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DETERMINATION OF PEDESTRIAN RAIL OFFSET REQUIREMENTS TO ELIMINATE VEHICLE INTERACTION

by

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16. Abstract

State Departments of Transportation (DOTs) provide a rail on top of concrete barriers to protect pedestrians from falling over the barrier. While this rail can provide protection for pedestrians, it can pose a hazard for motorists who errantly impact the barrier. Therefore, this rail is often located far enough away from the traffic side of the barrier to prevent vehicular interaction. The objective of this project was to determine the minimal offset required to locate a pedestrian rail on top of a concrete barrier.

Several videos of *MASH* Test 3-11 were analyzed to measure the amount the test vehicle extended over the top traffic side face of concrete barriers. These measurements were taken at both the maximum extension of the side view mirror and the corner of the test vehicle. A list of these maximum extensions can be found in the report.

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Chapter 1. INTRODUCTION

1.1 PROBLEM STATEMENT

The Roadside Safety Pooled Fund has prioritized their research needs for various barrier systems. For this project, State Departments of Transportation (DOTs) chose to determine the pedestrian rail offset requirements to eliminate vehicle interaction. DOTs are sometimes required to provide a rail on top of concrete barriers to protect pedestrians. While this rail can provide protection for pedestrians, it can pose a hazard for motorists who errantly impact the barrier. This rail could potentially break apart and penetrate the vehicle upon impact. Therefore, barriers are often crash tested with the rails installed to evaluate this potential.

When full-scale crash testing is not feasible, DOTs use guidance on vehicle interaction potential from previous crash tests. Therefore, TTI was tasked to evaluate the offset distance of pedestrian rails that is required to prevent vehicle interaction based upon previous crash tests.

1.2 WORK PLAN

The TTI research team first reviewed previous crash tests on concrete barriers. These barriers have been tested to the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) Test Level 3, and this project will focus on the *MASH* Test 3-11 performed on these barriers (*1*). This test involves a 5000 lbs pickup truck impacting a concrete barrier at a speed of 62 mph and an angle of 25°. This test was selected instead of *MASH* Test 3-10 with a small car because of the pickup truck's increased likelihood for interaction with the pedestrian rail.

The TTI research team analyzed the high-speed videos recorded during the crash tests. The analysis was comprised of measuring the amount of vehicle extension over the top of the barrier caused by the impacting pickup truck.

Lastly, the TTI research team prepared this research report documenting the work completed in this project. The information on the vehicle extension over the top of the barrier is presented in this report.

1.3 OBJECTIVE

The objective of this study was to determine the pedestrian rail offset requirements for concrete barriers based upon previous *MASH* 3-11 crash tests.

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Chapter 2. DETERMINATION OF RECOMMENDED PEDESTRIAN RAIL OFFSET

2.1 VIDEO ANALYSIS

The research team analyzed the high-speed videos of five full-scale *MASH* 3-11 crash tests. Table 2.1 shows the test conditions and evaluation criteria for *MASH* Test 3-11 for longitudinal barriers. *MASH* Test 3-11 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the critical impact point of a longitudinal barrier at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°.

Table 2.1. Test Conditions and Evaluation Criteria Specified for *MASH* test 3-11 for Longitudinal Barriers

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Longitudinal Barrier	3-11	2270P	62 mi/h	25°	A, D, F, H, I

Table 2.2 shows the five crash tests analyzed within this project, the shape of the concrete barrier used in the test, and the height of the concrete barrier above grade.

Table 2.2. *MASH* Tests Analyzed for Vehicle Extension

Test Number	Barrier Shape	Barrier Height (inches)
490024-2-1	Vertical Wall	32
476460-1-4	Jersey Shape	32
602191-1	Single Slope	48
405160-13-1	Single Slope	42
420020-3	Single Slope	36

2.2 TTI TEST NUMBER 490024-2-1

On June 26th, 2014, TTI crash tested a 32-inch tall vertical wall concrete barrier to *MASH* test 3-11 criteria. The barrier successfully redirected the test vehicle and passed all *MASH* requirements (*2*). Details of the barrier are shown below in Figure 2.1.

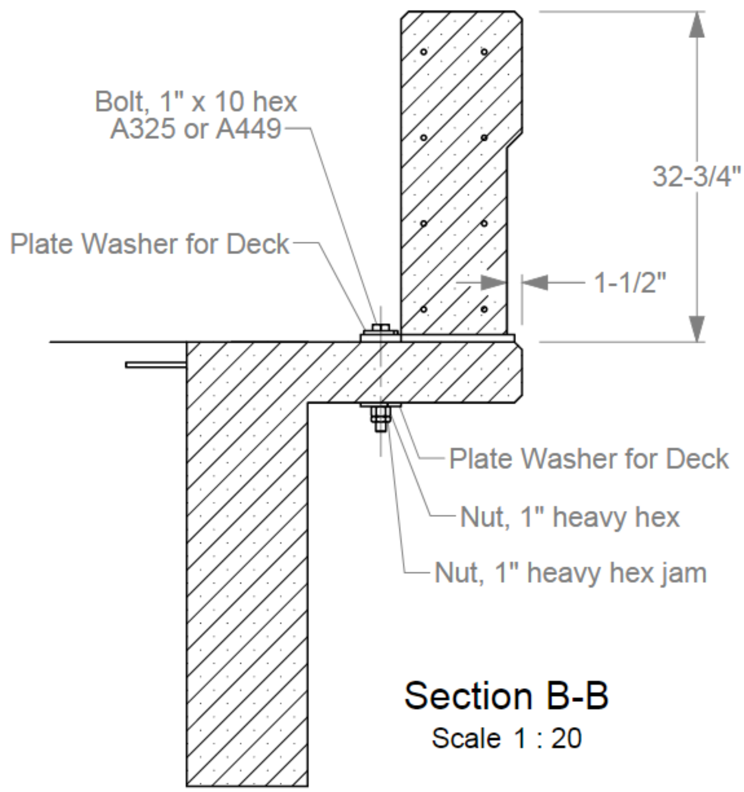

Figure 2.1. 32-inch Tall Vertical Wall (TTI Test Number 490024-2-1)

The research team analyzed the crash test video and measured the maximum extension of the test vehicle over the traffic side top corner of the barrier. Figure 2.2 shows the reference point from which the vehicle extension was measured as the barrier deflected during the impact. Figures 2.3, 2.4 and Table 2.3 show the maximum extension of the vehicle beyond the reference point of the barrier. The red line in Figure 2.3 represents the maximum extension of the vehicle's passenger side view mirror during the crash test. The yellow line in Figure 2.4 represents the maximum extension of the vehicle's back corner during the crash test. In this case, the maximum extension was caused by the passenger side view mirror (see Figure 2.5).

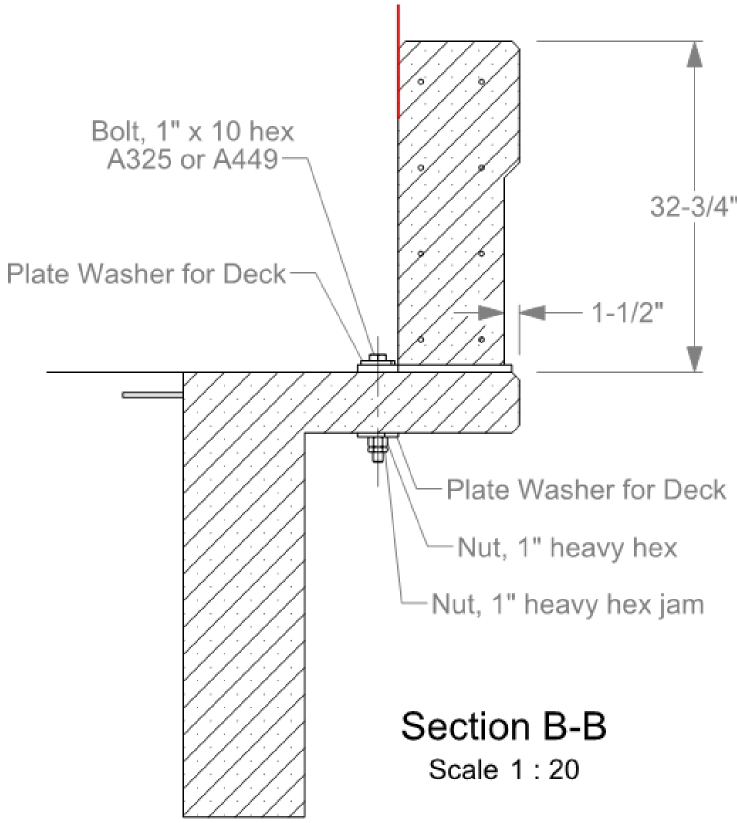

Figure 2.2. Vehicle Extension Reference Point for TTI Test Number 490024-2-1

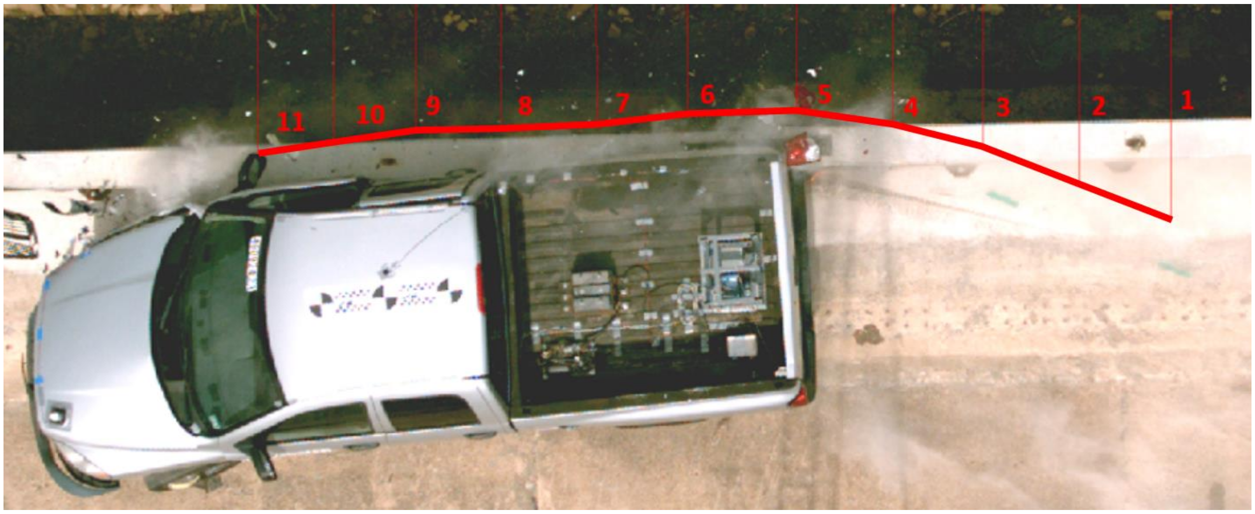

Figure 2.3. Sketch of Vehicle Extension (Side View Mirror) over Barrier (TTI Test Number 490024-2-1)

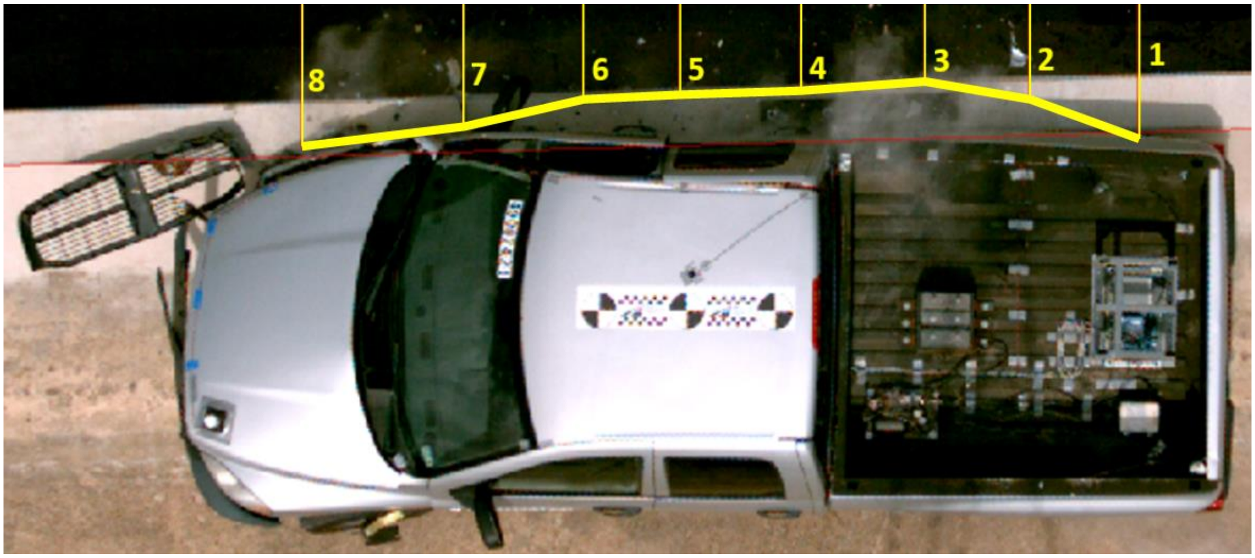

Figure 2.4. Sketch of Vehicle Extension (Front Passenger Corner) over Barrier (TTI Test Number 490024-2-1)


Figure 2.5. Vehicle Extension over Barrier (TTI Test Number 490024-2-1)

Table 2.3. Maximum Vehicle Extension over Barrier (TTI Test Number 490024-2-1)

Side Mirror Path (Red)		Front Passenger Corner Path (Yellow)	
POINT	**DISTANCE* (inches)**	**POINT**	**DISTANCE* (inches)**
1	0	1	0
2	0	2	7
3	4.5	3	11.5
4	12	4	11
5	18	5	11
6	18	6	10
7	15	7	4.5
8	15	8	1
9	15		
10	13		
11	8.5		
* Distance the side view mirror or corner of vehicle extended beyond the top edge of the barrier.			

2.3 TTI TEST NUMBER 476460-1-4

On January 30th, 2009, TTI crash tested a 32-inch tall Jersey Shape concrete barrier to *MASH* Test 3-11 criteria (*3*). The barrier successfully redirected the test vehicle and passed all *MASH* requirements. Details of the barrier are shown below in Figure 2.6.

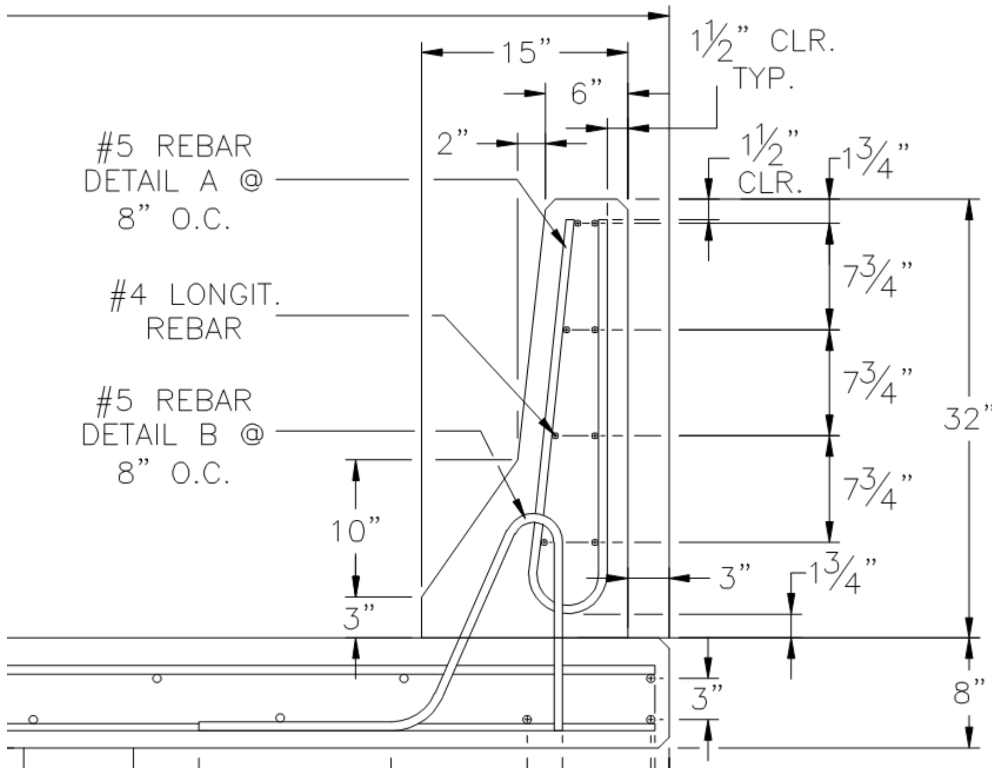

Figure 2.6. 32-inch Tall Jersey Shape (TTI Test Number 476460-1-4)

The research team analyzed the crash test video and measured the maximum extension of the test vehicle over the traffic side top corner of the barrier. Figure 2.7 shows the reference point from which the vehicle extension was measured as the barrier deflected during the impact. Figure 2.8 and Table 2.4 show the maximum extension of the vehicle beyond the reference point of the barrier. The red line in Figure 2.8 represents the maximum extension of the side view mirror during the crash test. The yellow line in Figure 2.8 represents the maximum extension of the front corner of the vehicle during the crash test. Figure 2.9 shows the approximate height of the side view mirror and the front corner of the vehicle.

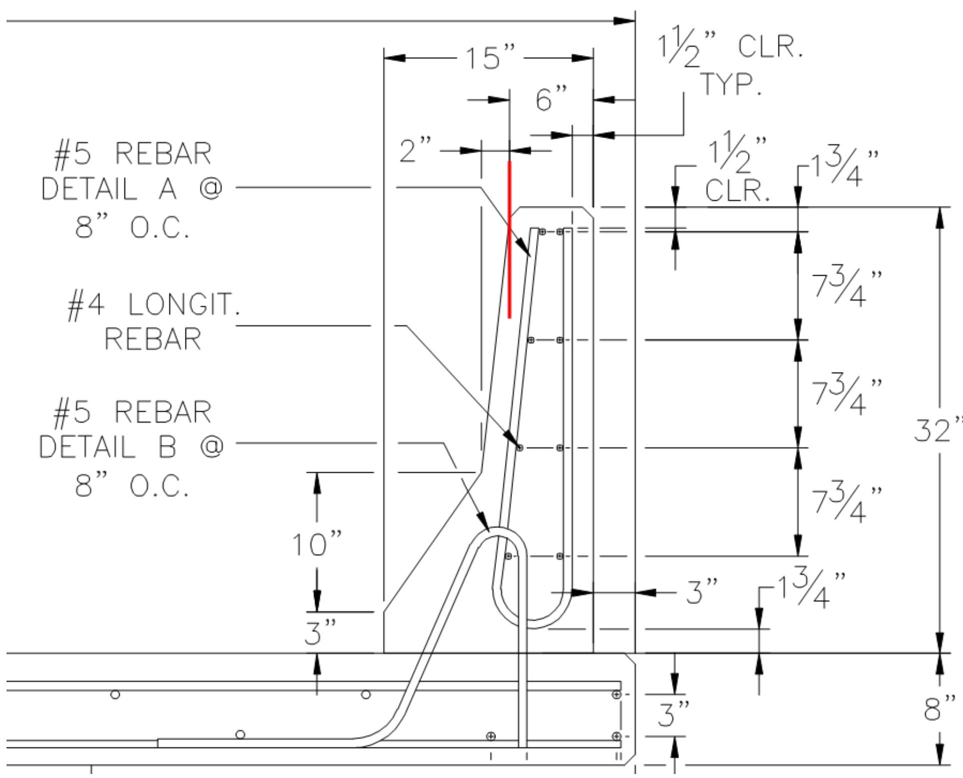

Figure 2.7. Vehicle Extension Reference Point for TTI Test Number 476460-1-4

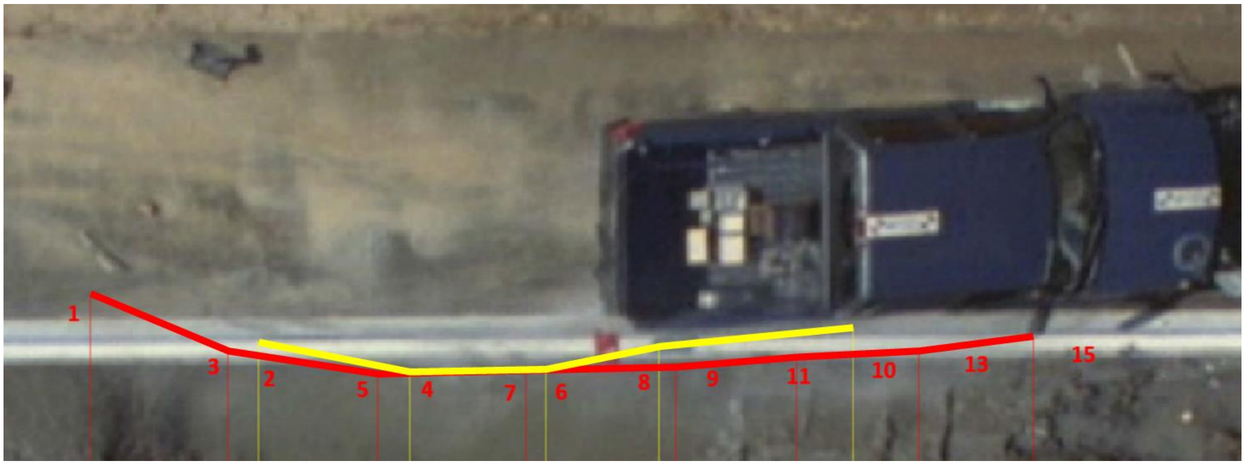

Figure 2.8. Sketch of Maximum Vehicle Extension over Barrier (TTI Test Number 476460-1-4)

Figure 2.9. Vehicle Extension over Barrier (TTI Test Number 476460-1-4)

Table 2.4. Maximum Vehicle Extension over Barrier (TTI Test Number 476460-1-4)

Side Mirror Path (Red)		**Right Front Corner Path (Yellow)**	
POINT	**DISTANCE* (inches)**	**POINT**	**DISTANCE* (inches)**
1	0	2	0
3	4	4	13
5	13	6	12.5
7	12.5	8	3
9	11.5	10	0
11	8		
13	3		
15	0		
* Distance the side view mirror or corner of vehicle extended beyond the top edge of the barrier.			

2.4 TTI TEST NUMBER 602191-1

On August 26th, 2013, TTI crash tested a 48-inch tall single slope concrete barrier to *MASH* test 3-11 criteria (*4*). The barrier successfully redirected the test vehicle and passed all *MASH* requirements. Details of the barrier are shown below in Figure 2.10.

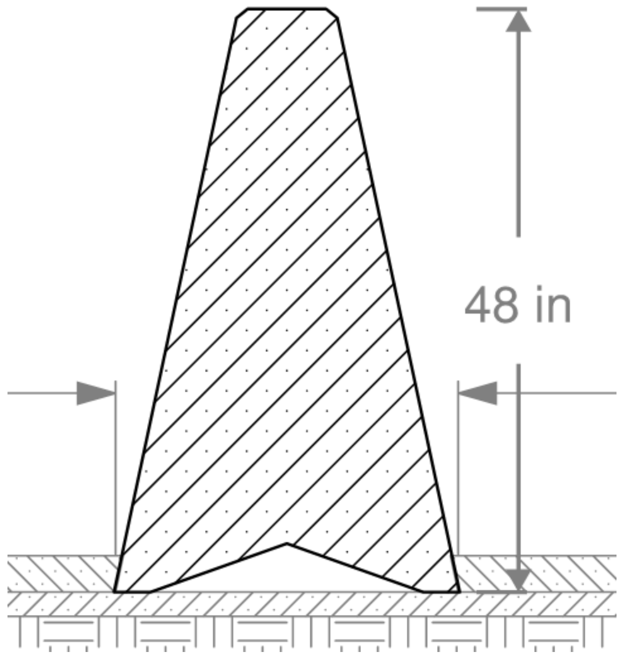

Figure 2.10. 48-inch Tall Single Slope (TTI Test Number 602191-1)

The research team analyzed the crash test video and measured the maximum extension of the test vehicle over the traffic side top corner of the barrier. Figure 2.11 shows the reference point from which the vehicle extension was measured as the barrier deflected during the impact. Figures 2.12, 2.13 and Table 2.5 show the maximum extension of the vehicle beyond the reference point of the barrier. The red line in Figure 2.12 represents the maximum extension of the vehicle's driver side view mirror during the crash test. The yellow line in Figure 2.13 represents the maximum extension of the vehicle's front corner during the crash test. In this case, the maximum extension was caused by the driver side view mirror (see Figure 2.14).

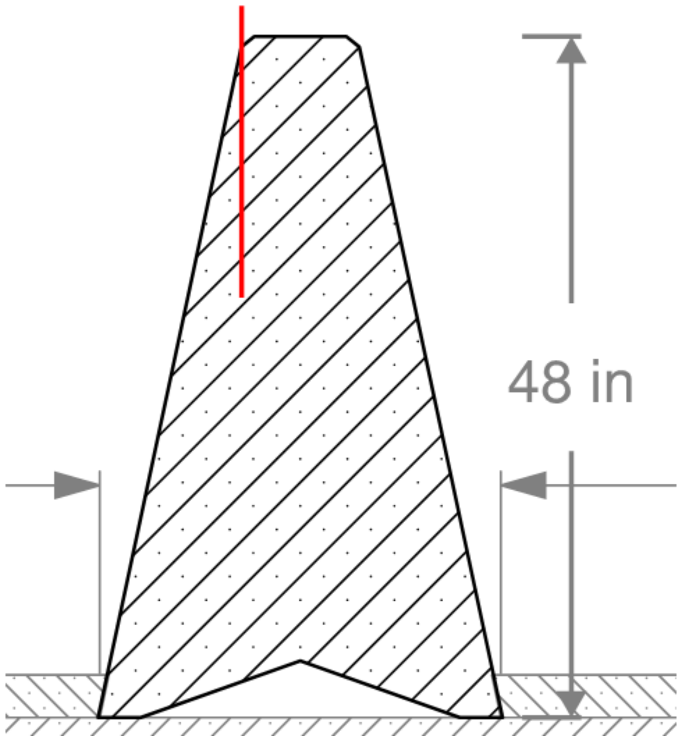

Figure 2.11. Vehicle Extension Reference Point for TTI Test Number 602191-1

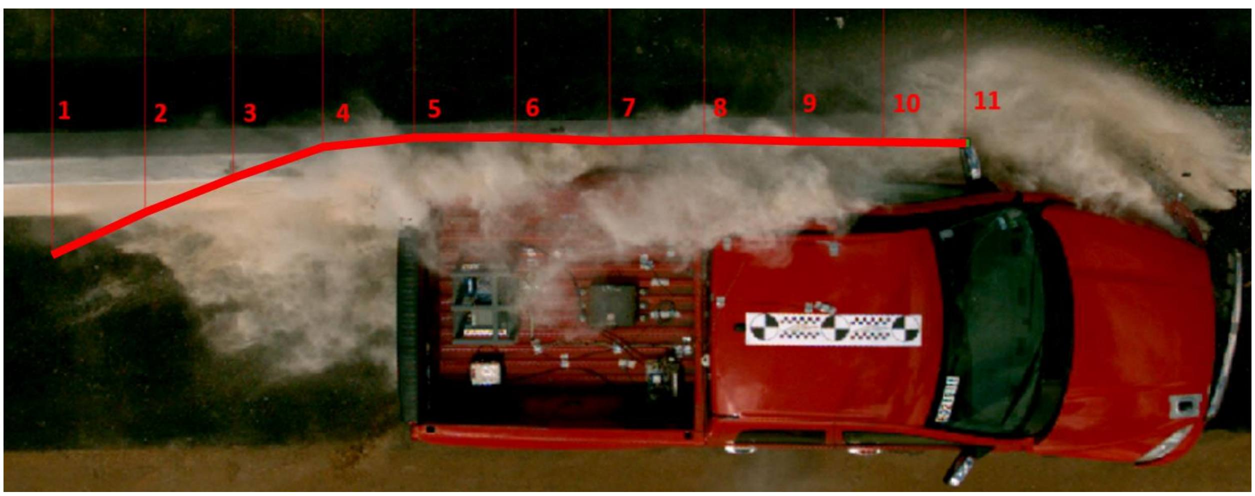

Figure 2.12. Sketch of Vehicle Extension (Side View Mirror) over Barrier (TTI Test Number 602191-1)

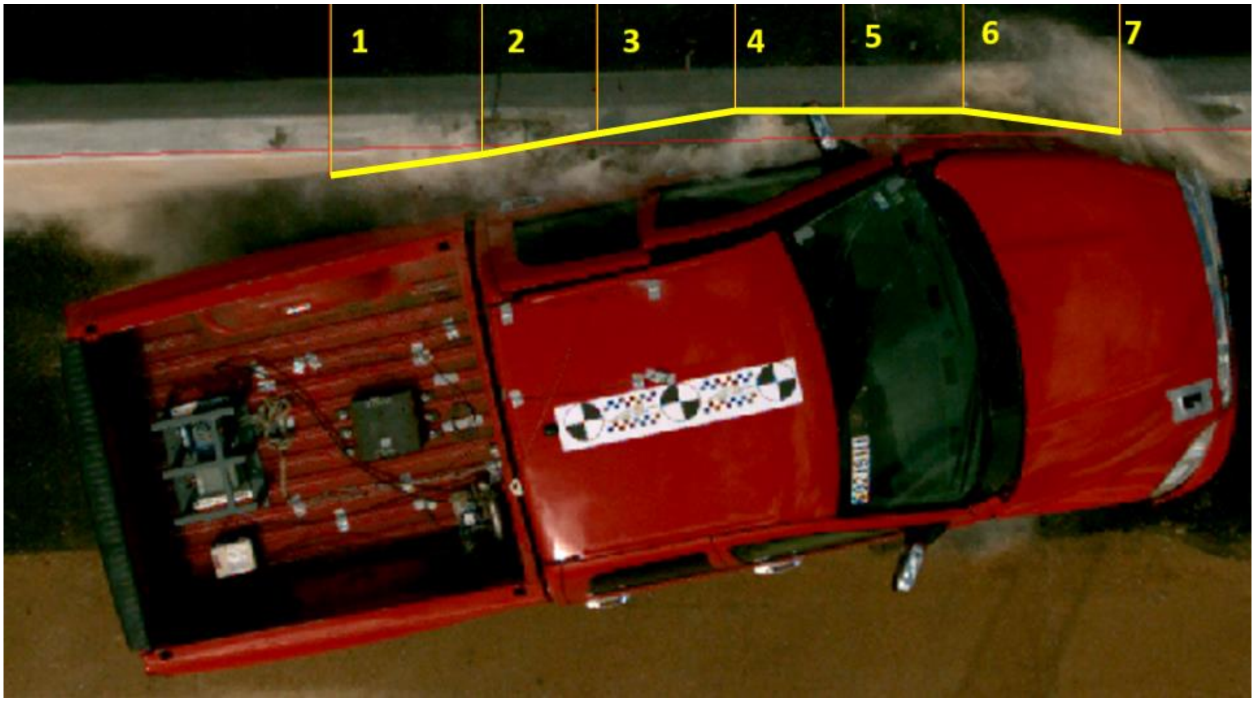

Figure 2.13. Sketch of Vehicle Extension (Front Driver Corner) over Barrier (TTI Test Number 602191-1)

Figure 2.14. Vehicle Extension over Barrier (TTI Test Number 602191-1)

Table 2.5. Maximum Vehicle Extension over Barrier (TTI Test Number 602191-1)

Side Mirror Path (Red)			Front Driver Corner Path (Yellow)		
POINT	**TIME (s)**	**DISTANCE* (inches)**	**POINT**	**TIME (s)**	**DISTANCE* (inches)**
1	0.000	0	1	0.000	0
2	0.025	0	2	0.025	0
3	0.050	0	3	0.050	3
4	0.075	10.5	4	0.075	8
5	0.100	11.5	5	0.100	8
6	0.125	11.0	6	0.125	7
7	0.150	10.5	7	0.150	0
8	0.175	10.5			
9	0.200	8			
10	0.225	7			
11	0.250	6			

* Distance the side view mirror or corner of vehicle extended beyond the top edge of the barrier.

2.5 TTI TEST NUMBER 405160-13-1

On April 6th, 2009, TTI crash tested a 42-inch tall single slope concrete barrier to *MASH* test 3-11 criteria (*5*). The barrier successfully redirected the test vehicle and passed all *MASH* requirements. Details of the barrier are shown below in Figure 2.15.

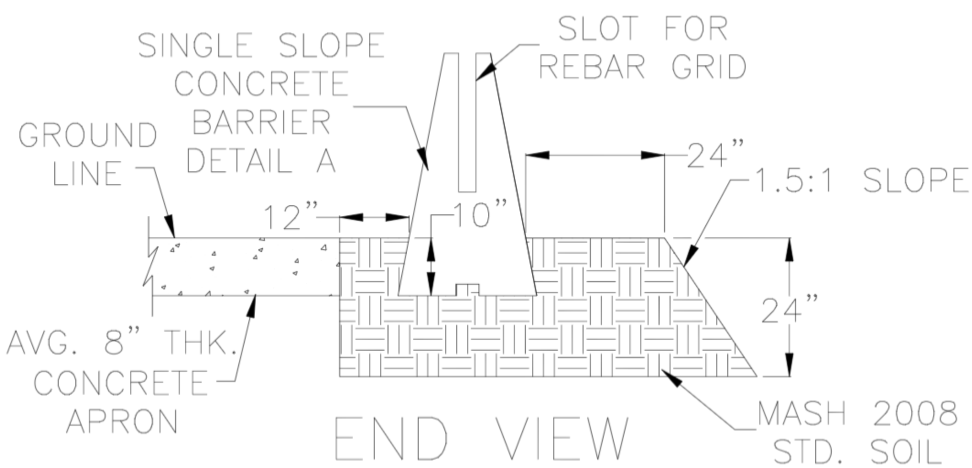

Figure 2.15. 42-inch Tall Single Slope (TTI Test Number 405160-13-1)

The research team analyzed the crash test video and measured the maximum extension of the test vehicle over the traffic side top corner of the barrier. Figure 2.16 shows the reference point from which the vehicle extension was measured as the barrier deflected during the impact.

Figure 2.17 and Table 2.6 show the maximum extension of the vehicle beyond the reference point of the barrier. The red line in Figure 2.17 represents the maximum extension of the passenger side view mirror during the crash test. The yellow line in Figure 2.17 represents the maximum extension of the rear corner of the vehicle during the crash test. Figure 2.16 shows the approximate height of the side view mirror and the rear corner of the vehicle.

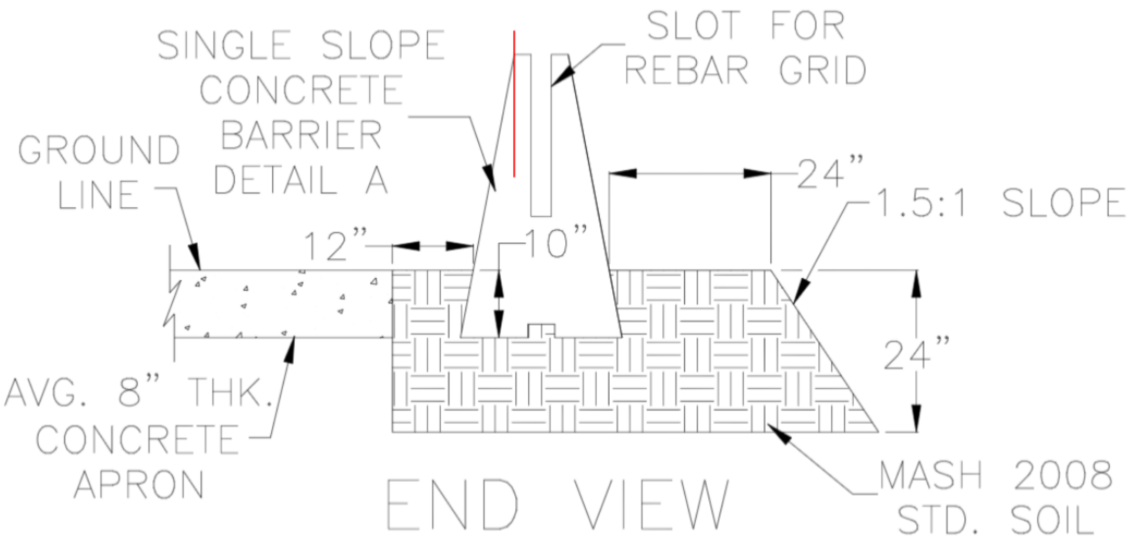

Figure 2.16. Vehicle Extension Reference Point for TTI Test Number 405160-13-1

Figure 2.17. Sketch of Maximum Vehicle Extension over Barrier (TTI Test Number 405160-13-1)

Figure 2.18. Vehicle Extension over Barrier (TTI Test Number 405160-13-1)

Table 2.6. Maximum Vehicle Extension over Barrier (TTI Test Number 405160-13-1)

Side Mirror Path (Red)		Right Front Corner Path (Yellow)	
POINT	DISTANCE* (inches)	POINT	DISTANCE* (inches)
1	0	2	0
3	8	4	9
5	9	6	9.5
7	12.5	8	9.5
9	14.5	10	10
11	13	12	12.5
13	10.5	14	13
15	8	16	12.5
		18	12.5
* Distance the side view mirror or corner of vehicle extended beyond the top edge of the barrier.			

2.6 TTI TEST NUMBER 420020-3

On August 3rd, 2010, TTI crash tested a 36-inch tall single slope concrete barrier to *MASH* test 3-11 criteria (6). The barrier successfully redirected the test vehicle and passed all *MASH* requirements. Details of the barrier are shown below in Figure 2.19.

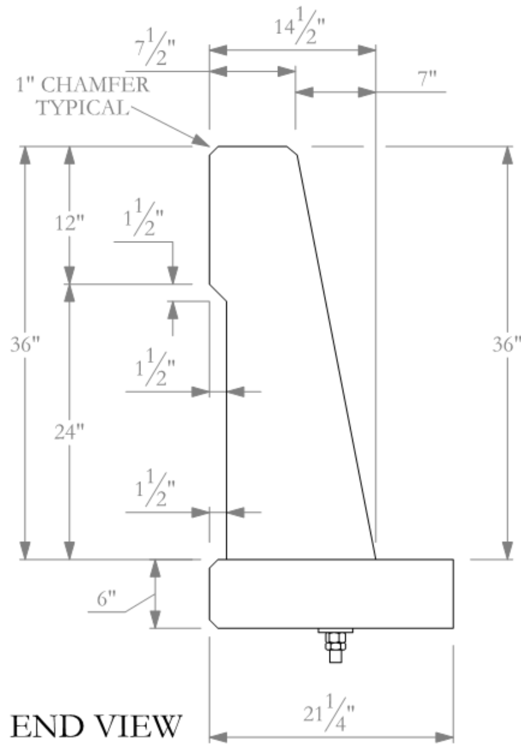

Figure 2.19. 36-inch Tall Single Slope (TTI Test Number 420020-3)

The research team analyzed the crash test video and measured the maximum extension of the test vehicle over the traffic side top corner of the barrier. Figure 2.20 shows the reference point from which the vehicle extension was measured as the barrier deflected during the impact. Figures 2.21, 2.22 and Table 2.7 show the maximum extension of the vehicle beyond the reference point of the barrier. The red line in Figure 2.21 represents the maximum extension of the vehicle's passenger side view mirror during the crash test. The yellow line in Figure 2.22 represents the maximum extension of the vehicle's front corner during the crash test. In this case, the maximum extension was caused by the passenger side view mirror (see Figure 2.23).

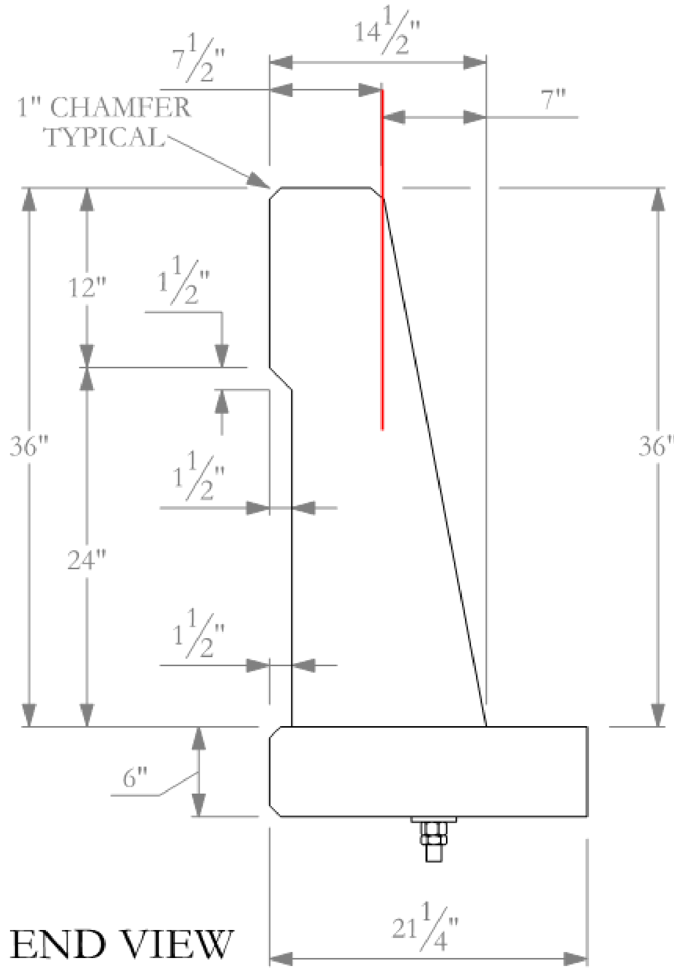

Figure 2.20. Vehicle Extension Reference Point for TTI Test Number 420020-3

Figure 2.21. Sketch of Vehicle Extension (Side View Mirror) over Barrier (TTI Test Number 420020-3)

Figure 2.22. Sketch of Vehicle Extension (Front Passenger Corner) over Barrier (TTI Test Number 420020-3)

Figure 2.23. Vehicle Extension over Barrier (TTI Test Number 420020-3)

Table 2.7. Maximum Vehicle Extension over Barrier (TTI Test Number 420020-3)

Side Mirror Path (Red)		Front Driver Corner Path (Yellow)	
POINT	**DISTANCE * (inches)**	**POINT**	**DISTANCE* (inches)**
1	0	1	0
2	0	2	6
3	8	3	7.5
4	9	4	7.5
5	11	5	7
6	8	6	5
		7	2
		8	0
* Distance the side view mirror or corner of vehicle extended beyond the top edge of the barrier.			

Chapter 3. SUMMARY AND CONCLUSIONS

3.1 SUMMARY OF VEHICLE EXTENSIONS

Table 2.8 below shows the maximum vehicle extensions over the top of the barrier for the side view mirror and corner of the vehicle.

Table 2.8. Maximum Vehicle Extensions

Test Number	Barrier Shape	Barrier Height (inches)	Maximum Vehicle Extension (Side View Mirror) (inches)	Maximum Vehicle Extension (Corner of Vehicle) (inches)
490024-2-1	Vertical Wall	32	18	11.5
476460-1-4	Jersey Shape	32	13	13
602191-1	Single Slope	48	11.5	8
405160-13-1	Single Slope	42	14.5	13
420020-3	Single Slope	36	11	7.5

3.2 CONCLUSIONS

The research team analyzed the videos from five MASH 3-11 crash tests to determine the maximum vehicle extension over the top of the barrier. This maximum vehicle extension was measured from the top traffic side face of the barrier, and the reference plane for each barrier is shown earlier in this report. This measurement will provide guidance to the Roadside Safety Pooled Fund for the minimum offset distance to avoid vehicle contact with pedestrian rails placed on concrete barriers. The scope of the study was limited to MASH TL-3 and did not review with the vehicle extension distance for single-unit truck impacts under MASH Test 4-12. For those barriers having the minimum height to accommodate MASH TL-4 (i.e., 36 inches), the pedestrian rail offset distance needed to avoid vehicle contact would increase.

The Roadside Safety Pooled Fund can use the measurements listed above to determine offset distances to avoid vehicle contact for pedestrian handrails under MASH TL-3 impact conditions. To minimize the chance for vehicle interaction with a pedestrian rail altogether, the vehicle extension values measured to the side view mirror would be appropriate to use. However, the side view mirror interaction with a pedestrian rail may not pose a significant risk. The side view mirrors are not typically a strong structural component of the vehicle, and they often fold inward if impacted. Therefore, states may elect to use the second set of vehicle extension values if the states desire to place the pedestrian rail closer to the roadway. Furthermore, pedestrian rails mounted closer than these values may still be MASH compliant. However, further evaluation would be needed to assess the effect of any vehicle interaction with the pedestrian rail. Lastly, the research team recommends more analysis in the future to corroborate these values because of the limited number of tests reviewed under this project.

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REFERENCES

1. AASHTO. *Manual for Assessing Roadside Safety Hardware, Second Edition.* 2016, American Association of State Highway and Transportation Officials: Washington, D.C.

2. W.F. Williams, R.P. Bligh, and W.L. Menges, "*MASH* Test 3-11 of the TxDOT T222 Bridge Rail," Research Report 9-1002-12-13, Texas Transportation Institute, College Station, TX, July 2016.

3. D.L. Bullard, R.P. Bligh, W.L. Menges, and R.R. Haug, "Volume I: Evaluation of Existing Roadside Safety Hardware Using Updated Criteria – Technical Report," Research Project 22-14(03), Texas Transportation Institute, College Station, TX, March 2010.

4. R.P. Bligh, W.L. Menges, and D.L. Kuhn, "*MASH* Test 3-11 on the Washington Concrete Traffic Barrier with Acoustic Coating," Research Report 602191-1, Texas A&M Transportation Institute, College Station, TX, October 2013.

5. N.M. Sheikh, R.P. Bligh, and W.L. Menges, "Development and Testing of a Concrete Barrier Design for Use in Front of Slope or on MSE Wall," Research Report 405160-13-1, Texas Transportation Institute, College Station, TX, August 2009.

6. W.F. Williams, R.P. Bligh, and W.L. Menges, "*MASH* Test 3-11 of the TxDOT Single Slope Bridge Rail (Type SSTR) on Pan-Formed Bridge Deck," Research Report 9-1002-3, Texas Transportation Institute, College Station, TX, March 2011.

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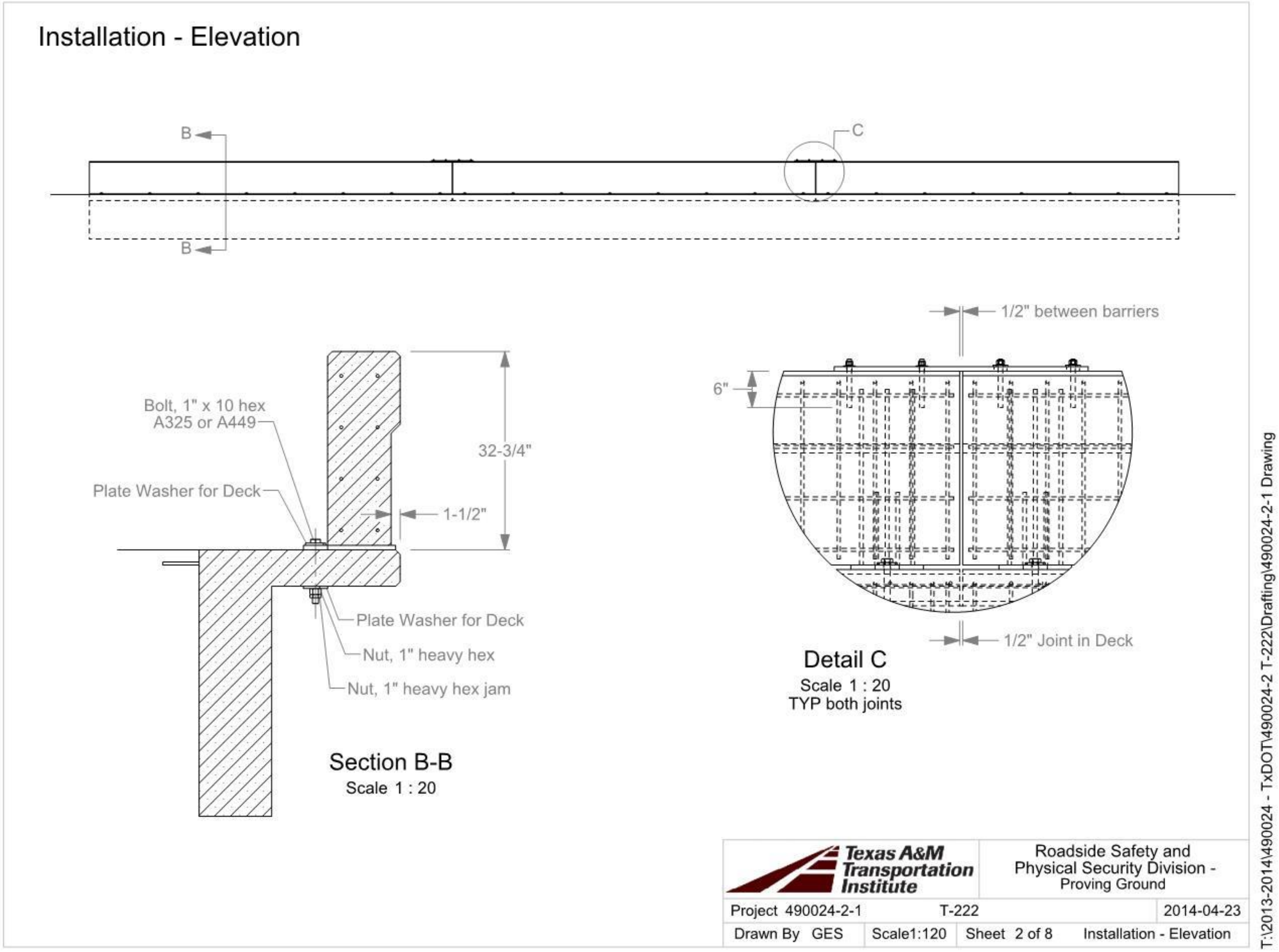
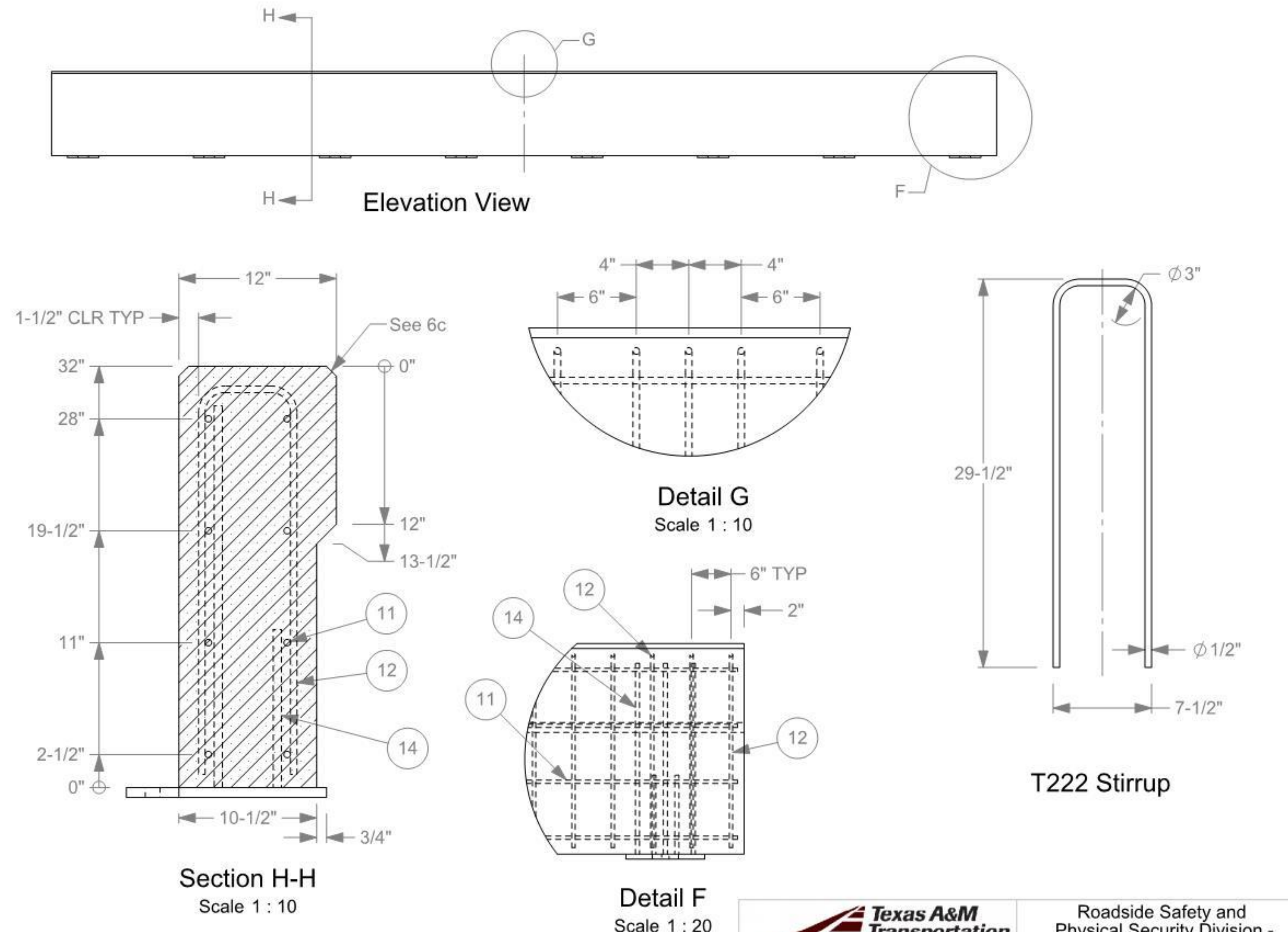
APPENDIX A. DETAILS OF TTI TEST INSTALLATION 490024-2-1



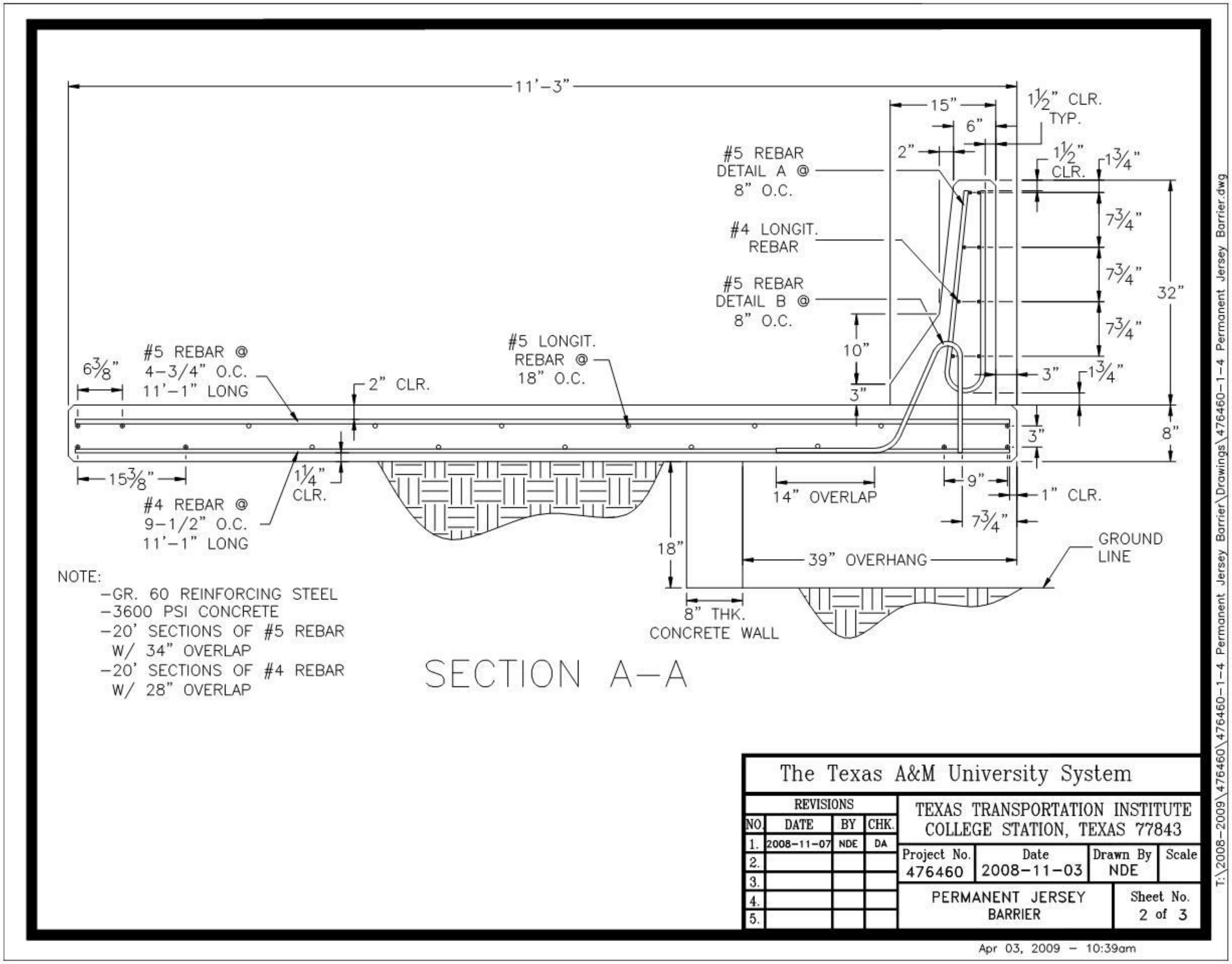


6a. Rebar shall be grade 60. Laps for #4 rebar shall be minimum 15".
6b. Concrete shall be TxDOT Class C (3600 psi).
6c. Chamfer edges 3/4" as shown.

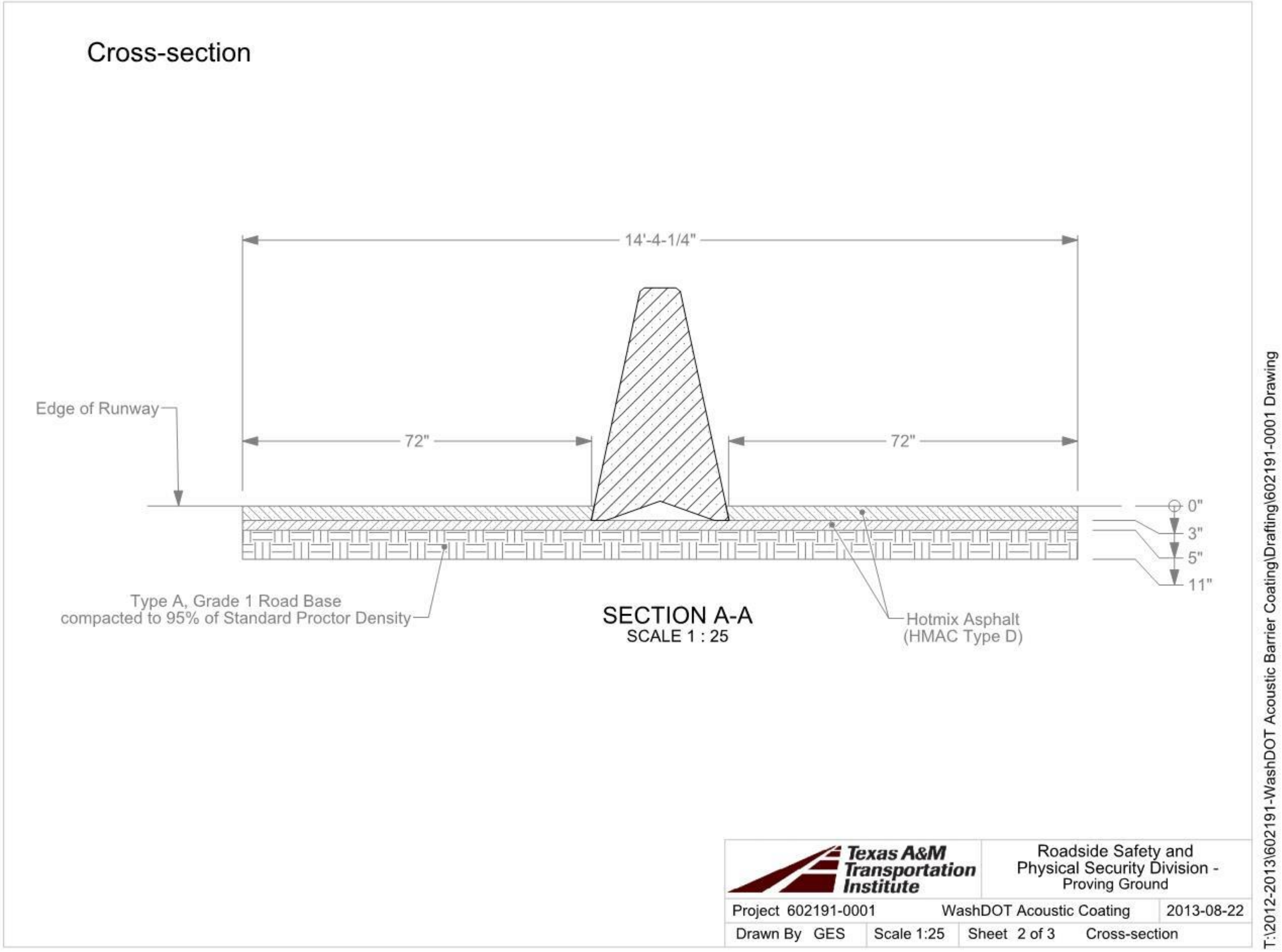
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project 490024-2-1	T-222		2014-04-23
Drawn By GES	Scale 1:50	Sheet 6 of 8	Barrier Details - Elevation

T:\2013-2014\490024 - TxDOT\490024-2 T-222\Drafting\490024-2-1 Drawing

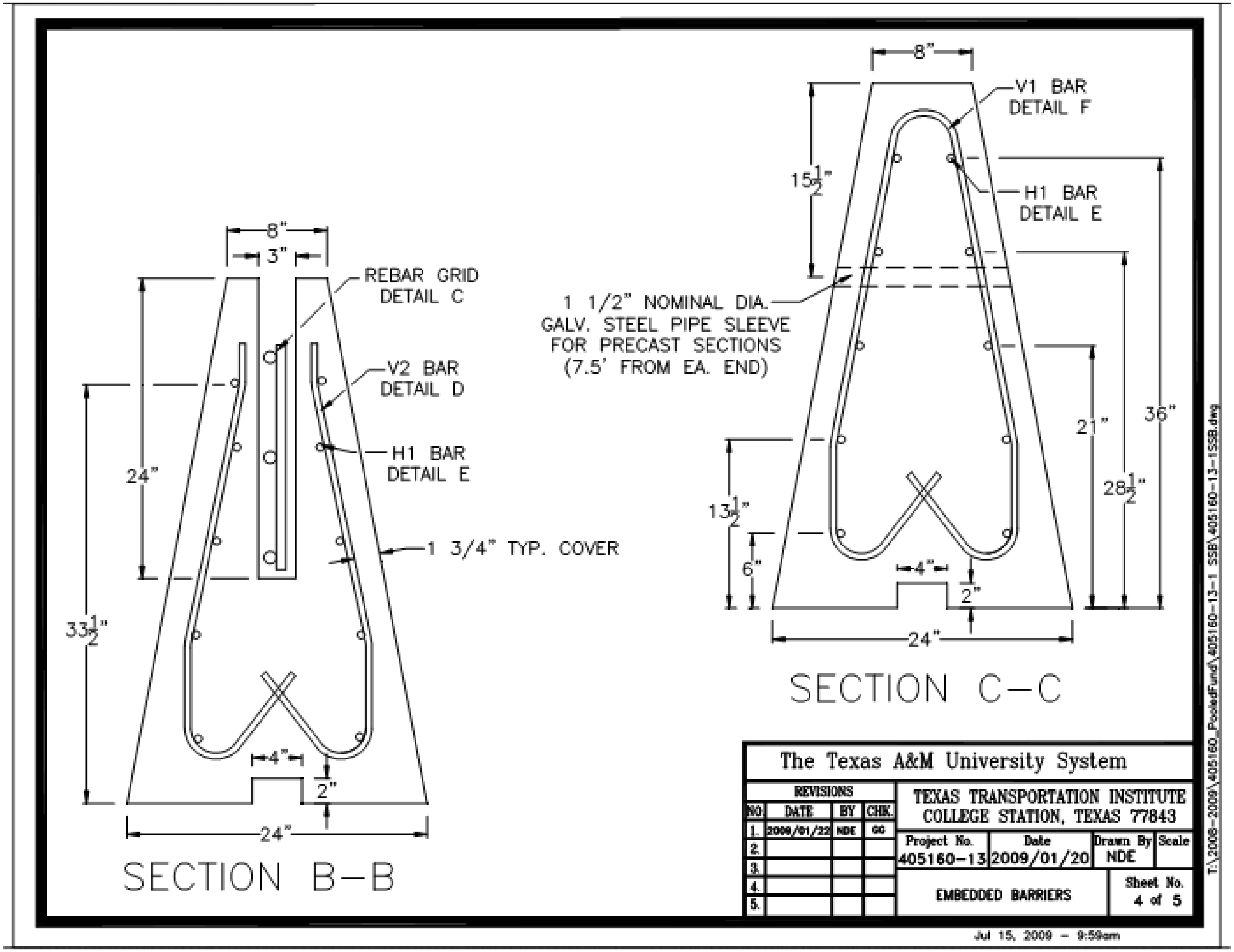
APPENDIX B. DETAILS OF TTI TEST INSTALLATION 476460-1-4

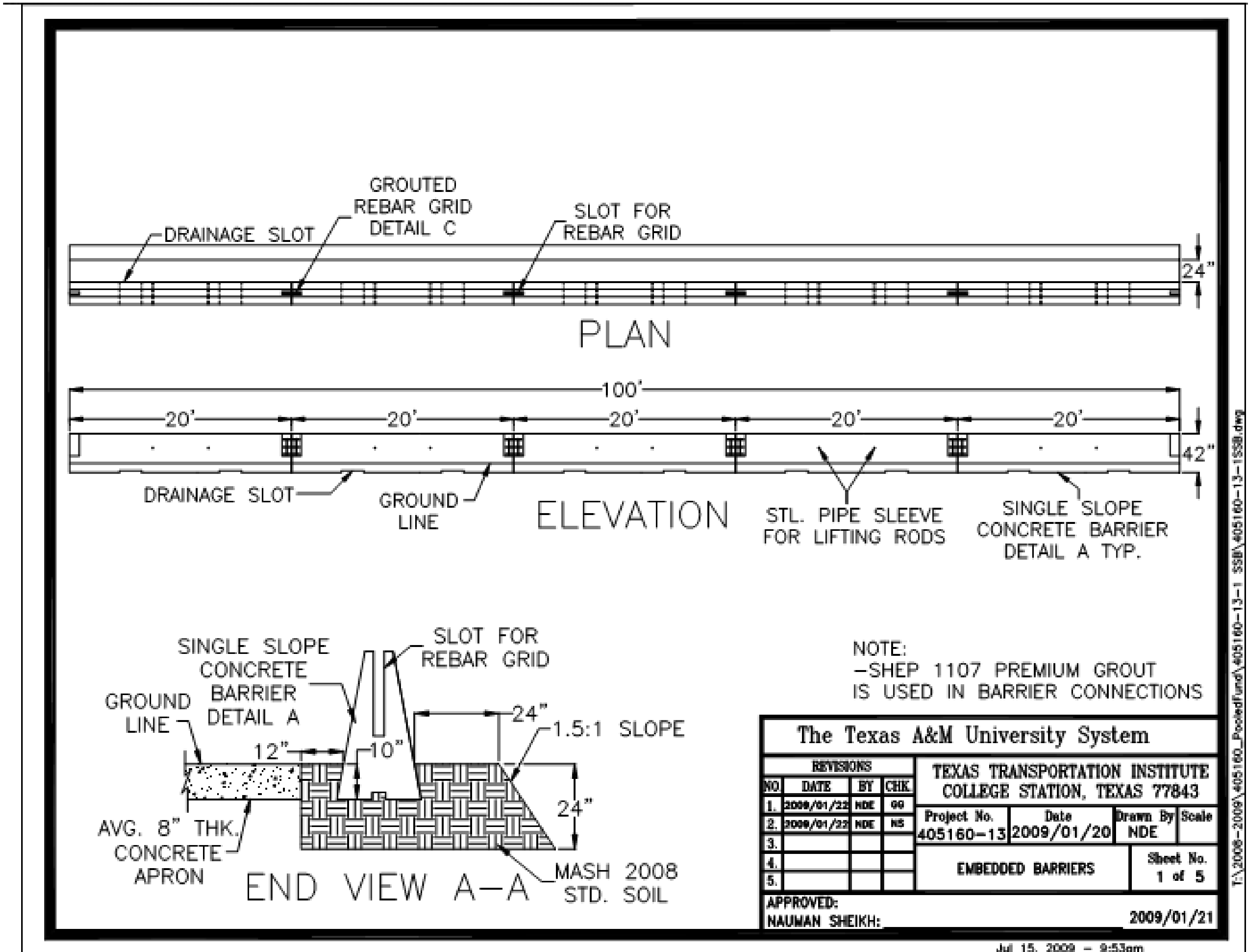


APPENDIX C. DETAILS OF TTI TEST INSTALLATION 602191-1



APPENDIX D. DETAILS OF TTI TEST INSTALLATION 405160-13-1

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REBAR GRID
DETAIL C
DRAINAGE SLOT
SLOT FOR
REBAR GRID
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PLAN
100'
20'
20'
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20'
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42"
DRAINAGE SLOT
GROUND
LINE
ELEVATION
STL. PIPE SLEEVE
FOR LIFTING RODS
SINGLE SLOPE
CONCRETE BARRIER
DETAIL A TYP.
SINGLE SLOPE
CONCRETE
BARRIER
DETAIL A
SLOT FOR
REBAR GRID
GROUND
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12"
10"
24"
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24"
AVG. 8" THK.
CONCRETE
APRON
END VIEW A–A
MASH 2008
STD. SOIL
NOTE:
–SHEP 1107 PREMIUM GROUT
IS USED IN BARRIER CONNECTIONS
The Texas A&M University System
REVISIONS
NO. DATE BY CHK.
1. 2009/01/22 NDE GG
2. 2009/01/22 NDE NS
3.
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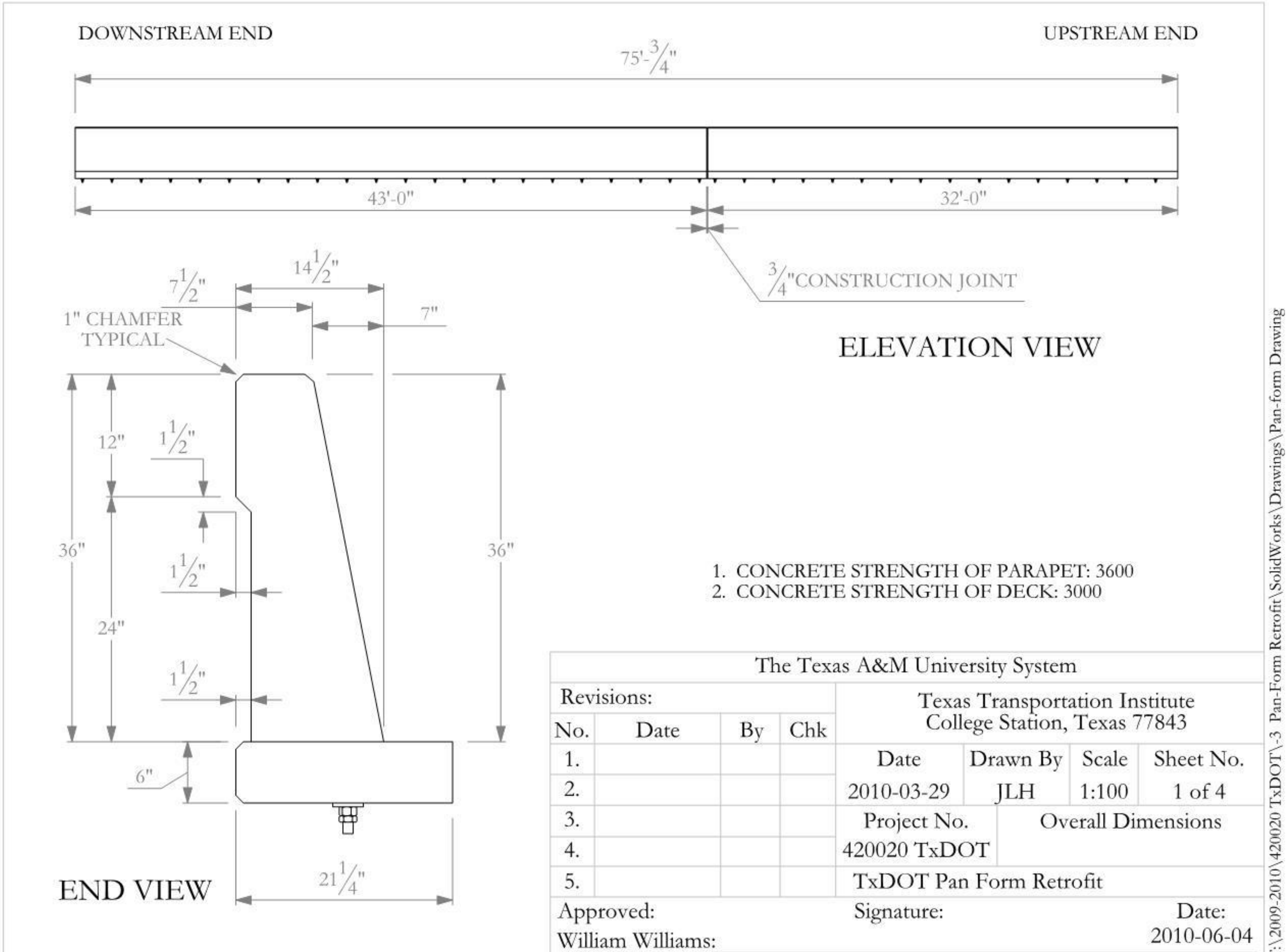
5.
TEXAS TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS 77843
Project No. 405160–13
Date 2009/01/20
Drawn By NDE
Scale
EMBEDDED BARRIERS
Sheet No. 1 of 5
APPROVED:
NAUMAN SHEIKH:
2009/01/21
Jul 15, 2009 – 9:53am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UPSTREAM END
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43'-0"
32'-0"
3/4" CONSTRUCTION JOINT
ELEVATION VIEW
14 1/2"
7 1/2"
7"
1" CHAMFER TYPICAL
12"
1 1/2"
36"
1 1/2"
24"
1 1/2"
36"
6"
21 1/4"
END VIEW
1. CONCRETE STRENGTH OF PARAPET: 3600
2. CONCRETE STRENGTH OF DECK: 3000
The Texas A&M University System
Revisions:
No. Date By Chk
1.
2.
3.
4.
5.
Texas Transportation Institute
College Station, Texas 77843
Date Drawn By Scale Sheet No.
2010-03-29 JLH 1:100 1 of 4
Project No.
420020 TxDOT
Overall Dimensions
TxDOT Pan Form Retrofit
Approved:
William Williams:
Signature:
Date:
2010-06-04
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