Texas A&M Transportation Institute
Proving Ground

Test Report No. 615251-01

EVALUATION OF *MASH* TL-3 TRANSITION DESIGN WITH A STORM DRAIN – TRANSITION DEVELOPMENT AND CRASH TEST OF 2270P VEHICLE (PICKUP TRUCK)

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ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle EVALUATION OF *MASH* TL-3 TRANSITION DESIGN WITH A STORM DRAIN – TRANSITION DEVELOPMENT AND CRASH TEST OF 2270P VEHICLE (PICKUP TRUCK)		5. Report Date October 2023 6. Performing Organization Code
7. Author(s) Sun Hee Park, Akram Abu-Odeh, William J. L. Schroeder, and Bill L. Griffith		8. Performing Organization Report No. Report 615251-01
9. Performing Organization Name and Address Texas A&M Transportation Institute Proving Ground 3135 TAMU College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project T 4541
12. Sponsoring Agency Name and Address Washington State Department of Transportation Research Office MS 47372 Olympia, WA 98504-7372		13. Type of Report and Period Covered Technical Report: January 2023 - October 2023 14. Sponsoring Agency Code

15. Supplementary Notes

Name of Contacting Representative: Derwood C. Sheppard

16. Abstract

This research focused on developing a *MASH* TL-3 Transition Design with a Storm Drain Inlet. The design was envisioned to accommodate storm drain inlet that cannot be addressed via a transition with a curb in front of it. The proposed design was developed based on a survey of State DOTs application needs and to accommodate constructability. The proposed transition design was evaluated through finite element analysis. The most critical inlet placement and impact point was determined and recommended for full-scale crash testing.

The purpose of the test reported herein was to assess the performance of the Transition with Storm Drain Inlet according to the safety-performance evaluation guidelines included in the second edition of the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*). The crash test was performed in accordance with *MASH* Test Level 3 (TL-3):

- ***MASH* Test 3-21:** A 2270P vehicle weighing 5000-lb impacting the Longitudinal Barrier while travelling at 62 mi/h and 25 degrees.

This report provides details on the Transition with Storm Drain Inlet, the crash tests and results, and the performance assessment of the Transition with Storm Drain Inlet for *MASH* TL-3 Longitudinal Barrier evaluation criteria.

The Transition with Storm Drain Inlet met the performance criteria for *MASH* TL-3 Longitudinal Barrier for crash test *MASH* Test 3-21. The installation was tested to MASH Test 3-20 in Test Report No. 619551-01.

17. Key Words	18. Distribution Statement
MASH, Crash Test, Finite Element Simulation, Transition, Inlet, LS-DYNA	No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia 22312 http://www.ntis.gov

19. Security Classification. (of this report)	20. Security Classification. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	92	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

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Report 615251-01
Contract No.: T 4541

Sponsored by the
Roadside Safety Pooled Fund

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The Washington State Department of Transportation

October 2023

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The results reported herein apply only to the article tested. The full-scale crash test was performed according to TTI Proving Ground quality procedures and American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware, Second Edition (*MASH*) guidelines and standards.

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ACKNOWLEDGEMENTS

This research project was performed under a pooled fund program between the following States and Agencies. The authors acknowledge and appreciate their guidance and assistance.

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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 yards	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 1000L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		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 yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	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 tons (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in^2

*SI is the symbol for the International System of Units

Chapter 1. INTRODUCTION

1.1. BACKGROUND

Storm Drain Inlets are meant to be free opening for discharging storm water from roadways as shown in Figure 1.

Figure 1. Example of a Storm Inlet.

However, having such an opening creates a discontinuity for a roadside safety device such as a transition. Some state DOTs are considering adopting the guardrail transition developed by the Midwest Roadside Safety Facility (MwRSF) that can be used with or without a 4-inch (maximum) tall curb and gutter configuration (*1*).

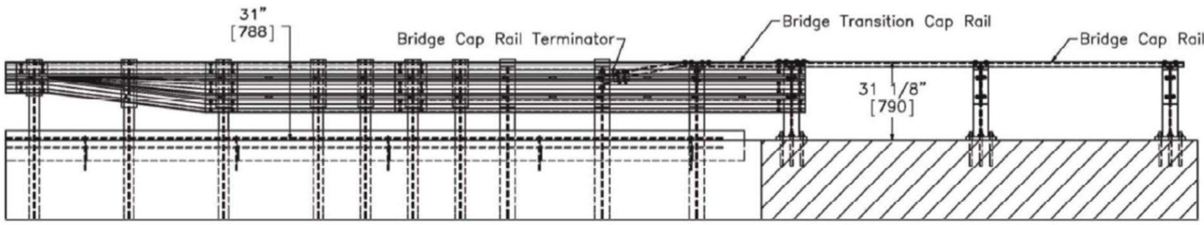


Figure 2. MwRSF Transition Design with Curb (*1*).

However, there is some concerns about a 4-inch (maximum) tall curb being insufficiently tall to contain the flow coming off the bridge on certain structures, and this could result in water flowing over the curb and lead to erosion issues. Thus, there is an interest in guidance on how to address the issue of accommodating inlets capable of handling moderate to high water flow coming off the bridge with a guardrail transition and a curb and gutter.

The design for such transition would help incorporating storm drain inlet into a crashworthy transition.

1.2. OBJECTIVES

The research objective is to develop a *MASH* TL-3 Transition Design with a Storm Drain Inlet. The design is envisioned to accommodate storm drain inlet that cannot be addressed via a transition with a curb in front of it. Computational simulation is used to evaluate the crashworthiness of the developed design under *MASH* TL-3.

The purpose of the test reported herein was to assess the performance of a proposed transition design with storm drain inlet according to the safety-performance evaluation guidelines included in the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*), Second Edition (2). The crash test was performed in accordance with *MASH* Test Level 3 (TL-3) as discussed in Chapter 6 of this report.

1.3. BENEFIT

The research outcome will provide design to help state agencies use crashworthy transitions while accommodating storm drain inlet. Transition being one of the most challenging devices to perform successfully per *MASH*. Adding a singularity makes it even more challenging to pass *MASH* criteria. Hence, a simulation-based approach backed by testing is recommended here to achieve a crashworthy transition that will also address the functional benefit of the storm drain inlet.

Chapter 2. COLLECT AND REVIEW STORM DRAIN INLET DESIGNS

This chapter describes the questionnaires designed to solicit information from the pool fund states. The researchers approached the technical representative of this project and other stakeholders, including state DOTs, to identify the critical inlet design or design elements to be incorporated into the transition design.

The collected information served to determine the initial parameters and improved characteristics to be considered while developing preliminary design options for the proposed system. The questionnaires were administered online using Qualtrics (3) and was sent to all state DOTs (with the addition of Ontario, Canada) participated in Roadside pool fund. The survey was distributed via email. A total of 15 state DOTs responded to the submitted questionnaires, and the state agencies are listed in Table 2.1.

Table 2.1. State Agency Participated in Questionnaires

Agency	State
Louisiana D.O.T.D.	LA
Ministry of Transportation Ontario	Ontario, Canada (Ontario)
Michigan DOT	MI
Utah DOT	UT
Connecticut DOT	CT
Maryland State Highway Administration	MD
Illinois DOT	IL
Iowa DOT	IA
West Virginia DOT	WV
Texas DOT	TX
Alaska Dept of Transportation and Public Facilities	AK
Massachusetts DOT	MA
Delaware DOT	DE
Florida DOT	FL
Alabama DOT	AL

2.1. RESPONSES TO QUESTIONNAIRES

The questions have developed to obtain key design parameters used in the field in each state. Figure 2.1 illustrates the key parameters to develop a new transition design to represent the most critical scenario. Questions asked to the state agencies and their answers are presented in Table 2.2 through Table 2.7.

Along with the answers to the questions, the state agencies provided standard inlet drawings to provided additional information. Drawings are provided in Figure 2.2 through Figure 2.10.

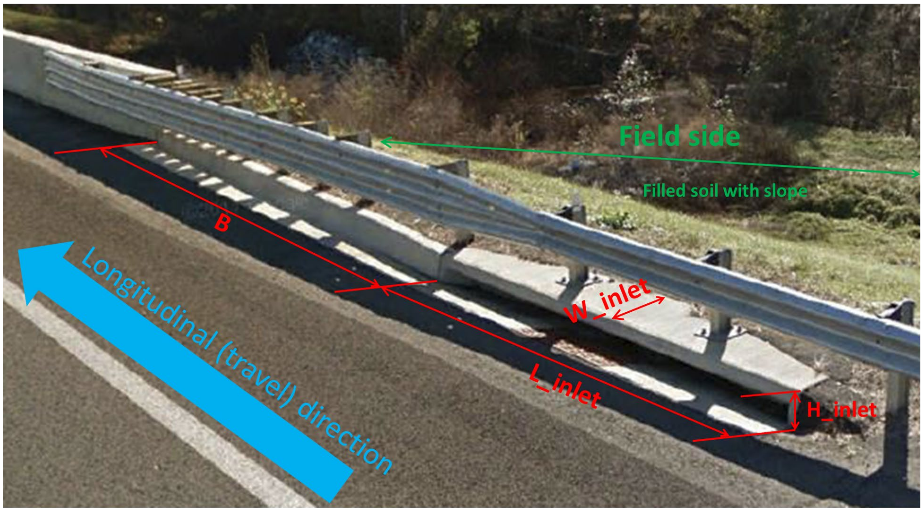


Figure 2.1. Key Parameters for Placing Storm Drain Inlet.

Table 2.2. Distance from Bridge Rail to Inlet (B).

Range	Agency	Note
Under 100 in.	UT, IL (old bridge)	Min. 3 in., max 40 in.
100 in < B ≤300 in.	LA, Ontario, IL (new bridge)	132in., 180in., 184 in., 300 in.
Over 300 in.	MD	38ft-6in.
Varies	MI	Length varies to ensure inlet is located between guardrail posts with a 6'-3" post spacing.
	CT, IA	N/A

Table 2.3. Size of Inlet.

Longitudinal Length (L_inlet)	Agency	Note
Under 30 in.	UT, IL, IA	19 in., 23 in.
30 in < B ≤ 60 in.	CT, MD	33 in., 52 in.
60 in < B ≤ 100 in	LA, Ontario, MI,	72 in., 85in., 63in.
Over 100 in.	LA, CT	120 in., 130 in.
Transverse Length (W_inlet)	**Agency**	**Note**
Under 30 in.	MI, CT, MD, IA, IL	8 – 14.5 in., 23 in. 24 in.
30 in < B ≤ 60 in.	IL, Ontario, UT,	27 in. -77 in., 49 in., 50 in.
60 in < B ≤ 100 in	IL	-77in.
Over 100 in.	LA	104 in. or open
Vertical Height (H_inlet)	**Agency**	**Note**
4 in.	MI IA	IA uses a grate intake next to a 4" curb
6 in.	LA, Ontario, CT	
Over 6 in.	CT, UT	

Table 2.4. Type of Field Side Filling.

Range	Agency	Note
Filled soil	LA, Ontario, MI, UT, CT, MD, IL, AK	Typically, an embankment is located behind the inlet to allow the runoff to flow away from the inlet by gravity. 2-ft shelf of embankment behind the guide rail with inlet located in the gutter line. Filled soil slope, sometimes with a riprap slope drain.
Sidewalk	IA, TX,	

Table 2.5. Existence of Back Slope.

Answer	Agency	Note
Yes	LA, Ontario, MD, IL, IW	It is adjacent to a 4"" curb, possibly erosion stone
No	MI, UT, TX	
Others	CT	We used standard curb or curb less catch basin tops Highway Design Standard sheet HW-586_07

Table 2.6. Use of Curb and Gutter at Transition with Inlet.

Range	Agency
Yes	LA, Ontario, MI, CT, MD, IL, IA
No	TX, AK

Table 2.7. Size of Curb and Gutter.

Width	Agency	Note
Under 6 in.	LA, IL	6 for curb. 4 for inlet.
6 in < B ≤ 10 in.	Ontario, MI, UT, CT	7 in. 8in. 10in.
Over 10 in.	IA	12 in.
Height	**Agency**	**Note**
4 in.	LA, Ontario, UT, CT, IL	
6 in.	CT, UT	
Length	**Agency**	**Note**
Under 100 in.	Ontario,	25 in.
100 in < B ≤300 in.	UT, LA, IL	132 in. for open drains, 144 in., up to 217 in.
Over 300 in.	LA	Min. 300 in. for inlets
Varies	MI, IA	

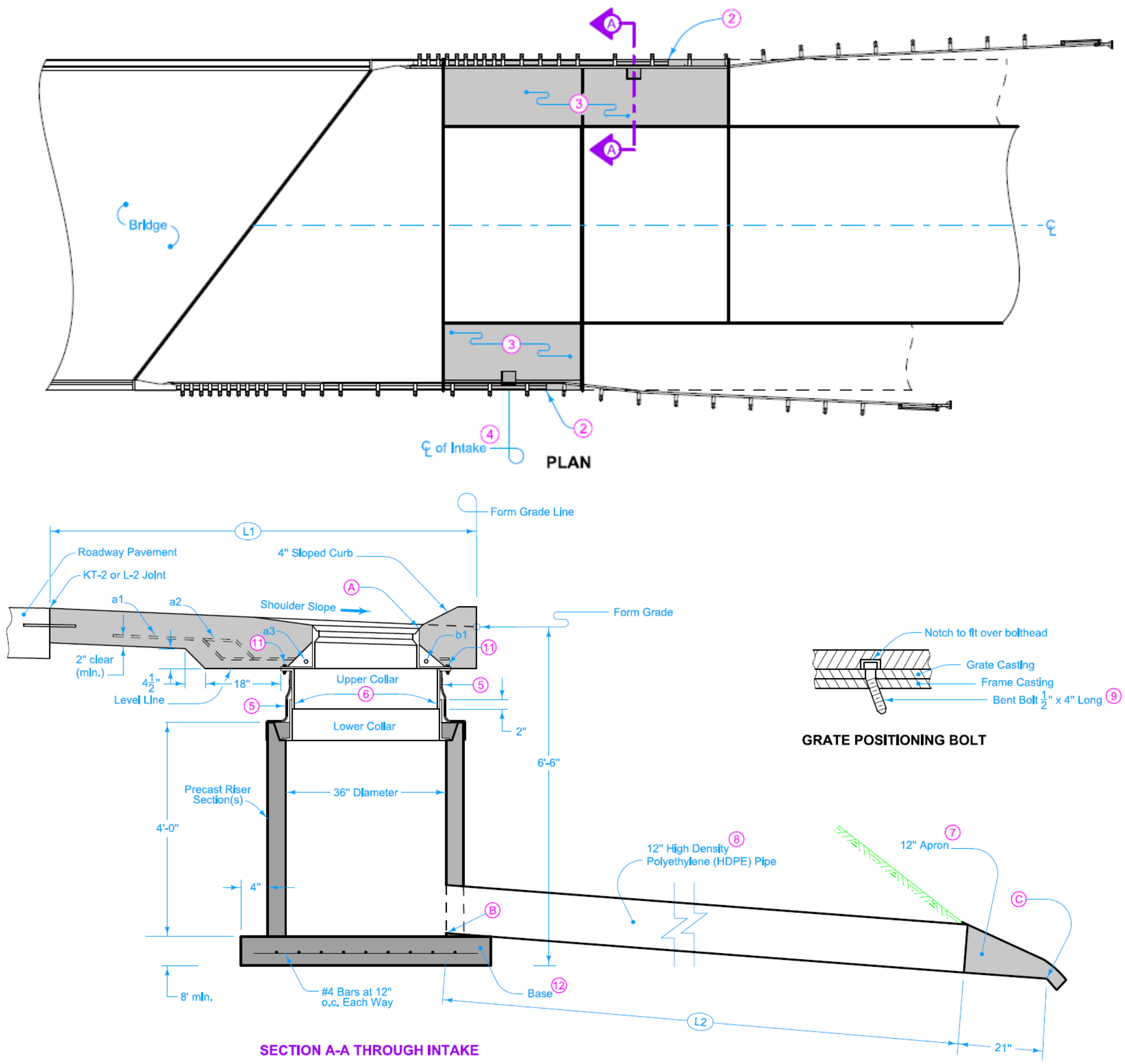


Figure 2.2. Standard Inlet Drawing–IA

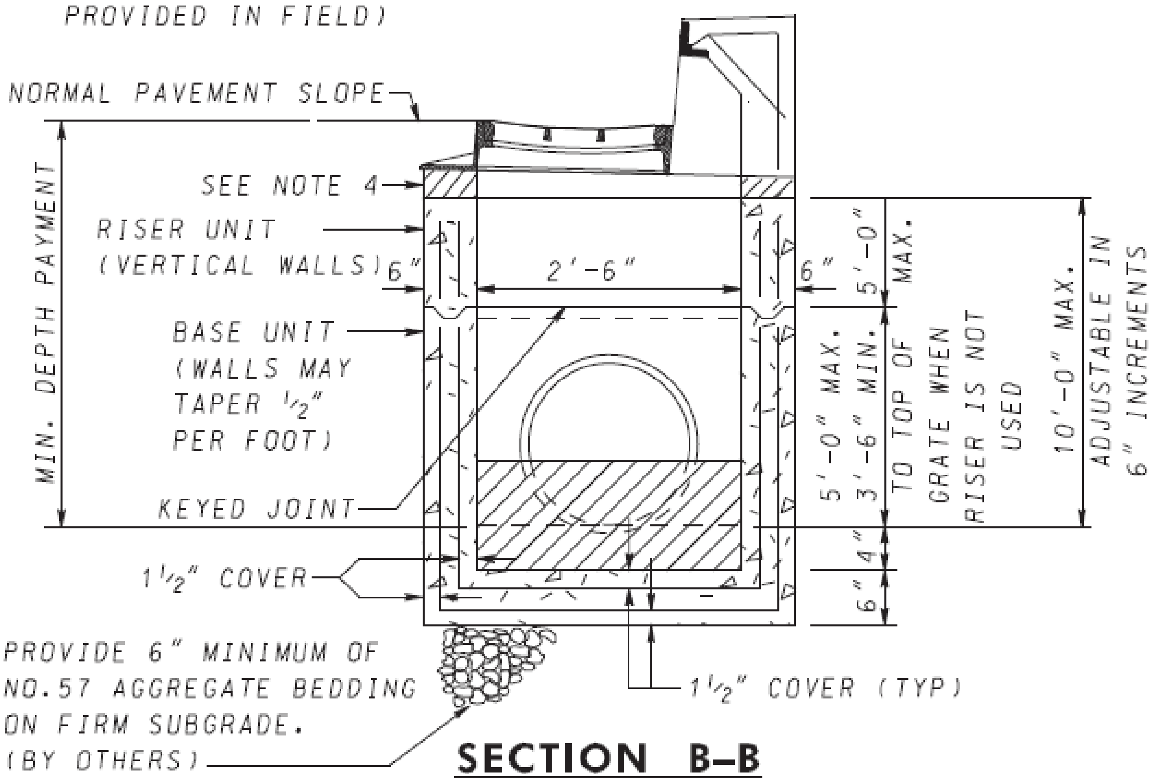


Figure 2.3. Standard Combination Inlet Drawing–MD

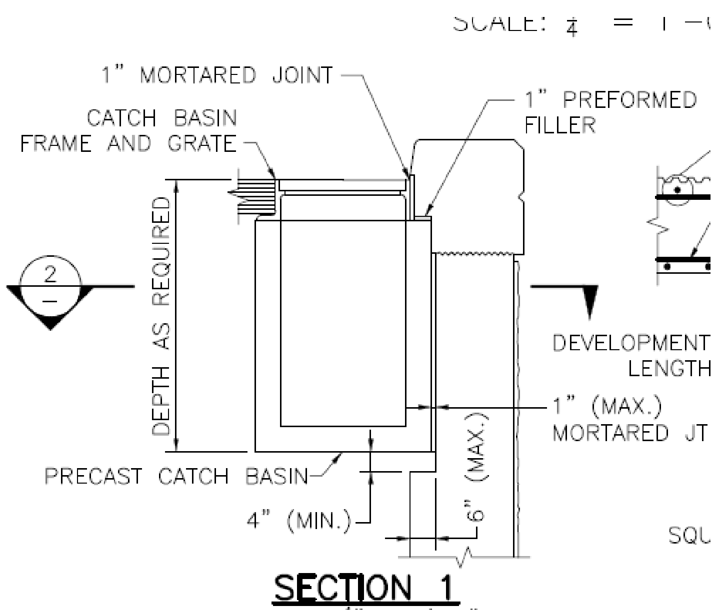


Figure 2.4. Standard Catch Basin at Wingwall–MA

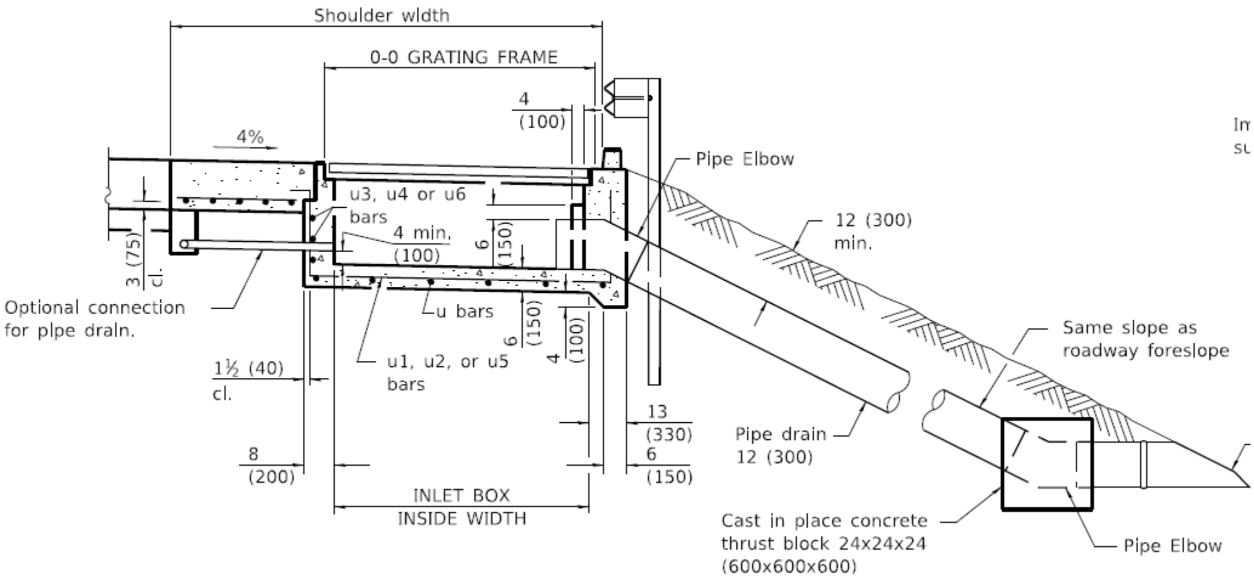


Figure 2.5. Standard Drawings for Shoulder Inlet with Curb–IL

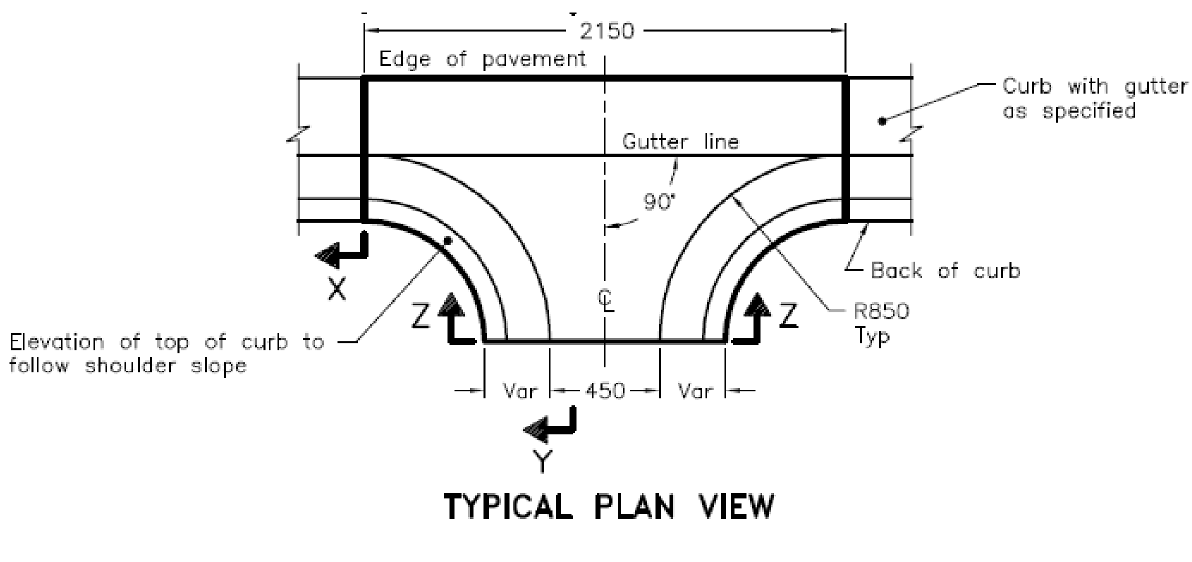


Figure 2.6. Concrete Outlet for Concrete Curb with Gutter–Ontario

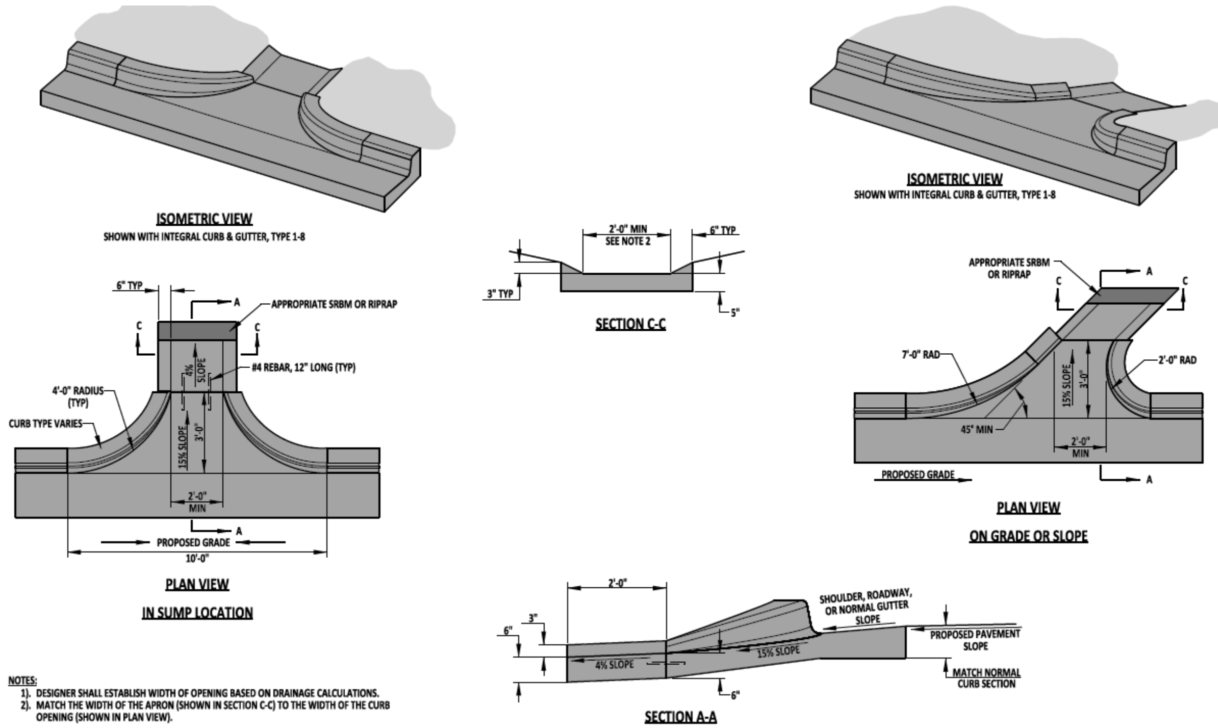


Figure 2.7. Curb Opening Standard Drawing–DE

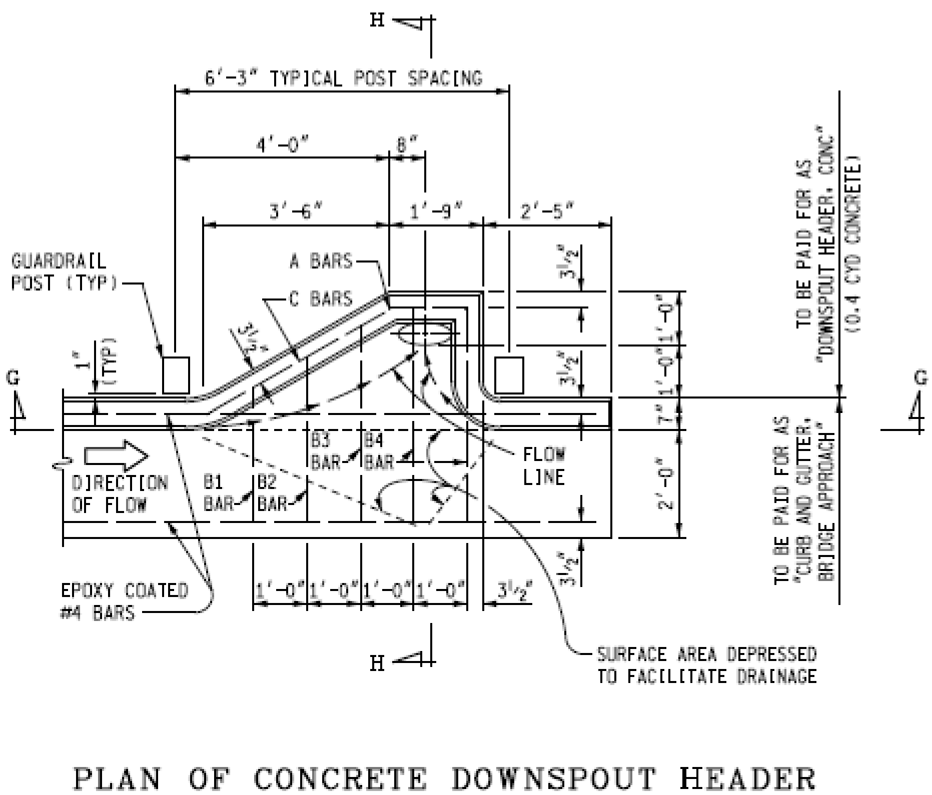


Figure 2.8. Standard Drawing for Approach Curb and Gutter Down spouts–MI

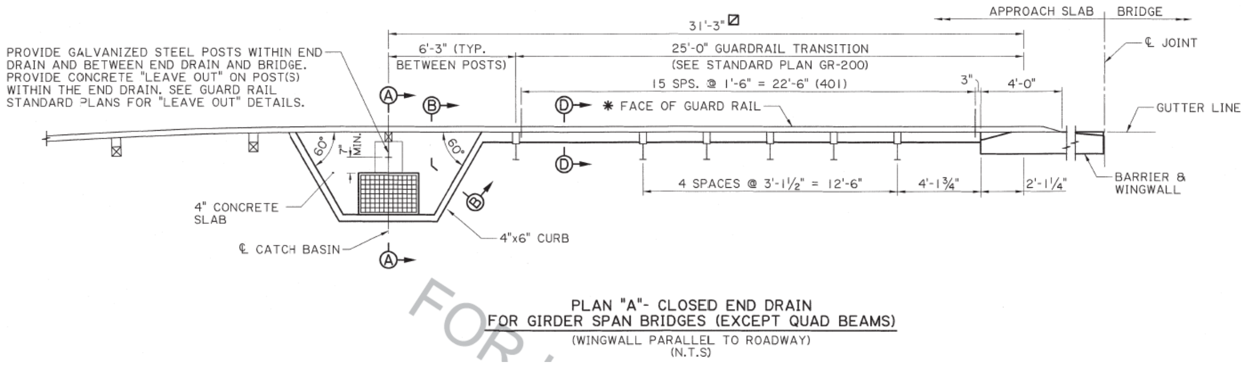


Figure 2.9. Standard Drawing for Bridge End Closed Drain–LA

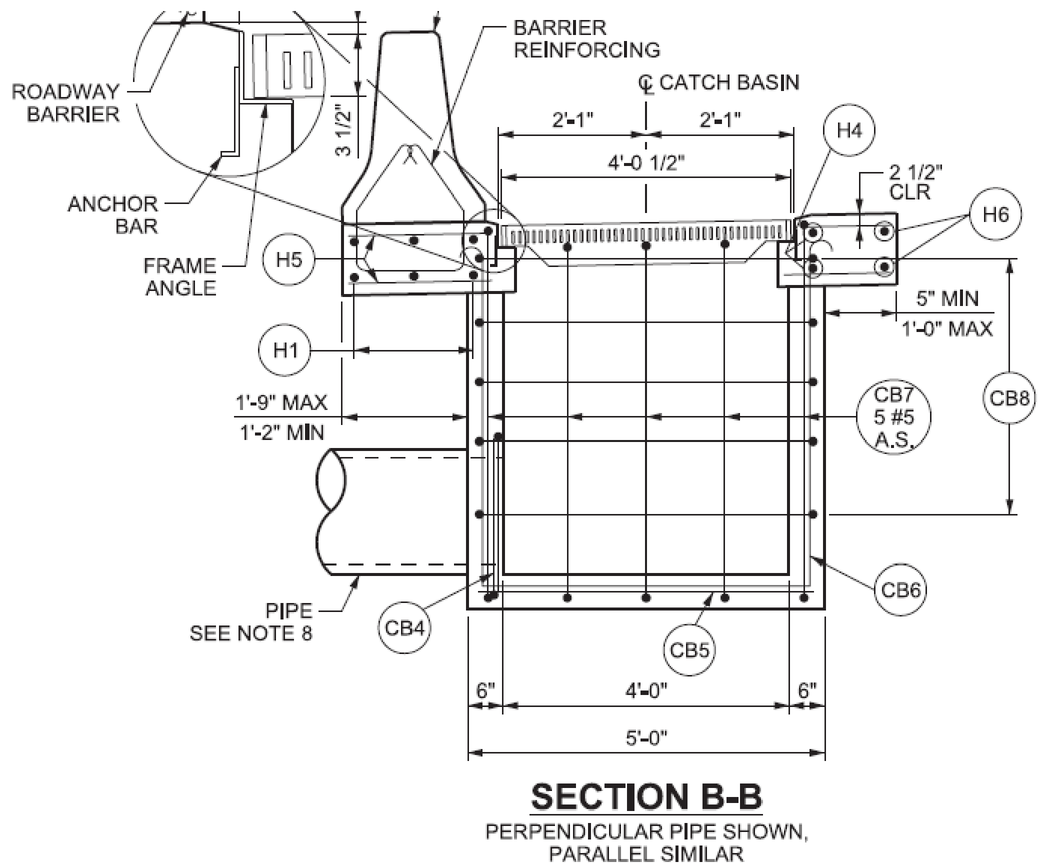


Figure 2.10. Standard Drawing for Catch Basin–UT

2.2. SUMMARY

In many states, drain inlet systems with curb and back slope are commonly used to position inlets between guardrail posts. However, when confronted with a transition system, there is often insufficient space to accommodate these drain inlet systems. In such situations, an alternative solution is to employ a curb opening inlet or a grate inlet in conjunction with curb and back slope. Therefore, in this study, a transition system with back sloped curb inlet was designed and investigated under *MASH* TL-3 evaluation criteria. The design parameters for this transition system were established based on the information obtained from questionnaires and discussions held with state agencies.

To initiate the transition design process, the median values from the questionnaires were selected as the basis. The selected parameters for the initial design based on the questionnaires are presented in Table 2.8.

The purpose of this study is to assess the effectiveness and safety of the proposed transition system with a curb inlet. By utilizing input from questionnaires and collaborating with state agencies, the design aims to address the challenges posed by limited space near the transition area and provide a viable solution for drainage.

Table 2.8. Selected Parameters for Initial Design Based on Survey Results.

Parameters	Median (or Majority) Value
Offset Distance from bridge rail to inlet (B)	180 in.
Inlet longitudinal length (L_inlet)	72 in.
Inlet transverse width (W_inlet)	50 in.
Inlet height (H_inlet)	6 in.
Field side Material	Filled Soil
Existence of back slope	Yes
Use of curb and gutter	Yes
Curb width	8 in.
Curb height	6 in.

Chapter 3. FINITE ELEMENT VEHICLE MODEL VALIDATION

3.1. INTRODUCTION

In this chapter, finite element (FE) models for a vehicle and system are calibrated for predictive analysis using LS-DYNA (*4*). The FE model was set as the same conditions as a full-scale crash testing to compare the results. If simulation results do not correlate with full-scale crash test results, the vehicle properties were investigated and calibrated to improve the correlation.

To validate the FE model, an FE dynamic impact simulation was conducted and compared to a full-scale crash test—Test No. 469549-01-04 and 469549-01-01 (*5*). Based on the details of the details of the test as described in the reference 3, the FE model was developed and set up with the same condition s as the test.

3.2. SYSTEM MODELS

In this study, Texas Department of Transportation (TxDOT) thrie-beam wingwall transition system (*5*) was used for the model verification. The system is shown in Figure 3.1, the guardrail to rigid barrier transition attached to bridge (or culvert structure) system was approximately 102 ft-10¾ inches long. A 27 ft-6¼ inch long W-beam to thrie-beam to parapet transition section was anchored at a 16-ft long reinforced concrete parapet. W-beam guardrail was 50-ft and connected to a downstream anchor terminal (DAT). The posts (six of the posts) in the thrie-beam portion of the transition system were mounted to a reinforced concrete wingwall that was 13 ft long, 12 inches thick, and 5 ft deep. The wingwall was embedded in the soil with the top at grade, and the rest of the posts were embedded directly into the soil. The top edge of the thrie-beam and W-beam rails were at 31 inches above ground. A C6×8.2 rub rail was positioned below the thrie-beam section.

Figure 3.1. Wingwall Transition System (*5*).

Figure 3.2 shows the transition system model used for the impact simulation. Each component of the system was modeled based on the sections and material properties of the actual material. The parts embedded in the soil in the actual system, such as concrete wingwalls and posts, were modeled with constrained boundary conditions in x-, y-, and z-directions. For the concrete components, rigid concrete material was used since a concrete damage was not a main concern.

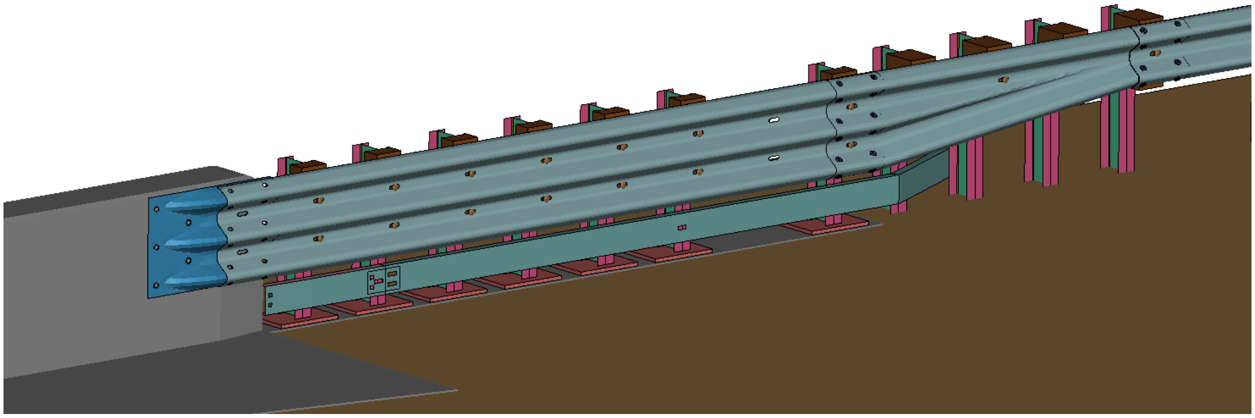


Figure 3.2. System Models used for FE Vehicle Model Validation.

3.3. VEHICLE MODELS

A FE model of 2018 Dodge Ram and a 2010 Toyota Yaris was used to represent a *MASH* 2270P pickup truck model and *MASH* 1100C passenger car model, respectively. Figure 3.3 and Figure 3.4 show the FE Dodge Ram model and the FE Yaris model, respectively, developed by the Center for collision safety and Analysis (CCSA) at George Mason University (6*, 7*).

(a) Front View

(b) Isometric View

Figure 3.3. Dodge RAM Model Used for FE Simulation.

(a) Front View *(b) Isometric View*

Figure 3.4. Yaris Model Used for FE Simulation.

Both vehicle models were modified for calibration and subsequently used for the usage of multiple simulations to adopt for crashworthiness predictive analysis. After the calibration, two vehicle models (i.e., V1 and V2) per each type of vehicle were used for the impact simulation.

3.4. VEHICLE MODEL CALIBRATION UNDER *MASH* TL-3 CONDITIONS

3.4.1. Pickup Truck Model Calibration–*MASH* Test 3-21

Using the initial Ram model, an impact simulation under *MASH* Test 3-21 conditions was performed with the TxDOT wingwall transition system. According to the TxDOT test report (*5*), the actual speed and angle were 62.7 mi/h and 24.8 degrees, and Figure 3.5 shows the truck model set with the actual speed and angles to replicate Test 469549-01-4.

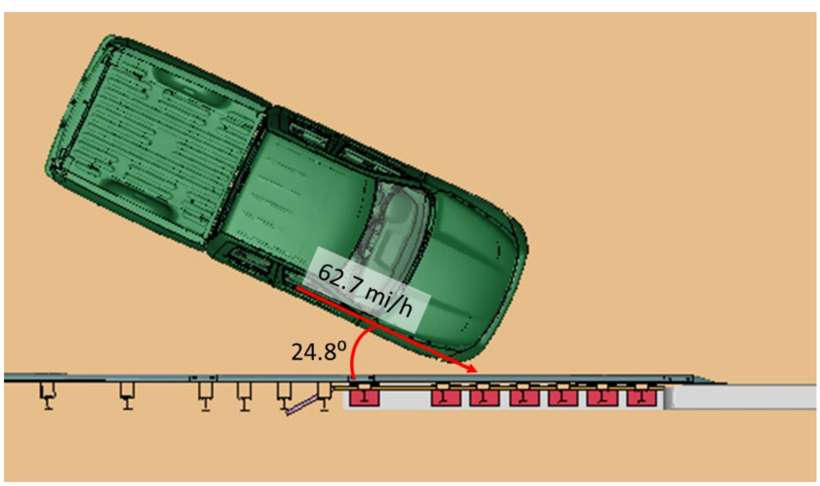
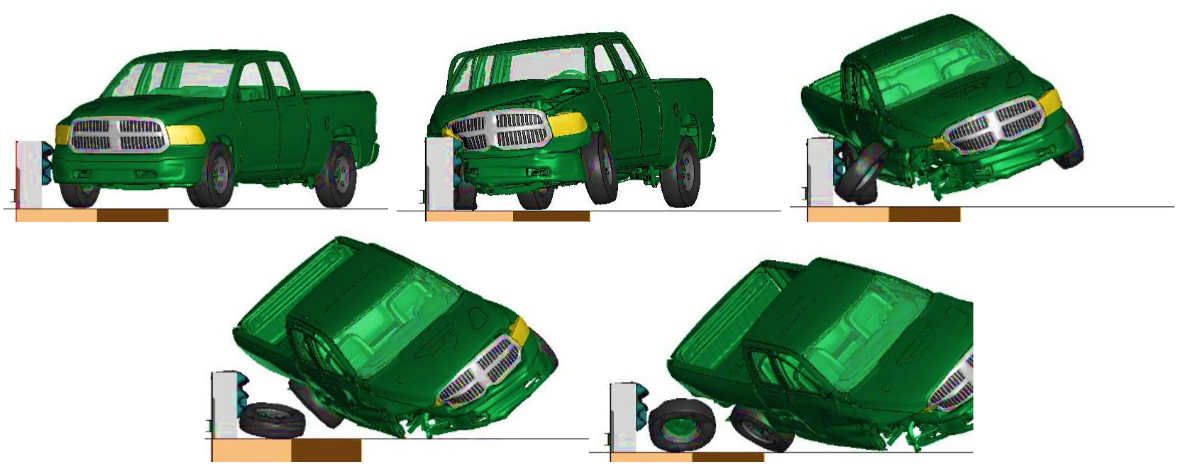


Figure 3.5. Simulation Set-Up Under TL 3-21 Conditions.

Figure 3.6 shows the sequential photos of the test and simulations, and Table 3.1 lists the occupant risk factors to compare actual test and simulations.

(a) Test (5)

(b) Truck_V1



(c) Truck_V2

Figure 3.6. Sequential Overhead Photos of Pickup Truck Under TL-3 Conditions.

The behavior of the initial truck model (Truck_V1) did not match to the actual test after impacting the transition and concrete parapet as shown in Figure 3.6(a) and (b). The main difference was the front tire detachment. Therefore, to improve the vehicle model to have similar vehicular behavior trend, several iterations were performed. After updating the vehicle properties including the spindle failure of the tires and the tire deflation, the final truck model (Truck_V2) was obtained. Using Truck_V2 model, *MASH* Test 3-21 simulation results were compared to the data from Test 469549-01-4 data. As shown in Figure 3.6(a) and (c), the Truck_V2 was reasonably follow the major trend of the vehicle behavior.

The occupant risk factors for the simulations were also compared to the actual test values. Comparing to the values obtained from Truck_V1 simulation, the values obtained from Truck_V2 simulation shows better agreement with the actual tests. For Truck_V2 simulation, the occupant impact velocities (OIVs) and ridedown accelerations (RAs) values was sufficiently correlated to the actual test although the roll-angle value was conservatively predicted.

Table 3.1. Comparisons of the Occupant Risk Factors

Category		Test	Truck_V1	Truck_V2
Impact Velocity (ft/sec)	Longitudinal	19.7	23.9	21.0
	Lateral	26.6	28.9	2.92
Ridedown Acceleration (g)	Longitudinal	6.0	3.9	5.1
	Lateral	9.1	8.5	9.2
Max. Angles (degrees)	Roll	27.6	30.8	45.2
	Pitch	15.1	4.1	8.2
	Yaw (at 0.8899 sec)	68.0	53.0	59.5

3.4.2. Small Car Model Calibration–*MASH* Test 3-20

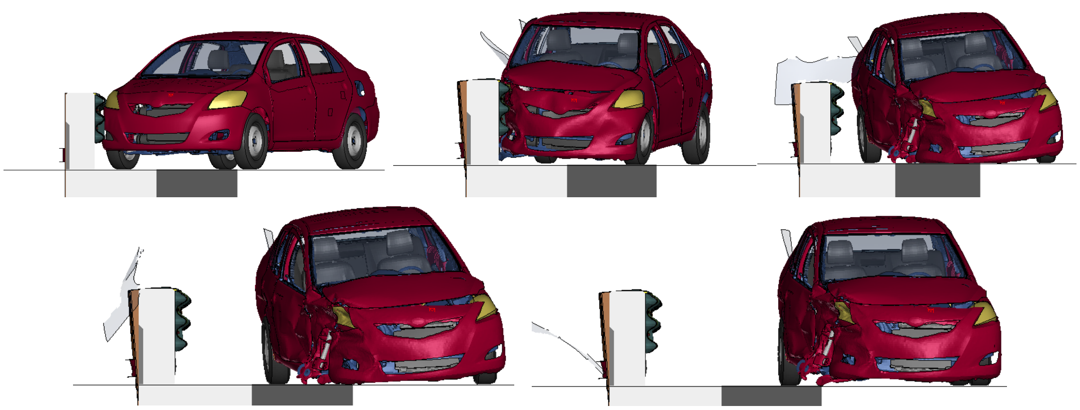
The results of the simulation under *MASH* TL 3-20 conditions were compared with the data from the TxDOT report (*5*). The TxDOT TL 3-20 test met all the *MASH* TL 3-20 evaluation criteria.

For the impact simulation, the initial Yaris (Car_V1) model was used and then the model was updated to the final Yaris (Car_V2) model based on the vehicular behavior. Simulations using each model were compared to the full-scale test results.

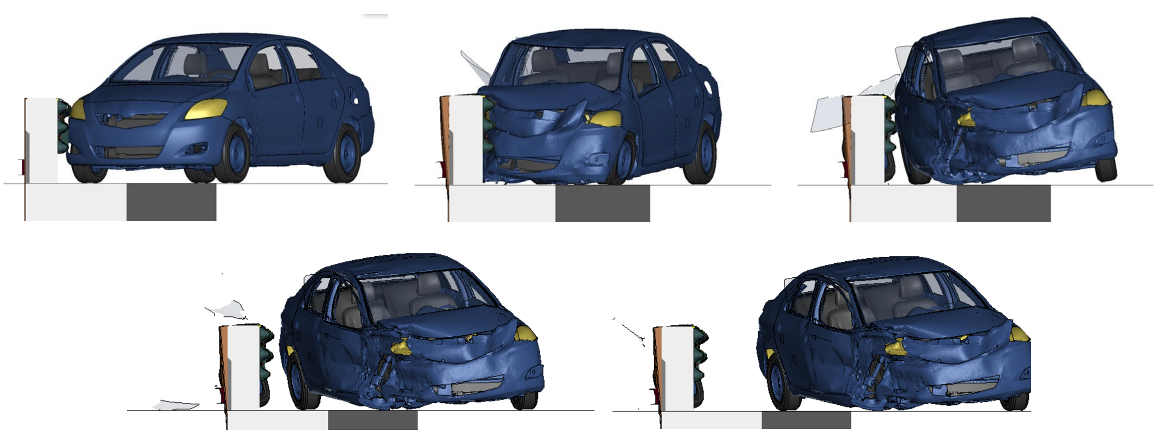
Figure 3.7 shows the sequential photos of the test from the front and the simulations. By comparing the simulation using initial Yaris model and the test, the Car_V2 model was updated from the Car_V1 including failures of vehicle and tire parts and the suspension stiffness to accommodate a variety vehicular behavior. The simulation results with Car_V2 model shows the more similar vehicular behavior when compared to the test result. Note that the passenger side front tire was ripped during the full-scale test, while the tire in the FE model was totally detached from the vehicle.

Table 3.2 presents the occupant risk factor for the test and simulations The simulation models resulted in less RA values and roll angles than the test. However, it should be noted that the simulation model adopted a different vehicle model (Toyota Yaris) from the full-scale tested vehicle model (Kia Rio), which may have caused minor differences when comparing the simulation results to the test results.

(a) Test (5)



(2) Car_V1



(b) Car_V2

Figure 3.7. Sequential Photos of Passenger Car Under TL 3-20 Conditions (Gut View).

Table 3.2. Comparisons of the Occupant Risk Factors

Category		Test	Car_V1	Car_V2
OIV (ft/s)	X	27.2	25.6	32.8
	Y	30.5	31.2	29.5
Ride-down Acceleration (g)	X	-19.4	-16.3	-12.1
	Y	-14.6	-8.7	-5.7
Max. Angle (degrees)	Roll	19.1	6.7	9.8
	Pitch	-10.8	-6.0	-5.6
	Yaw	-67.2	-33.2	-43.3

3.5. CONCLUSION

With several iterations of model calibration, the vehicle models were updated and validated for use in further predictive simulations. As a result of the simulations, both final vehicle models (Truck_V2 and Car_V2) exhibited a reasonable correlation with the actual tests based on the vehicular behavior and the occupant risk factors. Although the vehicle models yielded conservative values, the overall data showed good agreement, and the sequential vehicular trajectories were comparable. Therefore, the model can be employed for the predictive analysis for the transition design with a storm inlet as the model demonstrated reasonable accuracy and validity.

Chapter 4. TRANSITION SYSTEM WITH INLET DESIGN AND ANALYSIS

4.1. DETAILS OF TRAINSITION DESIGN

In most cases, there is not sufficient spaces to place guardrail posts near a drain inlet since the inlet system is usually placed along with curbs. Therefore, in this study, the researchers adopted the TxDOT wingwall transition system with a surface mounted wingwall post (*5*).

The finite element (FE) model of the guardrail to bridge parapet transition with curb inlet was developed to represent an actual system. Section properties of the model were based on the thickness and length of different components of the system shown in the drawings in Appendix A. To provide a sufficient stiffness, a 13.5-ft long nested thrie-beam to W-beam transition system was used with 31 inches high from the flat ground. One end of the nested Thrie-beam was connected to the parapet with a stee end-shoe, and another end was connected to asymmetric beam to connect to W-beam rail.

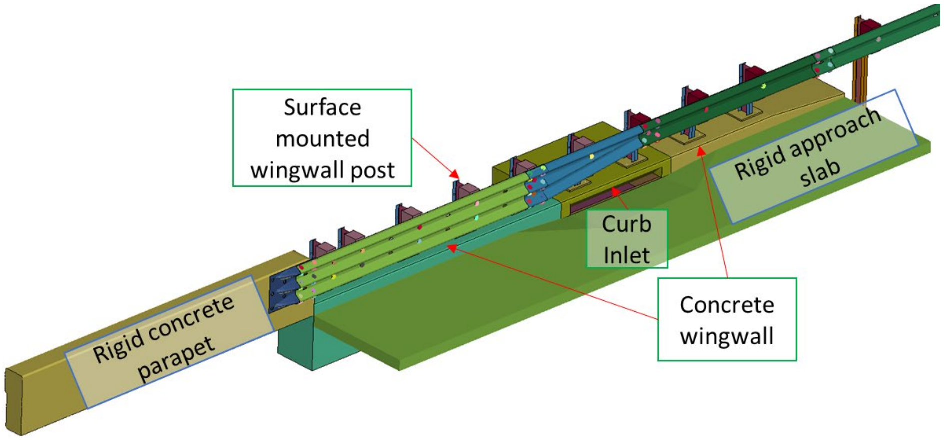
On the curb and inlet, a W6×8.5 surface mounted post with a height of 25.25-inch was used with a 0.75-inch thick square base plate. The post was mounted on the top of the concrete wingwall or inlet using 5.5-inch long screw anchors. Post spacings are varies on each section as shown in Figure 4.1 and drawings in Appendix A. From the second W-beam rail, 6 ft long W6×8.5 posts were used with a 75-inch spacing.

A total of six 6-inch×8-inch×18-inch transition blockouts was used at thrie-beam and asymmetric beam sections while the standard timber blockout (6-inch×8-inch×14-inch) was used at W-beam section.

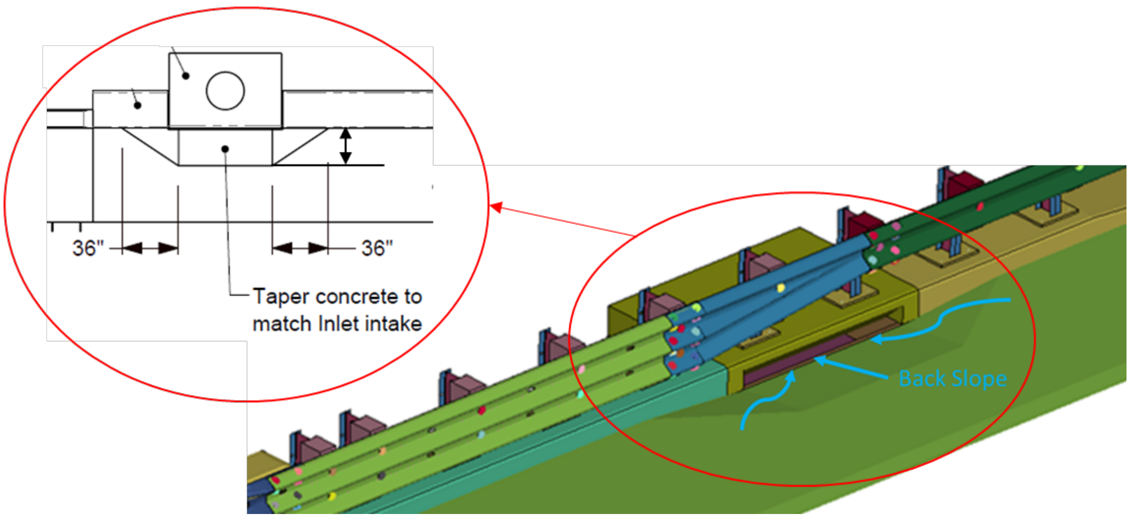
The steel components including posts, base plate, beams, and concrete rebars were modeled using linear plastic material with the corresponding material properties. While the concrete parapet and approaching concrete slab were modeled as a rigid material, a general concrete material model was used for the inlet components (top and riser) and the wingwalls to investigate damage on the concrete. The rebars and anchors embedded in the concrete blocks were modeled as a beam element and coupled to the concrete block to constrain the rebars with the concrete. To perform simulation time-efficiently, the posts embedded in the ground were fixed and constrained the movement at 4 inches below the ground instead of modeling a soil system under the ground. The terminal was modeled with a spring material and discrete mass element for time-efficient performance.

Figure 4.1 shows the FE transition system that was modeled to perform computational impact simulations. To represent the backslope, the approach concrete slab was modeled using tapered concrete block as shown in Figure 4.1(b). The slab was tapered to match the inlet intake (4-inch lower than the flat ground). The wingwall reinforcements and anchorage overview are as shown in Figure 4.1(c). The parts of wingwall and inlet parts placing under the ground was also fixed and constrained the movements in all directions for time-efficient simulation.

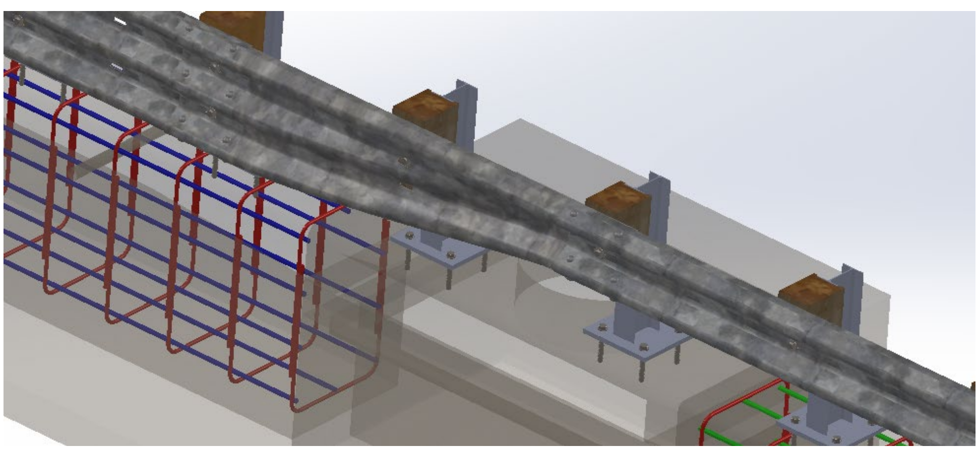
As a preliminary design concept, two curb inlet systems were investigated in the following sections: (a) a monolithic inlet system representing a single unit cast-in-place concrete inlet, and (b) an articulated inlet system representing precast concrete components that make up the inlet structure.



(a) Thrie-beam to W-beam Transition with Inlet System Components



(b) Details of Approach Concrete Slab



(c) Concrete Wingwall and Baseplate Anchorage

Figure 4.1. Finite Element Design Concept for Transition System with Drain Inlet.

4.2. TRANSITION SYSTEM WITH MONOLITHIC INLET

Figure 4.2 shows the monolithic inlet model components. The key component of the monolithic inlet is the vertical reinforcements that used to connect the inlet lid to the bottom rigid mass concrete part. This allowed the inlet to behave monolithically. The inlet details including concrete rebars were modeled based on TxDOT cast-in-place curb inlet details (8) as shown in Figure 4.3.

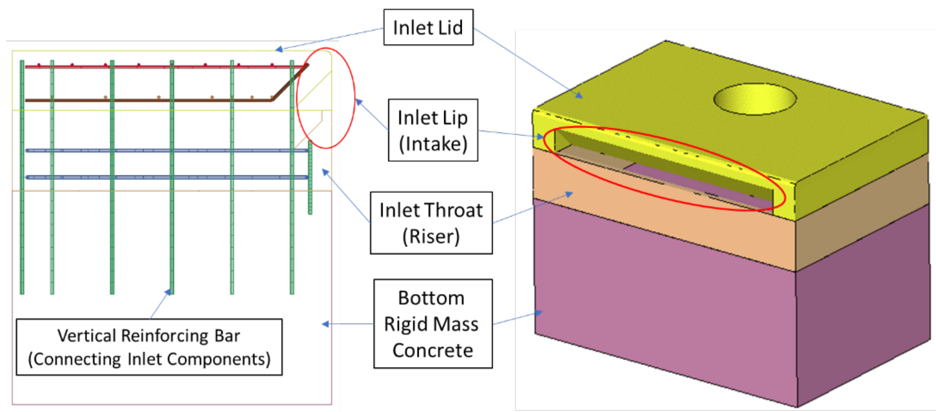


Figure 4.2. Finite Element Monolithic Inlet Model Components.

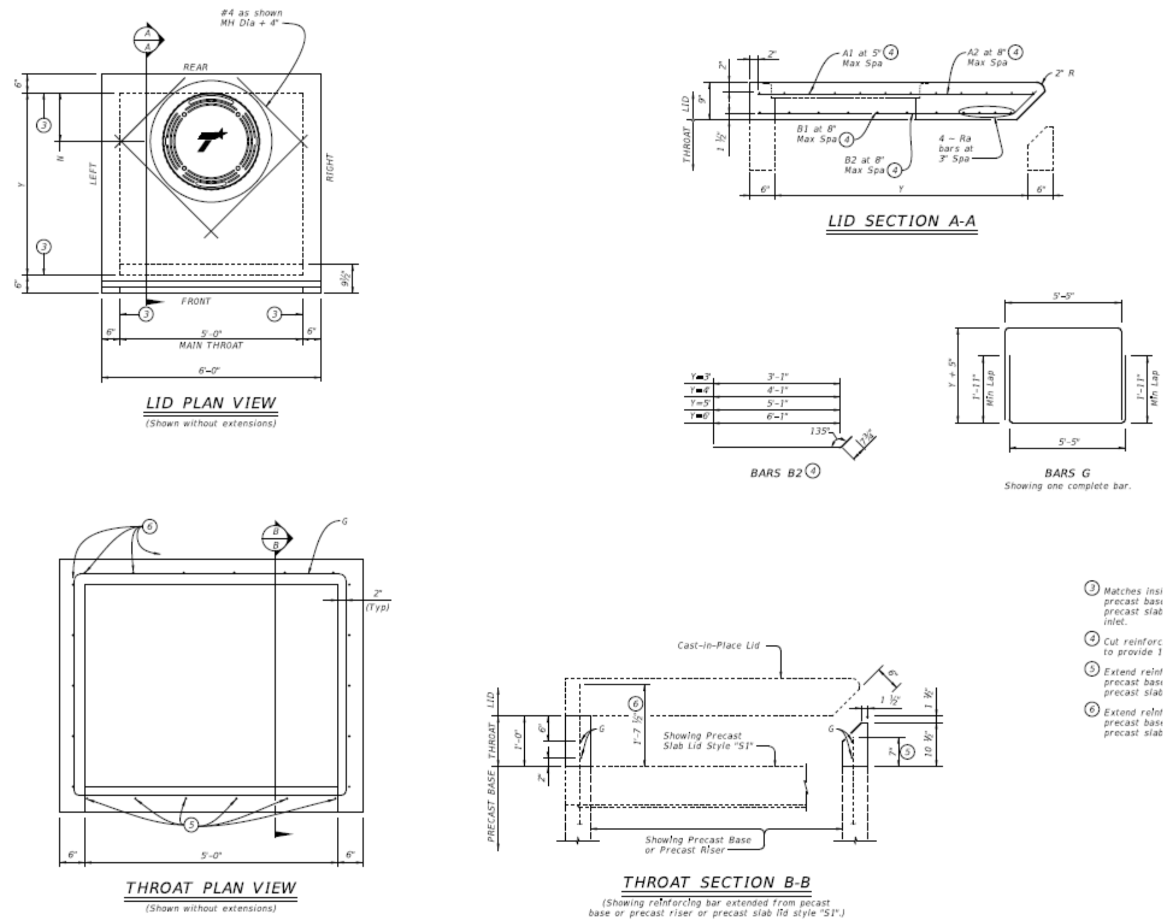


Figure 4.3. Example of Monolithic Inlet—TxDOT Cast-in-place Concrete Curb Inlet (8).

The design has two posts on the top of the inlet lid. The post details and anchorage details are shown in Figure 4.4. A 25.25-inch long W6x8.5 steel post was welded to a 0.75-inch thick 14-inch by 14-inch square steel plate. The post and baseplate set was anchored to the inlet lid with four of 5.5-inch long anchors, which was modeled as a beam element with corresponding material properties.

The monolithic inlet system was used for the preliminary impact simulations to determine the inlet offset distance from the parapet and the most critical impact point (CIP).

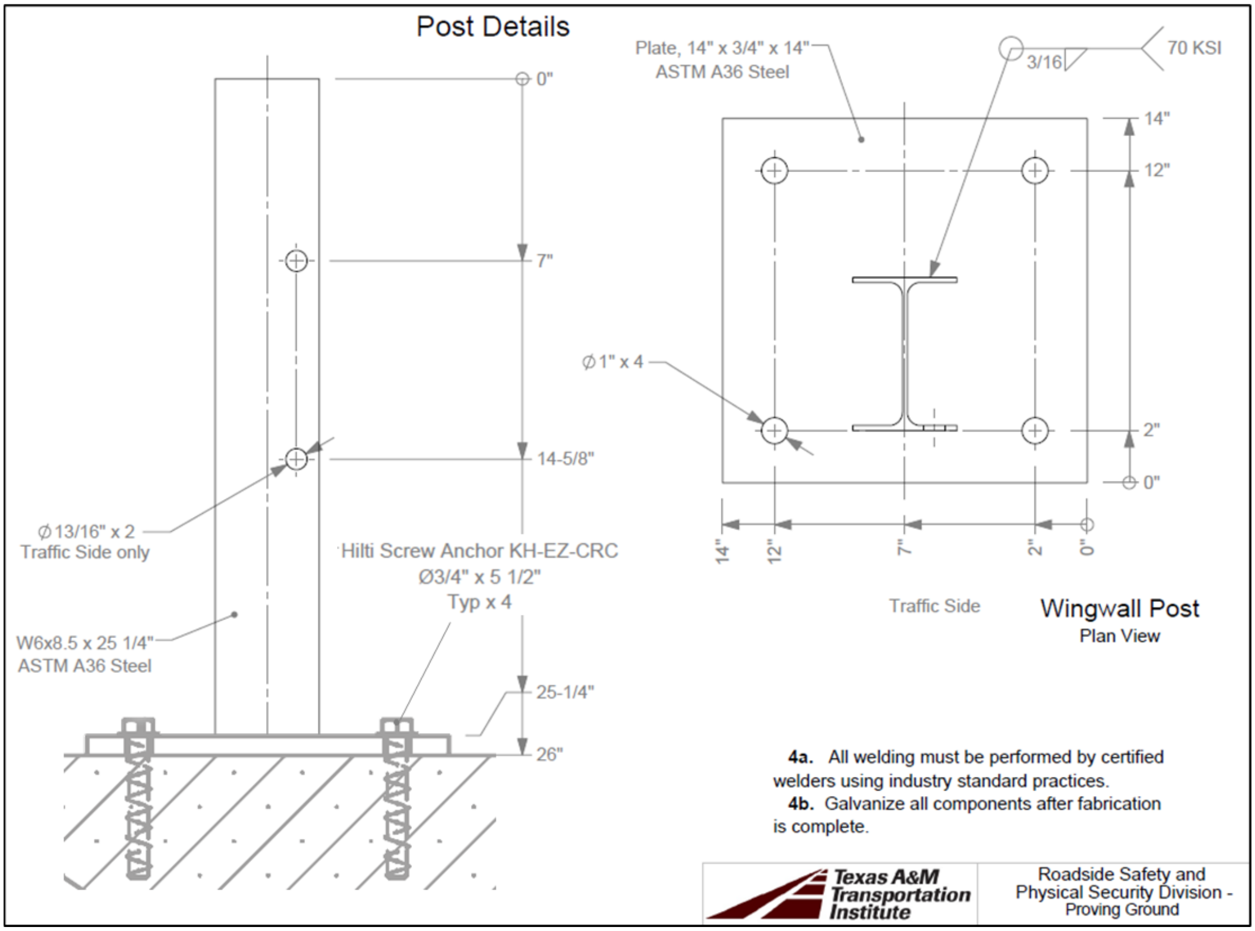


Figure 4.4. Post Mounting Details for FE Monolithic Inlet Model.

4.2.1. Different Offset Distance from Concrete Parapet

Based on the survey results presented in Chapter 2, a transition system with the monolithic inlet was modeled with three different inlet offset distance from the concrete parapet: 13.5 ft, 11 ft, and 40 inches (3.3 ft). The 13.5 ft offset distance was determined based on the median value of 180 inches (15 ft) from the survey and the constructability. The 11 ft was the minimum offset distance over 100-inch cases, and 40-inch (3.3 ft) was the maximum distance under 100-inch cases from the survey. Figure 4.6 shows the transition system with the monolithic inlet with 13.5 ft., 11 ft, and 3.3 ft offset distance from the concrete parapet.

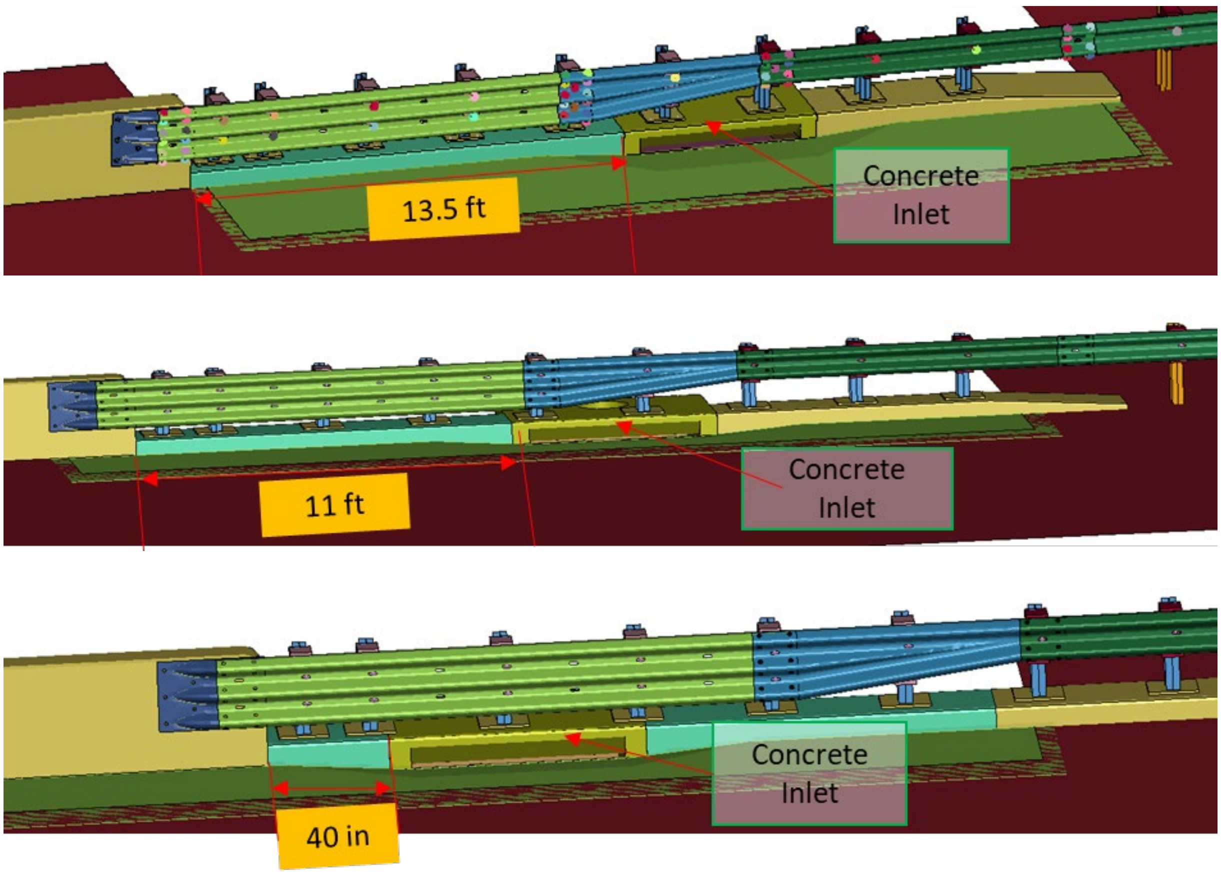
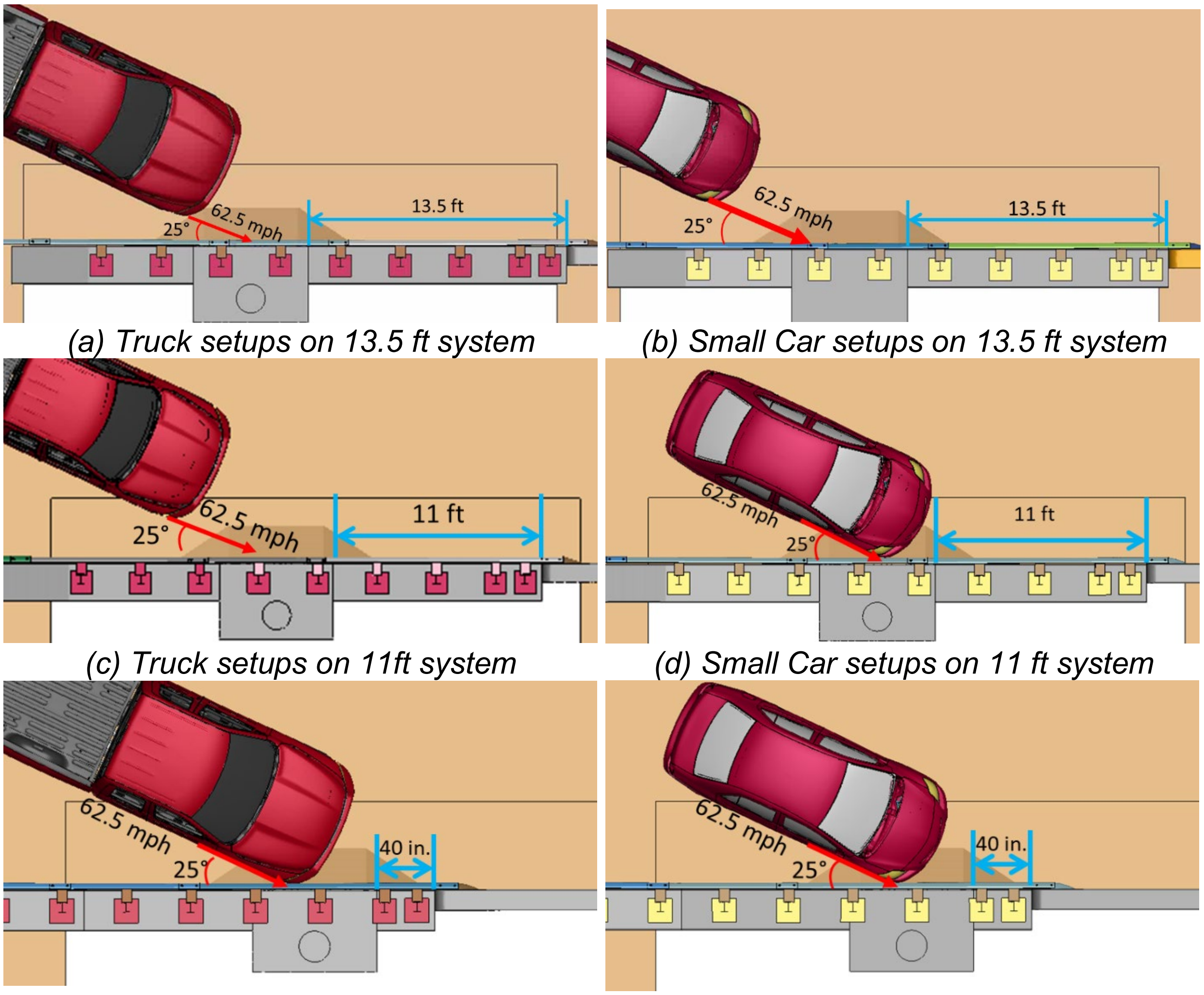


Figure 4.5. Transition Model with Monolithic Inlet with 13.5 ft, 11 ft, and 40 inches (3.3 ft) Offset Distance from Concrete Parapet.

By conducting predictive impact simulations, the most critical inlet placement was determined. The calibrated final vehicle models (Truck_V2 and Car_V2) were used to represent *MASH* Test 3-21 and 3-20 for the impact simulations. The vehicle models were set at initial angle and speed of 25 degrees and 62.5 mi/h, respectively, to represent *MASH* TL-3 test conditions. Figure 4.6 shows the vehicle setups on the transition system with the inlet placed 13.5 ft, 11 ft, and 40 inches (3.3 ft) away from the upstream end of concrete parapet. In this stage, the impact location was randomly placed near where the inlet placed.

To evaluate the criticality of the systems, the occupant risk factors were determined by TRAP and listed in Table 4.1. Based on the occupant risk factors, all systems satisfied *MASH* TL-3 evaluation criteria. The system with 40-inch inlet offset was determined as the most critical system for both vehicle with the highest roll-angles and second highest RAs. Therefore, in the following sections, the 40-inch inlet offset transition system was only investigated to determine the most critical impact point (CIP).



(a) *Truck setups on 13.5 ft system* (b) *Small Car setups on 13.5 ft system*

(c) *Truck setups on 11ft system* (d) *Small Car setups on 11 ft system*

(e) *Truck setups on 40-inch system* (f) *Small Car setups on 40-inch system*

Figure 4.6. Simulation Setups on Inlet at Transition System with 13.5 ft., 11 ft, and 40 inches (3.3 ft) of Inlet Offset Distance.

Table 4.1. Pickup Truck Occupant Risk Factors for Different Inlet Offset Distance.

Offset Distance		13.5 ft		11 ft		40-inch (3.3 ft)	
Vehicle type		2270P	1100C	2270P	1100C	2270P	1100C
Impact Velocity (ft/sec)	Longitudinal	21.3	28.9	21.3	25.3	20.7	25.3
	Lateral	26.9	32.8	28.5	31.2	29.2	31.8
Ridedown Acceleration (g)	Longitudinal	5.3	6.7	3.4	5.3	4.2	4.2
	Lateral	8.9	10.0	11.6	13.0	10.6	12.5
Max. Angles (degrees)	Roll	25.5	5.3	30.3	4.4	33.0	6.0
	Pitch	5.8	2.9	5.6	2.0	7.5	2.8
	Yaw	48.9	45.7	57.4	40.4	48.4	46.0

4.2.2. Investigation on Critical Impact Point (CIP)

To determine CIP, three different impact points was initially investigated: (a) the middle of the inlet (IP1); (b) downstream end of the inlet (IP2); and (c) upstream end of the inlet (IP3).

Table 4.2 shows the occupant risk factors for each impact point. All cases met *MASH* TL-3 evaluation criteria. IP3 was determined as the most critical case based on the high occupant risk factors such as the highest roll angle and second highest OIVs. Figure 4.7 shows the sequential images for the most critical case that impacting upstream end of the inlet (IP3) under *MASH* Test 3-21 conditions.

Table 4.2. Pickup Truck Occupant Risk Factors for Each Impact Point.

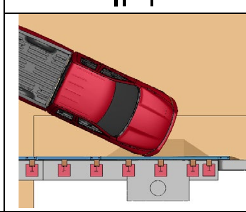
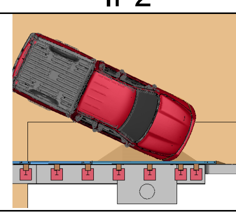
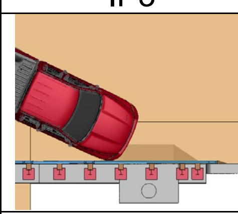
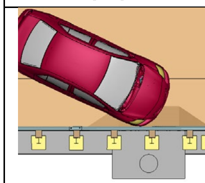
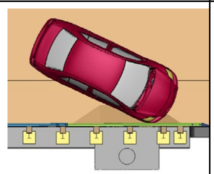
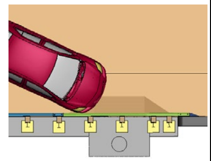
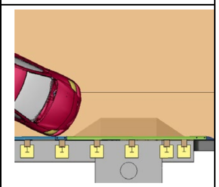
Impact Point		IP1	IP2	IP3
				
Impact Velocity (ft/sec)	Longitudinal	20.7	19.4	20.0
	Lateral	29.2	26.2	28.9
Ridedown Acceleration (g)	Longitudinal	4.2	6.7	5.1
	Lateral	10.6	11.9	10.1
Max. Angles (degrees)	Roll	33.0	25.2	33.5
	Pitch	7.5	9.4	6.9
	Yaw	48.4	45.4	53.1

Figure 4.7. Sequential Images of Truck Impacting the Transition System with 40-inch Inlet Offset at Upstream End of the Inlet (IP3).

Table 4.3 lists the occupant risk factors for passenger car impacting each impact point. For the small car, the lateral OIVs and RAs were gradually increased as the impacting points moved upstream. Therefore, an additional impact simulation was conducted at 3 ft upstream from the upstream end of the inlet (IP4) to determine whether the impact point need to be moved further upstream from IP3 to determine CIP. Based on all simulations including IP4, it was determined that IP3 is the CIP for the small car since the highest lateral RA and second highest OIVs was observed when the vehicle impacting IP3.Figure 4.8 shows the sequential images for the most critical case that impacting upstream end of the inlet (IP3) under *MASH* Test 3-20 condition.

Table 4.3. Passenger Car Occupant Risk Factors for Each Impact Point.

Impact Point		IP1	IP2	IP3	IP4
					
Impact Velocity (ft/sec)	Long.	25.3	26.2	25.3	24.6
	Lateral	31.8	30.2	32.5	33.1
Ridedown Acceleration (g)	Long,	4.2	6.1	4.3	7.7
	Lateral	12.4	7.7	14.3	10.5
Max. Angles (degrees)	Roll	6.0	6.5	2.6	5.6
	Pitch	2.8	3.4	2.8	3.2
	Yaw	46.0	44.5	36.0	39.2

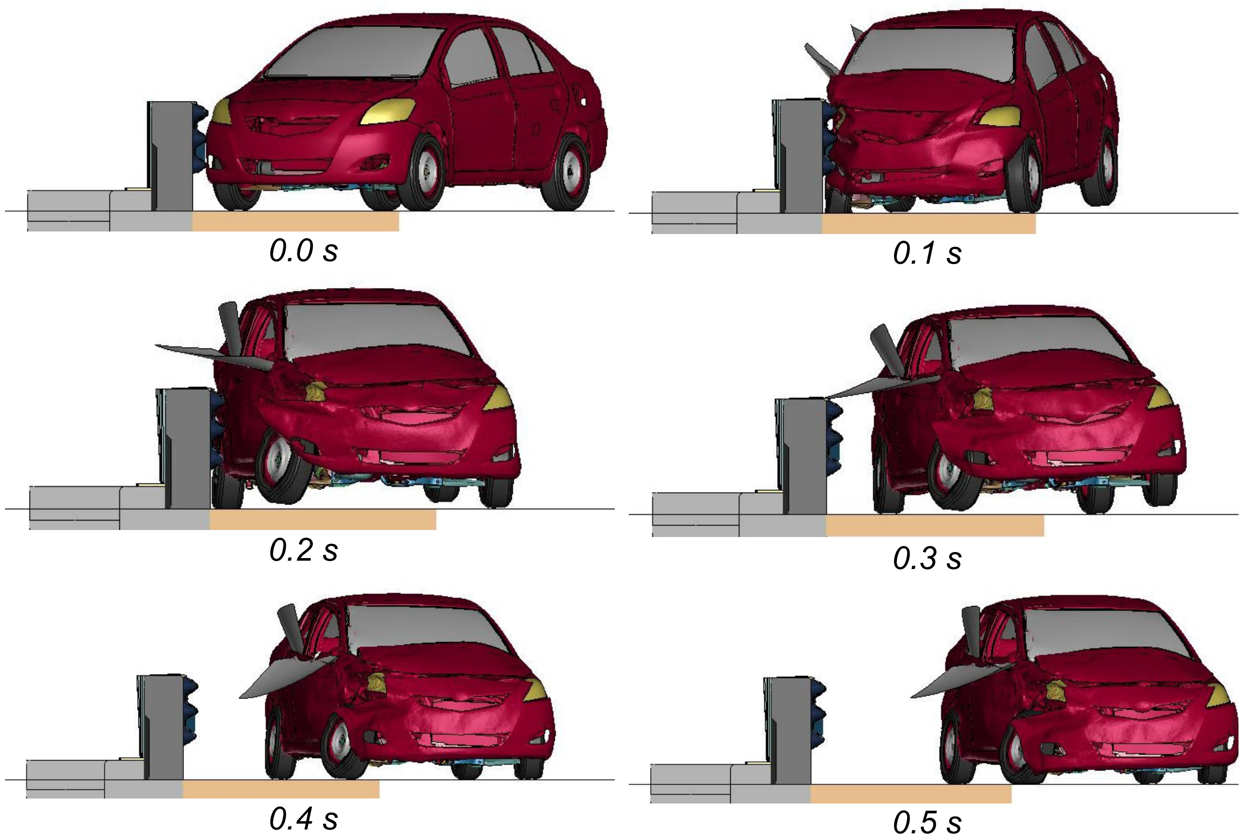
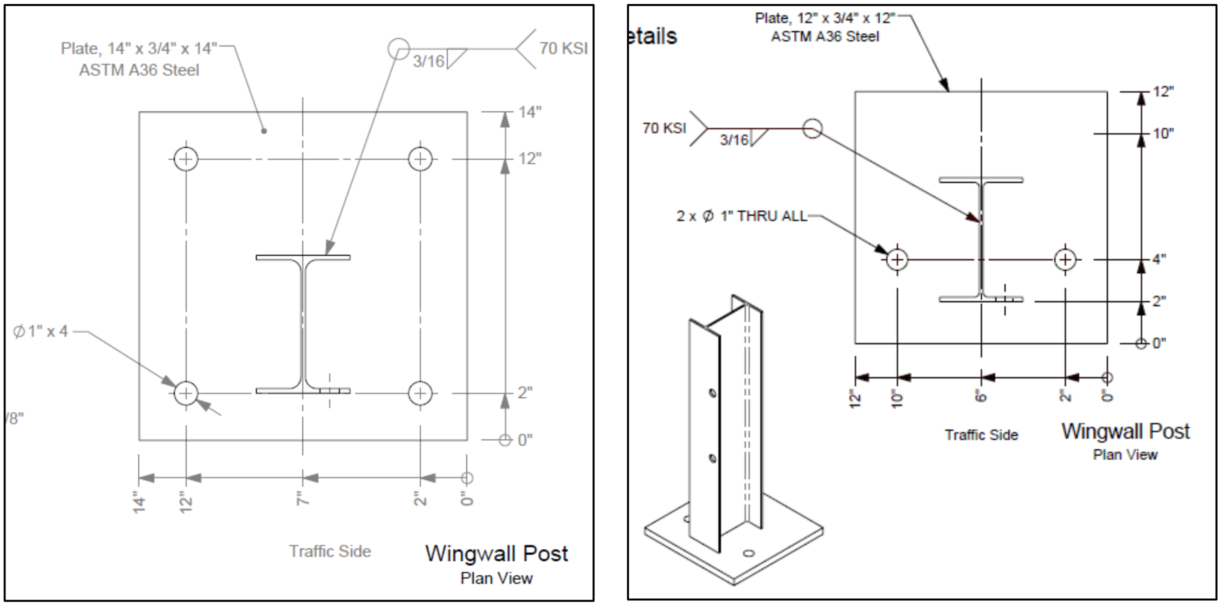


Figure 4.8. Sequential Images of Small Car Impacting the Transition System with 40-inch Inlet Offset at Upstream End of the Inlet (IP3).

4.2.3. Design Modification

After investigating the CIP of the transition with inlet system, a few constructability issues were arisen, and the issues led to the design modifications.

First, the number of anchors was reduced to minimize potential damage to the concrete and reinforcement of the inlet lid. Since the number of anchors was reduced to two, the baseplate size was also reduced, and the anchor locations were moved to ensure stable anchorage. Figure 4.9 shows before and after the changes. As shown in Figure 4.9(a), the initial design of a baseplate was 14-inch by 14-inch and used with four of 5½-inch long screw anchors. However, placing four of 5½inch long anchors on the inlet top has potential to occur concrete breakout under the inlet lip section which is thinner than 10-inch. Therefore, the modification was made to place the anchor to be located on the thicker area and to use less anchors as shown in Figure 4.9(b). The plate size was reduced to 12-inch by 12-inch, and two anchors were used 4-inch inside from the frontal edge of the plate.



(a) Initial Design *(b) Modified Design*

Figure 4.9. Details for Baseplate and Anchor Design Changes.

With the baseplate modification, the offset distance for the most critical case (40 inches off from the concrete parapet) was also changed to 48 inches to avoid a wingwall post and baseplate to be placed across the transition between the wingwall and inlet concrete blocks. If the baseplate sat across the wingwall and the inlet blocks, there would be a high potential to damage concrete cover or reinforcement. Figure 4.10 illustrates the offset changes and the post location. As the offset increased to 48 inches, two posts were placed on the inlet lid without a baseplate placing across the wingwall and inlet.

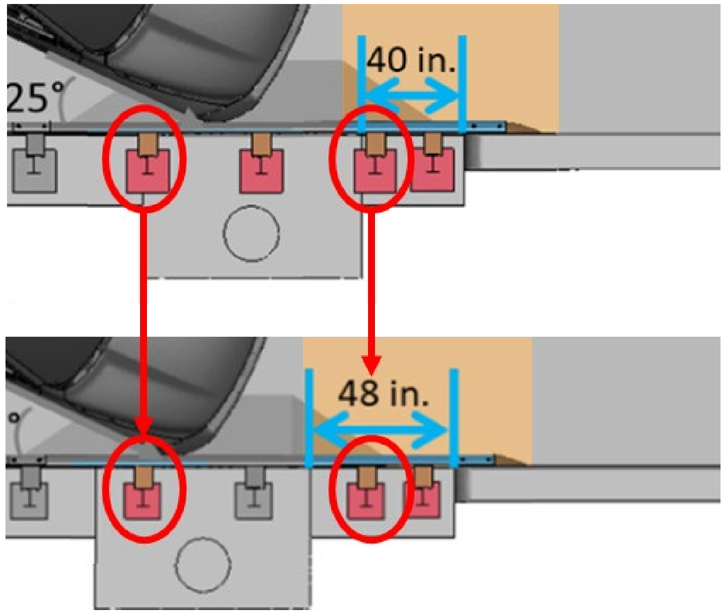
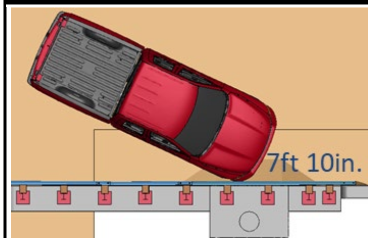
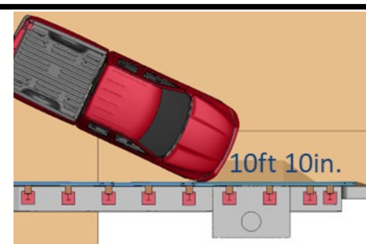


Figure 4.10. Inlet offset distance changes.

Since the minimum offset distance was changed, an additional simulation was performed to investigate the predictive result for a case with the anchors placed on the inlet lid lost their anchorage in such cases: anchor pullout, anchor failure, or concrete breakout. To represent the worst case that all four anchors lost their anchorage, the anchors were removed from the inlet lid section.

Table 4.4 lists the occupant risk factors under *MASH* Test 3-21 conditions for the transition system with 48-inch inlet offset. As IP1 was determined as the second critical case in the previous section, simulations on IP1 were also conducted as well as IP3, which was determined as the most critical case. Based on the predictive simulations, the most critical case is the truck impacting the upstream end of the inlet (IP3) without anchors on the inlet section. RA value for the case is 20.5 g which is 0.01 g higher than *MASH* limit of 20.49 g. As aforementioned, this is the worst-case scenario that all four anchors failed during an impact test. The researchers recommended IP3 case (the most critical case) for the full-scale crashworthiness test.

Table 4.4. Occupant Risk Factors for Truck Impacting Transition System with 48-inch Inlet Offset.

Impact Point		IP1		IP3	
					
System Variation		w/ anchor	w/o anchor	w/ anchor	w/o anchor
Impact Velocity (ft/sec)	Long.	20.7	32.2	20.0	23.0
	Lateral	28.9	29.9	28.9	22.6
Ridedown Acceleration (g)	Long.	4.4	14.9	3.0	20.5
	Lateral	12.9	10.7	10.3	17.1
Max. Angles (degrees)	Roll	31.0	20.5	52.1	38.5
	Pitch	6.4	13.7	28.1	19.6
	Yaw	46.8	58.3	65.1	68.5

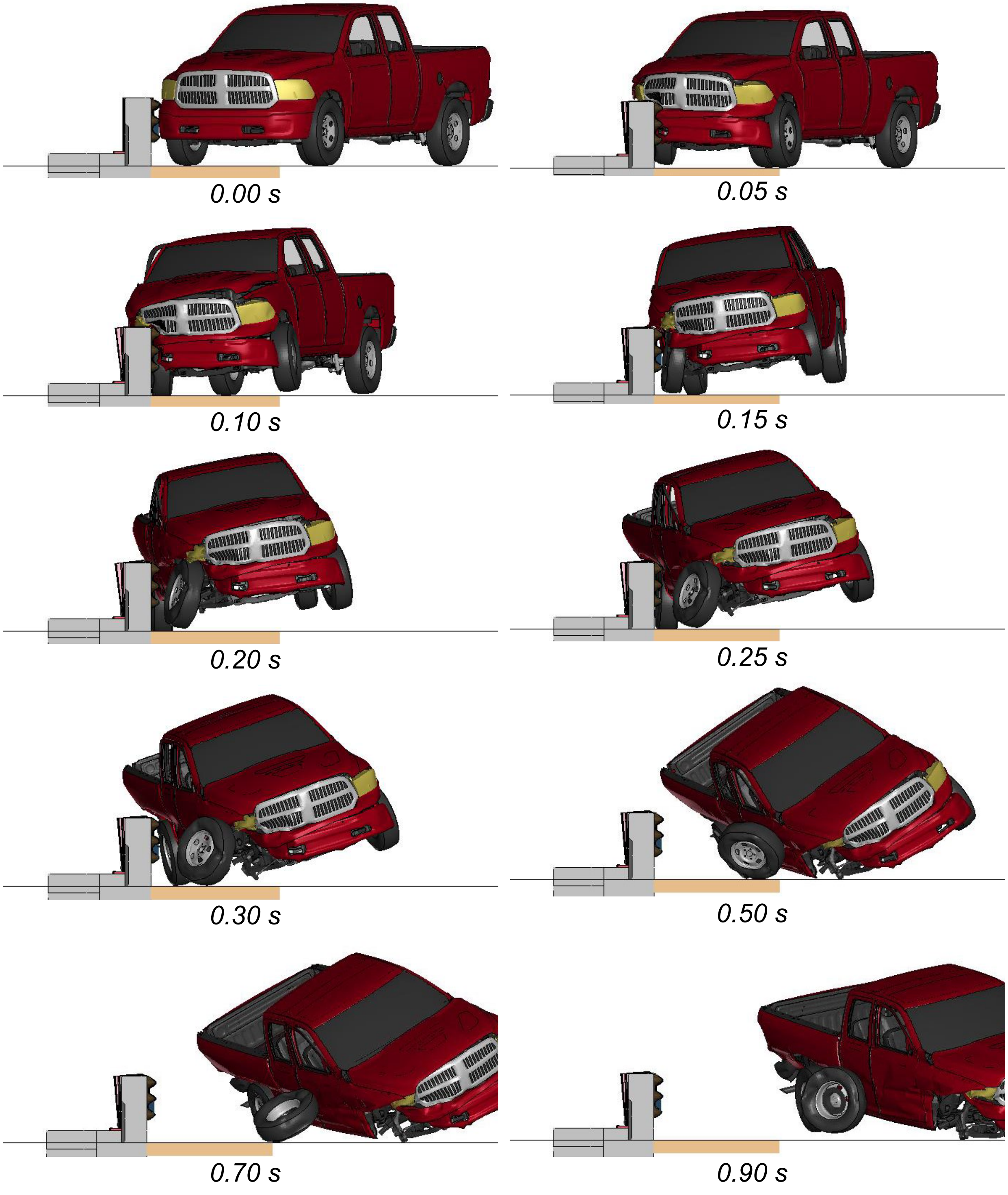
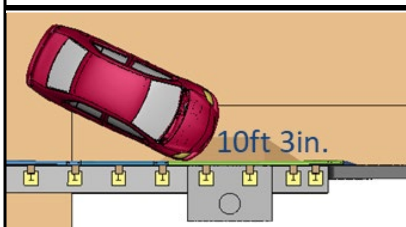


Figure 4.11. Sequential Images of Truck Impacting the Transition System with 48-inch Inlet Offset at Upstream End of the Inlet (IP3).

Table 4.5 lists the occupant risk factors under *MASH* Test 3-21 conditions for the transition system with 48-inch inlet offset. As IP1 was determined as the second critical case in the previous section, simulations on IP1 were also conducted as well as IP3, which was determined as the most critical case. Based on the predictive simulations, the most critical case is the truck impacting the upstream end of the inlet (IP3) without anchors on the inlet section. RA value for the case is 20.5 g which is 0.01 g higher than *MASH* limit of 20.49 g. As aforementioned, this is the worst-case scenario that all four anchors failed during an impact test. Although the worst-case could not meet *MASH* TL-3 evaluation criteria, the researchers recommended IP3 case for the full-scale crashworthiness test.

Table 4.5. Occupant Risk Factors for Small Car Impacting Transition System with 48-inch Inlet Offset.

Impact Point		IP3		IP 4	
					
System Variation		w/ anchor	w/o anchor	w/ anchor	w/o anchor
Impact Velocity (ft/sec)	Long.	24.9	24.3	25.6	20.7
	Lateral	32.2	28.5	32.2	28.5
Ridedown Acceleration (g)	Long.	4.1	11.3	3.4	6.7
	Lateral	13.1	18.0	10.4	11.3
Max. Angles (degrees)	Roll	4.3	7.6	4.8	6.9
	Pitch	2.8	3.5	3.3	2.5
	Yaw	36.8	44.6	39.6	37.7

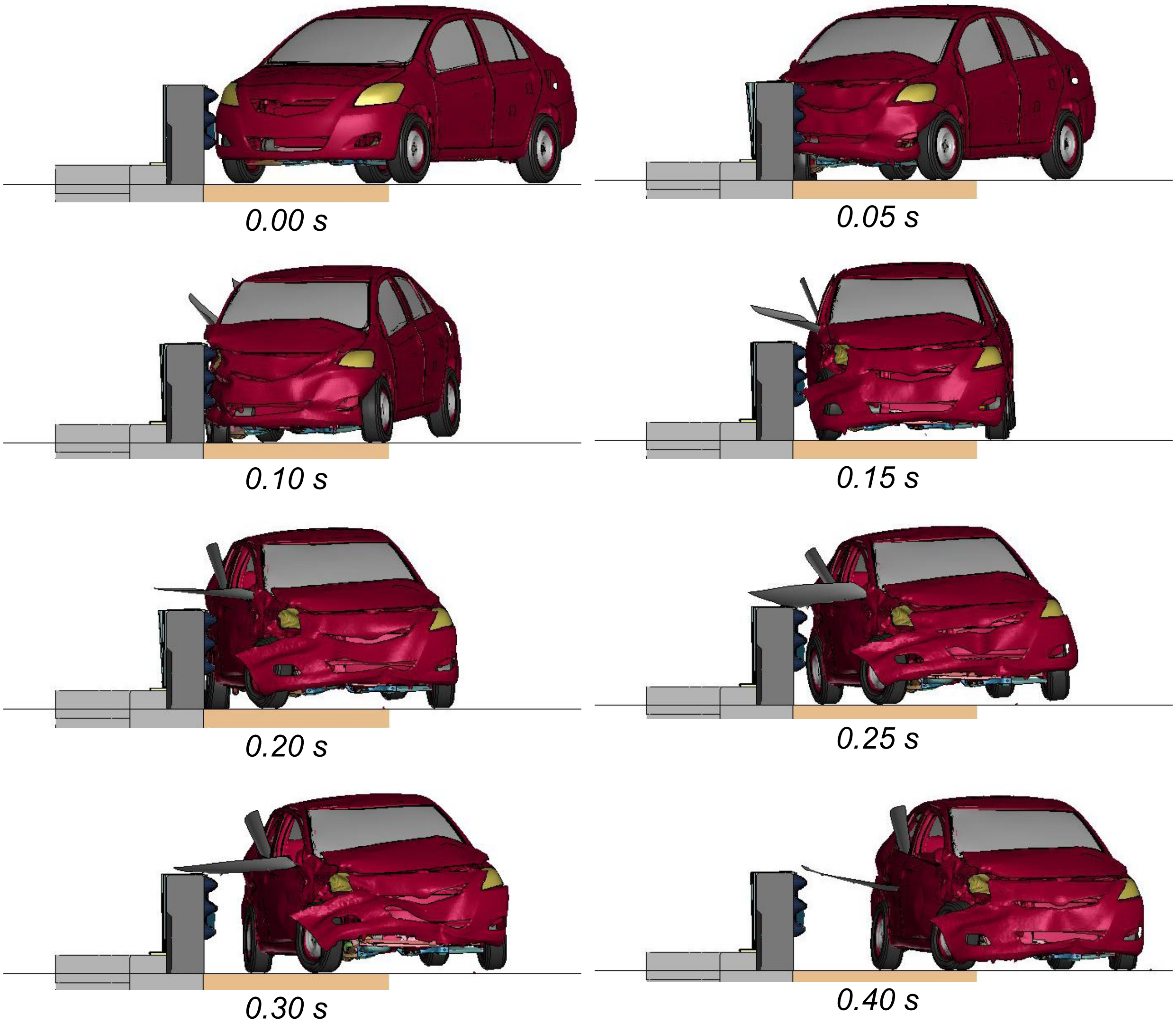


Figure 4.12. Sequential Images of Small Car Impacting the Transition System with 48-inch Inlet Offset at Upstream End of the Inlet (IP3).

4.3. TRANSITION SYSTEM WITH ARTICULATED INLET

The articulated inlet model was developed to represent a type of precast concrete curb inlet as shown in Figure 4.13. For the model, all details except the vertical reinforcement connecting the inlet components from top to bottom were the same as the monolithic inlet model.

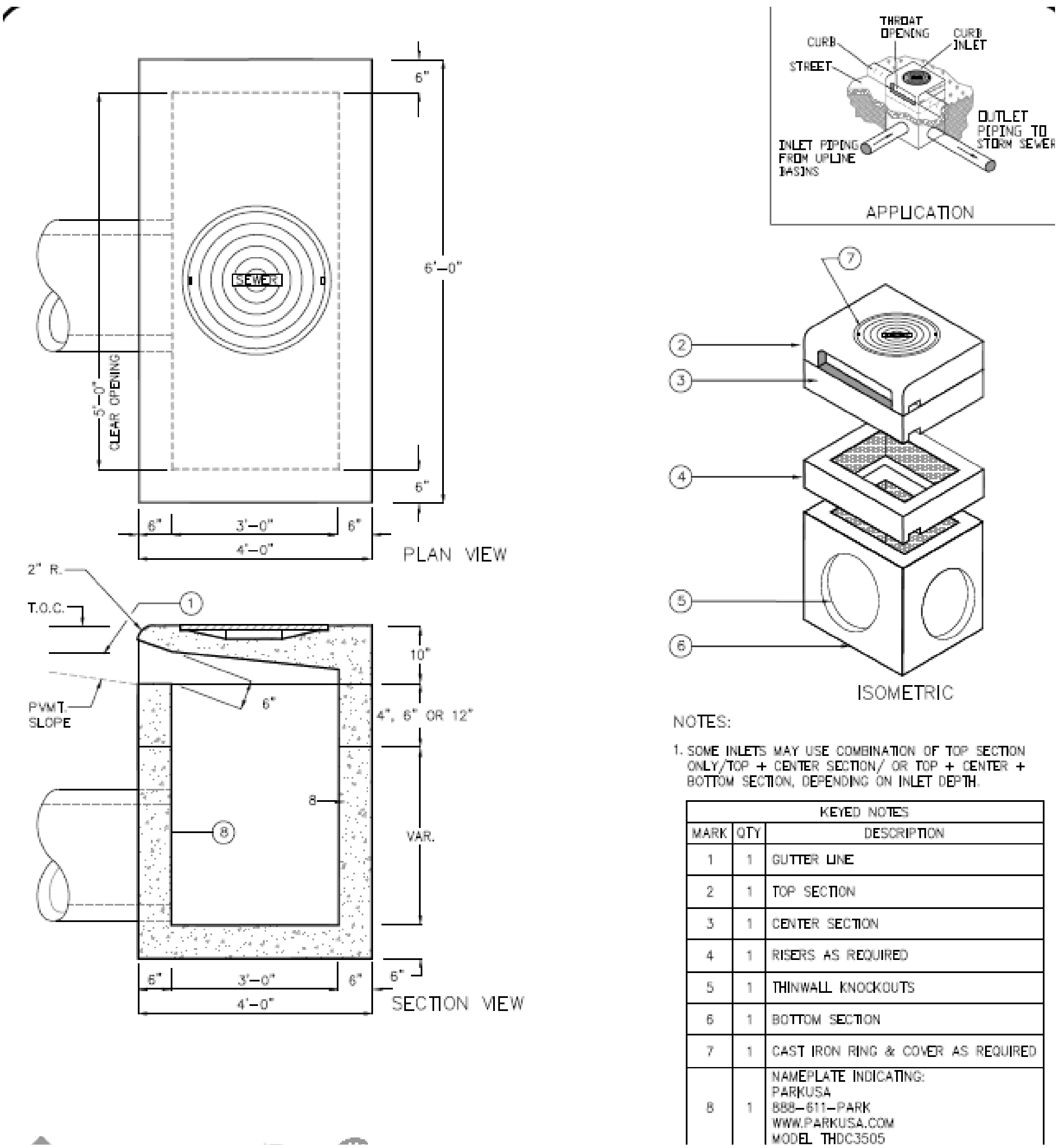


Figure 4.13. Example of Articulated Inlet—TYPE-C Precast Concrete Curb Inlet (*9*).

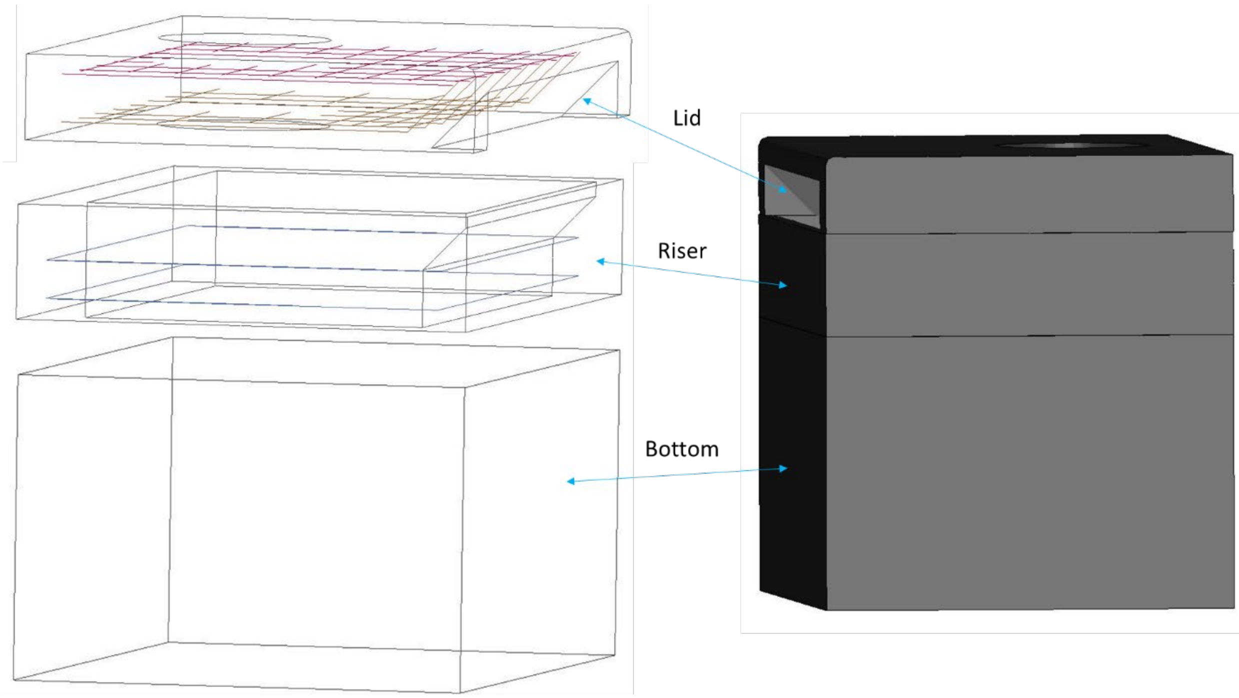


Figure 4.14. Articulated Inlet Components.

Based on the computational investigation on the transition system with the monolithic inlet, a set of critical cases were simulated using the transition system with an articulated inlet model. Therefore, the simulations with articulated inlet system were performed to impact only at IP3. The transition systems with 13.5 ft and 4 ft inlet offsets were investigated. Table 4.6 lists the occupant risk factors obtained from each simulation. For both truck (2270P) and small car (1100C), the most critical offset distance was determined as the system with 4 ft inlet offset distance. Especially for the small car the RA value acceded the recommended value of 15 g for *MASH* TL-3 evaluation criteria.

Table 4.6. Occupant Risk Factors for Truck and Small Car Simulations on Transition Systems with 13.5 ft and 4 ft Articulated Inlet Offset Distance.

Offset Distance		13.5 ft		4 ft	
Vehicle type		**2270P**	**1100C**	**2270P**	**1100C**
Impact Point		IP3 (near the upstream end of the inlet)			
Impact Velocity (ft/sec)	Longitudinal	22.0	23.0	20.0	24.6
	Lateral	27.2	30.5	28.9	2.1
Ridedown Acceleration (g)	Longitudinal	4.5	9.3	3.2	4.2
	Lateral	9.6	7.4	9.9	12.1
Max. Angles (degrees)	Roll	40.6	8.0	34.8	4.1
	Pitch	4.9	3.5	6.5	3.2
	Yaw	43.0	32.5	49.9	36.7

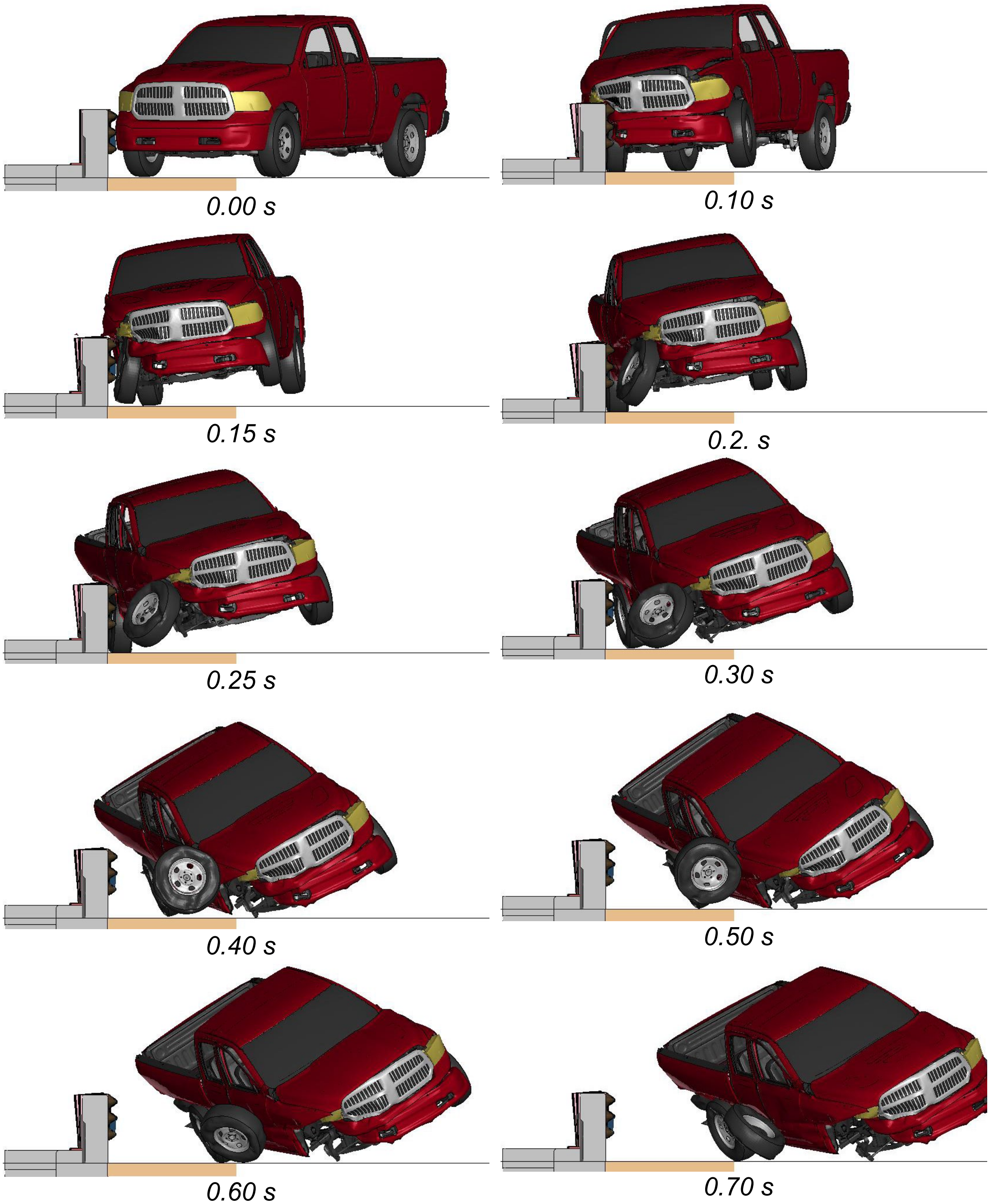


Figure 4.15. Sequential Images of Truck Impacting the Transition System with 48-inch Articulated Inlet Offset at Upstream End of the Inlet (IP3).

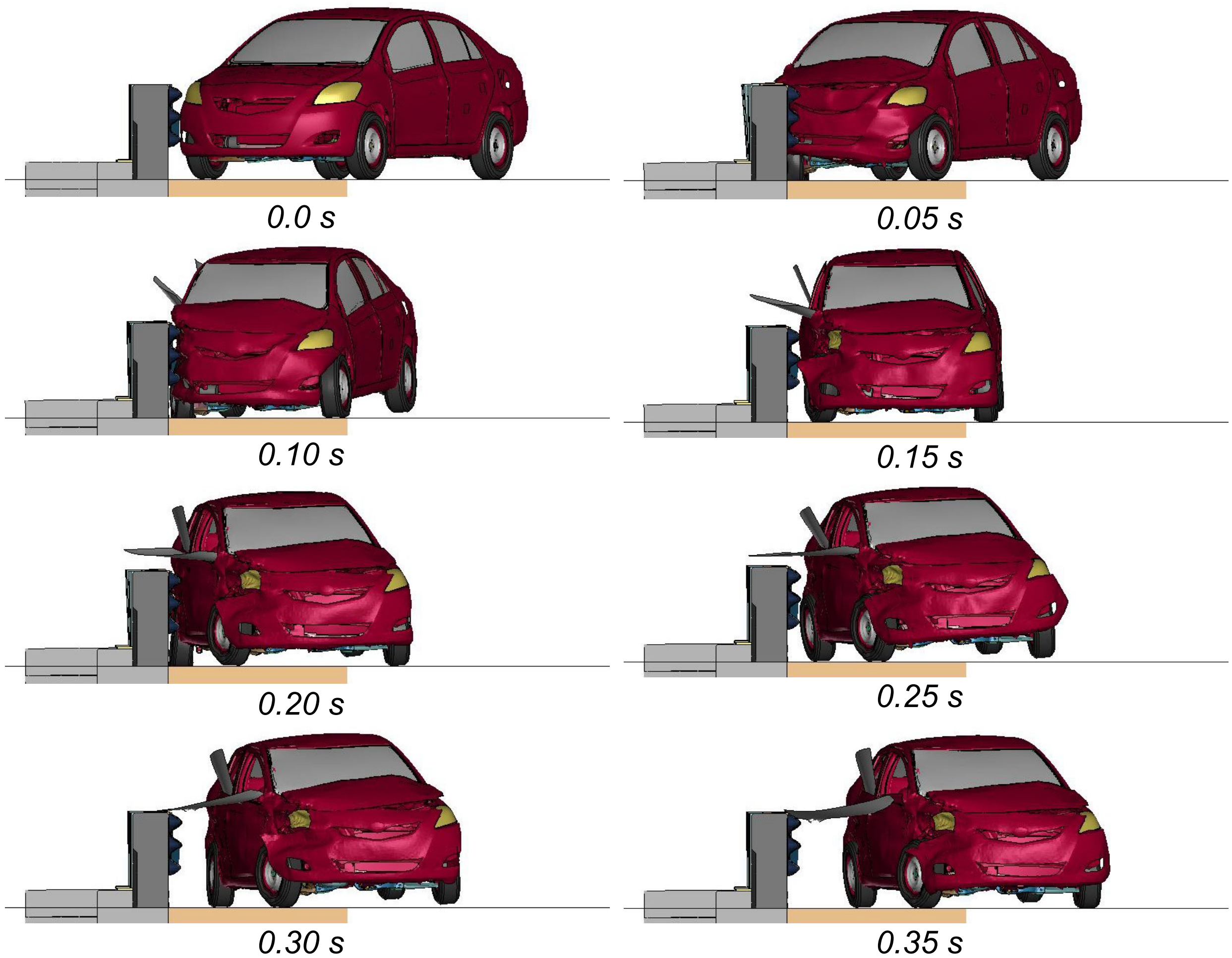


Figure 4.16. Sequential Images of Small Car Impacting the Transition System with 48-inch Inlet Offset at Upstream End of the Inlet (IP3).

4.4. SUMMARY AND CONCLUSION

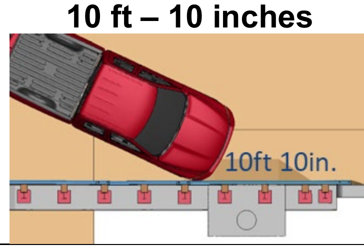
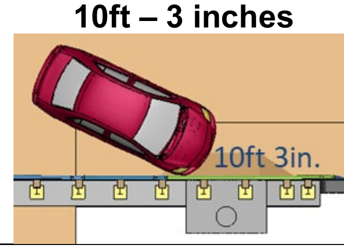
In this chapter, the transition system designs with a monolithic inlet and an articulated inlet were investigated. The primary objective of the computational analysis was to assess the crashworthiness of these transition designs. For this research, the wingwall surface mounted post system utilized in TxDOT wingwall transition (*5*) was adopted. Initially, a preliminary transition design was proposed and then modeled to conduct impact simulations using the LS-DYNA software.

To identify the most critical location of the inlet, three different inlet offset distances from the concrete parapet were considered for the impact simulations. The simulations aimed to assess the structural performance of the system and the vehicular behavior. The monolithic inlet model was used in these simulations, investigating three different impact points. Ultimately, it was determined that the case with a 40-inch inlet offset distance and the vehicle impacting the upstream end of the inlet presented the most critical case. However, while investigating the transition system, certain constructability issues were encountered and prompted modifications to be made to the transition system's design in order to address the issues.

Subsequently, the articulated inlet system was employed to identify the most critical case for the modified transition system. Similar impact simulations were conducted, revealing that the most critical case entailed a vehicle impacting the upstream end of the inlet with 48-inch offset. Table 4.7 provides a comprehensive list of the occupant risk factors associated with the most critical case for each vehicle type.

Since the most critical case met the *MASH* TL-3 evaluation criteria, it was recommended that the transition system incorporating this specific case be subject to a full-scale crash test. The test would provide further validation and verification of the system's crashworthiness and its ability to satisfy the *MASH* TL-3 criteria.

Table 4.7. Recommended Transition System and Analysis Results for *MASH* Tests 3-21 and 3-20.

<table>
<tr><th colspan="2">Vehicle type</th><th>2270P</th><th>1100C</th></tr>
<tr><td colspan="2">Impact Point Distance from Parapet for Transition System with 48-inch Inlet Offset</td><td>10 ft – 10 inches
</td><td>10ft – 3 inches
</td></tr>
<tr><td rowspan="2">Impact Velocity (ft/sec)</td><td>Longitudinal</td><td>20.0</td><td>24.6</td></tr>
<tr><td>Lateral</td><td>28.9</td><td>32.1</td></tr>
<tr><td rowspan="2">Ridedown Acceleration (g)</td><td>Longitudinal</td><td>-3.2</td><td>-4.2</td></tr>
<tr><td>Lateral</td><td>-9.9</td><td>-12.1</td></tr>
<tr><td rowspan="3">Max. Angles (degrees)</td><td>Roll</td><td>34.8</td><td>4.1</td></tr>
<tr><td>Pitch</td><td>-6.5</td><td>-3.2</td></tr>
<tr><td>Yaw</td><td>-49.9</td><td>-36.7</td></tr>
</table>

Chapter 5. SYSTEM DETAILS

5.1. TEST ARTICLE AND INSTALLATION DETAILS

Figure 5.1 presents the overall information on the Transition with Storm Drain Inlet, and Figure 5.2 thru Figure 5.7 provide photographs of the installation. Appendix A provides further details on the Transition with Storm Drain Inlet. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground. Construction was performed by MBC Management Inc. and supervised by TTI Proving Ground personnel.

5.2. DESIGN MODIFICATIONS DURING TESTS

No modifications were made to the installation during the testing phase.

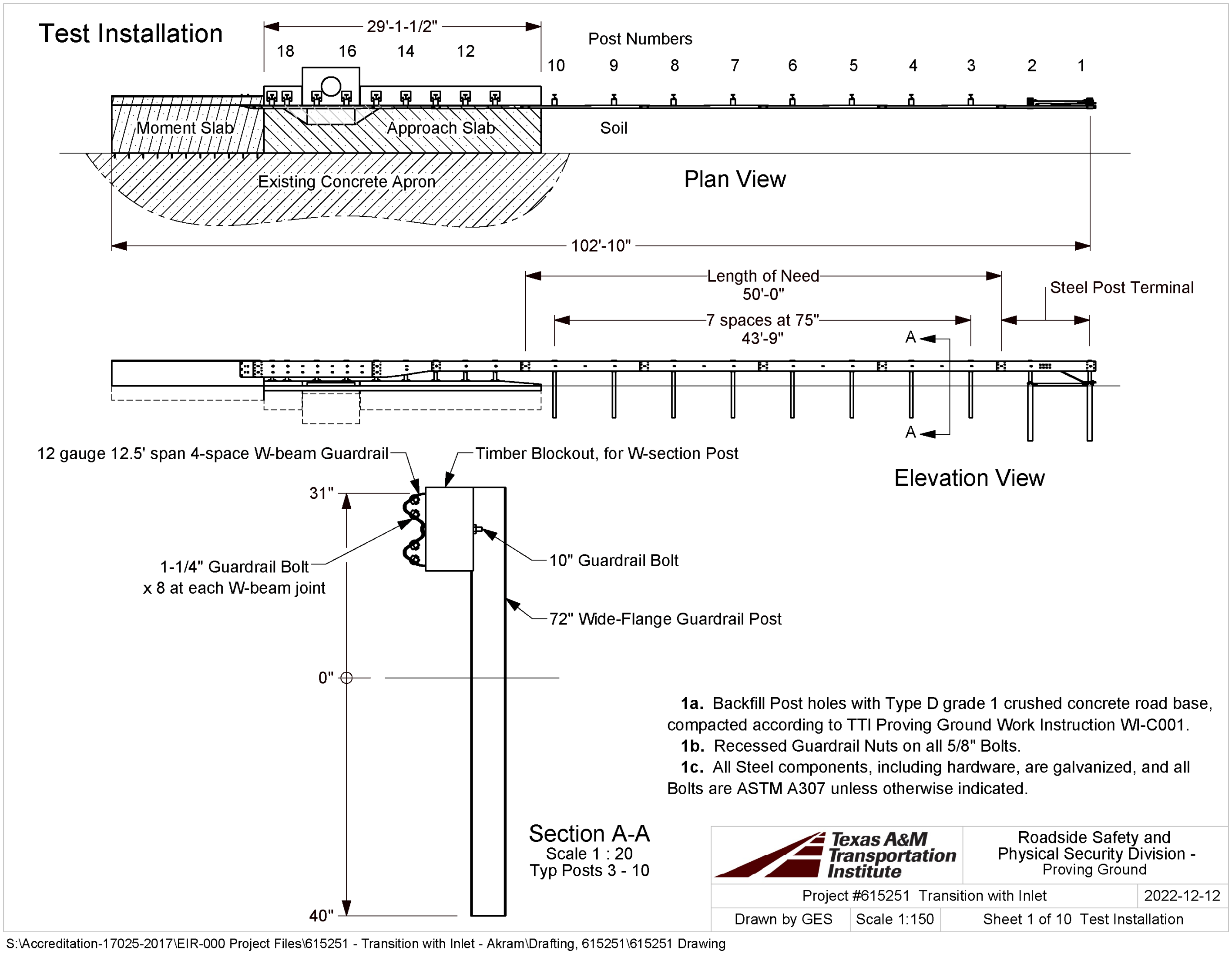


Figure 5.1. Details of Transition with Storm Drain Inlet.

Figure 5.2. Downstream View of the Transition with Storm Drain Inlet Prior to Testing.

Figure 5.3. Transition with Storm Drain Inlet Prior to Testing.

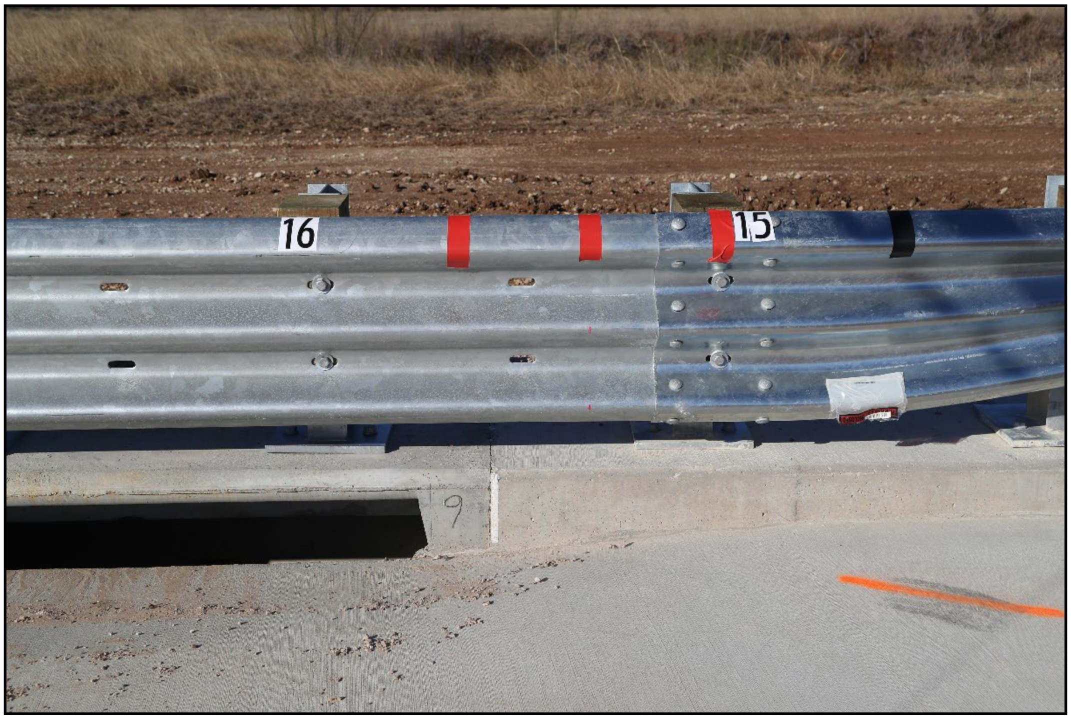


Figure 5.4. Transition with Storm Drain Inlet at Impact Prior to Testing.

Figure 5.5. Thrie Beam to Parapet Connection for the Transition with Storm Drain Inlet Prior to Testing.

Figure 5.6. Storm Drain Inlet Location Prior to Testing.

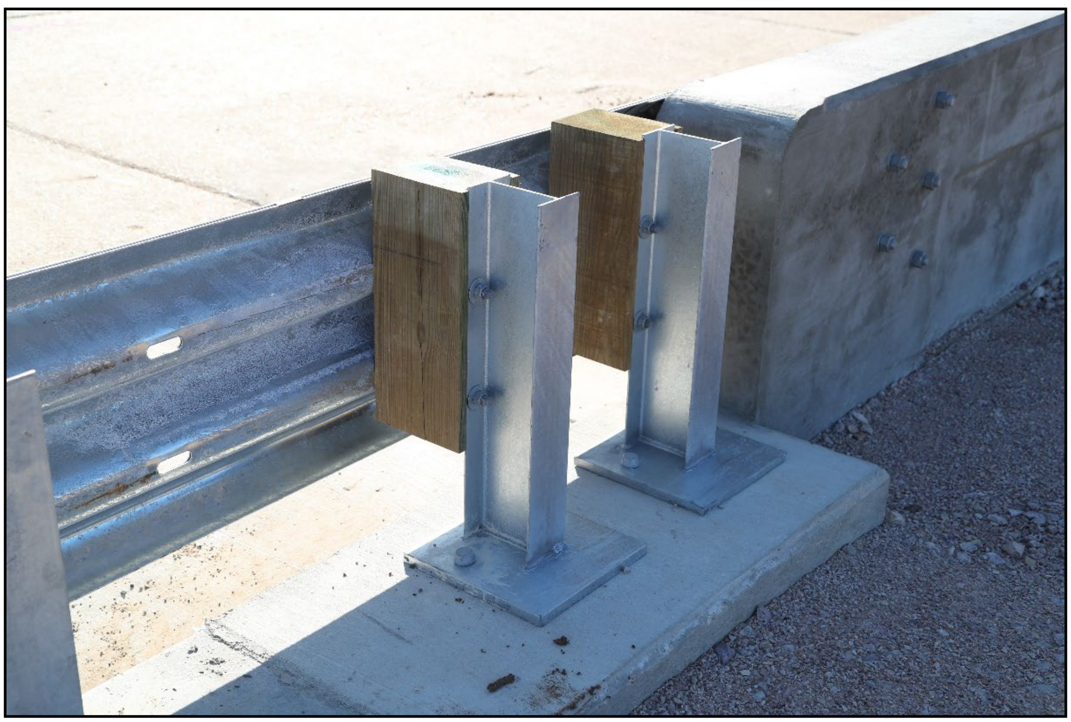


Figure 5.7. Field Side view of the Transition with Storm Drain Inlet Prior to Testing.

5.3. MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to install/construct the Transition with Storm Drain Inlet. Table 5.1 shows the average compressive strengths of the concrete on the day of the test (2023-01-26).

Table 5.1. Concrete Strength.

Location	Design Strength (psi)	Avg. Strength (psi)	Age (days)	Detailed Location
Moment Slab and Parapet	3600	3690	27	100% of slab and parapet
Wall	3600	3933	22	100% of wall
Parapet and Approach Slab	3600	3700	34	100% of parapet and approach slab

5.4. SOIL CONDITIONS

The test installation was installed in standard soil meeting Type 1 Grade D of AASHTO standard specification M147-17 “Materials for Aggregate and Soil Aggregate Subbase, Base, and Surface Courses.”

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the Transition with Storm Drain Inlet for full-scale crash testing, two 6-ft long W6×16 posts were installed in the immediate vicinity of the Transition with Storm Drain Inlet using the same fill materials and installation procedures used in the test installation and the standard dynamic test.

On the day of Test 3-21, 2023-01-26, loads on the post at deflections were as follows: the backfill material in which the Transition with Storm Drain Inlet was installed met minimum *MASH* requirements for soil strength.

Table 5.2. Soil Strength.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4420	6645
10	4981	7606
15	5282	8242

Chapter 6. TEST REQUIREMENTS AND EVALUATION CRITERIA

6.1. CRASH TEST PERFORMED/MATRIX

Table 6.1 shows the test conditions and evaluation criteria for *MASH* TL-3 for Longitudinal Barrier. The target critical impact point (CIP) for the test was determined using the information provided in *MASH* Section 2.2.1 and Section 2.3.2 and as a result of simulation findings. Figure 6.1 shows the target CIP for the *MASH* TL-3 test on the Transition with Storm Drain Inlet.

Table 6.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-3 Longitudinal Barrier.

Test Designation	Test Vehicle	Impact Speed	Impact Angle	Evaluation Criteria
3-21	2270P	62 mi/h	25º	A, D, F, H, I

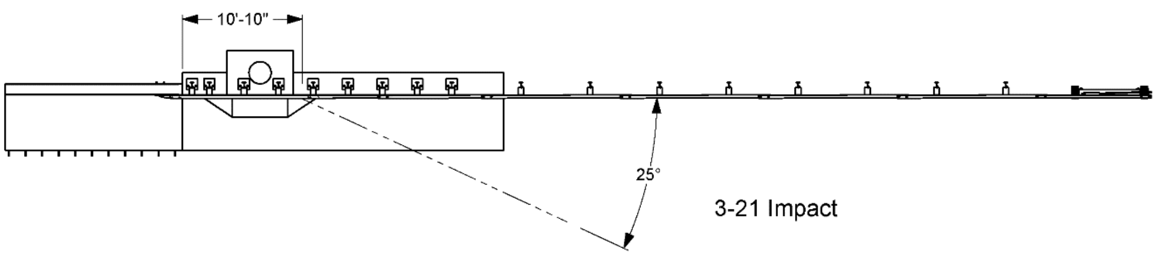


Figure 6.1. Target CIP for *MASH* TL-3 Tests on Transition with Storm Drain Inlet.

The crash tests and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 7 presents brief descriptions of these procedures.

6.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2.2 and 5.1 of *MASH* were used to evaluate the crash test reported herein. Table 6.1 lists the test conditions and evaluation criteria required for *MASH* TL-3, and Table 6.2 provides detailed information on the evaluation criteria.

Table 6.2. Evaluation Criteria Required for *MASH* Testing.

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

Chapter 7. TEST CONDITIONS

7.1. TEST FACILITY

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

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

7.2. VEHICLE TOW AND GUIDANCE SYSTEM

For the testing utilizing the 2270P vehicles, each was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point and through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2:1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released and ran unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site.

7.3. DATA ACQUISITION SYSTEMS

7.3.1. Vehicle Instrumentation and Data Processing

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

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

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

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

7.3.2. Anthropomorphic Dummy Instrumentation

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

7.3.3. Photographic Instrumentation Data Processing

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

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

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

Chapter 8. *MASH* TEST 3-21 (CRASH TEST 615251-01-1)

8.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 8.1 for details of *MASH* impact conditions for this test and Table 8.2 for the exit parameters. Figure 8.1 and Figure 8.2 depict the target impact setup.

Table 8.1. Impact Conditions for *MASH TEST 3-21,* Crash Test 615251-01-1.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5 mi/h	62.4
Impact Angle (deg)	25	±1.5°	25.1
Impact Severity (kip-ft)	106	≥106 kip-ft	117.7
Impact Location	130 inches upstream from upstream edge of concrete parapet	±12 inches	130.6 inches upstream from upstream edge of concrete parapet.

Table 8.2. Exit Parameters for *MASH TEST 3-21,* Crash Test 615251-01-1.

Exit Parameter	Measured
Speed (mi/h)	45.1
Trajectory (deg)	9.1
Heading (deg)	16.0
Brakes applied post impact (s)	3.6
Vehicle at rest position	214 ft downstream of impact point 17 ft to the traffic side 5° right
Comments:	Vehicle remained upright and stable. Vehicle crossed the exit box at 39 ft downstream from loss of contact.

[a] Not less than 32.8 ft downstream from loss of contact for cars and pickups is optimal.

Figure 8.1. Transition with Storm Drain Inlet/Test Vehicle Geometrics for Test 615251-01-1.

Figure 8.2. Transition with Storm Drain Inlet/Test Vehicle Impact Location 615251-01-1.

8.2. WEATHER CONDITIONS

Table 8.3 provides the weather conditions for 615251-01-1.

Table 8.3. Weather Conditions 615251-01-1.

Date of Test	2023-01-26 AM
Wind Speed (mi/h)	6
Wind Direction (deg)	333
Temperature (°F)	49
Relative Humidity (%)	63
Vehicle Traveling (deg)	195

8.3. TEST VEHICLE

Figure 8.3 and Figure 8.4 show the 2018 RAM 1500 used for the crash test. Table 8.4 shows the vehicle measurements. Figure C.1 in Appendix C.1 gives additional dimensions and information on the vehicle.

Figure 8.3. Impact Side of Test Vehicle before Test 615251-01-1.

Figure 8.4. Opposite Impact Side of Test Vehicle before Test 615251-01-1.

Table 8.4. Vehicle Measurements for Test 615251-01-1.

Test Parameter	***MASH***	**Allowed Tolerance**	**Measured**
Dummy (if applicable)[a] (lb)	165	N/A	N/A
Inertial Weight (lb)	5000	±110	5024
Gross Static[a] (lb)	5000	±110	5024
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40.0
Overall Length (inches)	237	±13	227.5
Overall Width (inches)	78	±2	78.5
Hood Height (inches)	43	±4	46.0
Track Width[b] (inches)	67	±1.5	68.25
CG aft of Front Axle[c] (inches)	63	±4	59.7
CG above Ground[c,d] (inches)	28	28	28.6

Note: N/A = not applicable; CG = center of gravity.
[a] If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.
[b] Average of front and rear axles.
[c] For test inertial mass.
[d] 2270P vehicle must meet minimum CG height requirement.

8.4. TEST DESCRIPTION

Table 8.5 lists events that occurred during Test 615251-01-1. Figures C.4, C.5, and C.6 in Appendix C.2 present sequential photographs during the test.

Table 8.5. Events during Test 615251-01-1.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0125	Post 16 began to lean toward field side
0.0150	Post 15 and 17 began to lean toward field side
0.0275	Inlet top cover began to slide toward field side
0.0280	Vehicle began to redirect
0.0330	Passenger side front tire contacted traffic side of inlet cover
0.1070	Drivers side front tire lifted off pavement
0.1290	Drivers side rear tire lifted off pavement
0.1940	Vehicle was parallel with installation
0.2200	Rear passenger side bumper began to contact rail
0.3740	Vehicle exited the installation at 45.2mi/h with a heading of 16.1 degrees and a trajectory of 9.1 degrees

8.5. DAMAGE TO TEST INSTALLATION

There was a 0.25-inch separation on the downstream short curb section from the deck, and the downstream traffic side corner of the curb was cracked and spalled. There was scuffing on the rail and curb at impact, and the manhole cover was loose. Table 8.6 describes the post lean and damage on the Transition with Storm Drain Inlet. Table 8.7 describes the deflection and working width of the Transition with Storm Drain Inlet. Figure 8.5 and Figure 8.6 show the damage to the Transition with Storm Drain Inlet.

Table 8.6. Post Lean and Damage on the Transition with Storm Drain Inlet for Test 615251-01-1.

Post #	Lean from Vertical	Notes:
15	0.9° t/s	5° clockwise twist and the concrete was spalled
16	1.8° t/s	Concrete was spalled and post was raised up 1.5 inches
17	5.5° f/s	Concrete was spalled and post was raised up 1.5 inches
18	4.6° t/s	Concrete was spalled and post was raised up 1 inch. Blockout was split
19	0.2° t/s	The post was raised up 0.5 inches

t/s: traffic side; f/s: field side

Table 8.7. Deflection and Working Width of the Transition with Storm Drain Inlet for Test 615251-01-1.

Test Parameter	Measured
Permanent Deflection/Location	9 inches toward field side, at the downstream base of the inlet
Dynamic Deflection	11.3 inches toward field side at post 17
Working Width [a] and Height	63.6 inches, at a height of 6.0 inches at the field side of the inlet cover

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

Figure 8.5. Transition with Storm Drain Inlet at Impact Location after Test 615251-01-1.

Figure 8.6. Field Side of the Transition with Storm Drain Inlet after Test 615251-01-1.

8.6. DAMAGE TO TEST VEHICLE

Figure 8.7 and Figure 8.8 show the damage sustained by the vehicle. Figure 8.9 and Figure 8.10 show the interior of the test vehicle. Table 8.8 and Table 8.9 provide details on the occupant compartment deformation and exterior vehicle damage. Figures C.2 and C.3 in Appendix C.1 provide exterior crush and occupant compartment measurements.

Figure 8.7. Impact Side of Test Vehicle after Test 615251-01-1.

Figure 8.8. Rear Impact Side of Test Vehicle after Test 615251-01-1.

Figure 8.9. Overall Interior of Test Vehicle after Test 615251-01-1.

Figure 8.10. Interior of Test Vehicle on Impact Side after Test 615251-01-1.

Table 8.8. Occupant Compartment Deformation 615251-01-1.

Test Parameter	**Specification** (inches)	**Measured** (inches)
Roof	≤4.0	0.0
Windshield	≤3.0	0.0
A and B Pillars	≤5.0 overall/≤3.0lateral	0.0
Foot Well/Toe Pan	≤9.0	1.0
Floor Pan/Transmission Tunnel	≤12.0	0.0
Side Front Panel	≤12.0	1.0
Front Door (above Seat)	≤9.0	0.5
Front Door (below Seat)	≤12.	0.0

Table 8.9. Exterior Vehicle Damage 615251-01-1.

Side Windows	Side windows remained intact
Maximum Exterior Deformation	14 inches in the front plane at the right front corner at bumper height
VDS	01RFQ4
CDC	01FREN3
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, hood, grill, radiator and support, right head light, right front quarter fender, right frame rail, right upper and lower control arms, right front tire and rim, right front floor pan, right front door, right rear door, right cab corner, right rear quarter fender, rear bumper, and left tire were damaged. The right front door had a 2-inch gap at the top.

8.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 8.10. Figure C.7 in Appendix C.3 shows the vehicle angular displacements, and Figures C.8 through C.10 in Appendix C.4 show acceleration versus time traces.

Table 8.10. Occupant Risk Factors for Test 615251-01-1.

Test Parameter	*MASH* [a]	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	20.9	0.0992 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	25.1	0.0992 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49 *15.0*	17.2	0.1027 - 0.1127 seconds
Ridedown, Lateral (g)	≤20.49 *15.0*	10.8	0.1046 - 0.1146 seconds
Theoretical Head Impact Velocity (THIV) (m/s)	N/A	9.8	0.0968 seconds on right side of interior
Acceleration Severity Index (ASI)	N/A	1.7	0.0573 - 0.1073 seconds
50-ms Moving Avg. Accelerations (MA) Longitudinal (g)	N/A	-10.4	0.0680 - 0.1180 seconds
50-ms MA Lateral (g)	N/A	-12.1	0.0396 - 0.0896 seconds
50-ms MA Vertical (g)	N/A	4.0	0.1195 - 0.1695 seconds
Roll (deg)	≤75	30.3	0.4811 seconds
Pitch (deg)	≤75	9.3	0.4805 seconds
Yaw (deg)	N/A	44.2	0.9005 seconds

[a.] *Values in italics are the preferred MASH values*

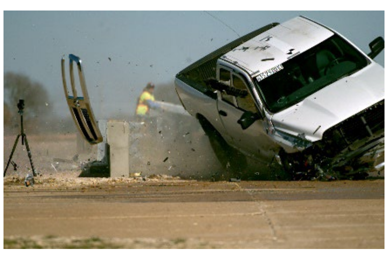
8.8. TEST SUMMARY

Figure 8.11 summarizes the results of *MASH* Test 615251-01-1.

0.000 s

0.200 s

0.400 s

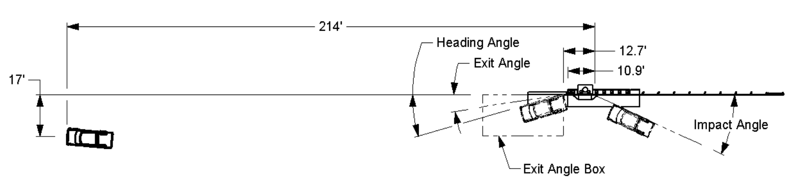


0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-21
TTI Project No.	615251-01-1
Test Date	2023-01-26
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Transition with Storm Drain Inlet
Length	102
Key Materials	Reinforced concrete, W-beam guardrail, steel guardrail posts, Thrie-beam guardrail, steel wingwall posts
Soil Type and Condition	AASHTO 147-17 Type 1 Grade D crushed concrete
TEST VEHICLE	
Type/Designation	2270P
Year, Make and Model	2018 RAM 1500
Inertial Weight (lb)	5024
Dummy (lb)	N/A
Gross Static (lb)	5024
IMPACT CONDITIONS	
Impact Speed (mi/h)	62.4
Impact Angle (deg)	25.1
Impact Location	130.6 inches upstream from upstream edge of concrete parapet.
Impact Severity (kip-ft)	117.7
EXIT CONDITIONS	
Exit Speed (mi/h)	45.1
Trajectory/Heading Angle (deg)	9.1 / 16.0
Exit Box Criteria	Vehicle crossed the exit box at 39 ft downstream from loss of contact.
Stopping Distance	214 ft downstream 17 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	11.3
Permanent (inches)	9
Working Width / Height (inches)	63.6 / 6.0
VEHICLE DAMAGE	
VDS	01RFQ4
CDC	01FREN3
Max. Ext. Deformation (inches)	14
Max Occupant Compartment Deformation	1-inch in the toe pan and in the side panel

OCCUPANT RISK VALUES

Long. OIV (ft/s)	20.9	Long. Ridedown (g)	17.2	Max 50-ms Long. (g)	-10.4	Max Roll (deg)	30.3
Lat. OIV (ft/s)	25.1	Lat. Ridedown (g)	10.8	Max 50-ms Lat. (g)	-12.1	Max Pitch (deg)	9.3
THIV (m/s)	9.8	ASI	1.7	Max 50-ms Vert. (g)	4.0	Max Yaw (deg)	44.2



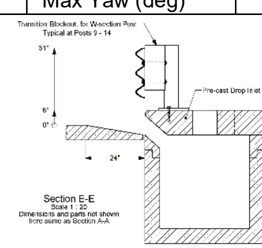


Figure 8.11. Summary of Results for *MASH* Test 3-21 on Transition with Storm Drain Inlet.

Chapter 9. SUMMARY AND CONCLUSIONS

9.1. ASSESSMENT OF TEST RESULTS

The crash test reported herein was performed in accordance with *MASH* TL-3 on the Transition with Storm Drain Inlet.

9.2. CONCLUSIONS

Table 9.1 shows that the Transition with Storm Drain Inlet met the performance criteria for *MASH* TL-3 Longitudinal Barrier once tested under the conditions of *MASH* TL-3-21.

Table 9.1. Assessment Summary for *MASH* TL-3 Tests on Transition with Storm Drain Inlet.

Evaluation Criteria	Description	Test 615251-01-1
A	Contain, Redirect, or Controlled Stop	S
D	No Penetration into Occupant Compartment	S
F	Roll and Pitch Limit	S
H	OIV Threshold	S
I	Ridedown Threshold	S
Overall		Pass

Note: S = Satisfactory; N/A = Not Applicable.
[1] See Table 6.2 for details

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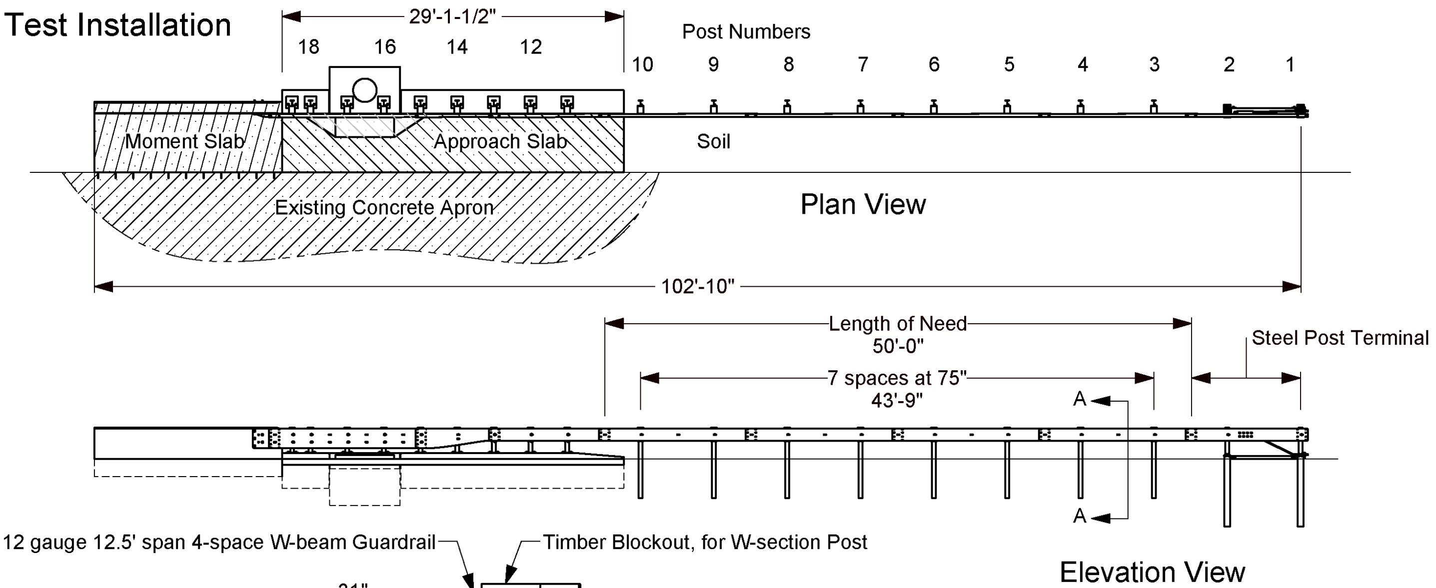
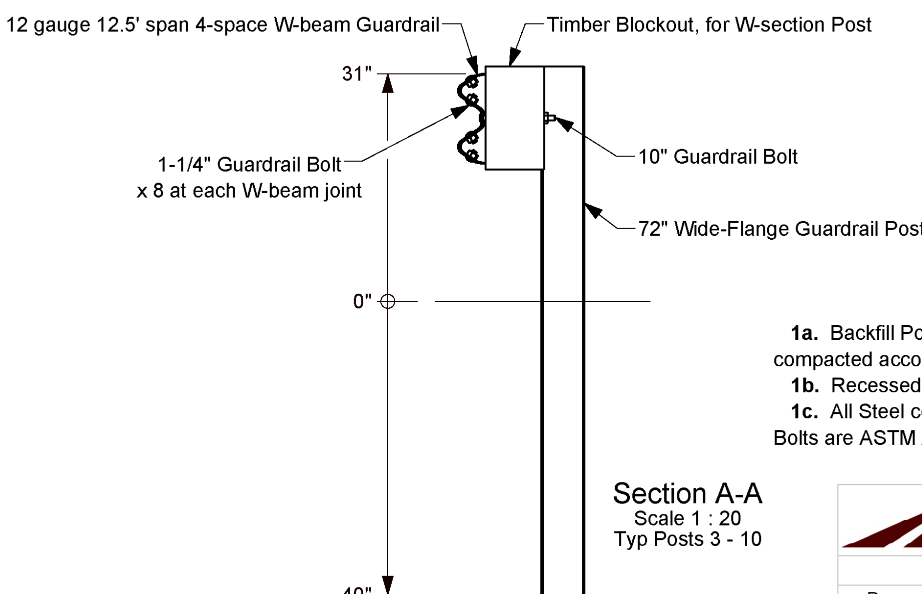
APPENDIX A. DETAILS OF TRANSITION WITH STORM DRAIN INLET

Test Installation



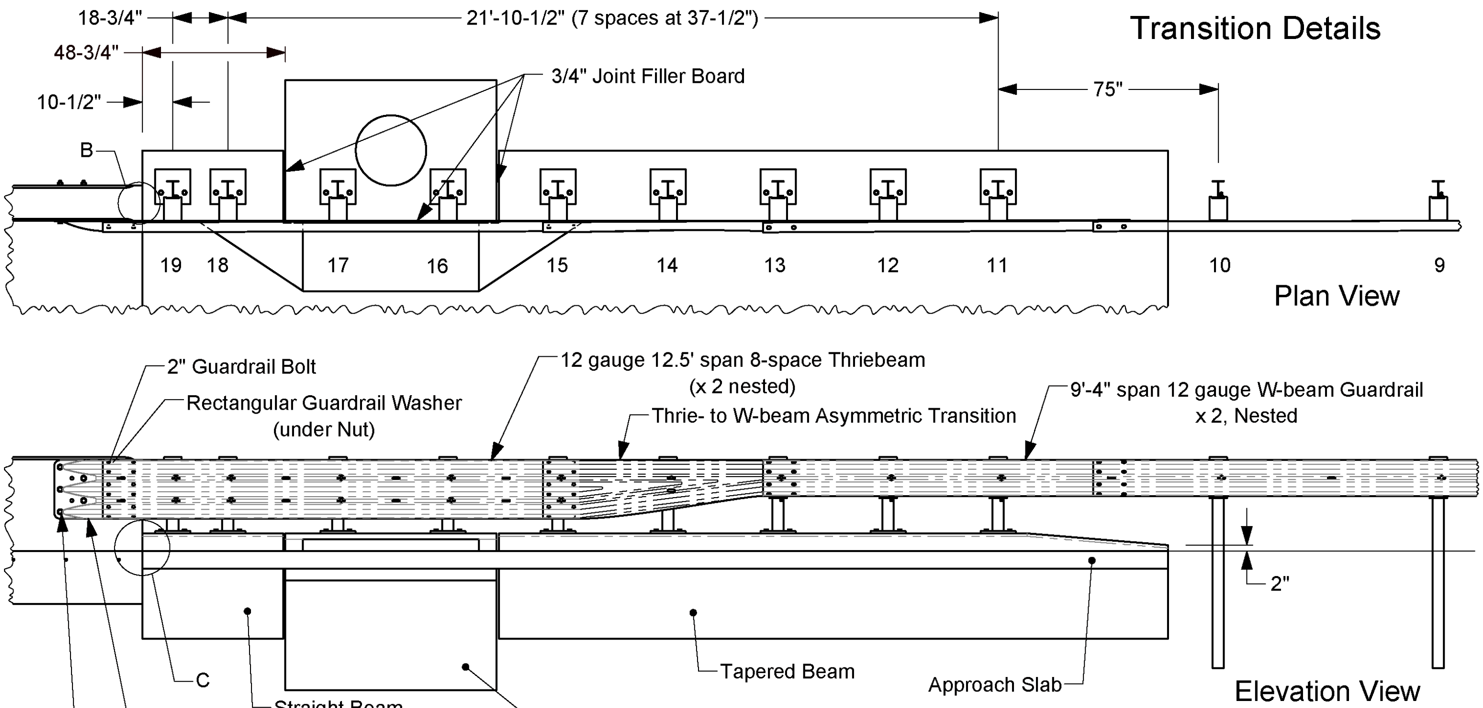


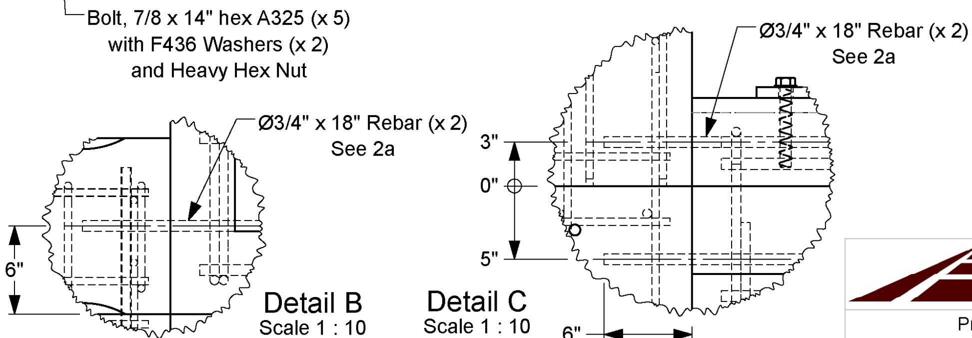
Section A-A
Scale 1 : 20
Typ Posts 3 - 10

1a. Backfill Post holes with Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C001.
1b. Recessed Guardrail Nuts on all 5/8" Bolts unless otherwise indicated.
1c. All Steel components, including hardware, are galvanized, and all Bolts are ASTM A307 unless otherwise indicated.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project #615251 Transition with Inlet		2023-06-26
Drawn by GES	Scale 1:150	Sheet 1 of 10 Test Installation

Transition Details





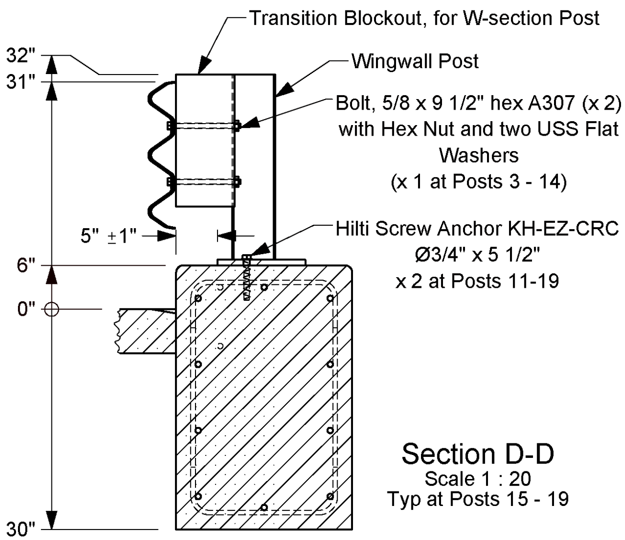
2a. Secure in existing concrete with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions.

2b. Excavate 6" below Pre-cast Inlet. Place 4" of Type A Grade 1 crushed limestone road base, compacted to 90% of standard proctor density, then 2" of Washed Sand. Backfill around all concrete with Type A Grade 1 crushed limestone road base, compacted to 90% of standard proctor density.

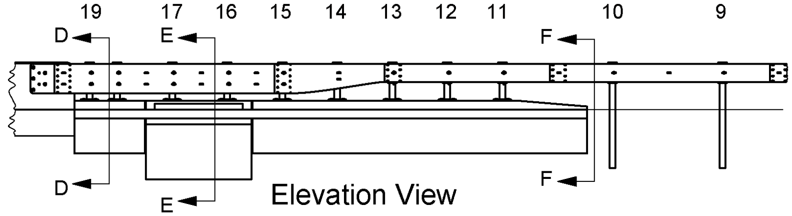
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project #615251 Transition with Inlet			2023-06-26
Drawn by GES	Scale 1:50	Sheet 2 of 10 Transition Details	

S:\Accreditation-17025-2017\EIR-000 Project Files\615251 - Transition with Inlet - Akram\Drafting, 615251\615251 Drawing

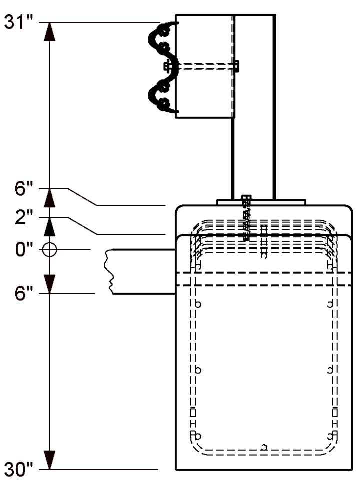
Cross Sections



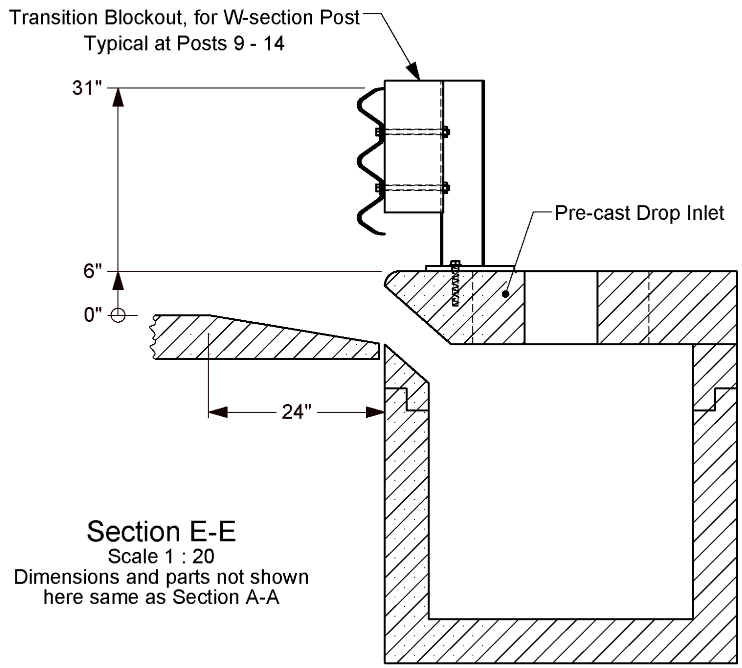
Section D-D
Scale 1 : 20
Typ at Posts 15 - 19



Elevation View
Transition Area



Section F-F
Scale 1 : 20

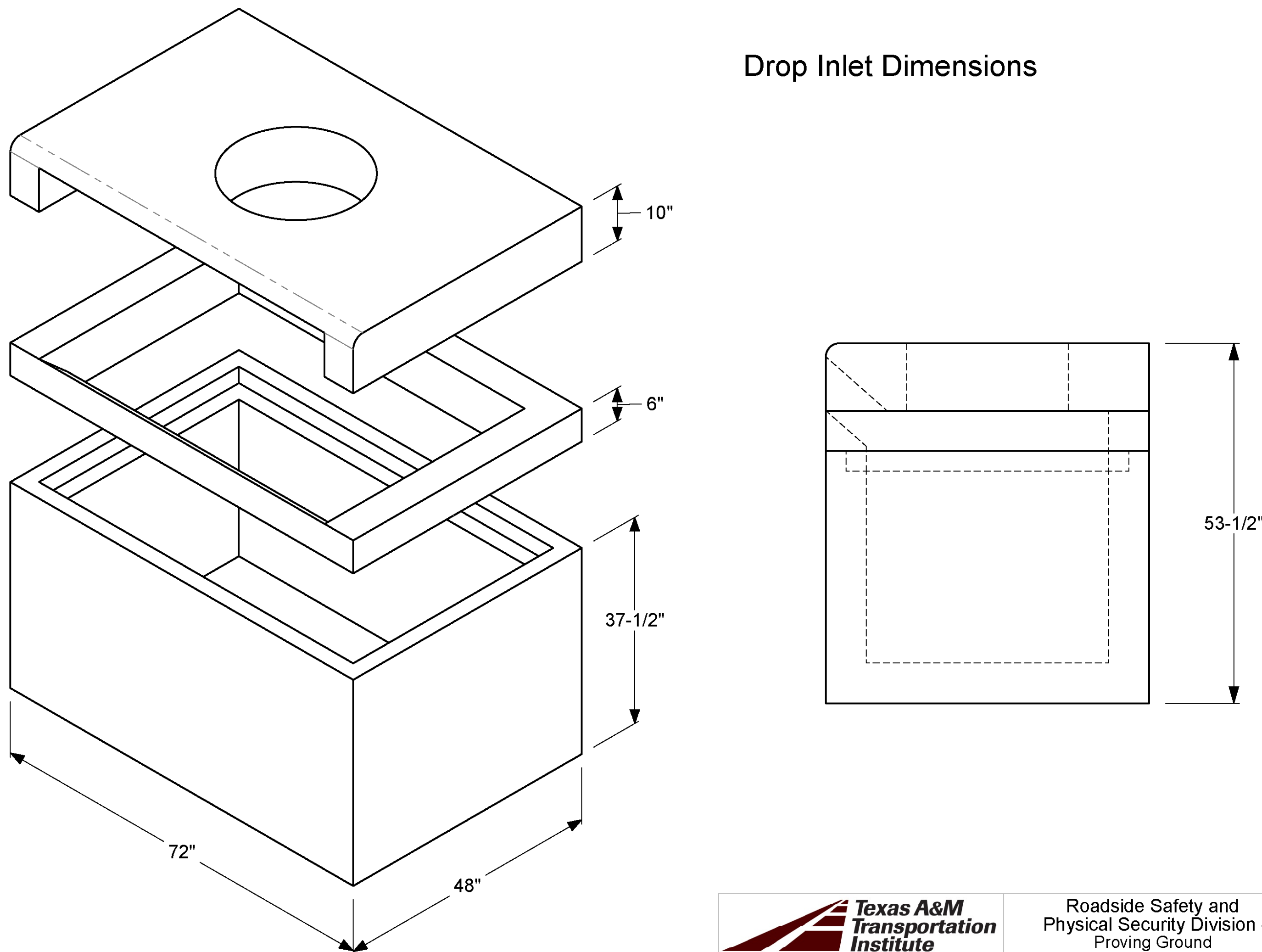


Section E-E
Scale 1 : 20
Dimensions and parts not shown here same as Section A-A

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615251 Transition with Inlet		2023-06-26
Drawn by GES	Scale 1:100	Sheet 3 of 10 Cross Sections

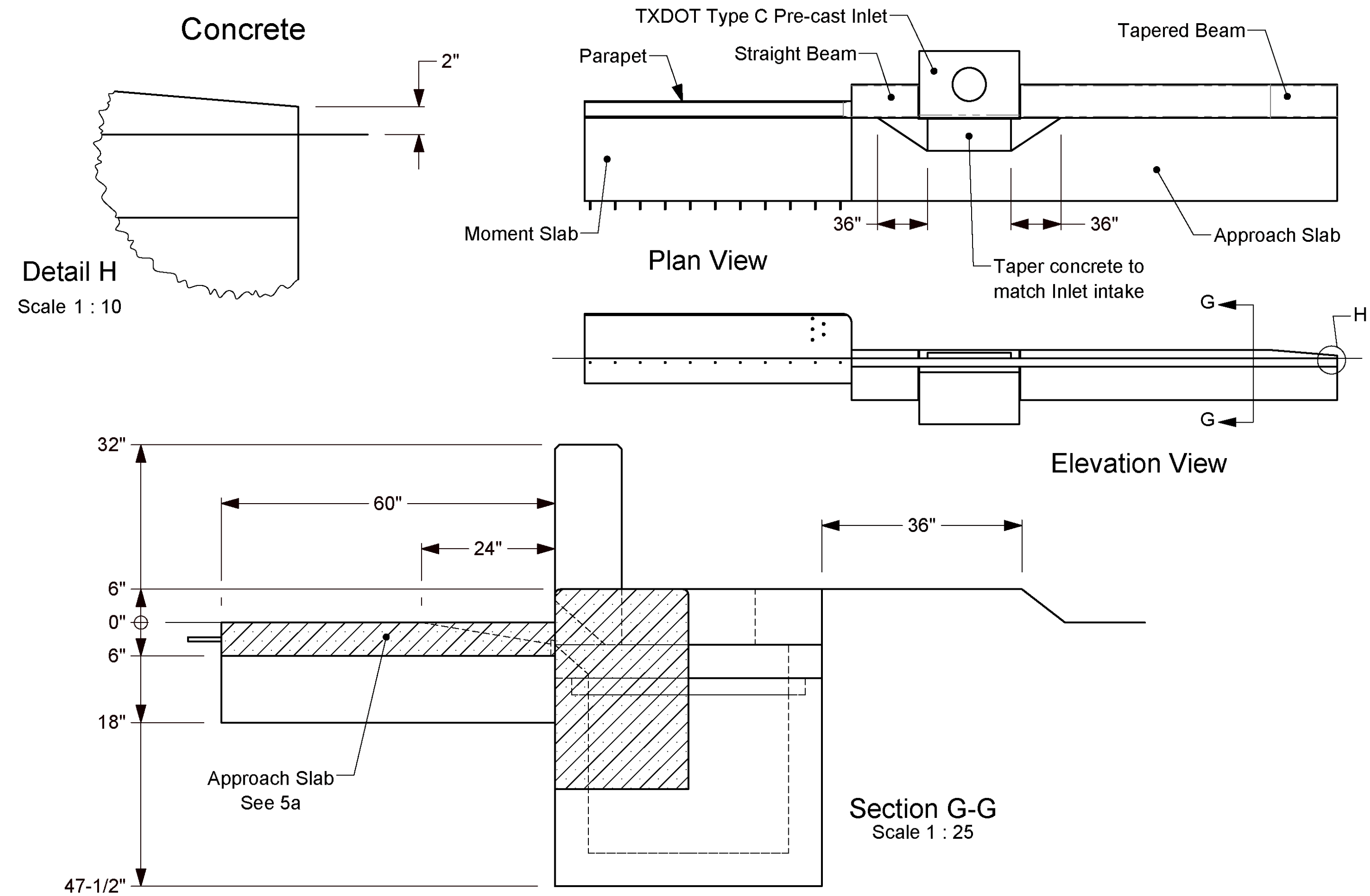
S:\Accreditation-17025-2017\EIR-000 Project Files\615251 - Transition with Inlet - Akram\Drafting, 615251\615251 Drawing

Drop Inlet Dimensions



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615251 Transition with Inlet		2023-06-26
Drawn by GES	Scale 1:20	Sheet 4 of 10 Drop Inlet Dimensions

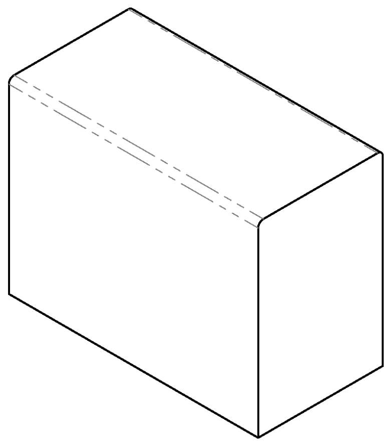
S:\Accreditation-17025-2017\EIR-000 Project Files\615251 - Transition with Inlet - Akram\Drafting, 615251\615251 Drawing



5a. Approach Slab is 3000 psi concrete, with one layer of #3 rebar (not shown here), with 1-1/2" cover at top. Space longitudinal bars at 12", with 12" laps, and transverse bars at 36".

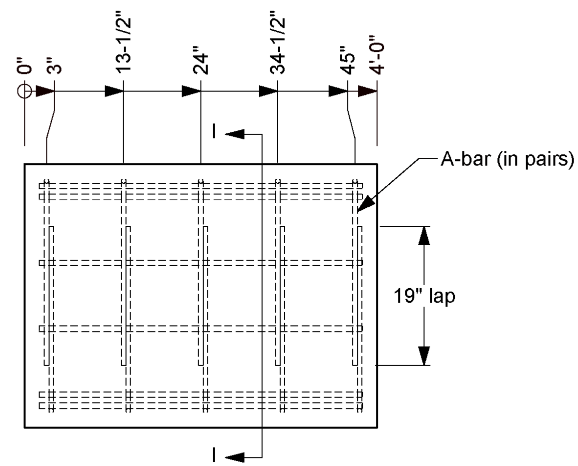
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615251 Transition with Inlet		2023-06-26
Drawn by GES	Scale 1:100	Sheet 5 of 10 Concrete

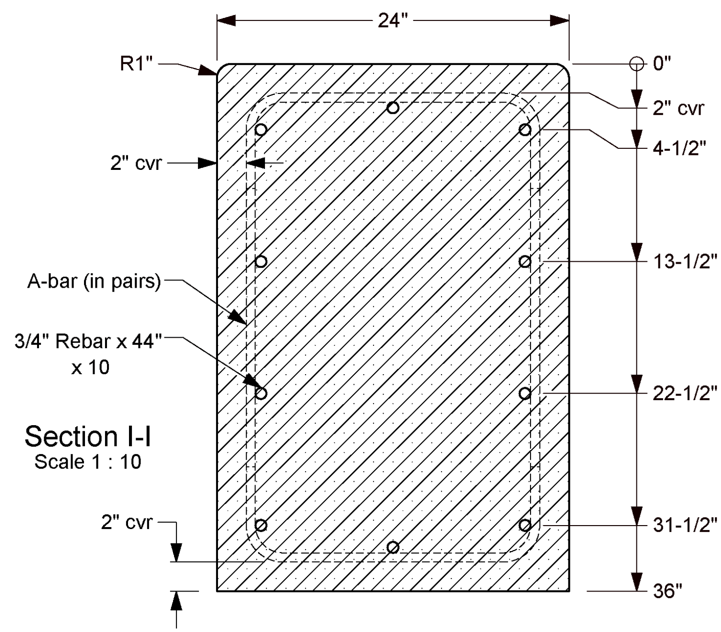
S:\Accreditation-17025-2017\EIR-000 Project Files\615251 - Transition with Inlet - Akram\Drafting, 615251\615251 Drawing



Straight Beam

Tx DoT Class C Concrete (3600 psi)
(Anchor bars not shown, see Detail Views on sheet 2)





Section I-I

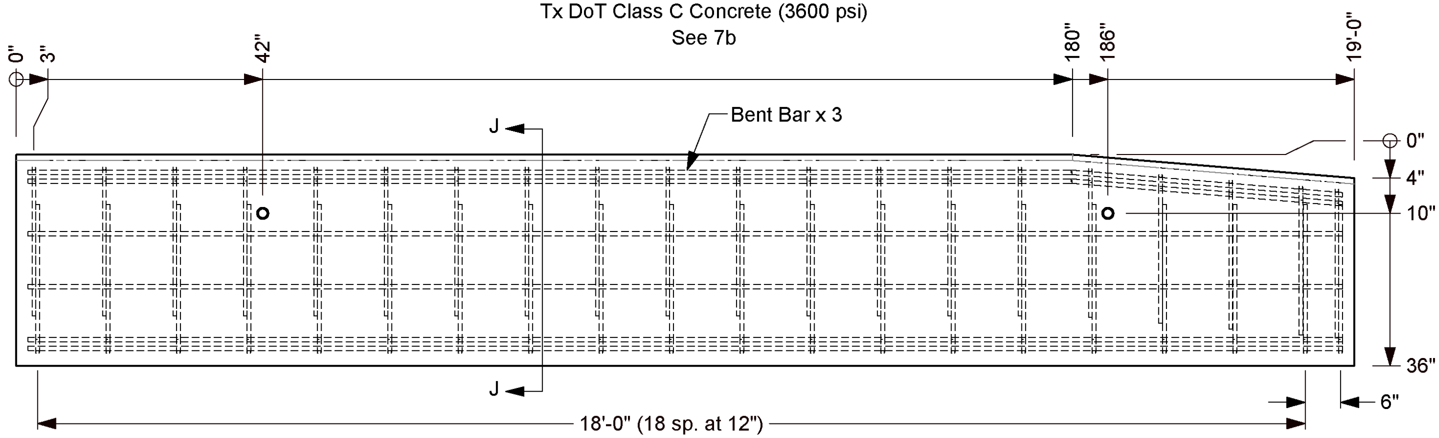
Scale 1 : 10

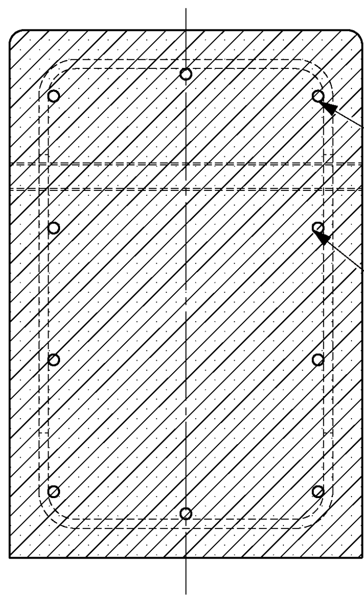
6a. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover).

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615251 Transition with Inlet		2023-06-26
Drawn by GES	Scale 1:20	Sheet 6 of 10 Straight Beam

Tapered Beam

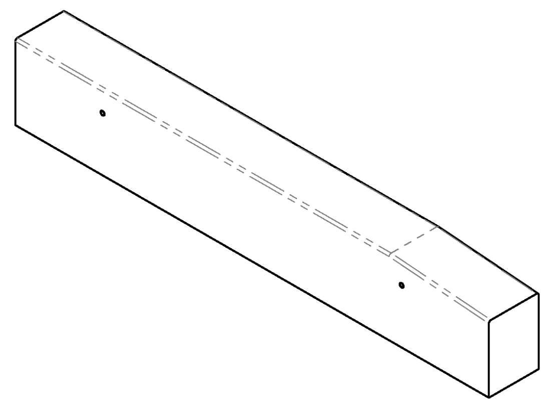
Tx DoT Class C Concrete (3600 psi)
See 7b





Section J-J

Scale 1 : 10



7a. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover).

7b. See Straight Beam (previous sheet) for all details not shown here.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615251 Transition with Inlet		2023-06-26
Drawn by GES	Scale 1:25	Sheet 7 of 10 Tapered Beam

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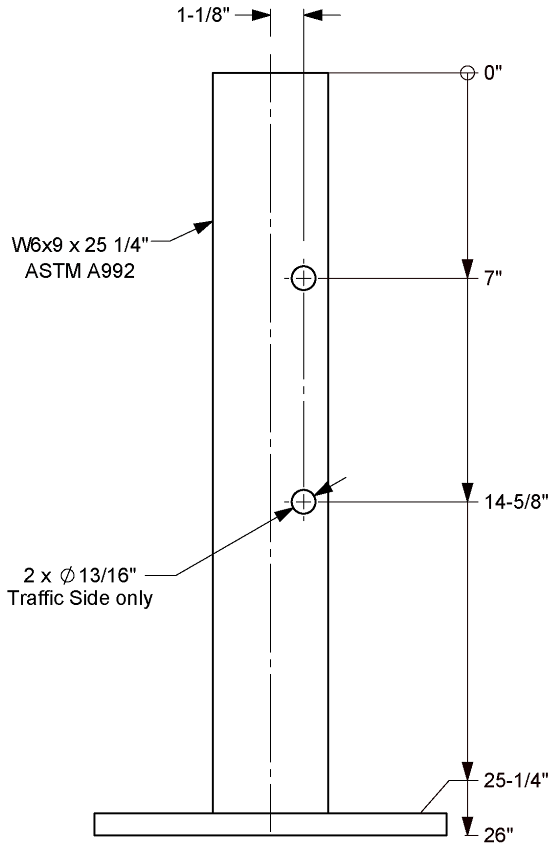
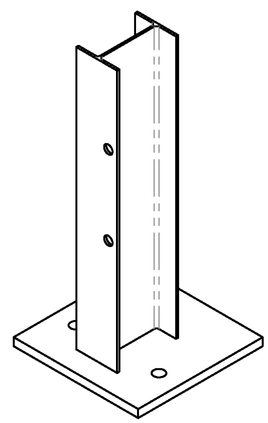
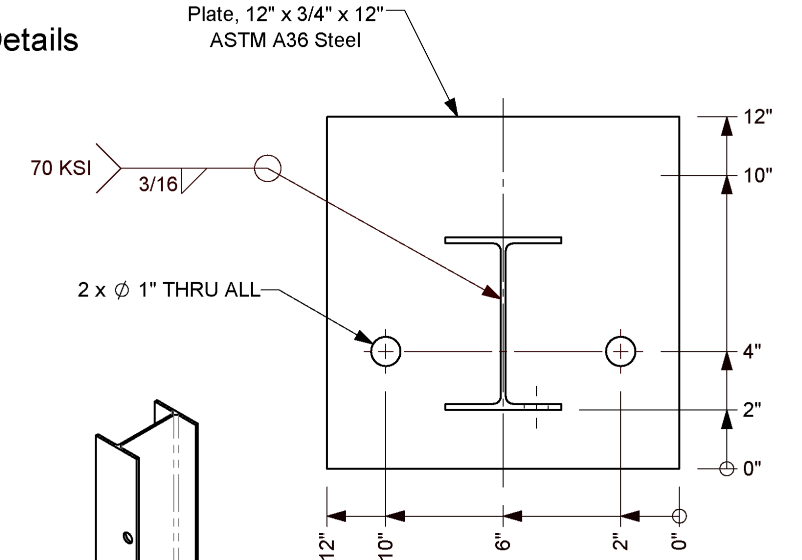
Post Details



Wingwall Post
Elevation View
Typical @ Posts 16 - 22



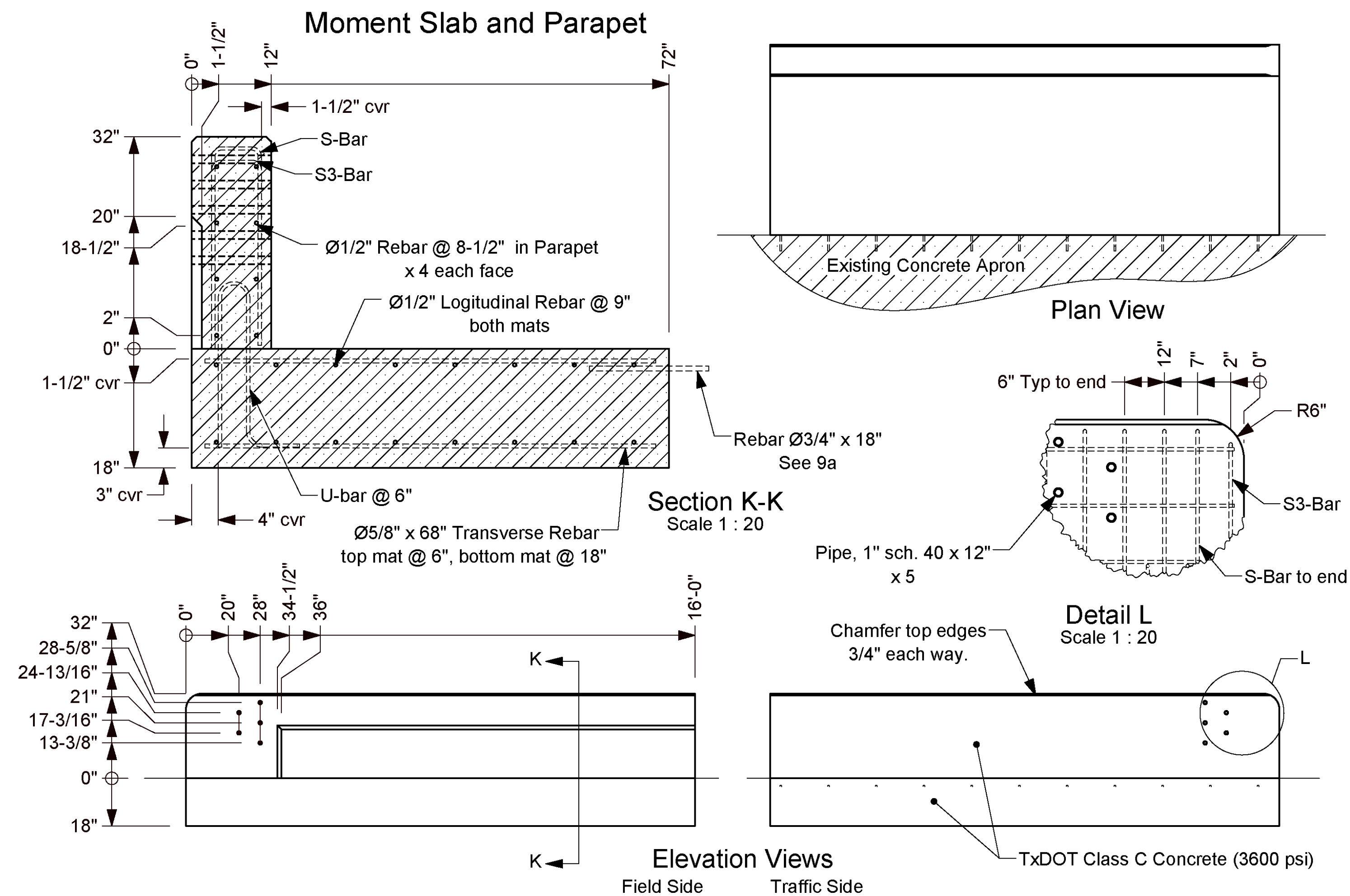


Wingwall Post
Plan View

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

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project #615251 Transition with Inlet		2023-06-26
Drawn by GES	Scale 1:5	Sheet 8 of 10 Post Details

S:\Accreditation-17025-2017\EIR-000 Project Files\615251 - Transition with Inlet - Akram\Drafting, 615251\615251 Drawing



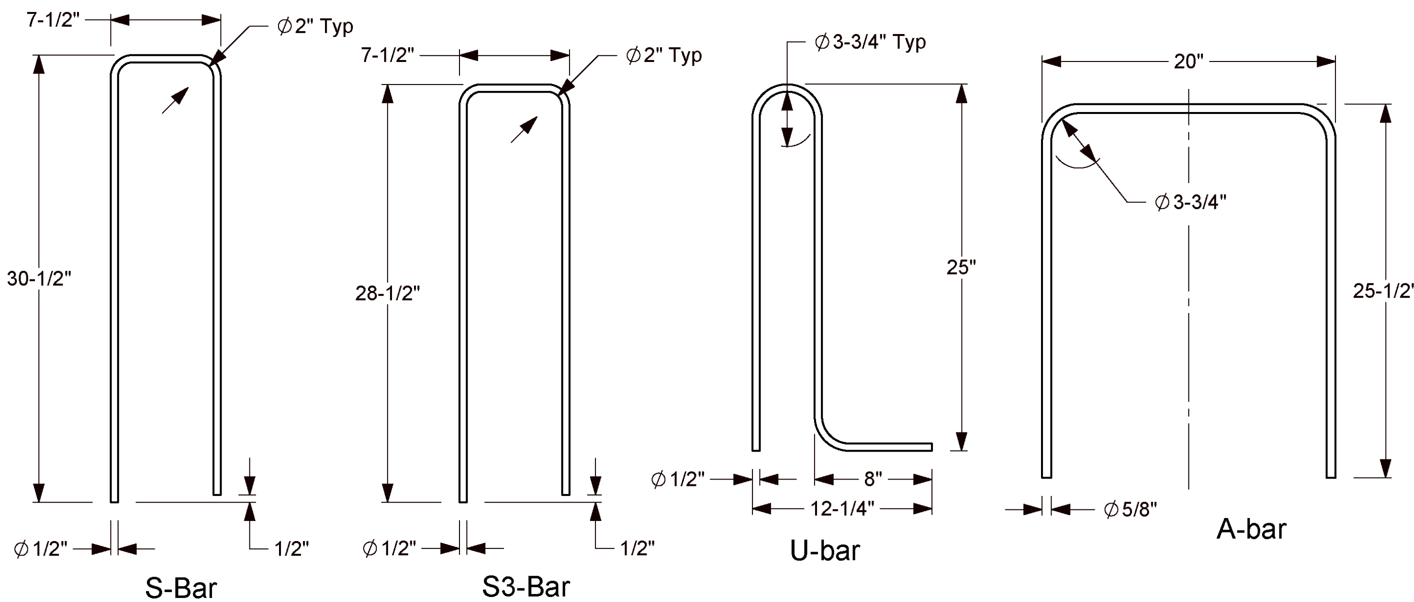
9a. Secure in existing concrete apron with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions, with 6" embedment at 18" spacing.

9b. All rebar dimensions are to center unless otherwise indicated by "cvr" (cover).

9c. All rebar is grade 60.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615251 Transition with Inlet		2023-06-26
Drawn by GES	Scale 1:50	Sheet 9 of 10 Moment Slab and Parapet

Rebar Bends

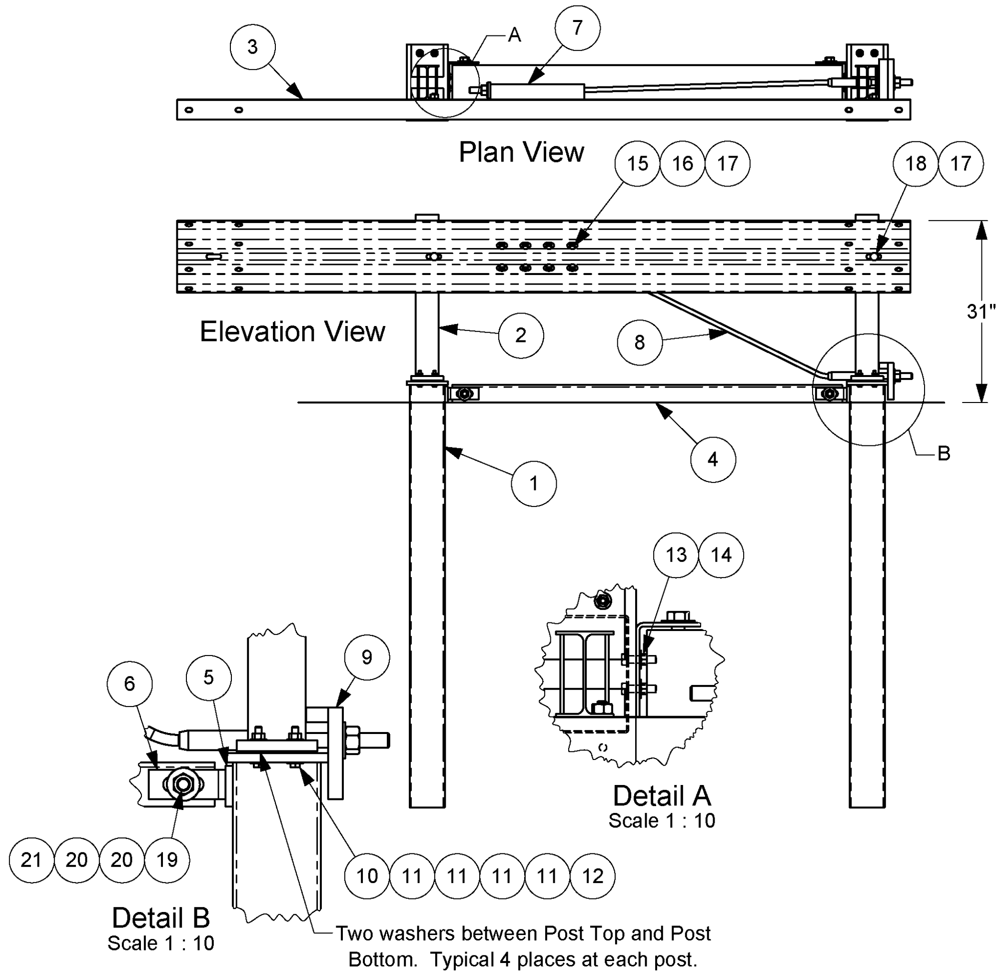


10a. All bars on this sheet are grade 60 rebar.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #615251 Transition with Inlet		2023-06-26
Drawn by GES	Scale 1:10	Sheet 10 of 10 Rebar Bends

S:\Accreditation-17025-2017\EIR-000 Project Files\615251 - Transition with Inlet - Akram\Drafting, 615251\615251 Drawing

Terminal Details



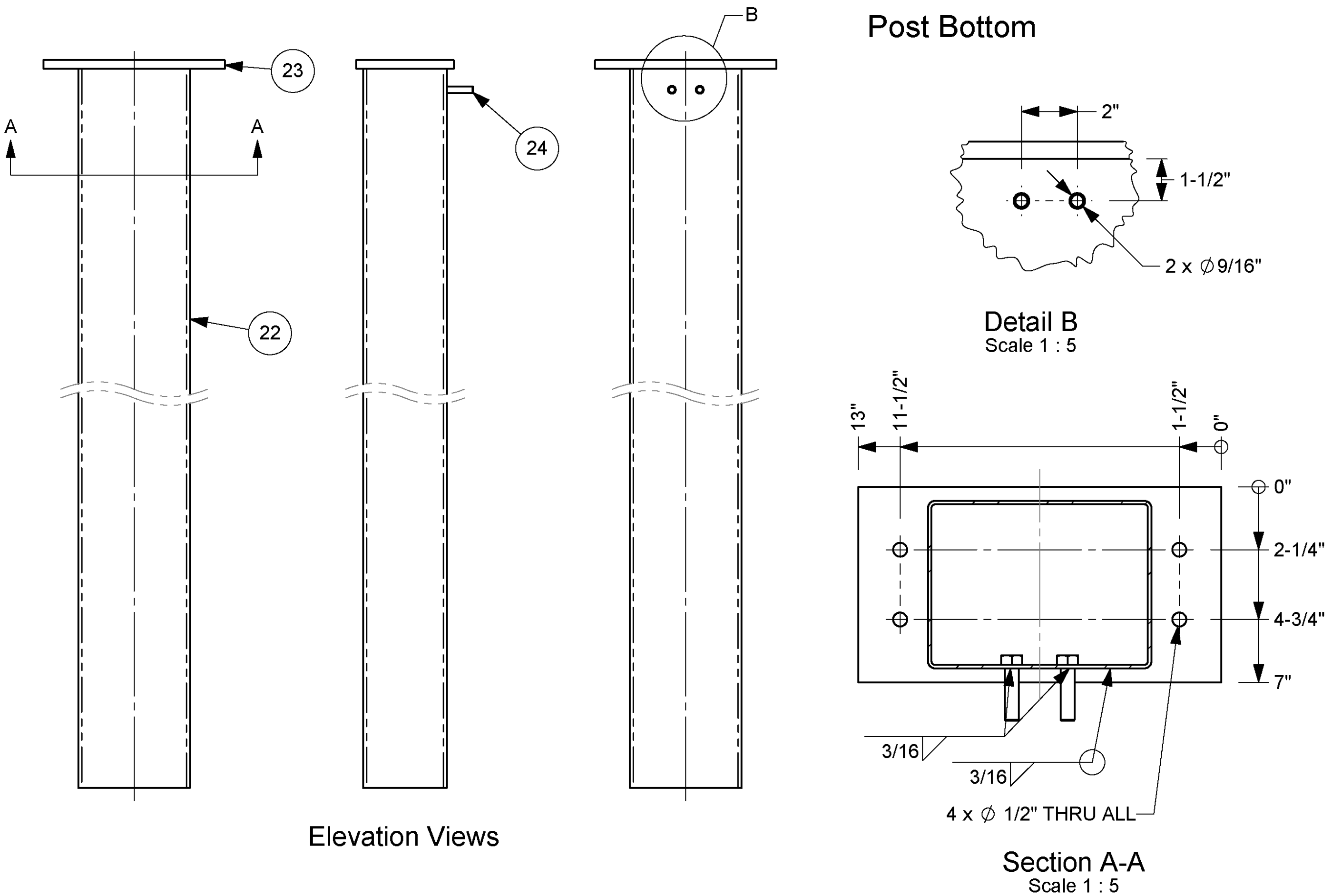
#	Part Name	QTY.
1	Post Bottom	2
2	Post Top	2
3	9'-4" span Terminal Rail	1
4	Strut	1
5	Strut Spacer	2
6	Strut Bracket	2
7	Guardrail Anchor Bracket	1
8	Anchor Cable Assembly	1
9	Bearing Plate	1
10	Bolt, 7/16 x 2 1/2" hex	8
11	Washer, 7/16 F844	32
12	Nut, 7/16 heavy hex	8
13	Nut, 1/2 hex	4
14	Washer, 1/2 F844	4
15	Bolt, 5/8 x 1 1/2" hex	8
16	Washer, 5/8 F844	8
17	Recessed Guardrail Nut	10
18	1-1/4" Guardrail Bolt	2
19	Bolt, 7/8 x 8 1/2" hex	2
20	Washer, 7/8 F844	4
21	Nut, 7/8 hex	2

1a. 7/16" x 2-1/2" Bolts are ASTM A449. All other Bolts are ASTM A307. All Nuts (except Recessed Guardrail Nuts) are ASTM A563A unless otherwise indicated.
1c. All steel parts shall be galvanized.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2022-07-08
Drawn by GES	Scale 1:25	Sheet 1 of 6 Terminal Details

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

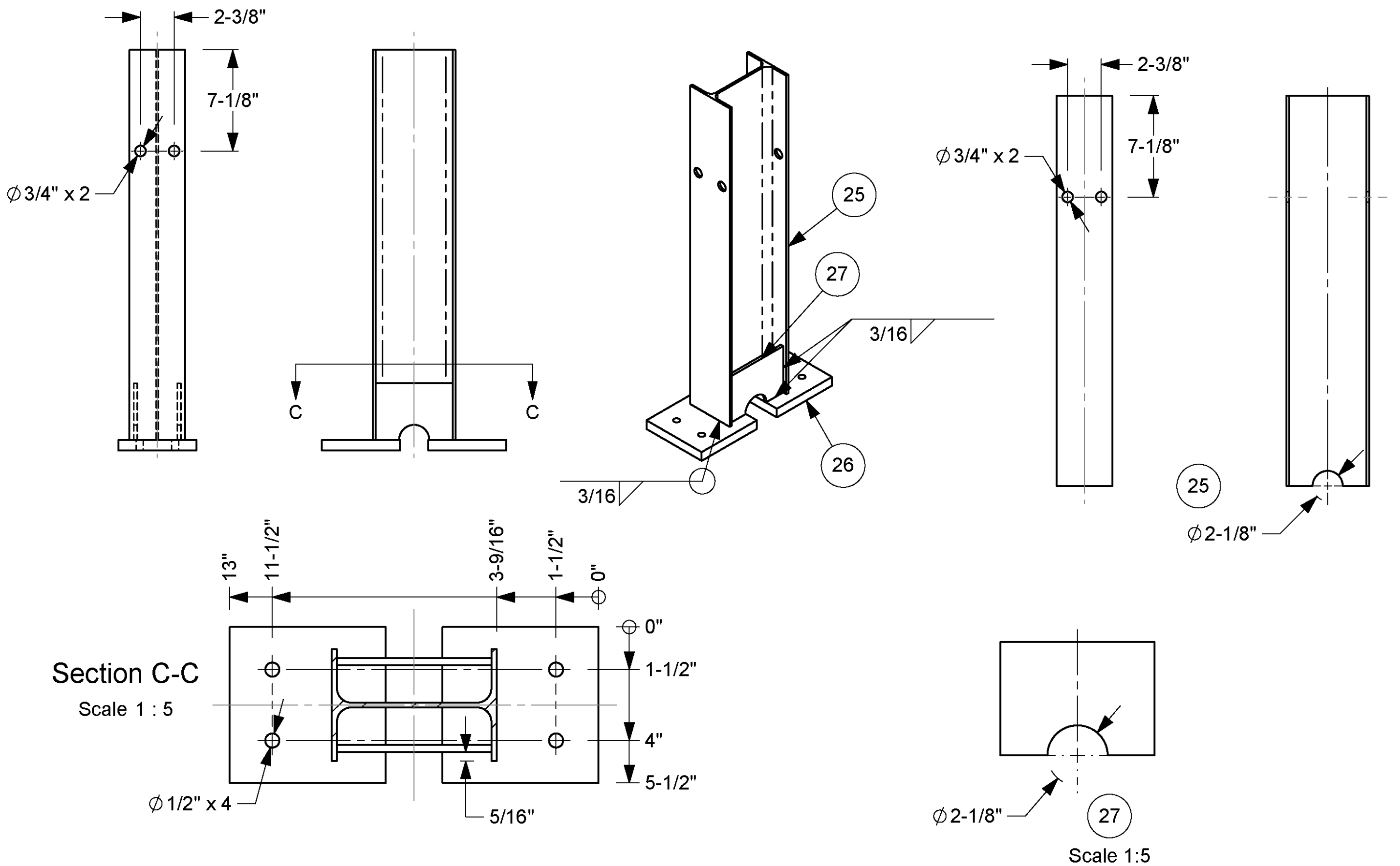
Post Bottom



#	Description	Length	Material	Qty
22	HSS 8" x 6" x 1/8"	72"	ASTM A500 Grade B	1
23	Plate, 7" x 5/8"	13"	ASTM A36	1
24	Bolt, 1/2 x 2 hex		ASTM A307	2

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2022-07-08
Drawn by GES	Scale 1:10	Sheet 2 of 6 Post Bottom

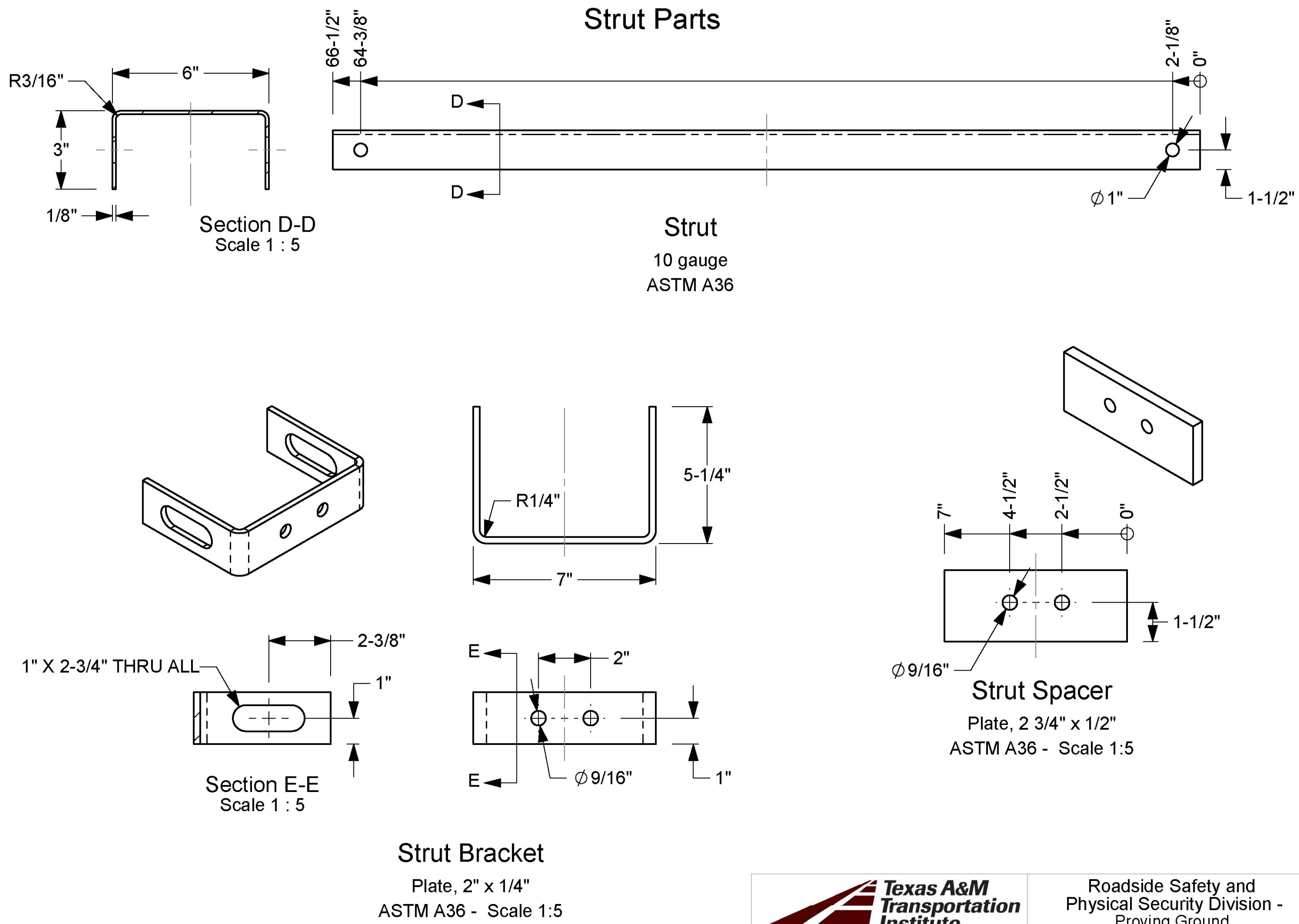
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Midwest Terminal



#	Description	Length	Material	Qty
25	W6x8.5	27 1/2"	ASTM A992	1
26	Plate, 5 1/2" x 3/4"	5 1/2"	ASTM A36	2
27	Plate, 5 7/16" x 1/4"	4"	ASTM A36	2

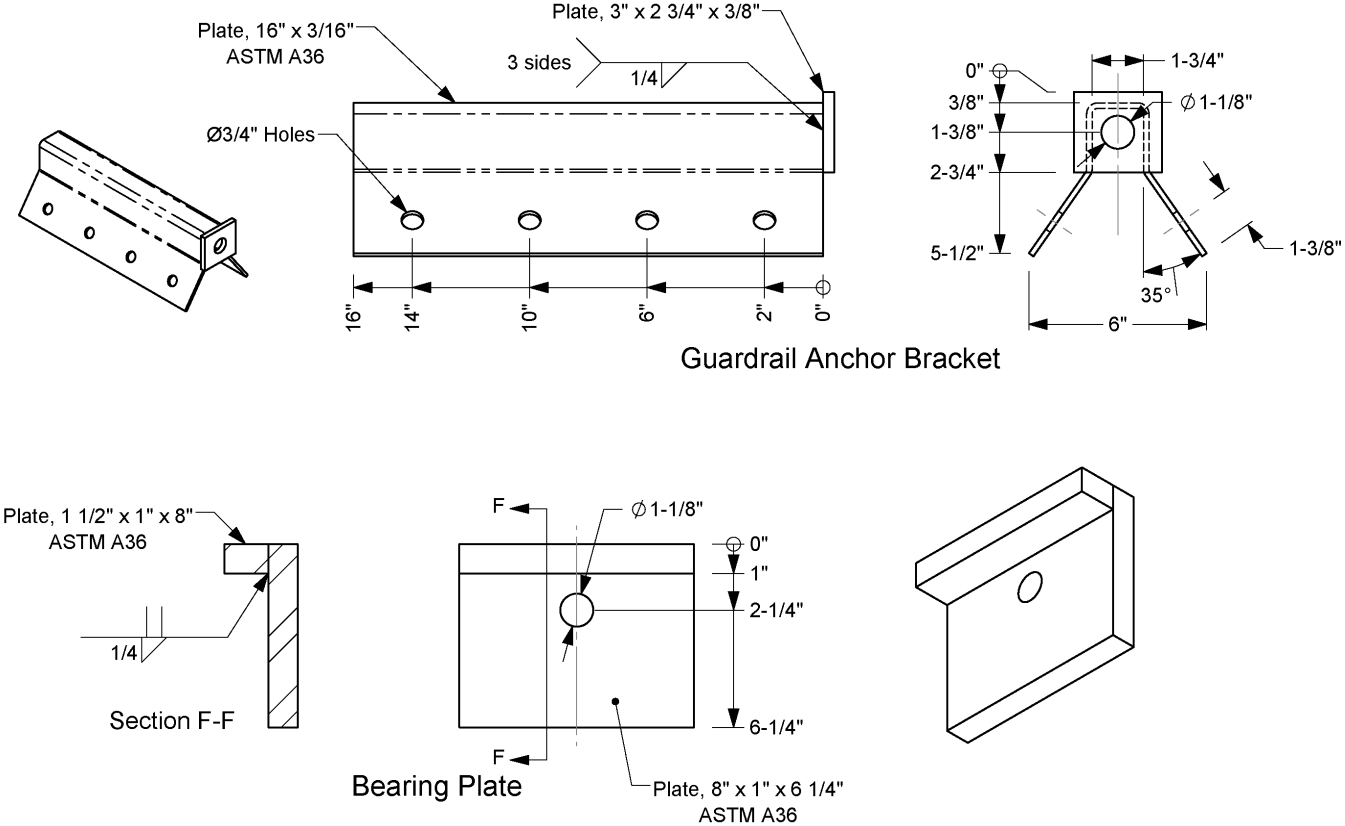
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
	Project # Terminal		2022-07-08
Drawn by GES	Scale 1:10	Sheet 3 of 6 Post Top	

Strut Parts



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2022-07-08
Drawn by GES	Scale 1:10	Sheet 4 of 6 Strut Parts

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

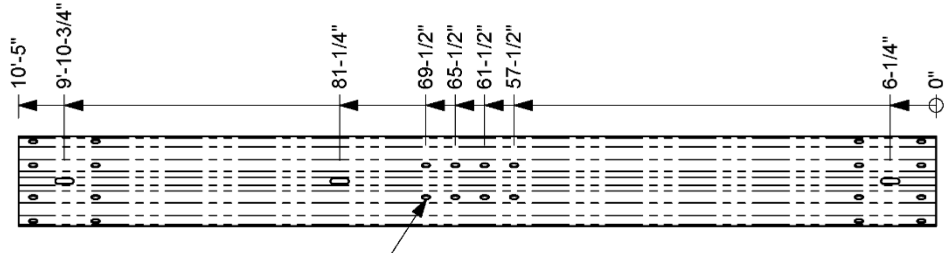


Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

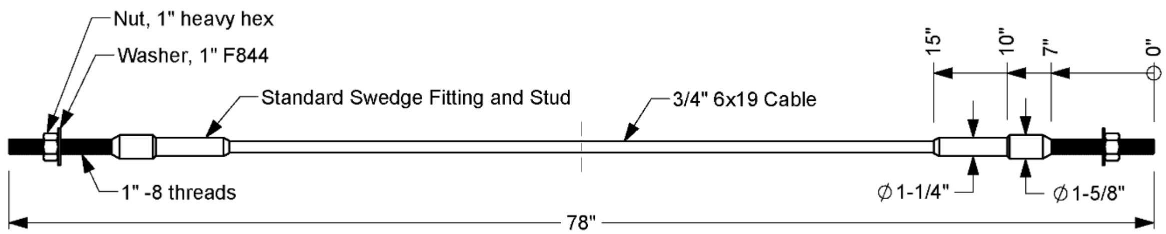
Project # Terminal		2022-07-08
Drawn by GES	Scale 1:5	Sheet 5 of 6 Assorted Parts A

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



9'-4" span Terminal Rail

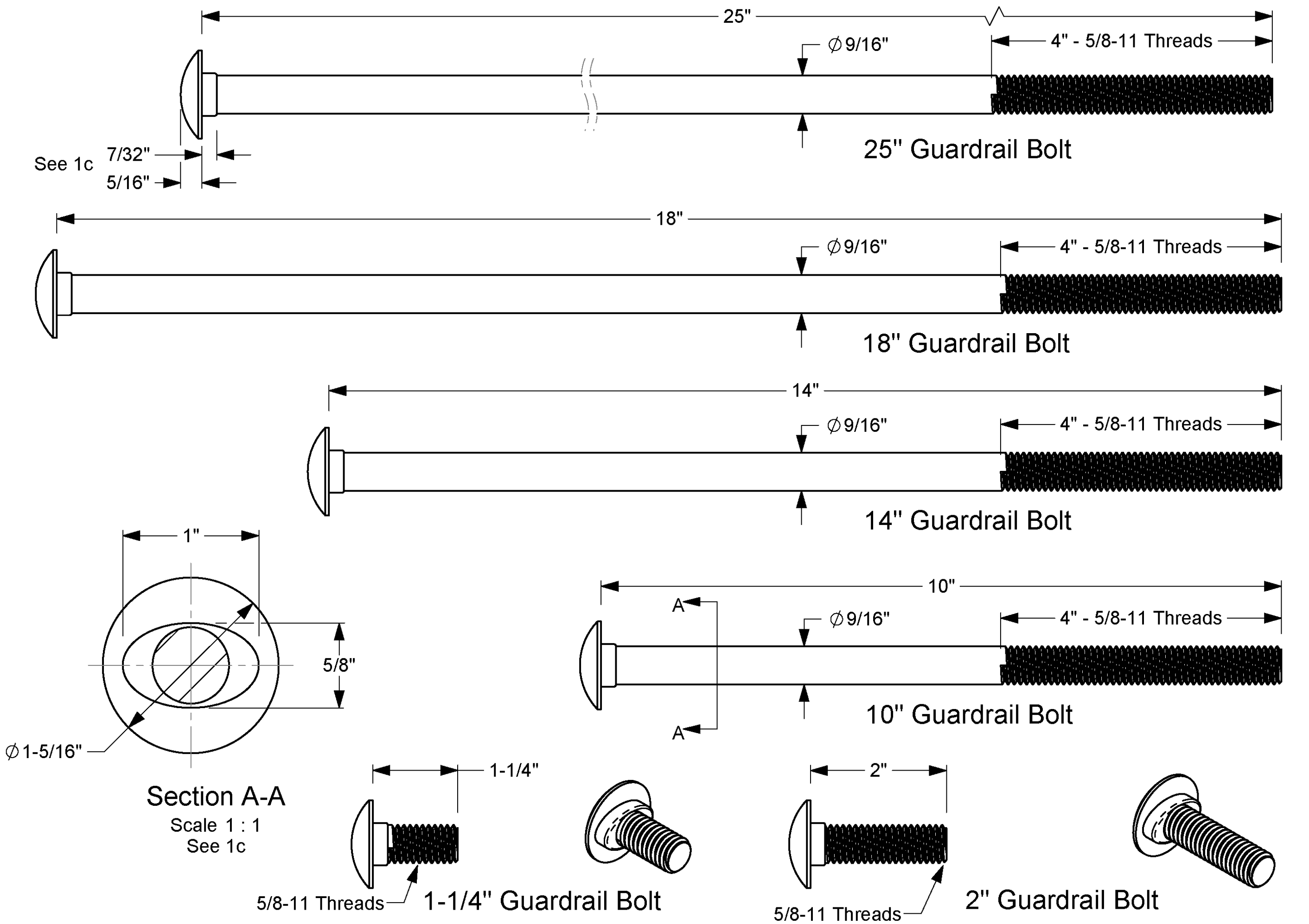
Scale 1:20 - See 4-space W-beam Guardrail drawing
for cross-section and other dimensions.



Anchor Cable Assembly

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground
Project # Terminal	2022-07-08
Drawn by GES	Scale 1:5
Sheet 6 of 6 Assorted Parts B	

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

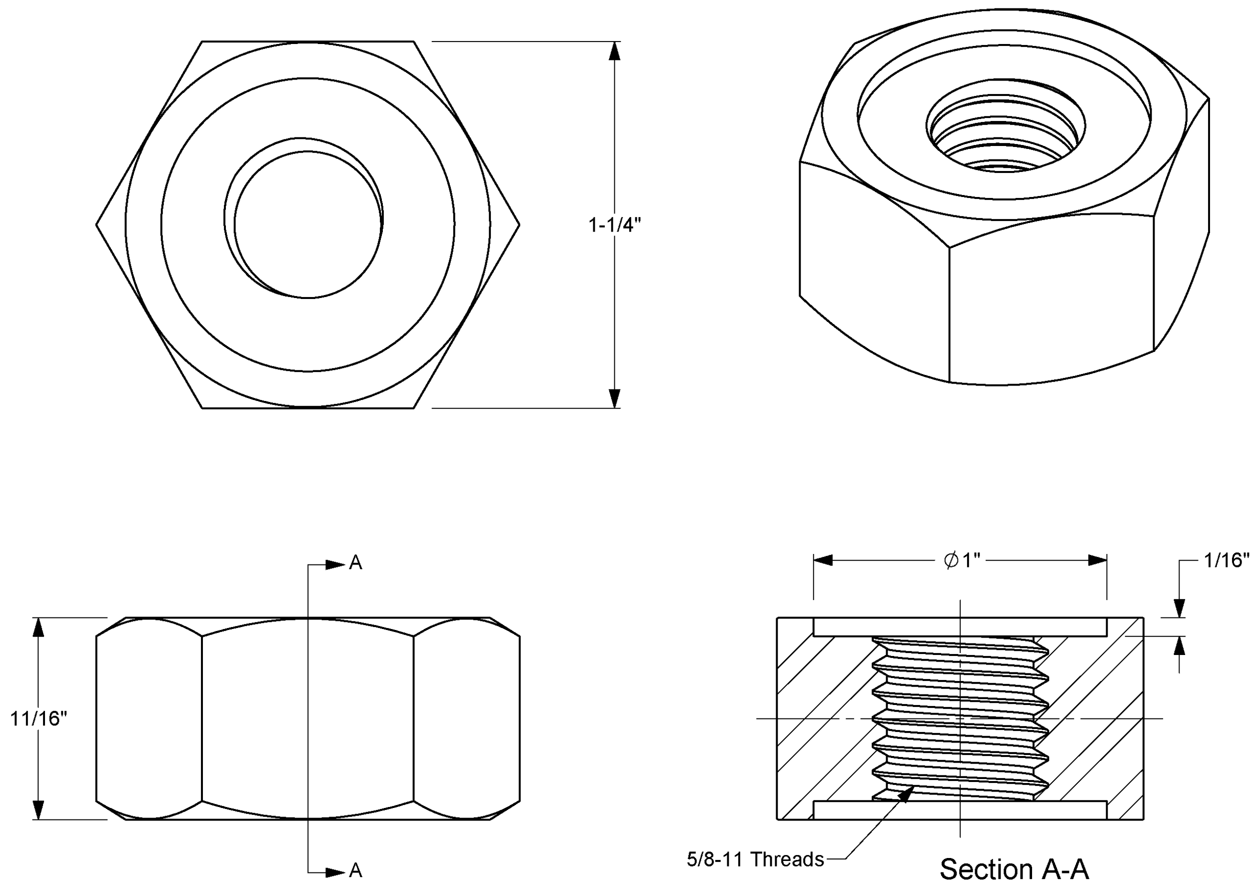


1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all lengths.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Guardrail Bolt		2020-07-08
Drawn by GES/WS	Scale 1:2	Sheet 1 of 1

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

Recessed Guardrail Nut



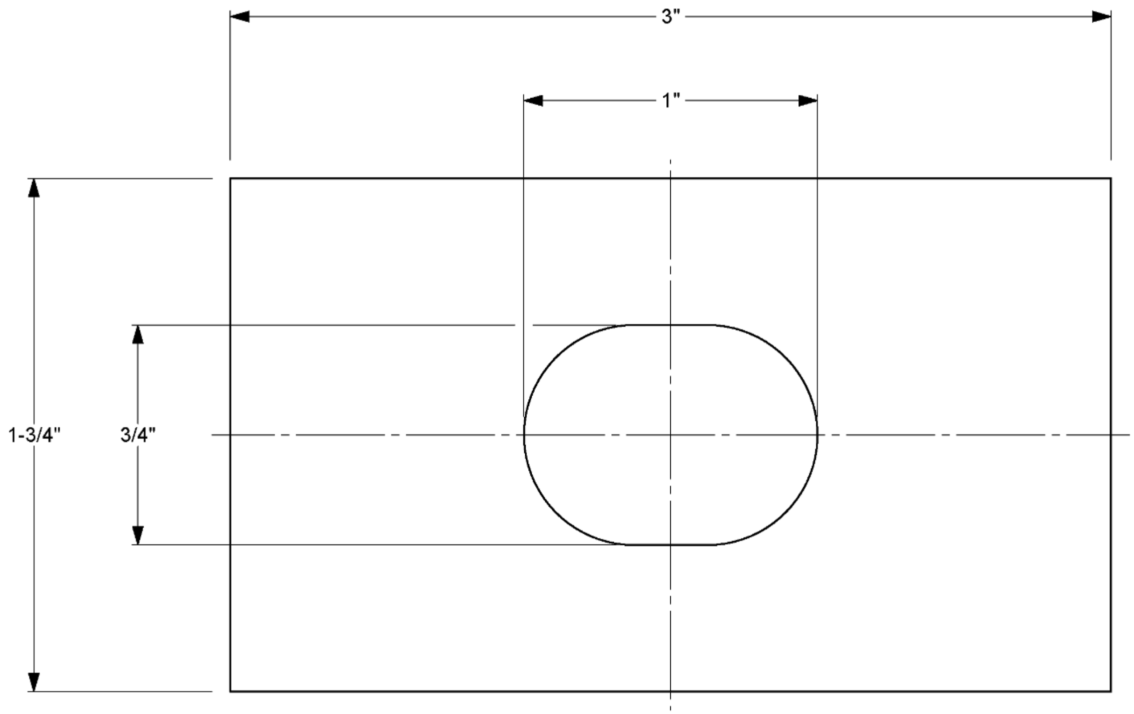
1a. Material is ASTM A 563 Grade A.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
Recessed Guardrail Nut			2022-07-18
Drawn by GES	Scale 2:1	Sheet 1 of 1	

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

Rectangular Guardrail Washer

0.20" thick

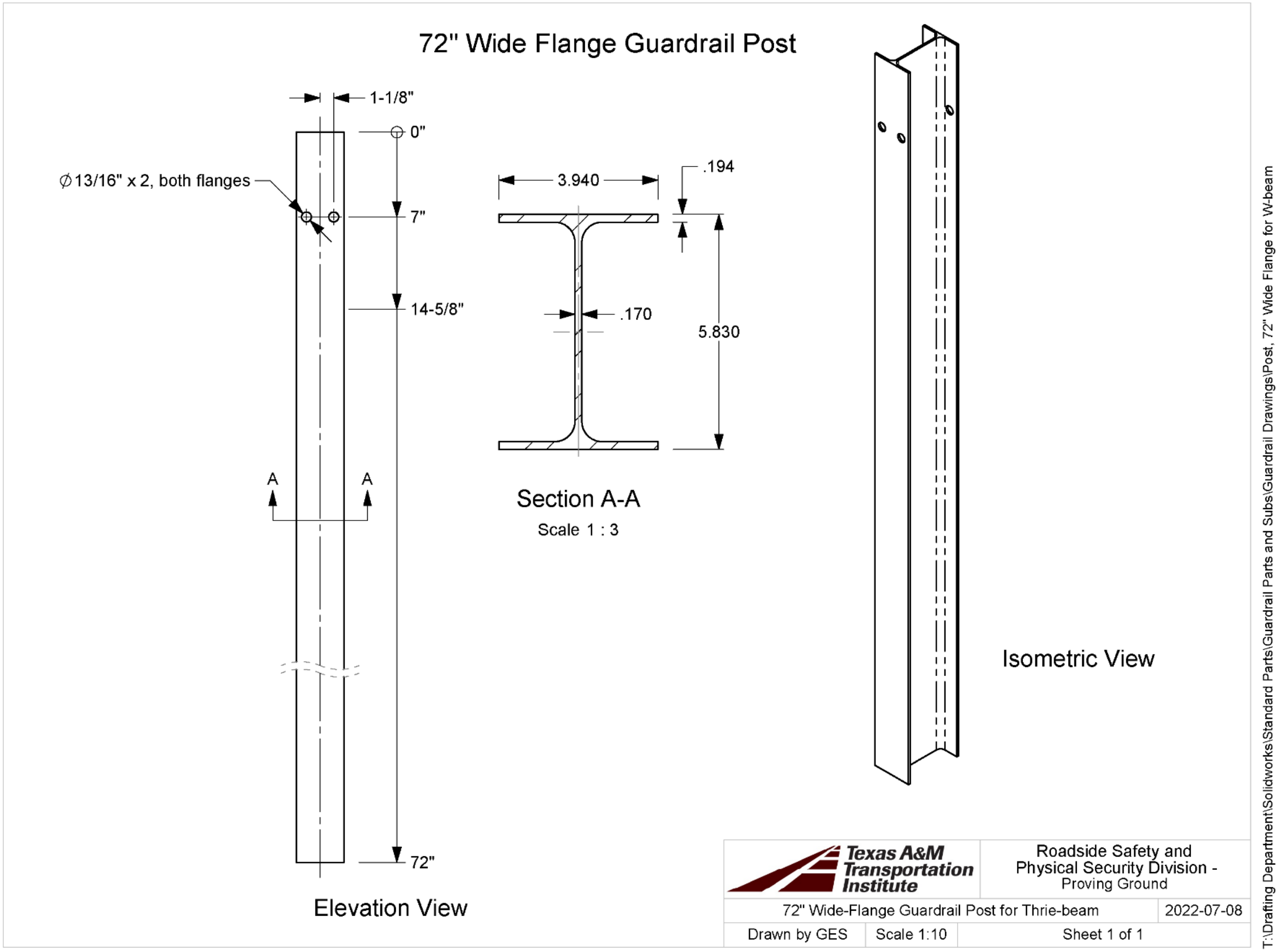


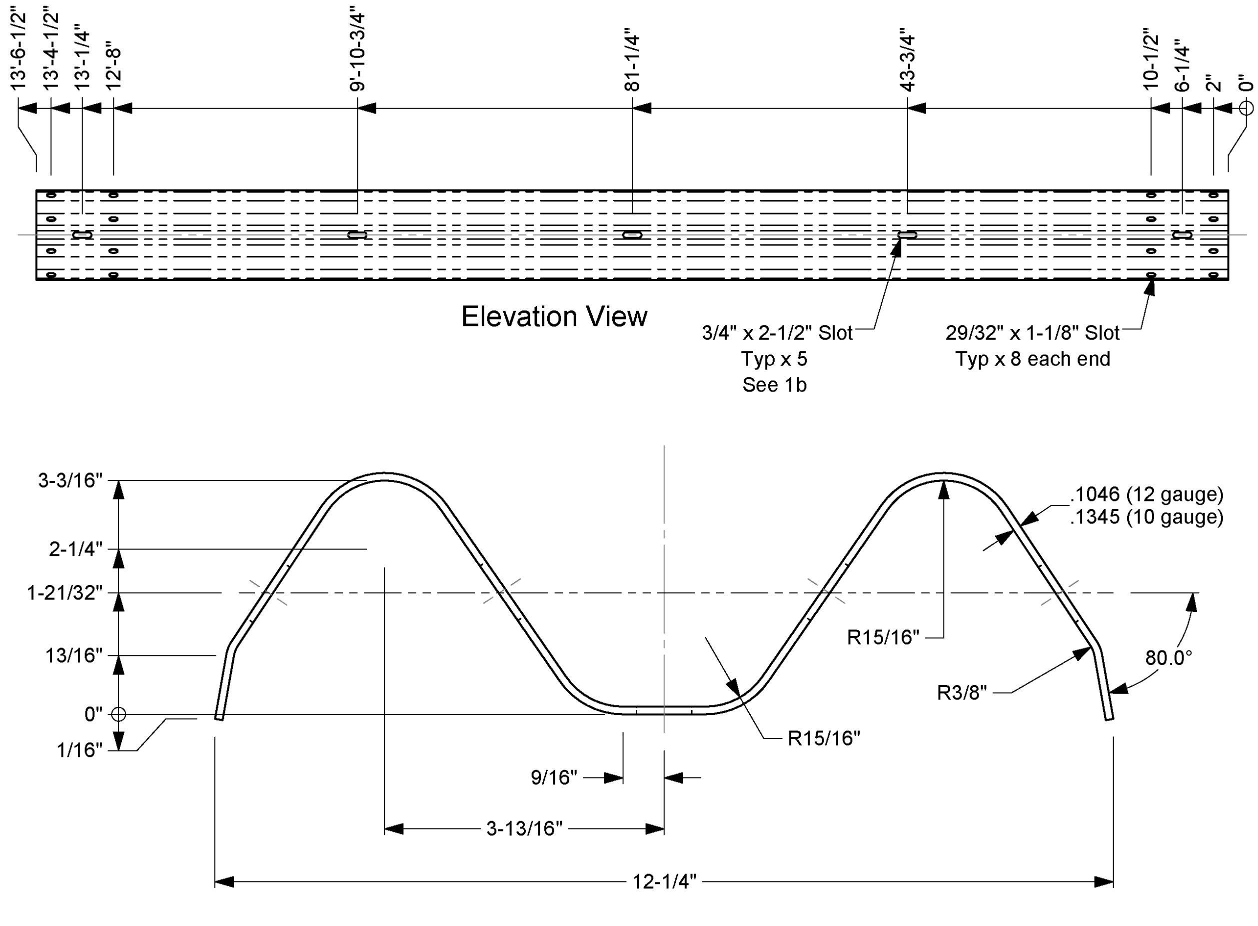
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Rectangular Guardrail Washer	2022-07-08
Drawn by GES	Scale 2:1	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Washer, rect.


72" Wide Flange Guardrail Post
1-1/8"
0"
⌀13/16" x 2, both flanges
7"
14-5/8"
A
A
72"
Elevation View
3.940
.194
.170
5.830
Section A-A
Scale 1 : 3
Isometric View
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
72" Wide-Flange Guardrail Post for Thrie-beam
2022-07-08
Drawn by GES
Scale 1:10
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, 72" Wide Flange for W-beam



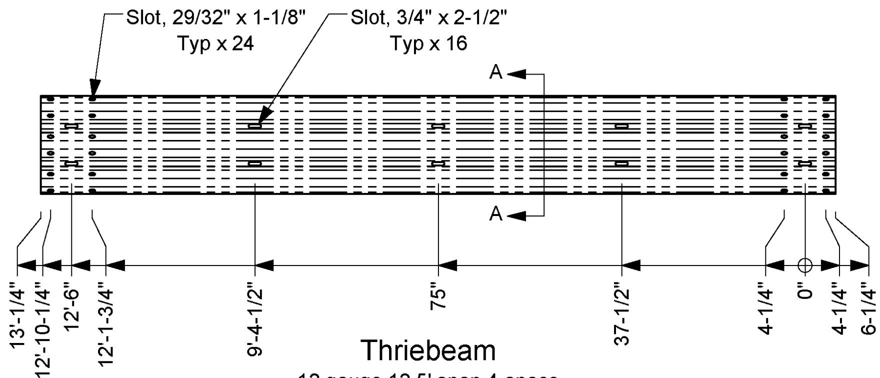
Section View

1a. Manufacture per AASHTO M180 specifications.

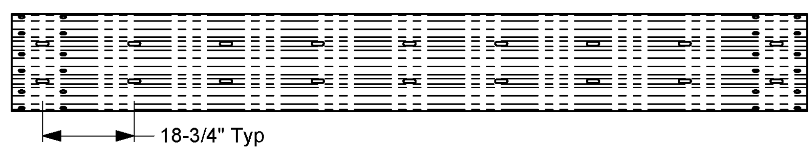
1b. 4-space Guardrail is shown. Slots typical x 3 for 2-space W-beam spaced at 75", and typical x 9 for 8-space W-beam spaced at 18-3/4". Slots are typical x 4 at 37-1/2" for 9'-4-1/2" span W-beam.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
W-beam Guardrail			2022-07-13
Drawn by GES	Scale 1:20	Sheet 1 of 1	

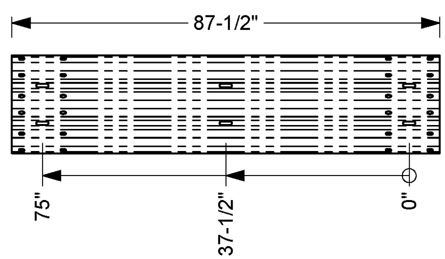
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\W-Beam Guardrail



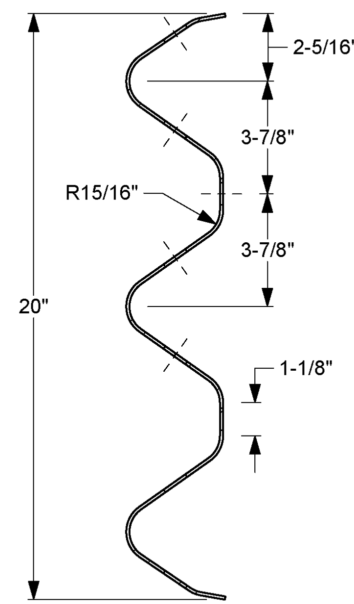
Thriebeam
12 gauge 12.5' span 4-space



Thriebeam
12 gauge 12.5' span 8-space
Dimensions not shown here same as 4-space Thriebeam



Thriebeam
12 gauge 75" span
Dimensions not shown here same as 4-space Thriebeam



Section A-A
Scale 1 : 5
Typical all Thriebeams

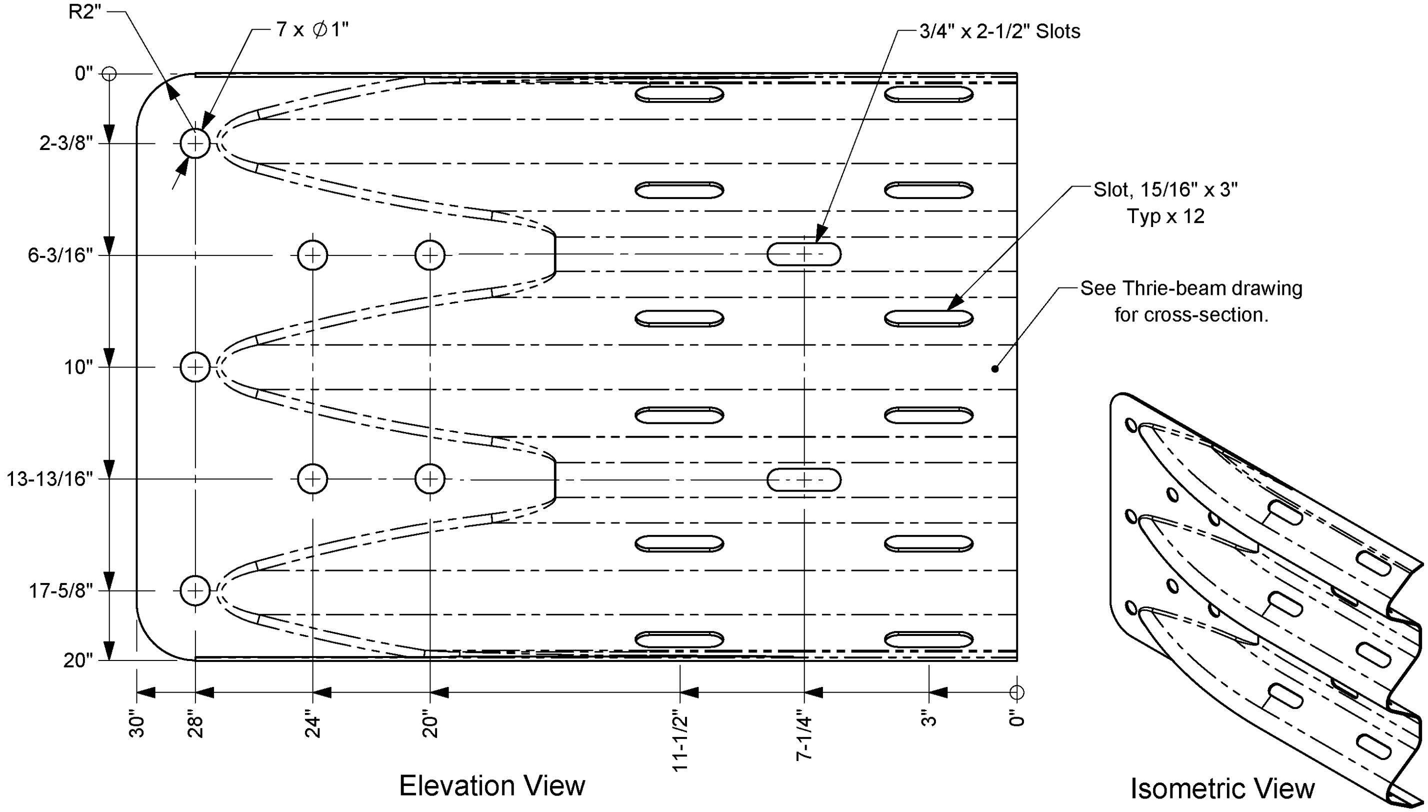
1a. 12 gauge is 0.1046" before galvanizing and 0.1084" after, and 10 gauge is 0.1345" before galvanizing and 0.1382" after.
1b. Not all versions shown here used in all installations.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Thrie-beam		2022-07-13
Drawn by GES	Scale 1:30	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Thrie-Beam

Thrie-beam End Shoe

10 gauge (0.1345" before galvanizing)

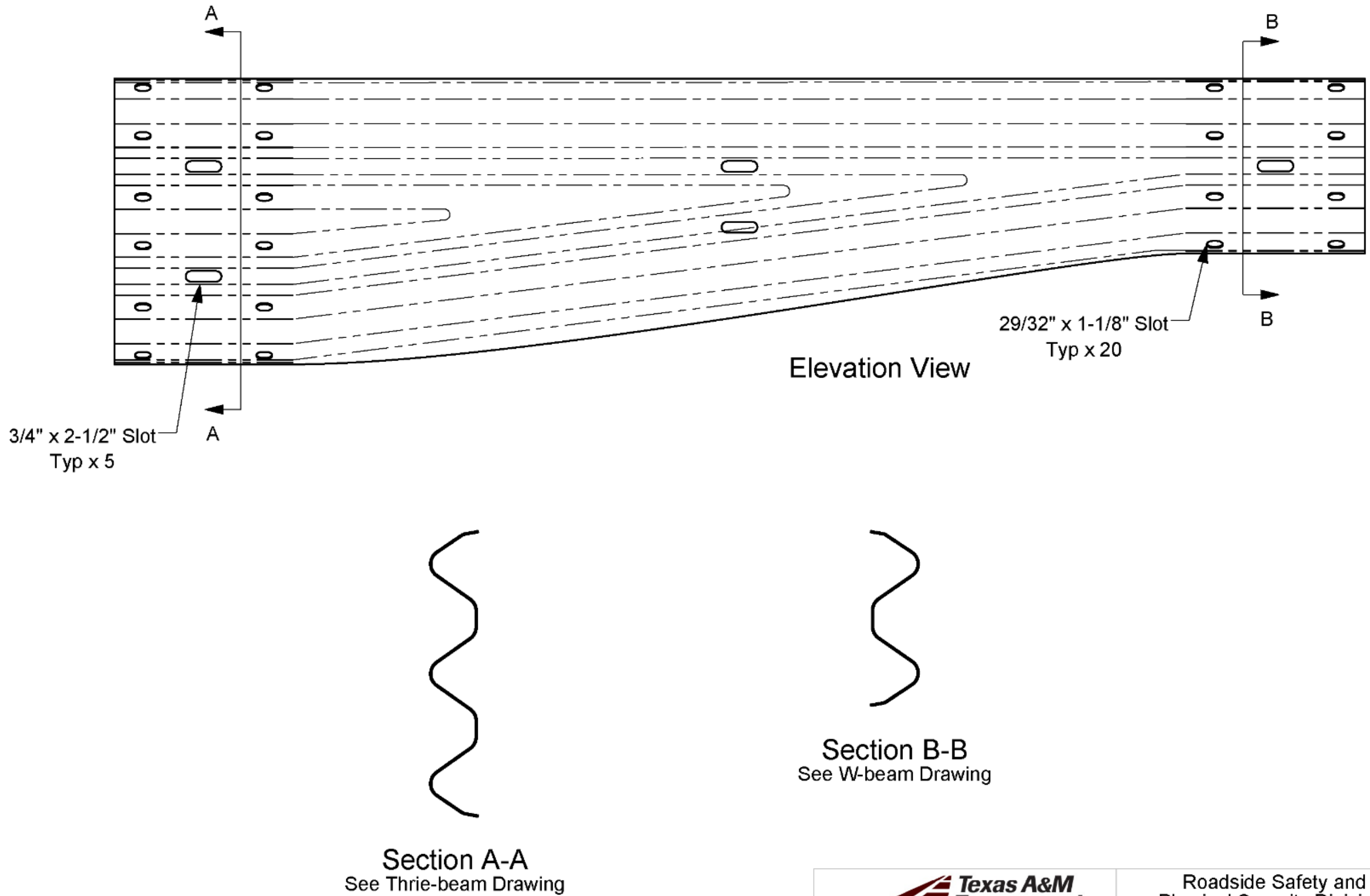


Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Thrie-beam Terminal Connector		202-07-18
Drawn by GES	Scale 1:5	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Parts and Subs\Guardrail Drawings\Thrie-beam End Shoe

Thrie to W-Beam, asymmetric

10 gauge



Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Thrie- to W-beam Asymmetric Transition		2022-07-18
Drawn by GES	Scale 1:10	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Parts and Subs\Guardrail Drawings\Thrie to W-Beam, asymmetric

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

Certified Analysis

615251

VALTIR

Valtir, LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499
Customer: TEXAS A&M TRANSPORTATION INSTI
ROADSIDE SAFETY & PHYSICA
BUSINESS OFFICE
3135 TAMU
COLLEGE STATION, TX 77843-3135

Project: STOCK

Order Number: 1352772 Prod Ln Grp: 0-OE2.0
Customer PO: 612541
BOL Number: 89568 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 11/11/22

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn
4	11G	12/12'6/3'1.5/S			2	F13122												
			M-180	A	2	277506	65,000	84,374	24.3	0.200	0.790	0.016	0.004	0.010	0.120	0.000	0.080	0.001
			M-180	A	2	277540	59,744	76,903	26.9	0.180	0.740	0.010	0.004	0.010	0.100	0.001	0.050	0.002
			M-180	A	2	277541	61,280	79,207	25.9	0.190	0.730	0.010	0.002	0.020	0.100	0.001	0.040	0.001
	11G				2	F13922												
			M-180	A	2	279432	63,794	82,495	22.6	0.180	0.730	0.015	0.002	0.020	0.090	0.000	0.070	0.003
			M-180	A	2	279435	64,684	84,763	23.1	0.190	0.730	0.013	0.002	0.030	0.090	0.000	0.060	0.002
			M-180	A	2	279436	63,668	82,065	23.1	0.200	0.720	0.012	0.003	0.010	0.090	0.000	0.060	0.002
			M-180	A	2	279440	53,591	83,174	24.2	0.200	0.740	0.009	0.003	0.020	0.110	0.000	0.060	0.002
			M-180	A	2	279442	60,706	78,007	24.6	0.170	0.730	0.008	0.004	0.010	0.100	0.001	0.050	0.001
4	211G	T12/12'6/3'1.5/S				F12722												
			M-180	A		276319	61,591	79,925	24.4	0.190	0.750	0.011	0.002	0.020	0.110	0.000	0.100	0.001
			M-180	A		276319	61,591	79,925	24.4	0.190	0.750	0.011	0.002	0.020	0.110	0.000	0.100	0.001
			M-180	A		276349	60,441	80,006	25.8	0.190	0.730	0.009	0.003	0.010	0.110	0.000	0.080	0.001
			M-180	A		276349	60,441	80,006	25.8	0.190	0.730	0.009	0.003	0.010	0.110	0.000	0.080	0.001
			M-180	A		276350	60,512	80,175	23.4	0.190	0.740	0.009	0.005	0.010	0.120	0.000	0.070	0.001
			M-180	A		276350	60,512	80,175	23.4	0.190	0.740	0.009	0.005	0.010	0.120	0.000	0.070	0.001
			M-180	A		276351	60,982	80,245	23.0	0.190	0.740	0.009	0.003	0.010	0.120	0.000	0.080	0.001
			M-180	A		276351	60,982	80,245	23.0	0.190	0.740	0.009	0.003	0.010	0.120	0.000	0.080	0.001
			M-180	A		276800	60,651	80,504	24.4	0.190	0.720	0.008	0.003	0.020	0.090	0.000	0.060	0.001
			M-180	A		276800	60,651	80,504	24.4	0.190	0.720	0.008	0.003	0.020	0.090	0.000	0.060	0.001
9	533G	6'0 POST/8.5/DDR/7	A-36			1114803	54,500	67,500	28.3	0.070	0.840	0.007	0.022	0.230	0.130	0.015	0.040	0.002
	533G		A-36			2104723	54,000	66,200	26.0	0.070	80.000	0.013	0.020	0.200	0.100	0.014	0.040	0.002
	533G		A-36			59106347	62,348	76,348	27.0	0.080	0.970	0.013	0.018	0.170	0.290	0.013	0.150	0.001

Certified Analysis

VALTIR

Valtir, LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499
Customer: TEXAS A&M TRANSPORTATION INSTI
ROADSIDE SAFETY & PHYSICA
BUSINESS OFFICE
3135 TAMU
COLLEGE STATION, TX 77843-3135
Project: STOCK

Order Number: 1352772 Prod Ln Grp: 0-OE2.0
Customer PO: 612541
BOL Number: 89568 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 11/11/22

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn
1	975G	T10/END SHOE	M-180	B	2	270936	48,995	60,112	35.8	0.050	0.480	0.012	0.003	0.020	0.110	0.000	0.070	0.001
24	3320G	3/16"X1.75"X3" WASHER	FAST			108093												
11	4076B	WD BLK RTD 6X8X14	WOOD			4850												
10	6149B	WD BLK RTD 6X8X18	WOOD			7080												
6	14784G	7'0 POST/8.5#/3HI TX	A-36			59106347	62,348	76,348	27.0	0.080	0.970	0.013	0.018	0.170	0.290	0.013	0.150	0.001
3	14785G	6'0 POST/8.5#/3HI TX/7:7	A-36			59106347	62,348	76,348	27.0	0.080	0.970	0.013	0.018	0.170	0.290	0.013	0.150	0.001
1	32218G	T10/TRAN/TB:WB/ASYM/RT	MISC			833M66260												

Upon delivery, all materials subject to Valtir, LLC Storage Stain Policy QMS-LQ-002.

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

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

Certified Analysis

VALTIR

Valtir, LLC

2548 N.E. 28th St.

Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: TEXAS A&M TRANSPORTATION INSTI
ROADSIDE SAFETY & PHYSICA
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COLLEGE STATION, TX 77843-3135

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Customer PO: 612541
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As of: 11/11/22

Project: STOCK

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

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

State of Texas, County of Tarrant. Sworn and subscribed before me this 11st day of November, 2022.

Notary Public:
Commission Expires: / /

Angela Ruth Humphrey
My Commission Expires
6/24/2026
Notary ID 133827723

Valtir, LLC
Certified By:
Quality Assurance

3 of 3

Certified Analysis

VALTIR

Valtir, LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499
Customer: TEXAS A&M TRANSPORTATION INSTI
ROADSIDE SAFETY & PHYSICA
BUSINESS OFFICE
3135 TAMU
COLLEGE STATION, TX 77843-3135

Order Number: 1353394 Prod Ln Grp: 0-OE2.0
Customer PO: 615251
BOL Number: 89569 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 11/11/22

Project: STOCK

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn
4	11G	12/12'6/3'1.5/S			2	F13122												
			M-180	A	2	277506	65,000	84,374	24.3	0.200	0.790	0.016	0.004	0.010	0.120	0.000	0.080	0.001
			M-180	A	2	277540	59,744	76,903	26.9	0.180	0.740	0.010	0.004	0.010	0.100	0.001	0.050	0.002
			M-180	A	2	277541	61,280	79,207	25.9	0.190	0.730	0.010	0.002	0.020	0.100	0.001	0.040	0.001
	11G				2	F13222												
			M-180	A	2	2122871	58,100	81,100	23.0	0.210	0.750	0.009	0.003	0.020	0.070	0.002	0.040	0.003
			M-180	A	2	2122872	50,800	74,300	26.0	0.220	0.790	0.009	0.002	0.030	0.080	0.001	0.040	0.003
			M-180	A	2	2122872	61,000	83,300	,999.0	0.220	0.790	0.009	0.002	0.030	0.080	0.000	0.040	0.003
			M-180	A	2	277506	65,000	84,374	24.3	0.200	0.790	0.016	0.004	0.010	0.120	0.000	0.080	0.001
			M-180	A	2	277540	59,744	76,903	26.9	0.180	0.740	0.010	0.004	0.010	0.100	0.001	0.050	0.002
			M-180	A	2	277541	61,280	79,207	25.9	0.190	0.730	0.010	0.002	0.020	0.100	0.001	0.040	0.001
			M-180	A	2	277542	61,872	79,516	25.8	0.200	0.760	0.009	0.005	0.010	0.100	0.000	0.050	0.001
8	533G	6'0 POST/8.5/DDR/7	A-36			1114803	54,500	67,500	28.3	0.070	0.840	0.007	0.022	0.230	0.130	0.015	0.040	0.002
	533G		A-36			2104723	54,000	66,200	26.0	0.070	80.000	0.013	0.020	0.200	0.100	0.014	0.040	0.002
	533G		A-36			59106347	62,348	76,348	27.0	0.080	0.970	0.013	0.018	0.170	0.290	0.013	0.150	0.001
40	3320G	3/16"X1.75"X3" WASHER	FAST			108093												
135	3340G	5/8" GR HEX NUT	FAST			22-35-011												
40	3360G	5/8"X1.25" GR BOLT	A307-3360G			A15007-8												
40	3400G	5/8"X2" GR BOLT	A307-3400G			A14956-9												
15	3500G	5/8"X10" GR BOLT A307	A307-3500G			A20068-2												

Certified Analysis

VALTIR

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Ft Worth (THP), TX 76111 Phn:(817) 665-1499

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ROADSIDE SAFETY & PHYSICA
BUSINESS OFFICE
3135 TAMU
COLLEGE STATION, TX 77843-3135

Order Number: 1353394 Prod Ln Grp: 0-OE2.0
Customer PO: 615251
BOL Number: 89569 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 11/11/22

Project: STOCK

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn
14	4076B	WD BLK RTD 6X8X14	WOOD			4850												
6	6149B	WD BLK RTD 6X8X18	WOOD			7080												
2	10967G	12/9'4.5/3'1.5/S			2	F14522												
			M-180	A	2	279437	63,668	82,065	23.1	0.200	0.720	0.012	0.003	0.010	0.090	0.000	0.060	0.002
			M-180	A	2	281434	61,121	79,287	26.0	0.180	0.740	0.014	0.004	0.010	0.120	0.000	0.050	0.004
			M-180	A	2	281442	61,762	80,996	25.6	0.019	0.730	0.012	0.004	0.010	0.110	0.000	0.060	0.002
			M-180	A	2	281442	61,762	80,996	25.6	0.019	0.730	0.012	0.004	0.010	0.110	0.000	0.060	0.002
	10967G		RHC		2	L12822												
			M-180	A	2	275639	62,212	82,063	25.3	0.190	0.073	0.014	0.003	0.020	0.140	0.000	0.080	0.002
			M-180	A	2	275642	63,791	82,357	23.2	0.190	0.740	0.015	0.005	0.010	0.120	0.000	0.100	0.002
			M-180	A	2	275875	61,764	79,897	23.9	0.190	0.730	0.011	0.001	0.010	0.110	0.000	0.060	0.002
			M-180	A	2	276471	61,104	80,038	25.5	0.190	0.720	0.011	0.003	0.010	0.110	0.000	0.050	0.001
			M-180	A	2	276472	62,468	79,978	25.4	0.200	0.730	0.011	0.002	0.010	0.110	0.000	0.050	0.001
			M-180	A	2	276474	63,174	81,018	24.8	0.190	0.720	0.009	0.002	0.020	0.100	0.000	0.060	0.001
			M-180	A	2	276477	61,527	80,001	24.7	0.190	0.720	0.012	0.005	0.010	0.100	0.000	0.060	0.001
			M-180	A	2	276478	60,258	79,671	21.8	0.200	0.740	0.010	0.005	0.010	0.110	0.000	0.050	0.002
			M-180	A	2	276480	62,278	80,531	24.5	0.200	0.720	0.010	0.004	0.010	0.100	0.001	0.050	0.002
			M-180	A	2	276481	60,277	78,610	23.2	0.190	0.740	0.009	0.004	0.010	0.110	0.000	0.050	0.001
			M-180	A	2	276800	60,651	80,504	24.4	0.190	0.720	0.008	0.003	0.020	0.090	0.001	0.060	0.000
2	12365G	T12/12'6/8@1'6.75/S				F14522												
			M-180	A		279437	63,668	82,065	23.1	0.200	0.720	0.012	0.003	0.010	0.090	0.000	0.060	0.002
			M-180	A		281434	61,121	79,287	26.0	0.180	0.740	0.014	0.004	0.010	0.120	0.000	0.050	0.004
			M-180	A		281442	61,762	80,996	25.6	0.019	0.730	0.012	0.004	0.010	0.110	0.000	0.060	0.002

Certified Analysis

VALTIR

Valtir, LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: TEXAS A&M TRANSPORTATION INSTI
ROADSIDE SAFETY & PHYSICA
BUSINESS OFFICE
3135 TAMU
COLLEGE STATION, TX 77843-3135

Order Number: 1353394 Prod Ln Grp: 0-OE2.0
Customer PO: 615251
BOL Number: 89569 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 11/11/22

Project: STOCK

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn
			M-180	A		281442	61,762	80,996	25.6	0.019	0.730	0.012	0.004	0.010	0.110	0.000	0.060	0.002
	12365G		RHC		2	L31318												
			M-180	A	2	222038	63,780	82,280	22.9	0.190	0.750	0.012	0.002	0.030	0.100	0.000	0.070	0.001
			M-180	A	2	222878	64,680	81,820	25.2	0.180	0.740	0.012	0.003	0.020	0.130	0.000	0.070	0.002
	12365G		RHC		2	L34919												
			M-180	A	2	245021	64,480	83,940	22.2	0.190	0.700	0.013	0.004	0.020	0.060	0.000	0.060	0.001
			M-180	A	2	245984	62,860	80,840	26.2	0.190	0.720	0.008	0.003	0.010	0.080	0.000	0.050	0.000
1	32218G	T10/TRAN/TB:WB/ASYM/RT	MISC			833M66260												

Upon delivery, all materials subject to Valtir, LLC Storage Stain Policy QMS-LQ-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.
ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)
FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329, UNLESS OTHERWISE STATED.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

Certified Analysis

VALTIR

Valtir, LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: TEXAS A&M TRANSPORTATION INSTI
ROADSIDE SAFETY & PHYSICA
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3135 TAMU
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Project: STOCK

Order Number: 1353394 Prod Ln Grp: 0-OE2.0
Customer PO: 615251
BOL Number: 89569 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 11/11/22

State of Texas, County of Tarrant. Sworn and subscribed before me this 11st day of November, 2022 .

Notary Public:
Commission Expires: / /

Angela Ruth Humphrey
My Commission Expires
6/24/2026
Notary ID 133827723

Certified By: Valtir, LLC
Quality Assurance

APPENDIX C. *MASH* TEST 3-21 (CRASH TEST 615251-01-1)

C.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2023-01-26 Test No.: 615251-01-1 VIN No.: 1C6RR6FT9JS188242

Year: 2018 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 130060

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

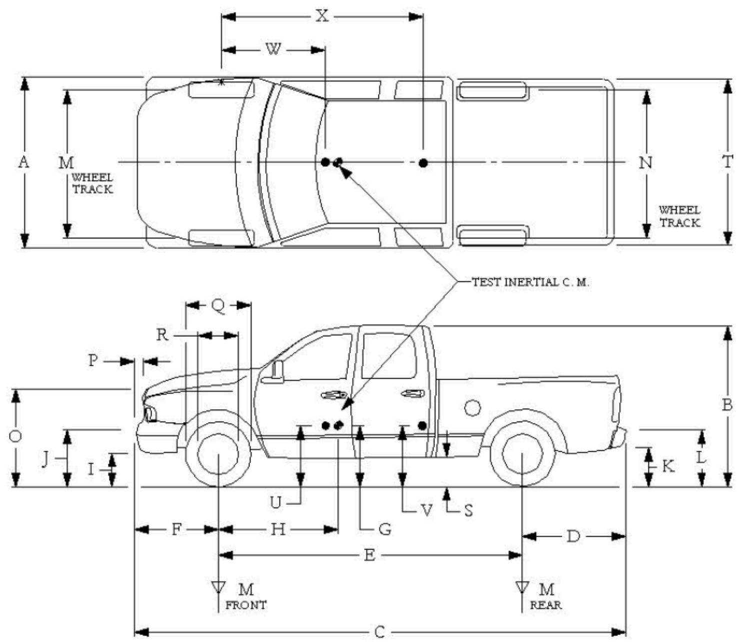
NOTES: None

Engine Type: V-8
Engine CID: 5.7 liter

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

Optional Equipment:
None

Dummy Data:
Type:
Mass: lb
Seat Position:



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.60	L	30.00	Q	30.50	V	30.25
C	227.50	H	59.73	M	68.50	R	18.00	W	59.75
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		

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

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2945	2888	2888
Back	3900	M_{rear}	2204	2136	2136
Total	6700	M_{Total}	5149	5024	5024

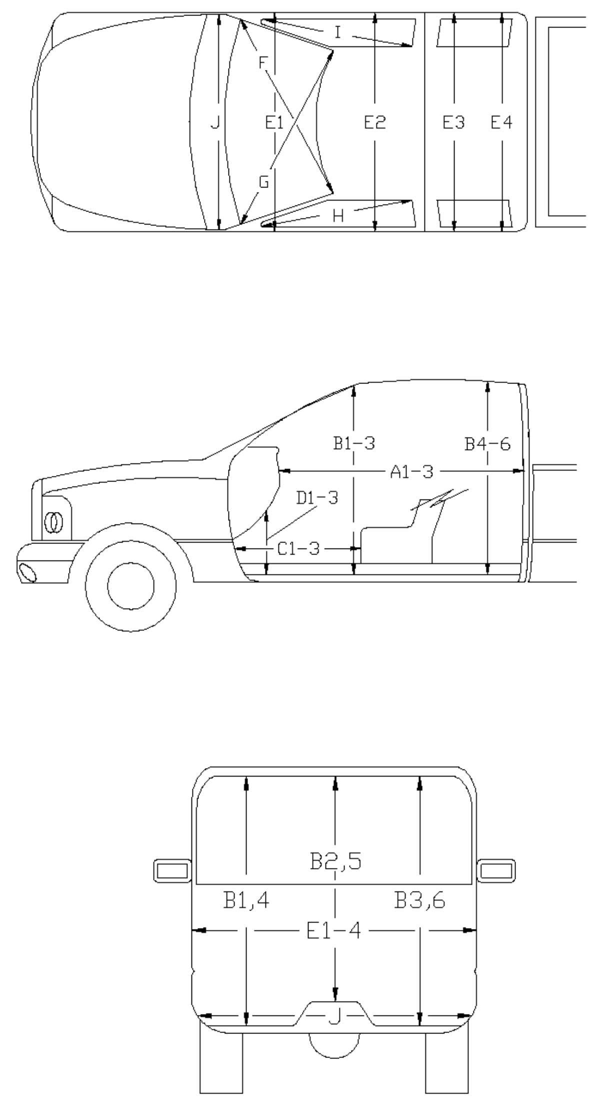
(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:
lb LF: 1461 RF: 1427 LR: 1096 RR: 1040

Figure C.1. Vehicle Properties for Test 615251-01-1.

Date: 2023-01-26 Test No.: 615251-01-1 VIN No.: 1C6RR6FT9JS188242

Year: 2018 Make: RAM Model: 1500



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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	25.00	-1.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	11.50	0.00
E1	58.50	58.00	-0.50
E2	63.50	64.50	1.00
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	24.00	-1.00

Figure C.2. Exterior Crush Measurements for Test 615251-01-1.

Date:	2023-01-26	Test No.:	615251-01-1	VIN No.:	1C6RR6FT9JS188242
Year:	2018	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	AT FT BUMPER	14	14	36							18
2	ABOVE FT BUMPER	14	12	60							70
	Measurements recorded										
	☑ inches or ☐ mm										

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

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

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

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

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

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

Figure C.3. Occupant Compartment Measurements for Test 615251-01-1.

C.2. SEQUENTIAL PHOTOGRAPHS

(a) 0.000 s

(b) 0.100 s

(c) 0.200 s

(d) 0.300 s

(e) 0.400 s

(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

Figure C.4. Sequential Photographs for Test 615251-01-1 (Overhead Views).

(a) 0.000 s (b) 0.100 s

(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

Figure C.5. Sequential Photographs for Test 615251-01-1 (Frontal Views).

(a) 0.000 s

(b) 0.100 s

(c) 0.200 s

(d) 0.300 s

(e) 0.400 s

(f) 0.500 s

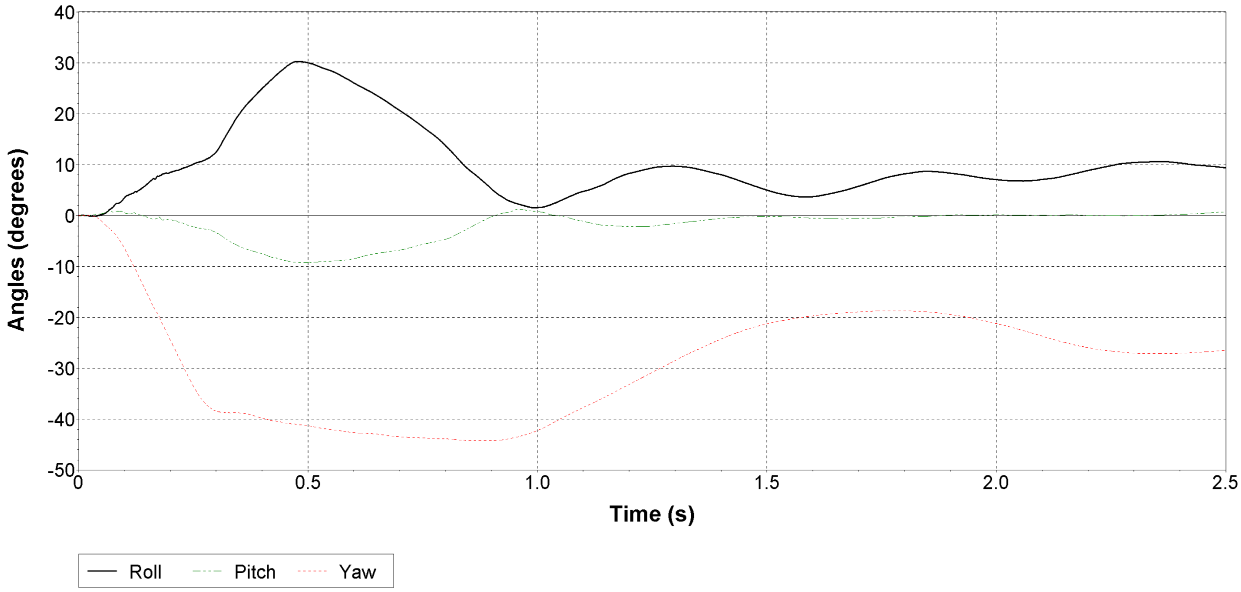
(g) 0.600 s

(h) 0.700 s

Figure C.6. Sequential Photographs for Test 615251-01-1 (Rear Views).

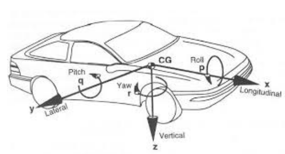
C.3. VEHICLE ANGULAR DISPLACEMENTS

Roll, Pitch and Yaw Angles



Axes are vehicle-fixed.
Sequence for
determining orientation:

1. Yaw.
2. Pitch.
3. Roll.



Test Number: 615251-01
Test Standard Test Number: *MASH* Test 3-21
Test Article: Transition with Storm Drain Inlet
Test Vehicle: 2018 RAM 1500
Inertial Mass: 5024 lbs
Gross Mass: 5024 lbs
Impact Speed: 62.4 mi/h
Impact Angle: 25.1°

Figure C.7. Vehicle Angular Displacements for Test 615251-01-1.

C.4. VEHICLE ACCELERATIONS

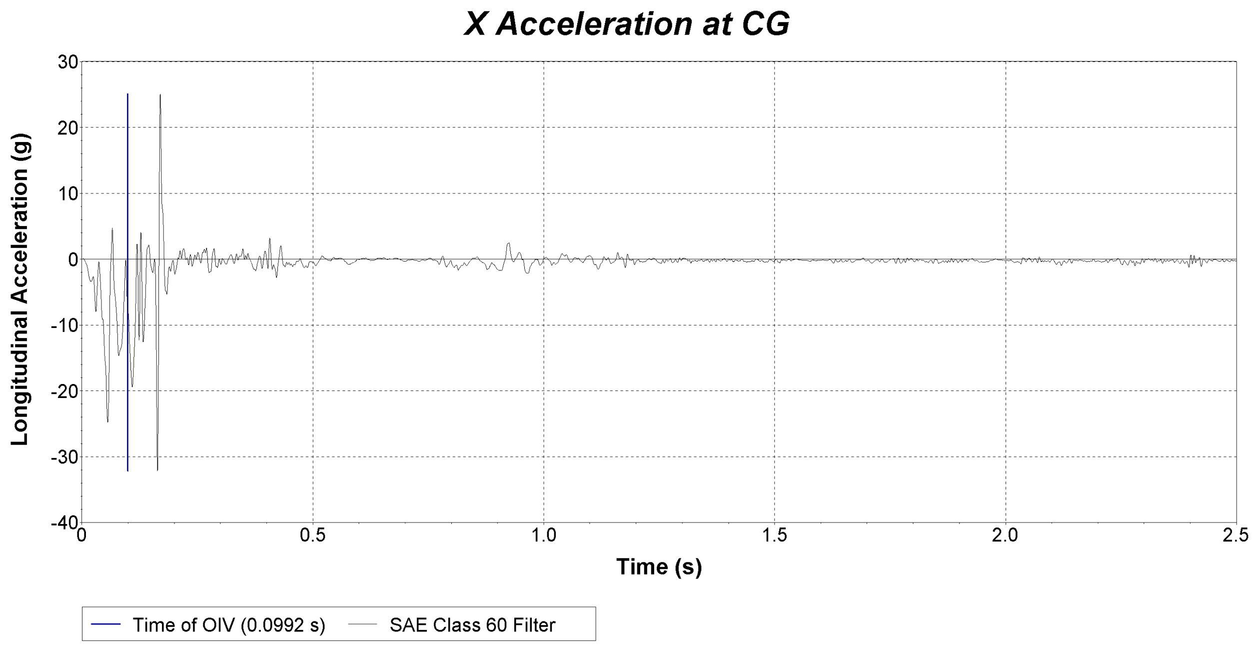


Figure C.8. Vehicle Longitudinal Accelerometer Trace for Test 615251-01-1 (Accelerometer Located at Center of Gravity).

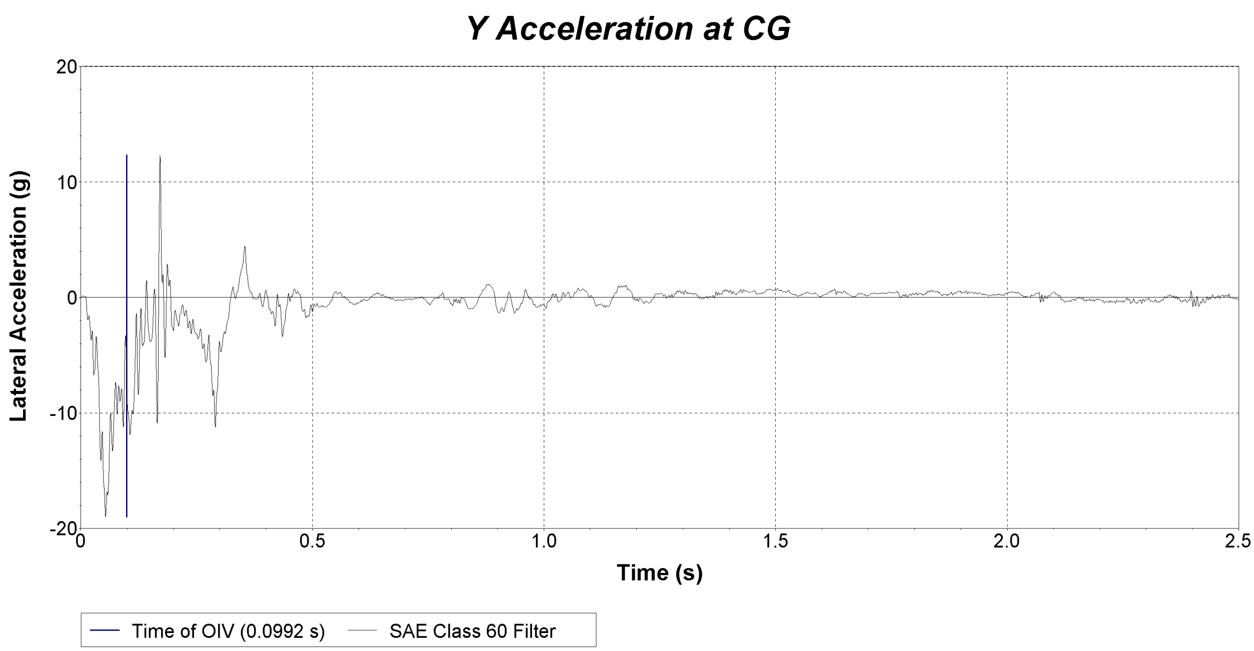


Figure C.9. Vehicle Lateral Accelerometer Trace for Test 615251-01-1 (Accelerometer Located at Center of Gravity).

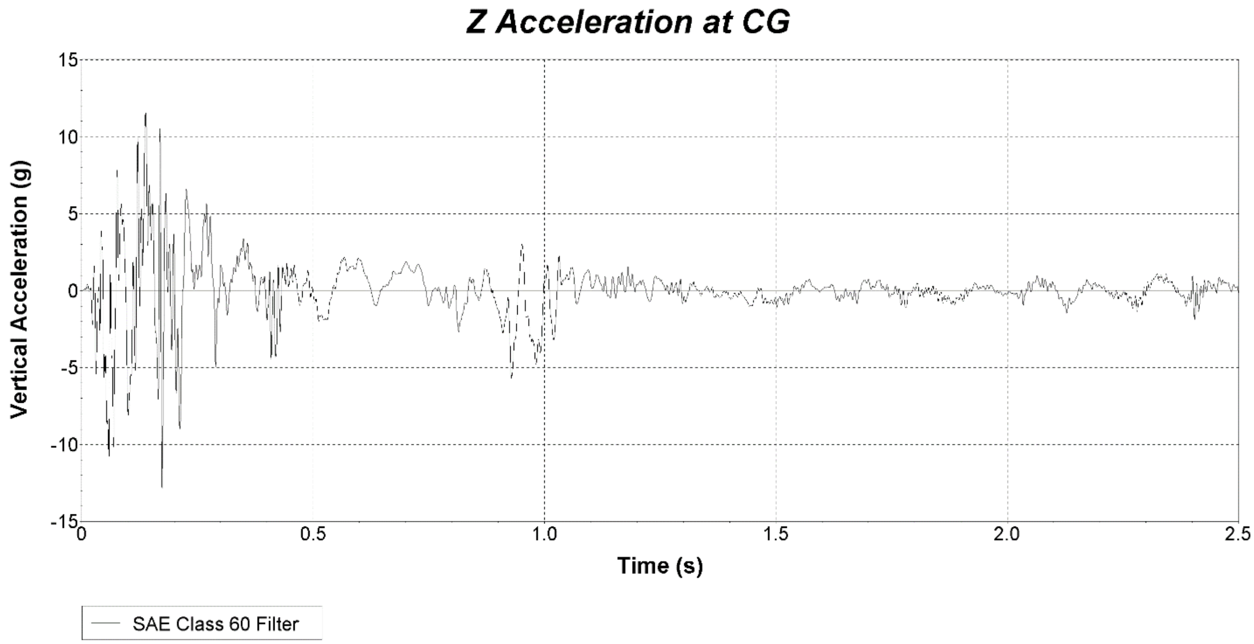


Figure C.10. Vehicle Vertical Accelerometer Trace for Test 615251-01-1 (Accelerometer Located at Center of Gravity).