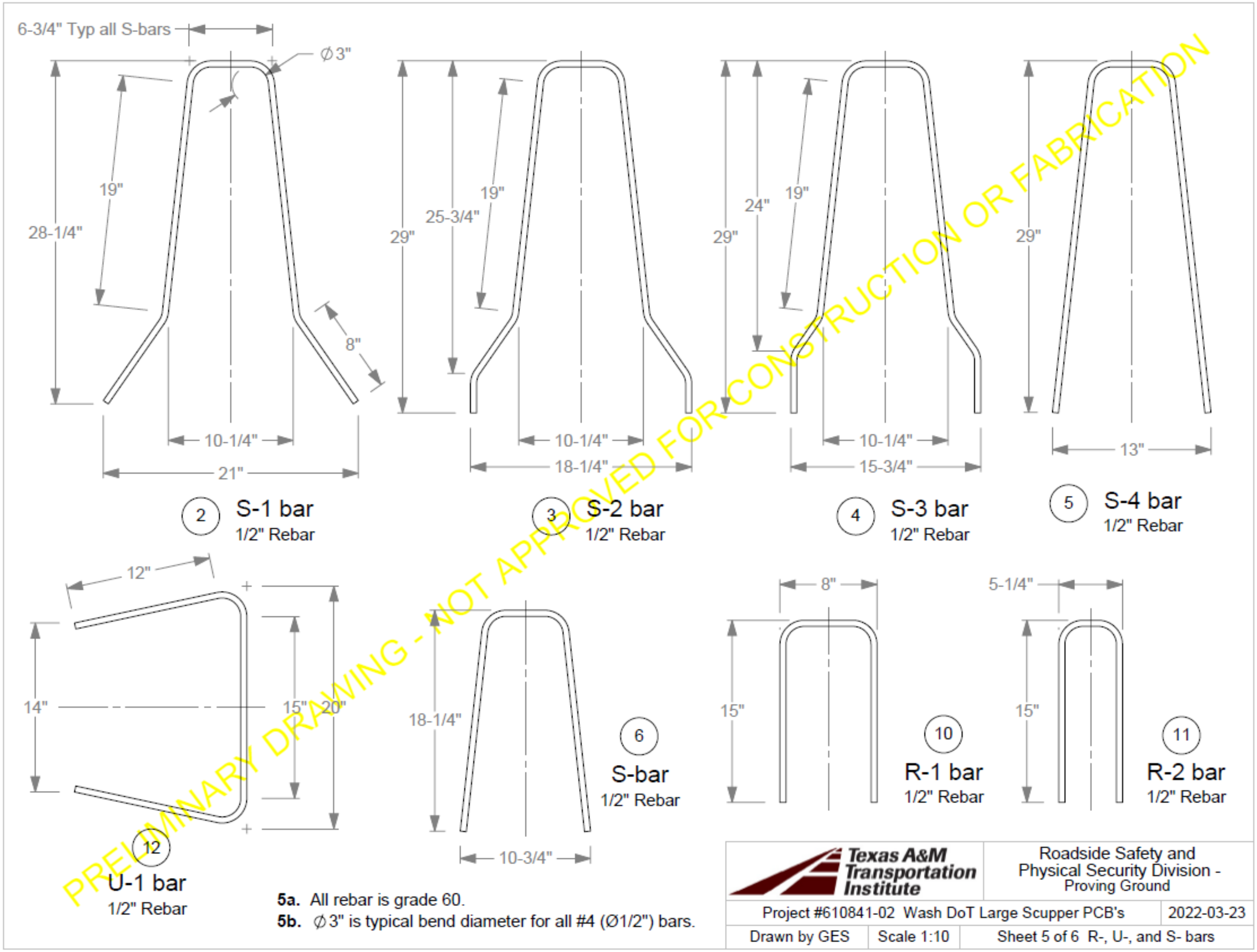


Figure 5 – Rebar Details.

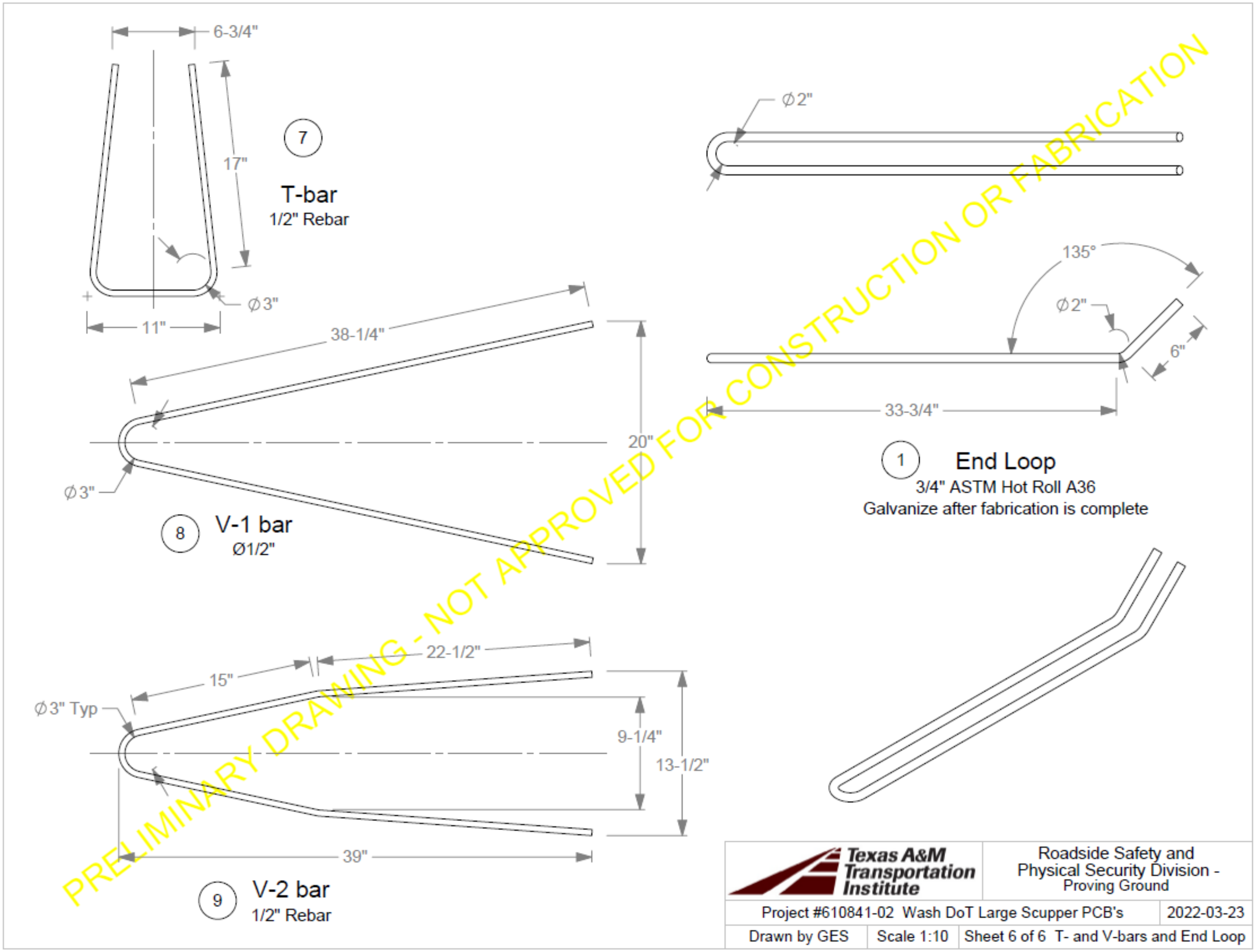


Figure 6 – Rebar Details Cont'd.

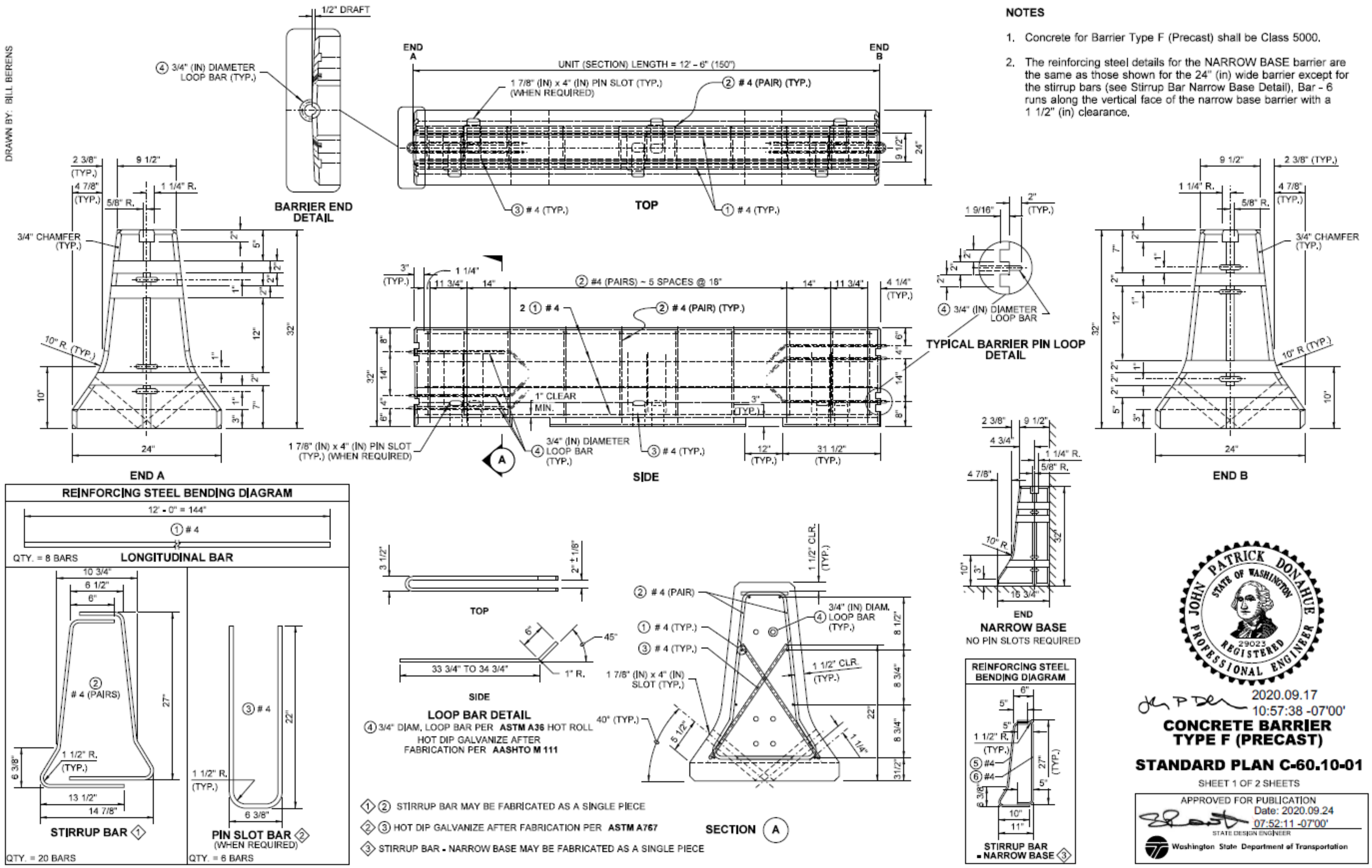


Figure 7 – Details of WADOT Concrete Barrier Type F Precast Standard Plan C-60.10-01.

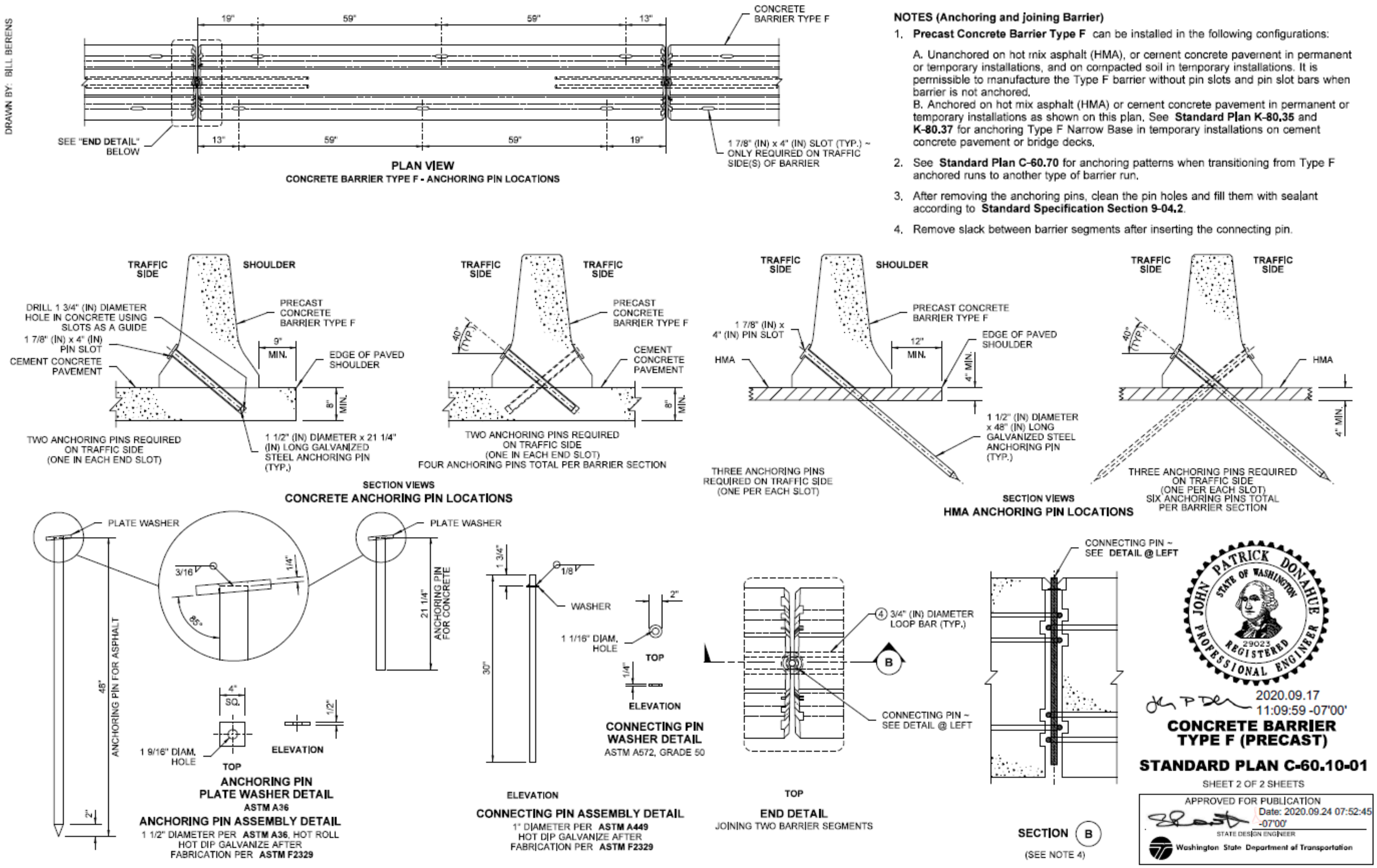


Figure 8 – Details of WADOT Concrete Barrier Type F Precast Standard Plan C-60.10-01 Cont'd.

Phase 2: MASH Test 3-10 Crash Test Results

On August 21, 2023, MASH Test 3-10 was performed on the test installation shown in Figures 1 through 8 above. The critical impact point for MASH Test 3-10 was 88 ¼ inches upstream of the centerline of the joint between barrier units 8 and 9 with the vehicle traveling from left to right as shown in Figure 1 above. This MASH Test 3-10 was successful and met all the requirement of MASH Test 3-10 Specifications.

Phase 2: MASH Test 3-11 Crash Test Results

On October 13, 2023, MASH Test 3-11 was performed on the test installation shown in Figures 1 through 8 above. The critical impact point for MASH Test 3-11 was 4.3 feet upstream of the centerline of barrier Number 8 with the pickup traveling from left to right as shown in Figure 1 above. MASH Test 3-11 was not successful. Several loops in the scupper barriers were ruptured and the vehicle rolled over resulting in a failed test with respect to MASH Test 3-11 Specifications. The maximum dynamic deflection from the test was 76.0 inches (6'-4"). Pictures of the crash test installation and the vehicle before and after the crash test are provided as follows.

Figure 9 – Photos of MASH Test 3-11 Before Crash Test

Figure 10 – Photos of MASH Test 3-11 After Crash Test

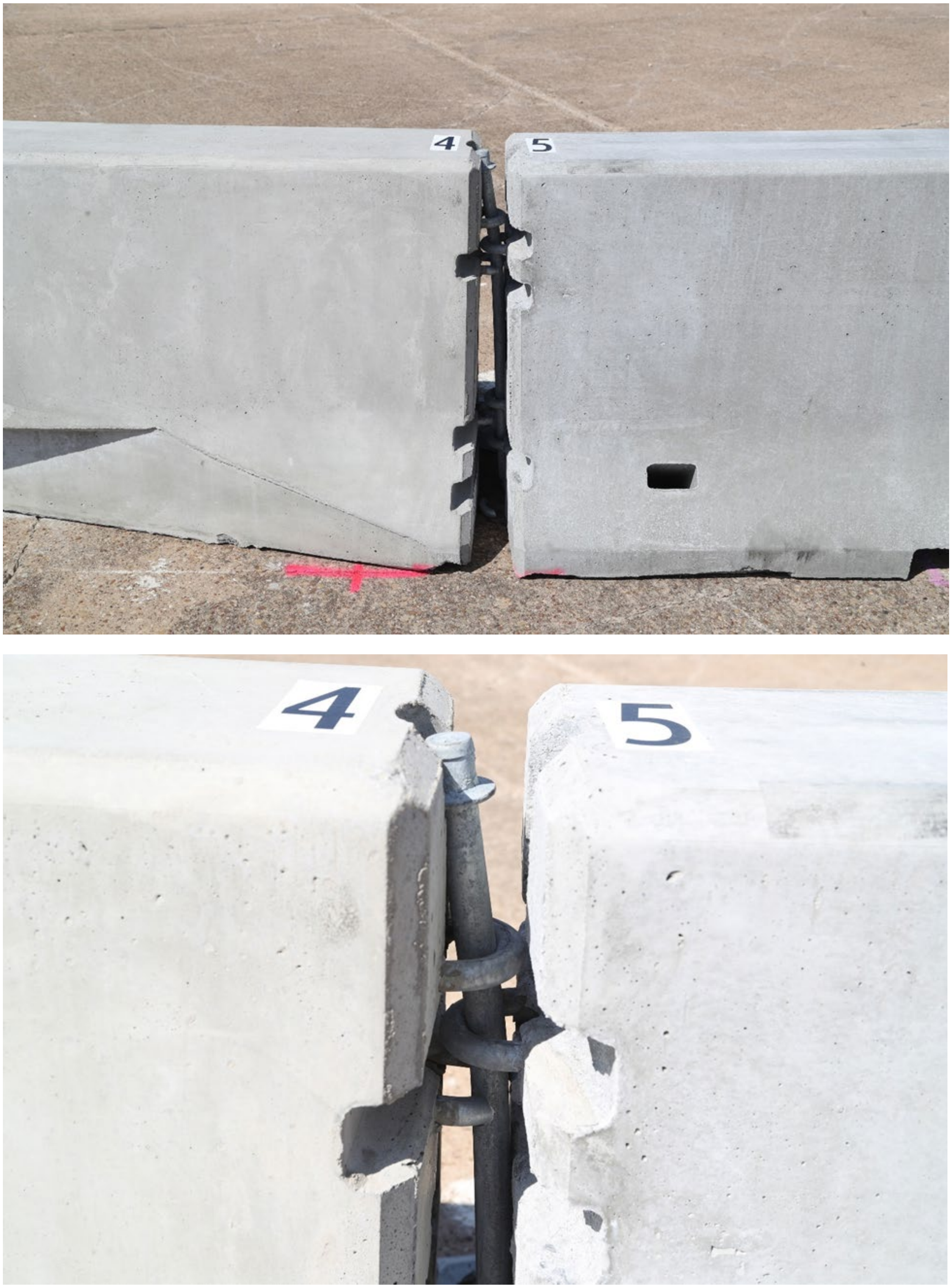


Figure 11 – Photos of Connection Between Barriers 4 & 4

Figure 12 – Photos of Connection Between Barriers 4 & 5 Cont'd.

Figure 13 – Photos of Connection Between Barriers 7 & 8

Figure 14 – Photos of Connection between Barriers 8 & 9

Phase 2: Evaluation of Test Results and Material Testing of Failed Loops Phase 3

The project team evaluated the test results and concluded that the failed/ruptured loops contributed to the poor performance of the barrier with respect to MASH Test 3-11 Specifications. Research work was added to Phase 2, material testing was performed on several failed loops (4B, 4M,8T) and one not ruptured (9T) from the crash test to determine if the strength of the loops were deficient with respect to ASTM A36 Material Specifications. Table 1 provides a summary of the tensile testing on the loops. The tensile testing on the loops concluded that the loops met the design strength of ASTM A36 Material. Therefore, the loop material for the scupper barriers used for this project was satisfactory. The failed loops likely contributed to the dynamic deflection of the barrier and causing instability of the pickup truck during the MASH Test 3-11. For additional information on the material testing of the loops, please refer to the testing information in Appendix A.

Sample ID	RND Dimensions		Ultimate Strength		Yield Strength		Elong. %	R.A. %
	Diameter, (in.)	Area, (in^2)	Load, (lbs)	PSI	Load, (lbs)	PSI		
4B	0.5010	0.1971	14,788	75,000	10,402	52,800	36.7	70.0
4M	0.5010	0.1971	14,713	74,600	10,670	54,100	33.0	65.0
8T	0.4995	0.1960	15,459	78,900	10,894	55,600	35.3	67.0
9T	0.5005	0.1967	14,923	75,900	10,708	54,500	30.8	66.3
		ASTM A36	**--**	***58-80 KSI***	**--**	***36 KSI min***	***21 min***	**--**

Table 1 – Summary of Material Testing results on Scupper Barrier Loops

Phase 2: New Barrier Design for Full-Scale Crash Testing for Phase 3

Based on the evaluation of the material testing results, it was recommended to improve the strength of the loops. Increasing the strength of the loops and preventing rupture will likely improve the performance of the pickup truck for the MASH Test 3-11 requirements (prevent rollover). The loops were modified using ¾" wide by 1" high bent plate. The loop material was also change to ASTM A572 Grade 50 Material. Engineering details of the new design are shown in Figures 15 to 20 below. This design is recommended for full-scale crash testing to MASH Test 3-11 Specifications as part of Phase 3 to be performed later.

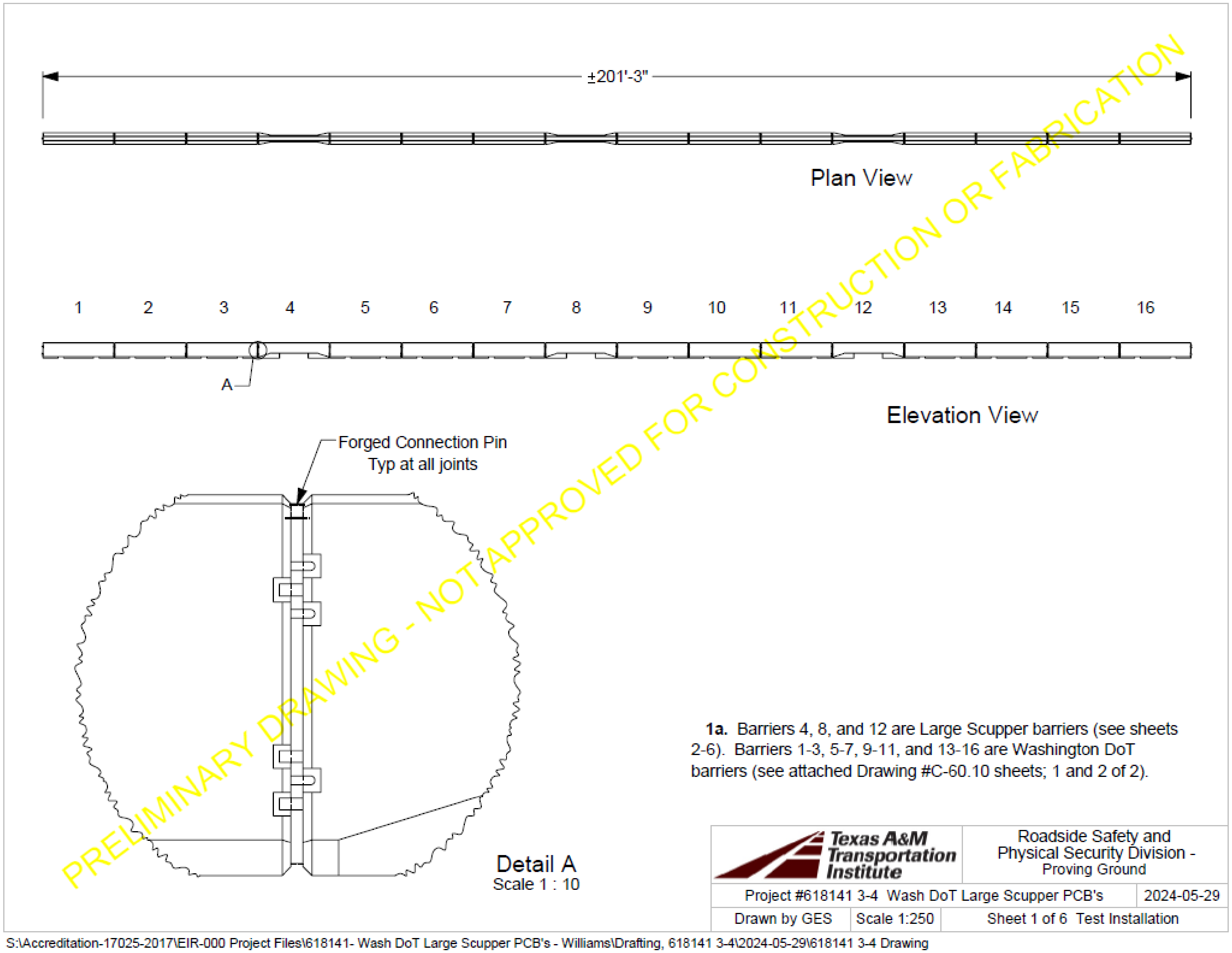


Figure 15 – Layout of Barrier Gap Test Installation Phase 4.

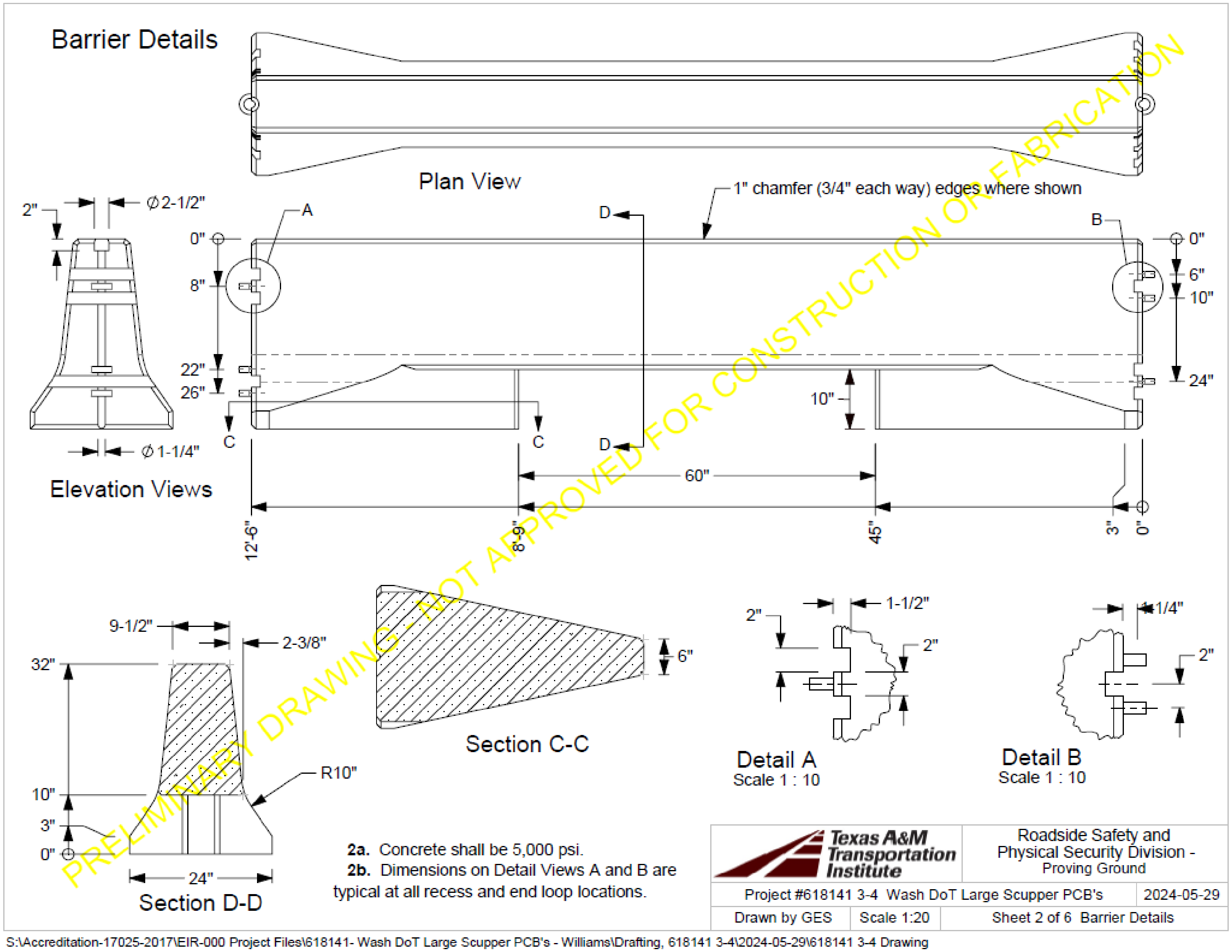
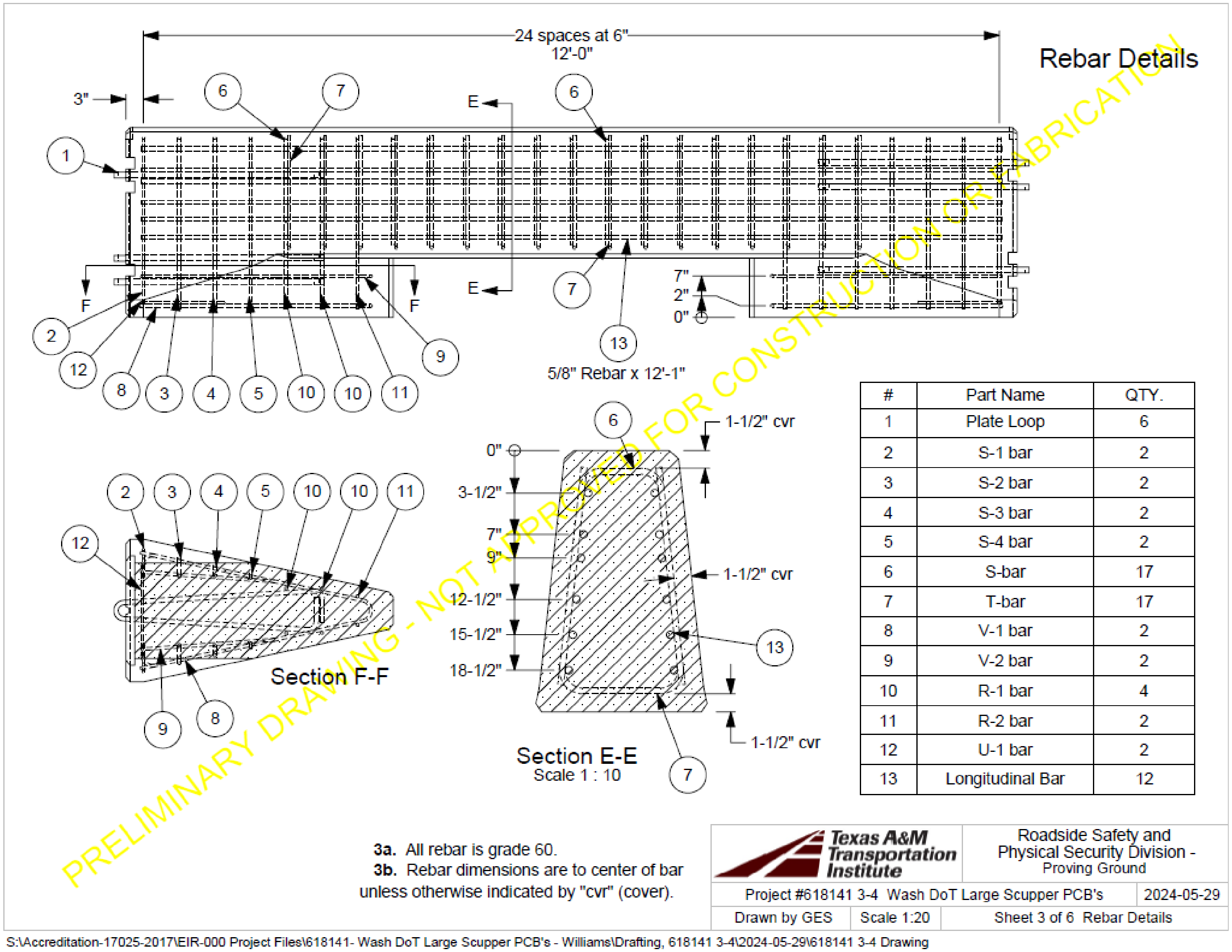


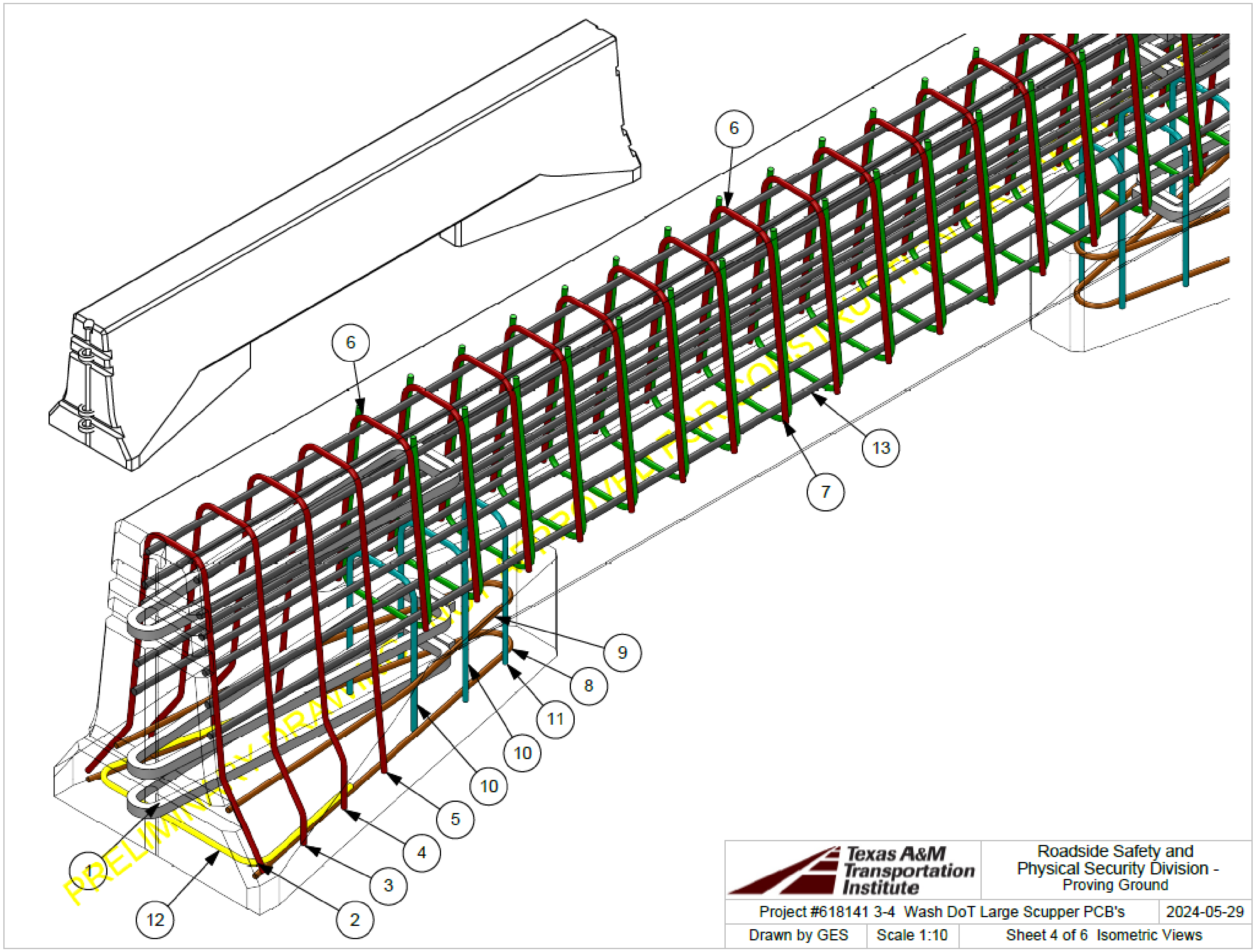
Figure 16 – Barrier Details Phase 4.



#	Part Name	QTY.
1	Plate Loop	6
2	S-1 bar	2
3	S-2 bar	2
4	S-3 bar	2
5	S-4 bar	2
6	S-bar	17
7	T-bar	17
8	V-1 bar	2
9	V-2 bar	2
10	R-1 bar	4
11	R-2 bar	2
12	U-1 bar	2
13	Longitudinal Bar	12

3a. All rebar is grade 60.
3b. Rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover).

Figure 17 – Reinforcement Details Phase 4.



S:\Accreditation-17025-2017\EIR-000 Project Files\618141- Wash DoT Large Scupper PCB's - Williams\Drafting, 618141 3-4\2024-05-29\618141 3-4 Drawing

Figure 18 – Isometric View of Barrier Gap Design Phase 4.

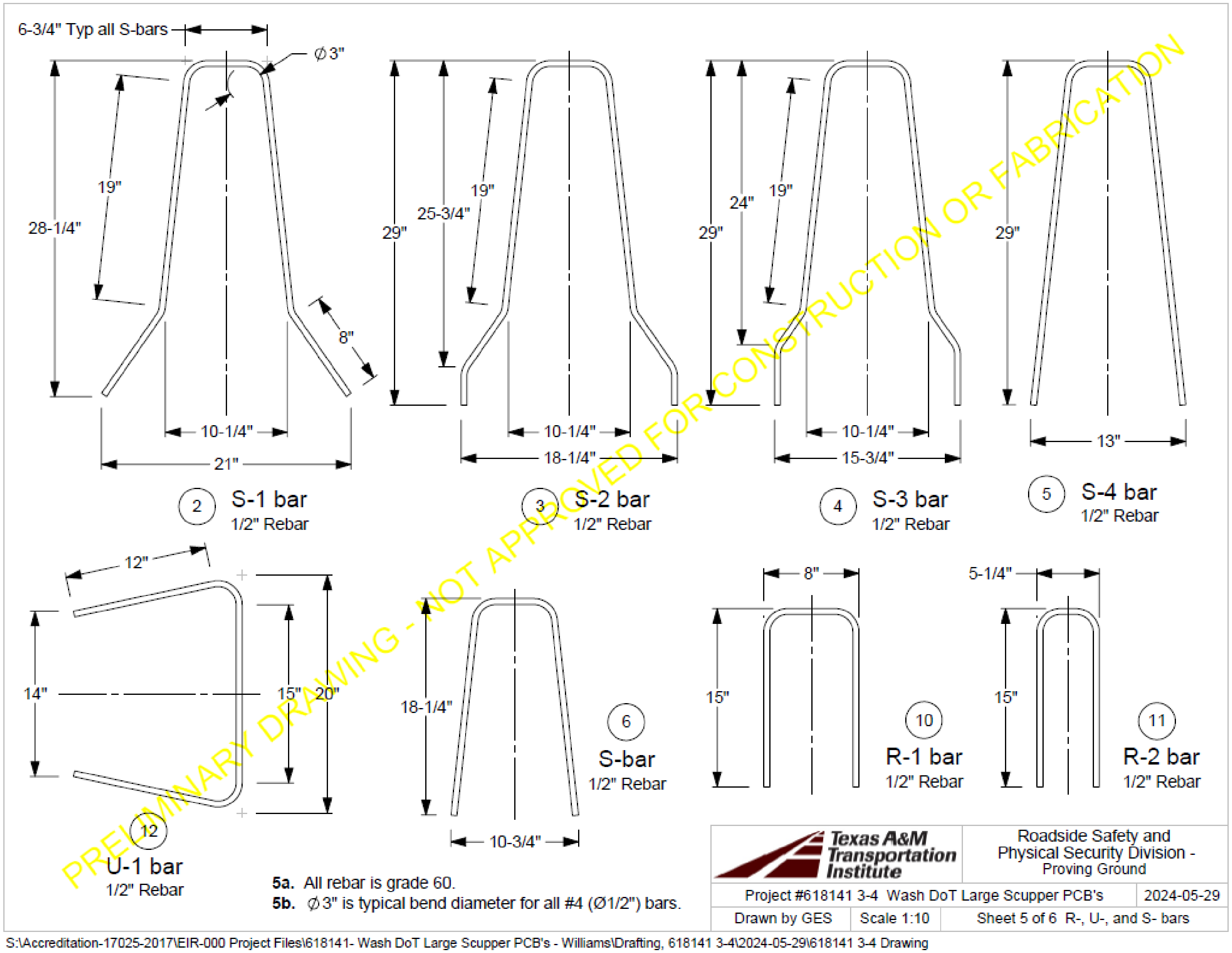


Figure 19 – Rebar Details Phase 4.

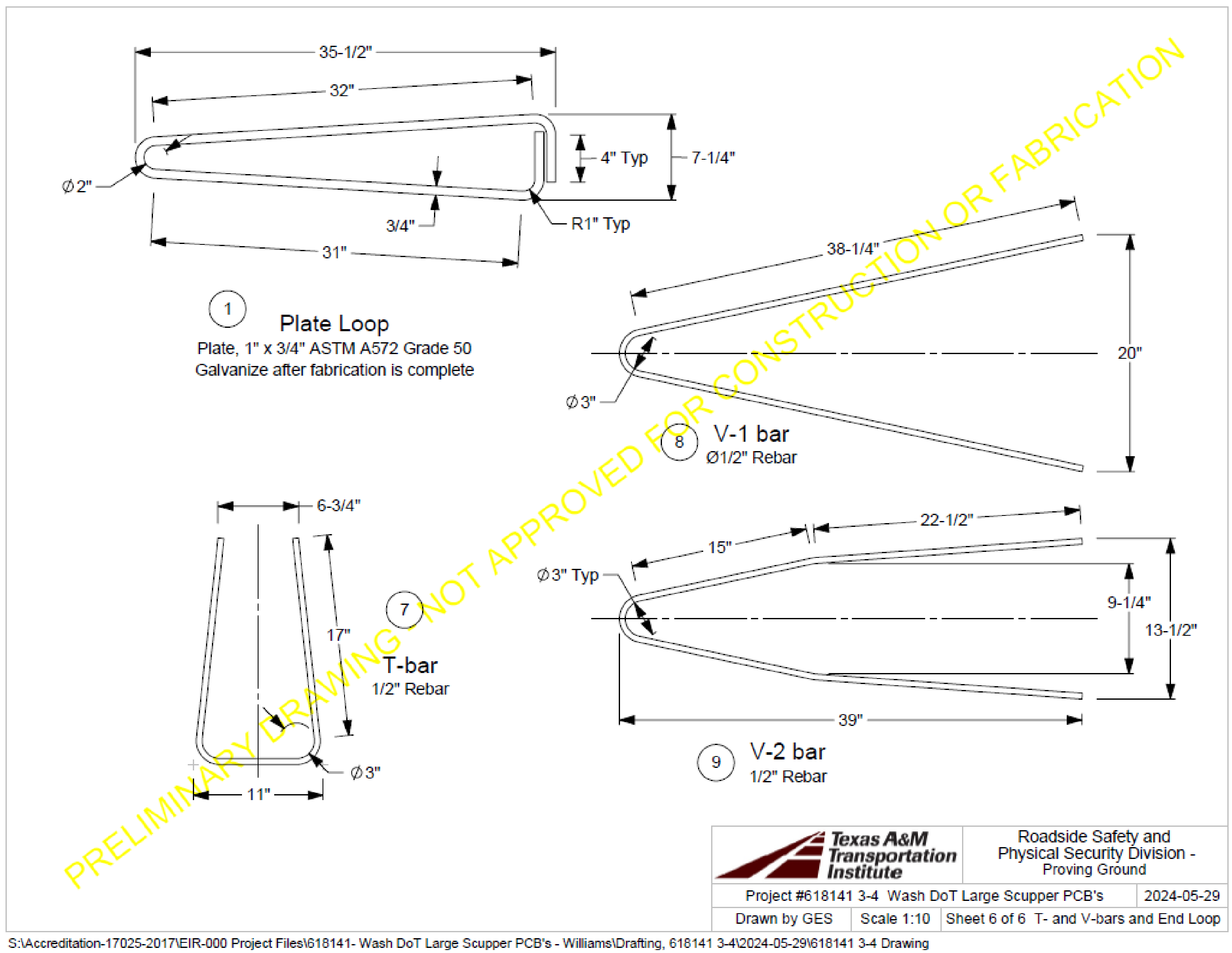


Figure 20 – Rebar Details Cont'd. Phase 4.

APPENDIX A

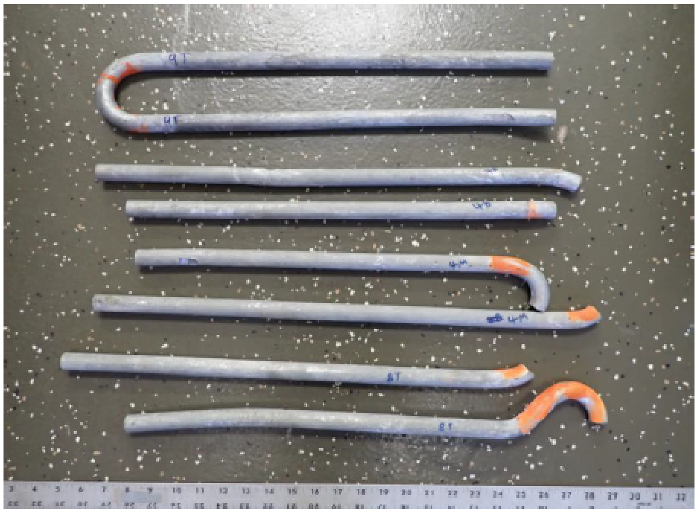
January 2, 2024

REPORT OF: Material Analysis

REPORT TO: Texas A&M Transportation Institute
Attn: Adam Mayer
3135 TAMU
College Station, TX 77843

DATE APPROVED: December 19, 2023

IDENTIFICATION: 4 ea. ¾" ASTM Hot Rolled A36 Material Loops, client identified as:
- 9T
- 4B (2 pcs., considered as 1)
- 4M (2 pcs., considered as 1)
- 8T (2 pcs., considered as 1)



PROCEDURES

Tensile testing was performed per ASTM E8-22 using a Satec Model: 120HVL, S/N: 1263, with a calibration due date of 4/05/2024. Testing was performed on 01/02/2024.

Rockwell hardness testing was performed per ASTM E18-22 standards using a Mitutoyo HR-521 hardness test machine (S/N: 160501, with a calibration due date of 4/06/2024). Testing was performed on 12/29/2023.

RESULTS: ***Next Page***

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Material Analysis
Texas A&M Transportation Institute
January 2, 2024

TENSILE TESTING

Sample ID	RND Dimensions		Ultimate Strength		Yield Strength		Elong. %	R.A. %
	Diameter, (in.)	Area, (in^2)	Load, (lbs)	PSI	Load, (lbs)	PSI		
4B	0.5010	0.1971	14,788	75,000	10,402	52,800	36.7	70.0
4M	0.5010	0.1971	14,713	74,600	10,670	54,100	33.0	65.0
8T	0.4995	0.1960	15,459	78,900	10,894	55,600	35.3	67.0
9T	0.5005	0.1967	14,923	75,900	10,708	54,500	30.8	66.3
		ASTM A36	**--**	***58-80 KSI***	**--**	***36 KSI min***	***21 min***	**--**

HARDNESS TESTING

Sample ID	Test Location	Individual Hardness Values, HRBw						Average, HRBw	Cylindrical Conv., HRBw
4B	Surface	76.7	75.7	78.7	77.3	78.3	77.2	77	79
4M	Surface	77.3	78.5	78.5	78.9	77.7	77.6	78	80
8T	Surface	76.9	77.4	75.5	73.5	77.8	77.6	76	78
9T	Surface	76.9	80.7	79.6	77.2	74.6	78.8	78	80

These results are based on the tests performed and are subject to change upon the receipt of new or additional information.

Respectfully submitted,

METALLURGICAL ENGINEERING SERVICES, INC.
Firm Registration No. F-2674

Daniel A. Stolk, PE, CWI
Principal Engineer