Texas A&M Transportation Institute
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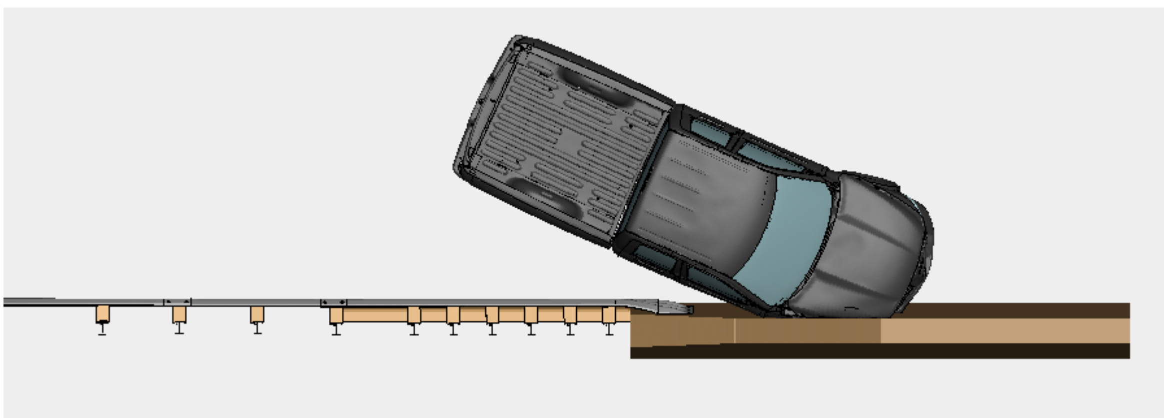
GUIDELINES FOR ATTACHING MASH-COMPLIANT THRIE-BEAM TRANSITIONS TO RIGID CONCRETE BARRIERS OTHER THAN THE RIGID BARRIER TESTED

Report No. 616001-01



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16. Abstract

The objective of this project was to explore the feasibility of attaching *Manual for Assessing Safety Hardware* (MASH)-compliant thrie-beam transition systems onto rigid concrete barriers other than the one that was tested. The Texas A&M Transportation Institute (TTI) research team used a state survey, literature review, engineering experience, and limited finite element simulation study to determine key features associated with the concrete parapet that can influence impact performance of a transition system. Recommendations were then developed regarding the application of selected features to permit attachment of a MASH-compliant thrie-beam transition to other concrete parapets than the one tested. The key features enabling use of the tested transition with other parapets were parapet profile, parapet height, parapet toe tapering, and curb or rubrail presence in the tested transition. The study findings and recommendations are summarized in this report.

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DISCLAIMER

The contents of this report reflect the views of the authors, who are solely responsible for the facts and accuracy of the data and the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Roadside Safety Pooled Fund, The Texas A&M University System, or the Texas A&M Transportation Institute. This report does not constitute a standard, specification, or regulation. In addition, the above listed agencies/companies assume no liability for its contents or use thereof. The names of specific products or manufacturers listed herein do not imply endorsement of those products or manufacturers.

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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. PROBLEM STATEMENT

The impact performance of roadside safety devices is evaluated using the criteria of the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (MASH) [1]. Transitions are an example of safety hardware addressed by MASH; design engineers use these devices to vary the stiffness between adjoining barrier types or configurations to avoid abrupt changes. One common application is a transition from a flexible or semi-rigid approach guardrail to a rigid concrete parapet or bridge rail. Designers transition the stiffness using different rail elements as well as post size, spacing, and embedment depth. Features such as rubrails or curbs are sometimes used below the primary transition rail element to help mitigate vehicle snagging on the transition posts and the end of the parapet to which the transition is attached.

Although guardrail systems are more standardized, state departments of transportation (DOTs) use a variety of MASH-compliant bridge rail and transition systems. Testing each transition system with multiple variations in parapet profile and height is impractical. Further, design engineers need to accommodate a variety of site conditions. Consequently, designers could benefit from guidance that expands the range of applicable concrete parapet types to which a tested stiffness transition can be attached.

1.2. OBJECTIVE

The objective of this research was to develop guidance for connecting MASH-compliant thrie-beam transitions to rigid barriers other than the barrier tested. Texas A&M Transportation Institute (TTI) researchers conducted a survey of the members of the Roadside Safety Pooled Fund to identify common parapet types based on frequency and/or interest in usage by participating member agencies. To the extent the available crash test data permitted, researchers considered F-shape, New Jersey (NJ)–shape, single-slope, and vertical profile parapets. The research scope included a literature review, engineering evaluation of transition crash tests, and limited finite element simulation. Performance considerations included vehicle snagging potential on the parapet end above and below the transition components. Researchers identified key parapet attributes associated with the crash-tested transition parapets and incorporated them into general guidance where appropriate.

Chapter 2. SURVEY AND LITERATURE REVIEW

A common use of stiffness transitions is to connect a W-beam approach guardrail to rigid concrete parapets or bridge rails. A nested 12-guage thrie beam is one of the most common rail types used in these transition systems. Designers achieve additional stiffness by varying post size, spacing, and embedment depth. A curb or rubrail element is often used beneath the primary thrie-beam transition rail adjacent to the parapet to reduce snagging potential on the transition posts and parapet end.

The concrete parapets to which the thrie-beam stiffness transitions attach vary in terms of shape and height. F-shape, NJ-shape, single-slope, and vertical concrete parapets have been or are currently used. The parapet height typically varies between 32 inches and 42 inches. A minimum 32-inch height is required for attachment of a 31-inch-tall thrie-beam transition rail, which is commonly achieved using a thrie-beam terminal connector or end shoe, sometimes in combination with other plates or structural components to accommodate the parapet geometry. Designers may flare or taper portions of the parapet end to reduce potential for vehicle snagging during an impact. Shape transitions are sometimes used to change the profile of a transition parapet from a vertical profile, which simplifies the transition connection, to a desired bridge rail shape.

Establishing recommendations for connecting a MASH-compliant Test Level 3 (TL-3) thrie-beam transition to various configurations of rigid concrete barriers can provide flexibility to state DOTs by enhancing hardware adaptability. The following sections provide a review of state standard practices and selected crash-tested transition systems. Researchers used this review to identify and evaluate key transition parapet features that enhance impact performance. The features formed the basis for the transition parapet guidance developed under this project.

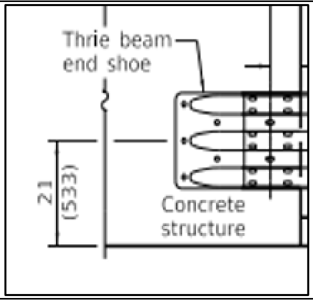
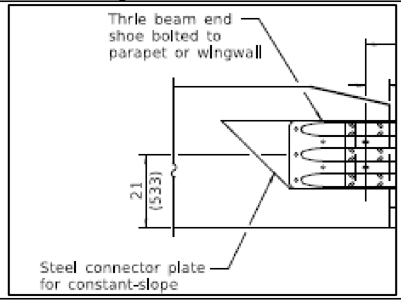
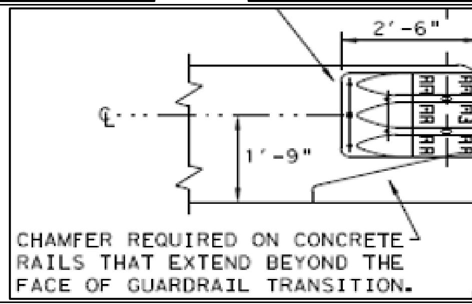
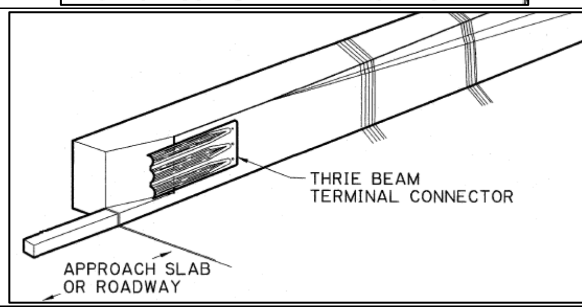
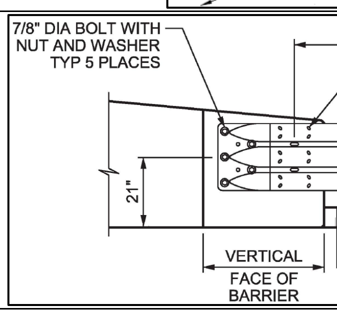
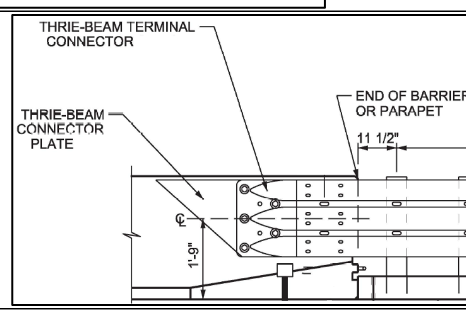
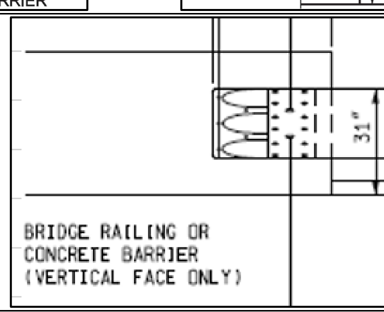
2.1. STATE DOT SURVEY AND STANDARDS REVIEW

TTI researchers polled the state members and reviewed their standard drawings to identify concrete barrier modifications commonly used in conjunction with the attachment of thrie-beam stiffness transitions. Table 2.1 summarizes some of the most common practices identified in state standards, including chamfering/tapering the parapet toe, chamfering/tapering the parapet traffic-side face near the end, using a steel connector plate to attach the thrie beam to a sloped barrier face, attaching to a vertical face and transitioning to other parapet shapes farther downstream, and tapering to the top of the concrete parapet above the transition rail to provide a height transition [2–6].

2.2. SHAPE TRANSITION

In 2019, TTI researchers investigated and developed shape transition designs for three cast-in-place (CIP) concrete barrier combinations for MASH TL-3 criteria [7]. The transitions included (a) 36-inch-tall single-slope traffic rail (SSTR) to 42-inch-tall single-slope concrete barrier (SSCB), (b) 32-inch-tall F-shape concrete barrier to SSCB, and (c) 32-inch-tall vertical concrete wall to SSCB.

Table 2.1. Most Common DOT Practices for Parapet Treatment at Transition Attachment.

DOT	Standard Drawing
Illinois [2]	 
Texas [3]	
Louisiana [4]	
Utah [5]	 
Michigan [6]	

The researchers evaluated three shape transition combinations using computer simulation. The simulation effort included evaluation of both MASH design vehicles (i.e., 1100C passenger car and 2270P pickup truck) impacting from both directions of the shape transitions. The most critical transition design was selected for crash testing. Based on vehicle stability and MASH occupant risk metrics, the researchers considered the vertical wall-to-SSCB transition to be the most critical transition design configuration. Figure 2.1 shows this shape transition. This transition was designed to connect the geometric profiles of the two barriers and account for a 10-inch height difference. The initial 6-ft transition length simulated did not satisfy MASH criteria, so the researchers increased the length of the transition section to 15 ft [7].

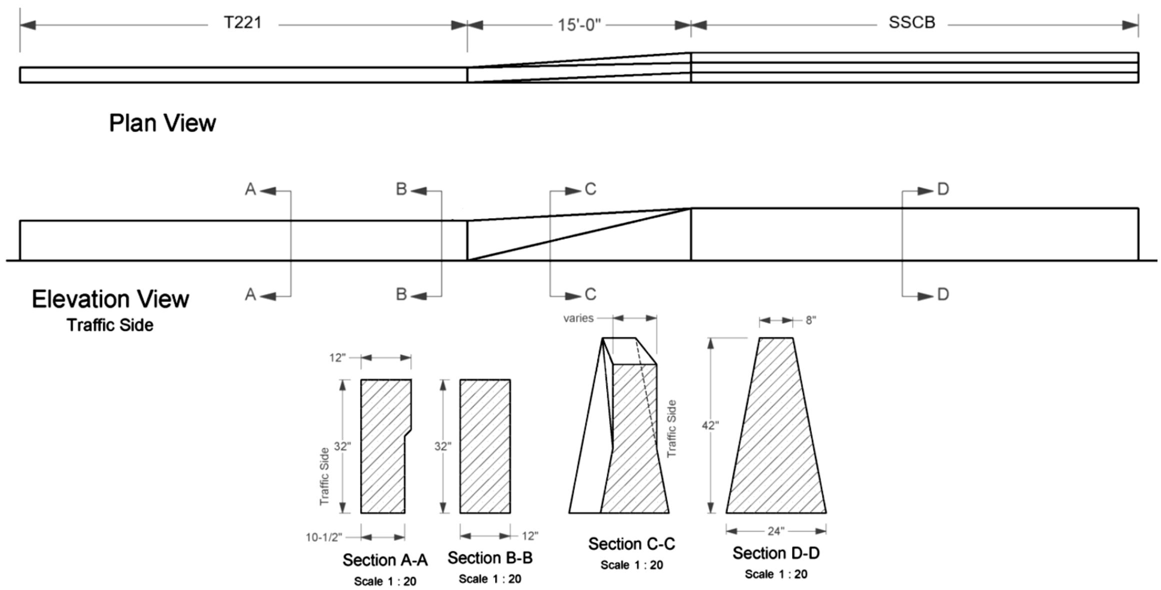


Figure 2.1. T221 to SSCB Transition Concept [7].

For MASH Test 3-20 and Test 3-21, the impact points were 3.6 ft and 4.3 ft upstream of the start of the transition section, respectively. The direction of impact in both tests was from the SSCB to vertical wall, which simulation indicated was the critical case. Based on the successful crash tests of this transition configuration, researchers expect the other two transition combinations to perform acceptably under MASH TL-3 impact conditions.

2.3. HEIGHT TRANSITION

In 1995, researchers at the Midwest Roadside Safety Facility (MwRSF) performed two crash tests on a thrie-beam transition attached to a single-slope concrete median barrier [8, 9]. Initially, the single-slope barrier had a 2:1 height transition at the end of the parapet to transition the height from 32 inches to 42 inches (see Figure 2.2) [8]. During NCHRP Report 350 Test 3-21, the impacting pickup truck experienced significant snagging with the top of the single-slope barrier that resulted in unsatisfactory impact performance. The researchers modified the parapet to have a more gentle 8:1 height transition over a length of 7.4 ft (see Figure 2.3), and the subsequent crash test satisfied all criteria [9].

Figure 2.2. Single-Slope Concrete Median Barrier with 2:1 Height Transition for Attachment to Thrie-Beam Transition [8].

Figure 2.3. Single-Slope Concrete Median Barrier with 8:1 Height Transition for Attachment to Thrie-Beam Transition [9].

In 2010, researchers at MwRSF developed a transition from a 32-inch tall, F-shape, portable concrete barrier (PCB) to a 42-inch-tall CIP California single-slope concrete median barrier (see Figure 2.4) [10]. The transition design utilized a thrie-beam rail element with thrie-beam terminal connectors at each end and a 5:1 steel transition cap to transition the height between the two barrier types. The system was successfully crash tested under MASH Test 3-21 impact conditions [10].

Figure 2.4. Transition from Freestanding F-shape PCB to Rigid Single-Slope Barrier [10].

In 2012, TTI researchers developed a transition between an F-shape PCB and CIP vertical parapet for roadside applications [11]. The transition system was designed to be pinned to concrete pavement. To provide a smooth transition surface and reduce snagging, the researchers used a thrie-beam rail element on the traffic/impact side of the system. A steel cap provided a height transition between the two barriers on a 4.8:1 slope, as Figure 2.5 shows. On the field side, a ¼-inch-thick steel plate provided additional connectivity between the two concrete barriers, as Figure 2.6 illustrates.

Figure 2.5. Transition Design for Anchored F-shape PCB to Rigid Vertical Concrete Barrier (Traffic Side) [11].

Figure 2.6. Transition Design for Anchored F-shape PCB to Rigid Vertical Concrete Barrier (Field Side) [11].

2.4. TRAFFIC FACE TAPER

In 2019, researchers at MwRSF developed a standardized buttress to attach to an increased-height thrie-beam approach guardrail transition [12]. Most thrie-beam transition systems have a 31-inch mounting height to the top of the thrie-beam rail. The researchers increased the mounting height to 34 inches to account for a future 3-inch pavement overlay. The standardized transition buttress incorporated a dual-chamfered front face to reduce the possibility of vehicle snagging on the upstream blunt end of the buttress. Figure 2.7 shows details of the buttress [12]. The bottom chamfer was incorporated to reduce wheel snag, while the upper chamfer was intended to mitigate vehicle bumper and frame snagging. In addition to the front face chamfers, the top of the buttress had a 6H:1V height transition to reduce vehicle snag potential with the concrete parapet above the thrie-beam rail. The system was evaluated through two full-scale crash tests in accordance with MASH TL-3 and met all evaluation criteria [12].

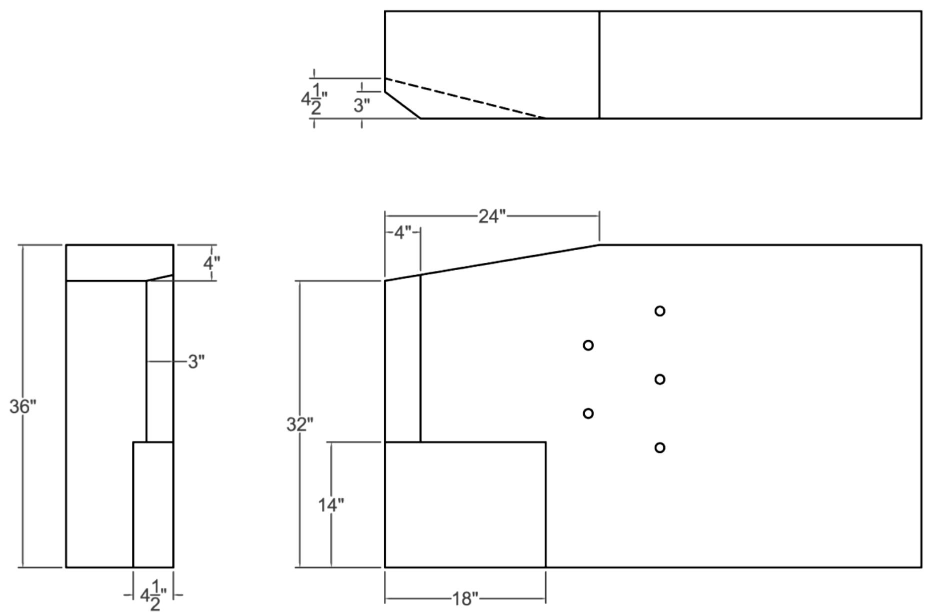


Figure 2.7. Standardized Transition Buttress Geometry [12].

2.5. EFFECTIVENESS OF A CURB

In 2013, TTI researchers evaluated the performance of a simplified approach transition design without a curb or a rubrail (see Figure 2.8) [13]. The test was performed in accordance with the MASH criteria following the impact conditions for Test 3-21 with the 2270P pickup truck. The 31-inch-tall nested thrie-beam transition was attached to a 36-inch-tall single-slope concrete parapet using a 10-gauge thrie-beam end shoe and a steel adapter plate that kept the thrie-beam rail vertically aligned. The parapet incorporated a taper at the toe below the thrie-beam transition rail, and the top of the parapet was rounded to reduce potential for snagging above the thrie-beam rail. The steel posts used in the thrie-beam transition section adjacent to the concrete parapet were spaced at 18¾ inches and had a length of 84 inches.

The transition did not perform acceptably for MASH Test 3-21 due to a pickup truck rollover. Researchers concluded that wheel snagging on the blunt end of the single-slope concrete parapet (see Figure 2.9) may have contributed to the instability of the vehicle.

Figure 2.8. Thrie-Beam Transition without Curb or Rubrail [13].

Figure 2.9. Tire Snagging on End of Single-Slope Concrete Transition Parapet [13].

In 2019, TTI researchers investigated attaching a thrie-beam approach guardrail transition directly to the face of an SSCB without the use of an adaptor block between the sloped traffic face of the parapet and the nested thrie-beam transition rail [14]. This configuration does not utilize a tapered blockout or end-shoe adapter but rather twists the nested thrie beam and end terminal directly onto the sloped face of the concrete barrier. The critical test for evaluating the need for the tapered end shoe block was MASH Test 3-21 with a pickup truck. The stability of the pickup truck was most likely to be influenced by the twisted thrie-beam rail.

TxDOT bridge rail standards include two parapet configurations for approach transitions with sloped faces: a 32-inch F-shape parapet (Type T551) and a 36-inch SSTR. The SSTR has an 11-degree slope on the traffic face compared to a 6.5-degree slope on the upper face of the F-shape parapet. The greater slope of the SSTR made it the more critical profile for evaluating the thrie-beam transition without adaptor block. Thus, a successful result with the more critical SSTR would also be applicable to the T551 F-shape bridge rail.

The parapet incorporated a taper at the toe below the thrie-beam transition rail, and the top of the parapet was rounded to reduce potential for snagging above the thrie-beam rail. The steel posts used in the thrie-beam transition section adjacent to the concrete parapet were spaced at 18¾ inches and had a length of 84 inches. A 6-inch curb element was incorporated below the thrie-beam transition rail with the face of the curb approximately flush with the tapered end of the concrete parapet.

The researchers conducted MASH Test 3-21 on the thrie-beam system attached to the 36-inch-tall SSTR shown in Figure 2.10. The system performed acceptably according to MASH Test 3-21 evaluation criteria.

Figure 2.10. Thrie-Beam Transition without End Shoe Block [14].

In 2021, TTI researchers investigated development of a shorter W-beam transition to a concrete parapet [15]. The objective was to develop a short, simplified TL-3 transition that did not require a rubrail or curb. The transition consisted of a 75-inch-long section of nested thrie beam that was asymmetrically transitioned to a W-beam guardrail system. The length of the nested thrie-beam rail was half the length of a standard thrie-beam transition rail.

To mitigate the possibility of tire snagging to the parapet's blunt end, the researchers attached a deflector plate to the concrete parapet below the thrie-beam transition rail (see Figure 2.11). The system was crash tested under MASH Test 3-21 criteria. Due to the high occupant ridedown acceleration during the crash test, the short transition did not satisfy the performance criteria for MASH Test 3-21 for transitions. Figure 2.12 shows damage to the transition near the parapet end.

Figure 2.11. Shortened TL-3 Transition [15].

Figure 2.12. Damage Resulting from Snagging Interaction of Pickup Truck [15].

Chapter 3. EVALUATION OF TRANSITION ATTACHED TO TALL WALL

One of the design scenarios that user agencies face is the connection of a stiffness transition from an approach guardrail to a tall wall. The tall wall can be representative of a feature such as a sound wall, a retaining wall, or even a tunnel entrance above the concrete parapet. A limited finite element simulation study was incorporated into the project scope to further evaluate this scenario.

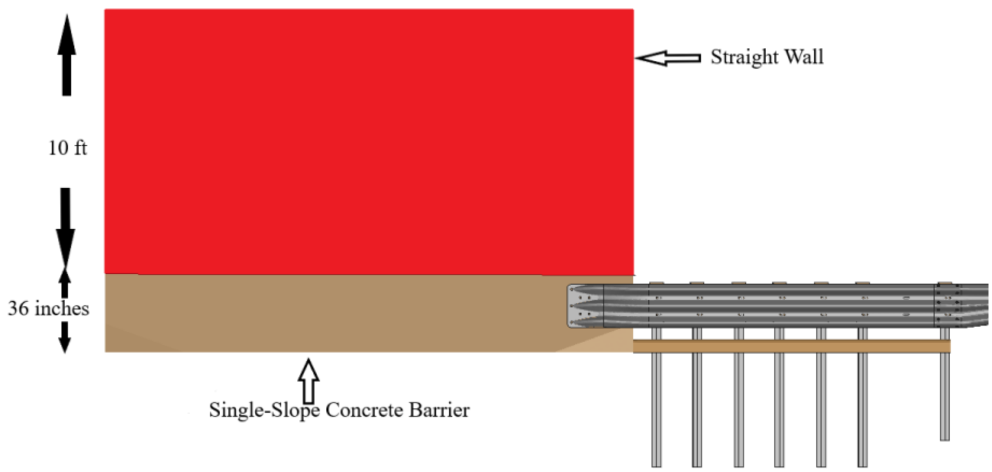
Researchers modeled the lower portion of the parapet as a rigid 36-inch-tall single-slope barrier. Various rigid extensions were modeled above the concrete parapet. These included a vertical wall as well as a parapet extension with a 5:1 height transition to the vertical wall. The results of the simulations evaluated the effectiveness of the transition system in terms of vehicle stability, vehicle snagging, and MASH occupant risk metrics.

3.1. THRIE-BEAM TRANSITION ATTACHED DIRECTLY TO PARAPET WITH TALL WALL

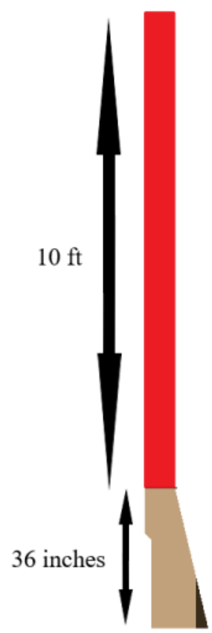
The initial design configuration involved a vertical wall extending from the top of the rigid concrete barrier (see Figure 3.1). The simulation followed MASH Test 3-21 impact conditions. This test involves a 5,000-lb pickup truck impacting the transition at a speed of 62 mi/h and an angle of 25 degrees. Researchers analyzed multiple impact locations to determine the critical impact point (CIP) in terms of occupant risk factors such as occupant impact velocity (OIV) and ridedown acceleration (RDA), as well as vehicle snagging above and below the thrie-beam transition rail. Researchers observed that a distance of 3.6 ft from the blunt end of the concrete barrier and wall section (see Figure 3.2) was most critical since it generated the most interaction with the occupant compartment.

Figure 3.3 and Figure 3.4 provide overhead- and end-view sequential images of the pickup truck simulation into the thrie-beam transition attached to a concrete parapet with vertical wall extension on top. One key observation from this impact simulation is penetration of the hood into the front windshield, which increases the risk of injury to the occupant on the passenger (impact) side. Figure 3.5 shows a closeup view of the pickup truck, highlighting the interaction of the hood with the windshield.

Table 3.1 shows the occupant risk metrics derived from the simulation data. The values of the risk parameters are below the limiting values recommended in MASH. However, the penetration of the vehicle hood into the occupant compartment makes the result of this simulation unsatisfactory.



a. Elevation View



b. End View

Figure 3.1. Thrie-Beam Transition Attached to Concrete Parapet with Wall Above.

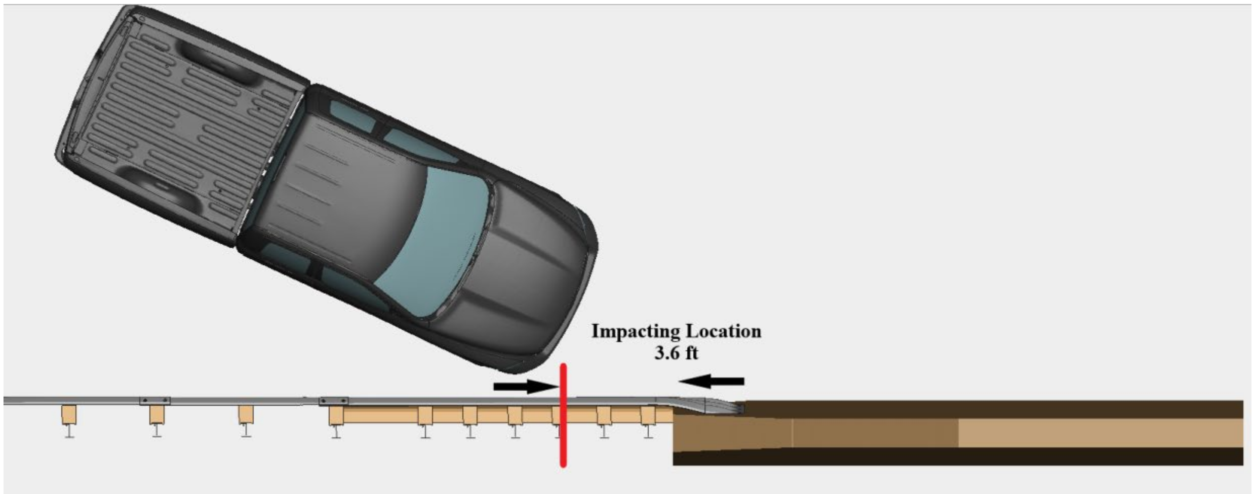
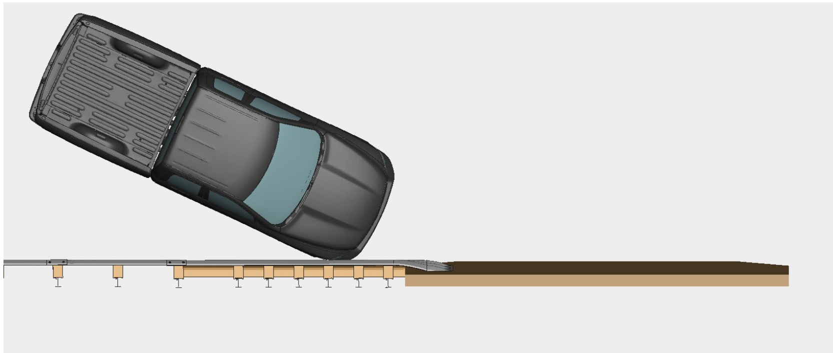
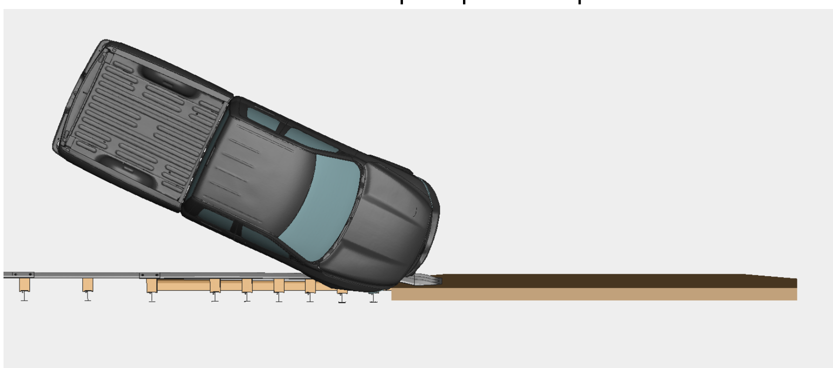


Figure 3.2. Pre-Impact View of Transition System Depicting Impacting Location.

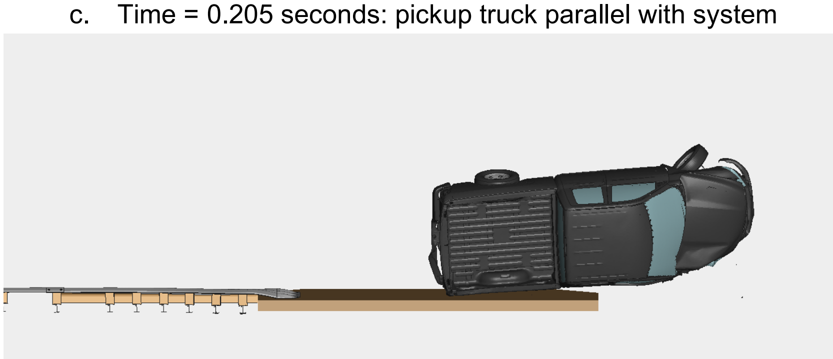


a. Time = 0.025 seconds: pickup truck impacts thrie beam



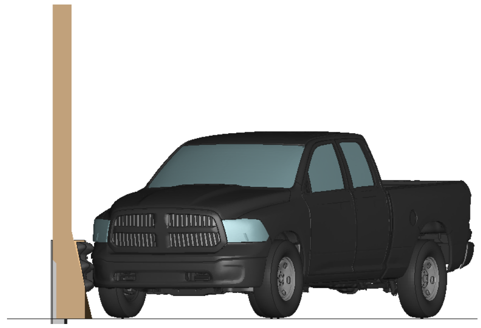
b. Time = 0.060 seconds: pickup truck impacts end of vertical wall

c. Time = 0.205 seconds: pickup truck parallel with system

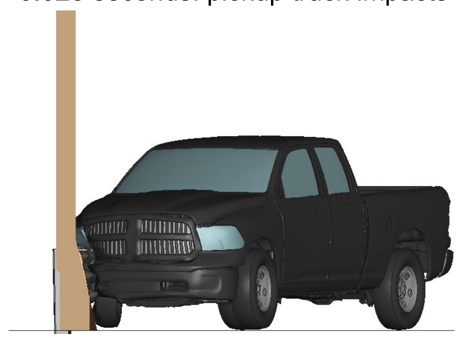


d. Time = 0.420 seconds: pickup truck loses contact with parapet

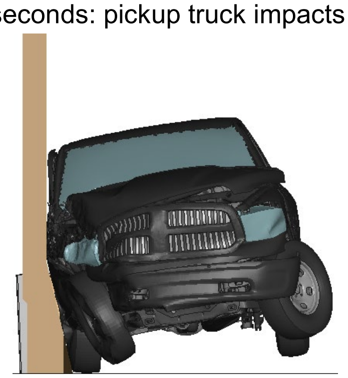
Figure 3.3. Sequential Images of Pickup Truck Simulation into Thrie-Beam Transition Attached to Parapet with Tall Vertical Wall—Overhead View.



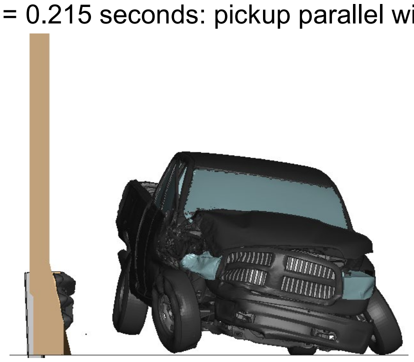
a. Time = 0.025 seconds: pickup truck impacts thrie beam



b. Time = 0.060 seconds: pickup truck impacts end of vertical wall



c. Time = 0.215 seconds: pickup parallel with system



d. Time = 0.750 seconds: pickup truck after exiting system

Figure 3.4. Sequential Images of Pickup Truck Simulation into Thrie-Beam Transition Attached to Parapet with Tall Vertical Wall—End View.

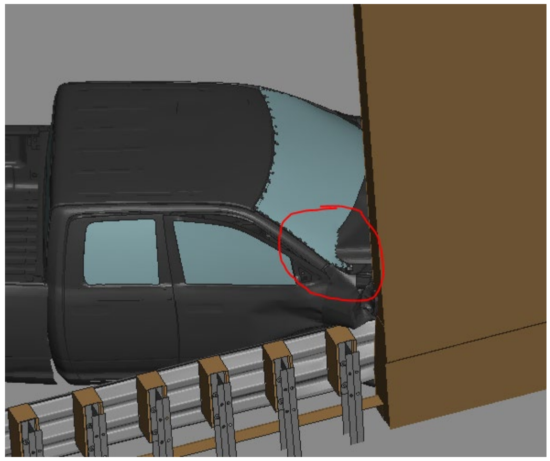


Figure 3.5. Corner of Hood Intruding into Windshield.

Table 3.1. Occupant Risk Factors for Pickup Truck Simulation into Thrie-Beam Transition Attached to Parapet with Tall Vertical Wall.

Parameter	MASH Threshold	Simulation Result
OIV (ft/s)	40	26.0
RDA (g)	20.49	16.0
Yaw (deg)	NA	35.6
Pitch (deg)	75	7.6
Roll (deg)	75	16.4

Note: NA = not applicable.

3.2. THRIE-BEAM TRANSITION ATTACHED TO TAPERED WALL (5 FT FROM BLUNT END)

Although the occupant risk metrics were satisfactory, windshield penetration resulting from hood snagging on the end of the tall vertical wall led to an unacceptable outcome in the MASH Test 3-21 simulation. The simulation result illustrated that some form of height transition to the tall wall was needed. Since the tall wall is intended to represent an existing feature such as a sound wall, retaining wall, or tunnel structure, cutting or tapering the end of the wall is not practical. The concept explored through simulations is a short transition parapet extension in front of the tall wall feature that permits incorporation of a parapet height transition upstream of the wall. The length of the parapet extension was 5 ft, and the height transition had a 5:1 slope. Figure 3.6 depicts this configuration.

Researchers simulated MASH Test 3-21 with the 2270P pickup impacting 3.6 ft upstream of the end of the parapet extension. Figure 3.7, Figure 3.8, and Figure 3.9 present the overhead, front, and rear sequential images of the simulation, respectively. Some hood snagging of the hood on the tall wall resulted in penetration of the front windshield. Figure 3.10 shows a closeup view of the pickup truck, highlighting the interaction of the hood with the windshield. Table 3.2 shows the occupant risk metrics derived from the simulation data. The values of the risk parameters are below the limiting values recommended in MASH. However, the penetration of the vehicle hood into the occupant compartment makes the result of this simulation unsatisfactory.

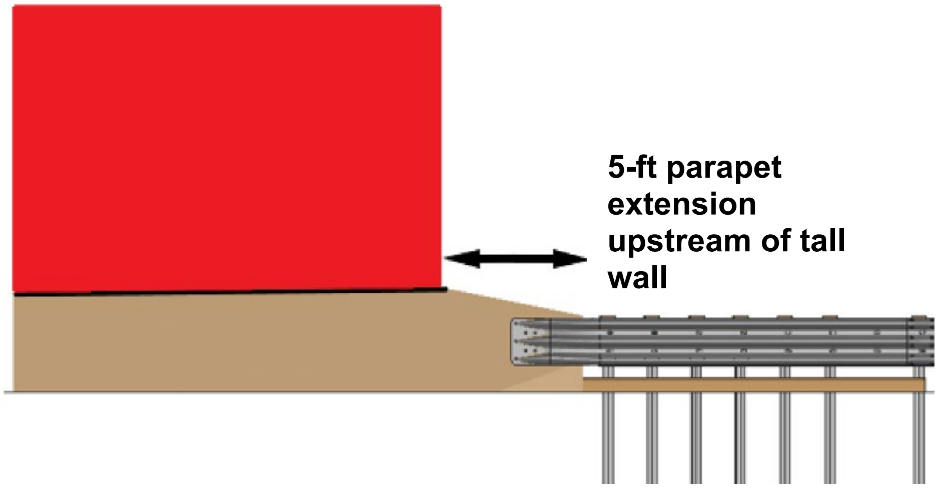
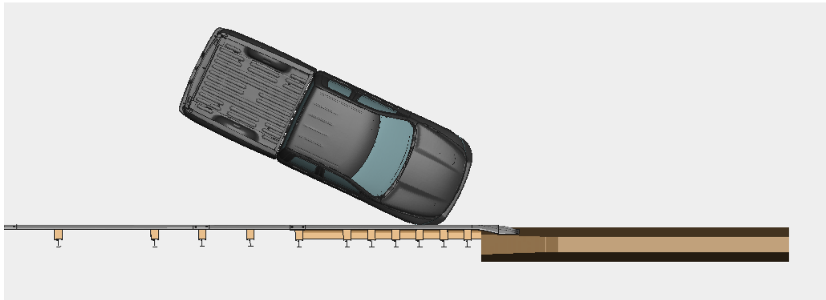
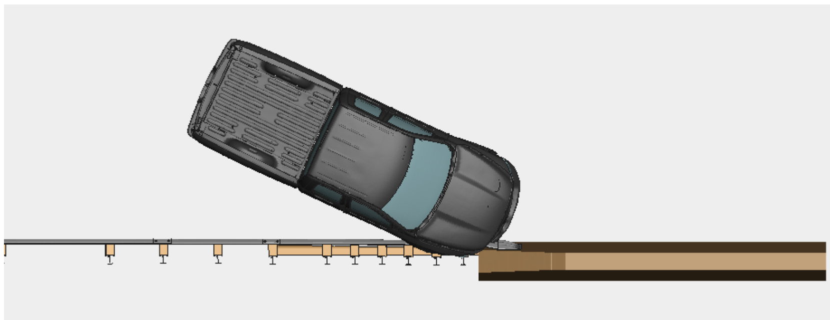


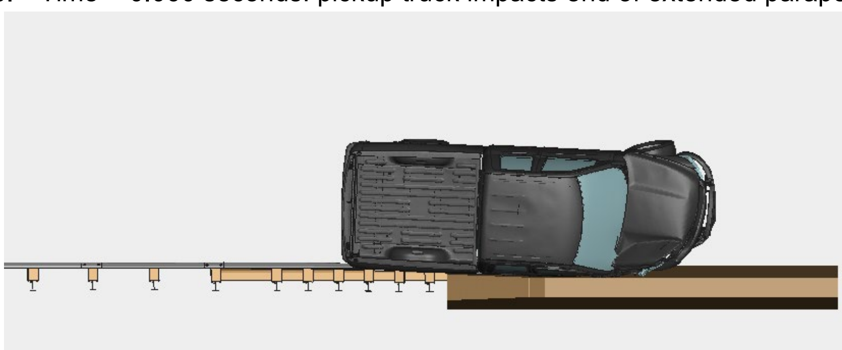
Figure 3.6. 5-ft Transition Parapet Extension with 5:1 Height Transition.



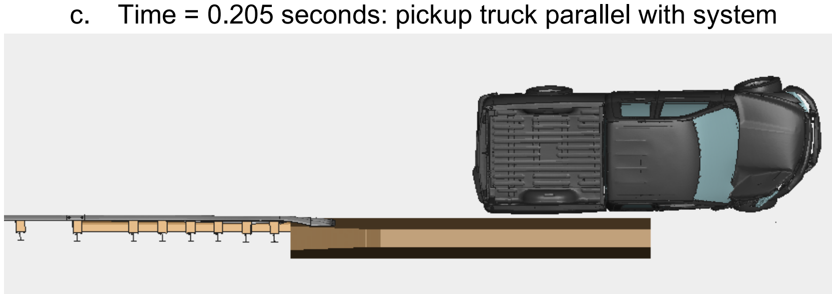
a. Time = 0.025 seconds: pickup truck impacts thrie beam



b. Time = 0.060 seconds: pickup truck impacts end of extended parapet



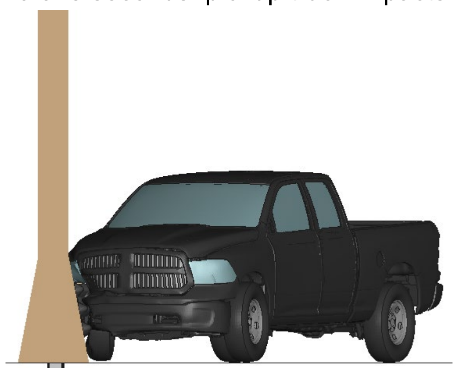
c. Time = 0.205 seconds: pickup truck parallel with system



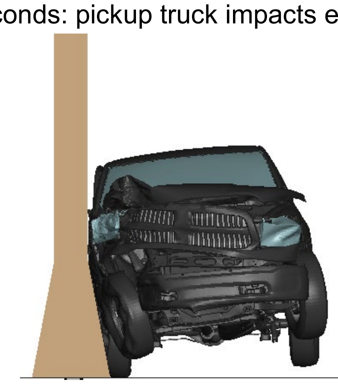
d. Time = 0.420 seconds: pickup truck loses contact with system

Figure 3.7. Sequential Images of Pickup Truck Simulation into Thrie-Beam Transition Attached to Extended Parapet in Front of Tall Vertical Wall—Overhead View.

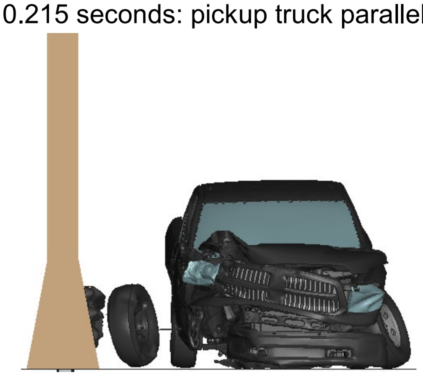
a. Time = 0.025 seconds: pickup truck impacts thrie beam



b. Time = 0.060 seconds: pickup truck impacts end of extended parapet

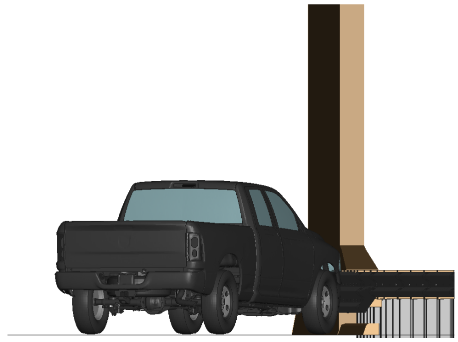


c. Time = 0.215 seconds: pickup truck parallel with system

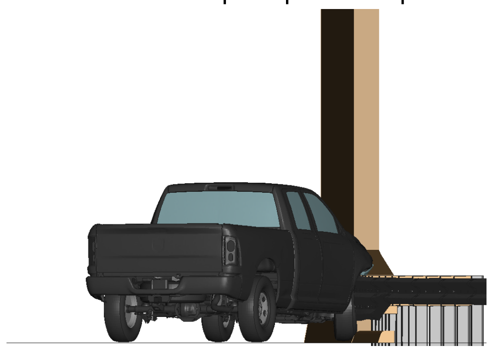


d. Time = 0.750 seconds: pickup truck after exiting system

Figure 3.8. Sequential Images of Pickup Truck Simulation into Thrie-Beam Transition Attached to Extended Parapet in Front of Tall Vertical Wall—Front-End View.

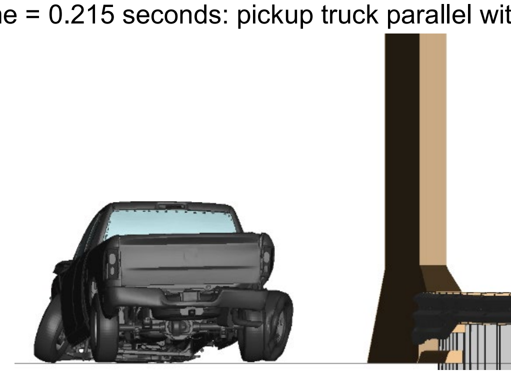


a. Time = 0.025 seconds: pickup truck impacts thrie beam



b. Time = 0.060 seconds: pickup truck impacts end of extended parapet

c. Time = 0.215 seconds: pickup truck parallel with system



d. Time = 0.750 seconds: pickup truck after exiting system

Figure 3.9. Sequential Images of Pickup Truck Simulation into Thrie-Beam Transition Attached to Extended Parapet in Front of Tall Vertical Wall—Rear-End View.

Figure 3.10. Corner of Hood Intruding into Windshield after Hood Contact with Tall Wall.

Table 3.2. Occupant Risk Factors for Pickup Truck Simulation into Thrie-Beam Transition Attached to Extended Parapet in Front of Tall Vertical Wall.

Parameter	MASH Threshold	Simulation Result
OIV (ft/s)	40	25.4
RDA (g)	20.49	14.8
Yaw (deg)	NA	33.6
Pitch (deg)	75	6.1
Roll (deg)	75	12.9

Note: NA = not applicable.

3.3. THRIE-BEAM TRANSITION ATTACHED TO EXTENDED PARAPET WITH HEIGHT TRANSITION

Although the occupant risk metrics were satisfactory, windshield penetration resulting from hood snagging on the end of the tall vertical wall led to an unacceptable outcome in the MASH Test 3-21 simulation of the thrie-beam transition attached to a 5-ft parapet extension upstream of a tall wall. The next design iteration utilized a longer 10-ft parapet extension in front of the tall wall feature (see Figure 2.11). This further reduced the opportunity for the pickup truck to interact with the end of the tall wall. A 5:1 height transition was maintained on top of the parapet along its length.

Researchers simulated MASH Test 3-21 with the 2270P pickup impacting 3.6 ft upstream of the end of the parapet extension. Figure 3.12, Figure 3.13, and Figure 3.14 present overhead, front, and rear sequential images of the simulation, respectively. No hood penetration with the front windshield occurred with this design.

Table 3.3 shows the occupant risk metrics derived from the simulation data. The values of the risk parameters are below the limiting values recommended in MASH. The simulated impact satisfied MASH criteria for Test 3-21.

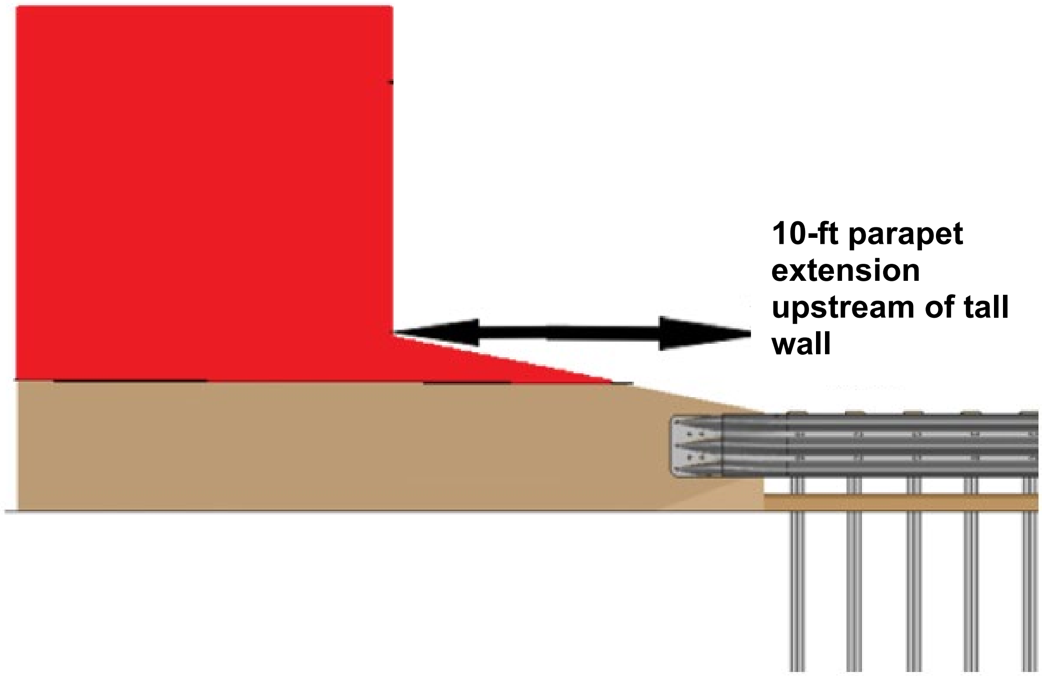
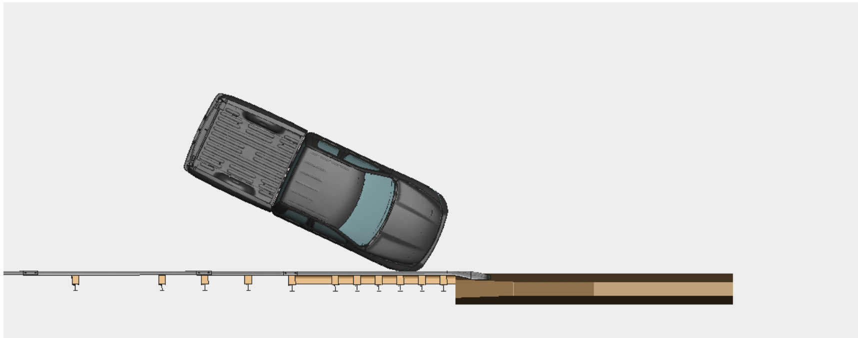
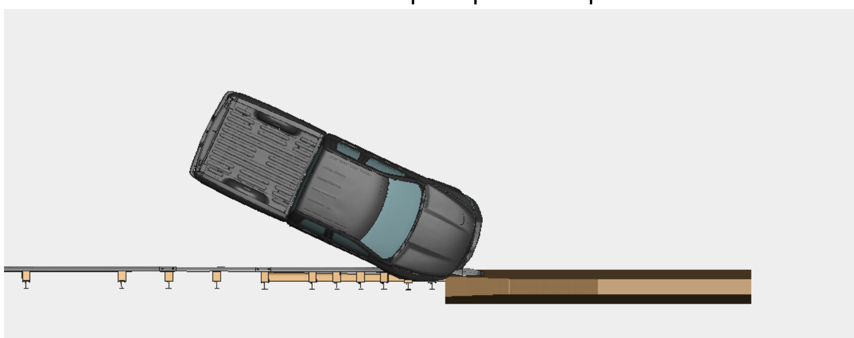


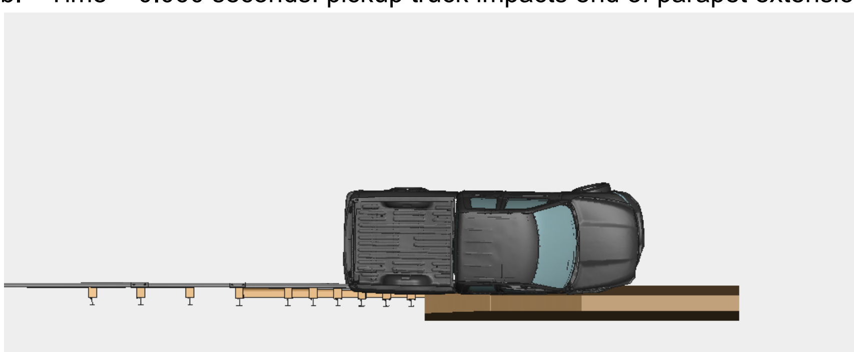
Figure 3.11. 10-ft Transition Parapet Extension with 5:1 Height Transition.



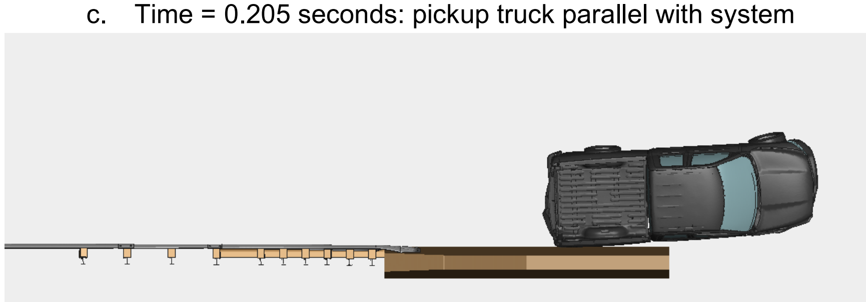
a. Time = 0.025 seconds: pickup truck impacts thrie beam



b. Time = 0.060 seconds: pickup truck impacts end of parapet extension

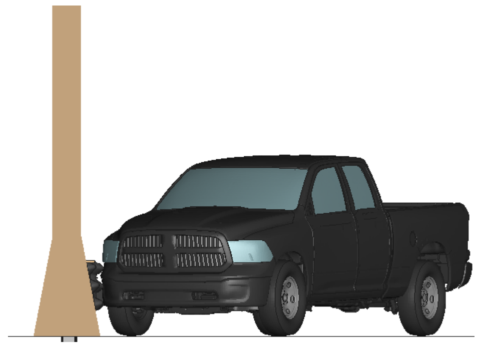


c. Time = 0.205 seconds: pickup truck parallel with system

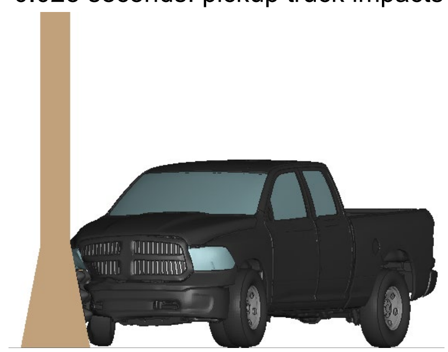


d. Time = 0.420 seconds: pickup truck loses contact with system

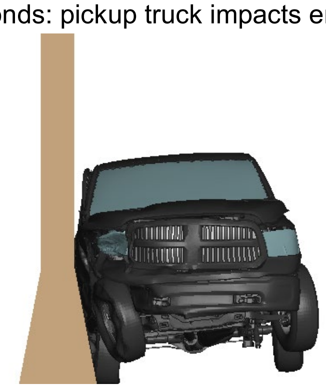
Figure 3.12. Sequential Images of Pickup Truck Simulation into Thrie-Beam Transition Attached to 10-ft-Long Extended Parapet in Front of Tall Vertical Wall—Overhead View.



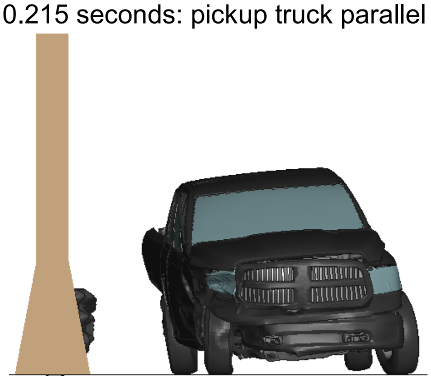
a. Time = 0.025 seconds: pickup truck impacts thrie beam



b. Time = 0.060 seconds: pickup truck impacts end of parapet extension

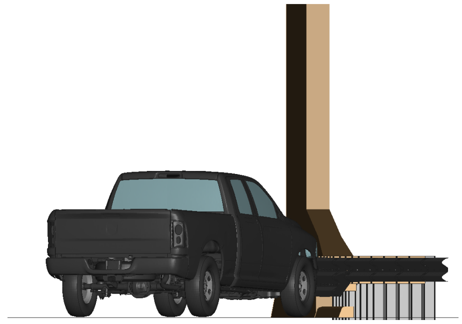


c. Time = 0.215 seconds: pickup truck parallel with system

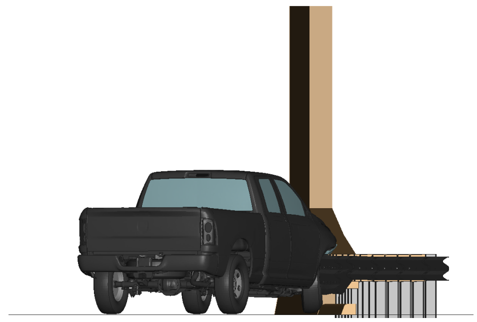


d. Time = 0.750 seconds: pickup truck after exiting system

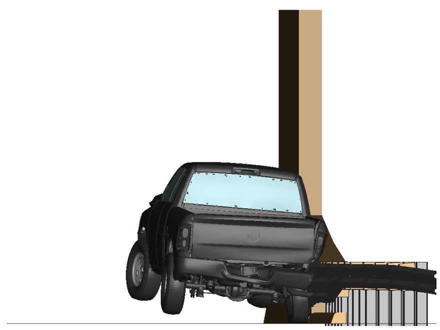
Figure 3.13. Sequential Images of Pickup Truck Simulation into Thrie-Beam Transition Attached to 10-ft-Long Extended Parapet in Front of Tall Vertical Wall—Front-End View.



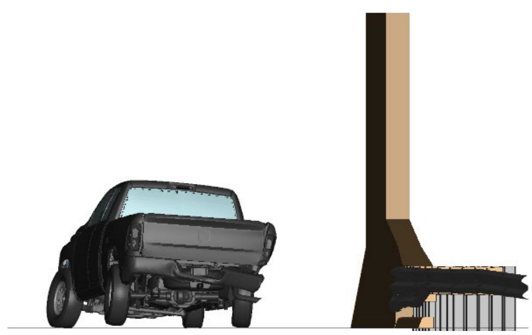
a. Time = 0.025 seconds: pickup truck impacts thrie beam



b. Time = 0.060 seconds: pickup truck impacts end of parapet extension



c. Time = 0.215 seconds: pickup truck parallel with system



d. Time = 0.750 seconds: pickup truck after exiting system

Figure 3.14. Sequential Images of Pickup Truck Simulation into Thrie-Beam Transition Attached to 10-ft-Long Extended Parapet in Front of Tall Vertical Wall—Rear-End View.

Table 3.3. Occupant Risk Factors for Pickup Truck Simulation into Thrie-Beam Transition Attached to 10-ft-Long Extended Parapet in Front of Tall Vertical Wall.

Parameter	MASH Threshold	Simulation Result
OIV (ft/s)	40	25.6
RDA (g)	20.49	16.3
Yaw (deg)	NA	14.7
Pitch (deg)	75	8.8
Roll (deg)	75	12.0

Note: NA = not applicable.

The 10-ft extended parapet with height transition satisfied MASH requirements for a Test 3-21 impact into the thrie-beam transition. The extended parapet with height transition moved the transition away from the tall wall a sufficient distance to avoid the hood contact that was resulting in windshield penetration. Researchers performed an additional simulation with the pickup truck impacting the extended parapet upstream of the tall wall to evaluate if the height transition was sufficient to prevent hood snagging closer to the wall. The impact location was 5 ft upstream of the wall edge (see Figure 3.15).

The pickup truck was redirected in a stable manner. Figure 3.16, Figure 3.17, and Figure 3.18 present overhead, front, and rear sequential images of the simulation, respectively. No hood snagging with the end of the tall wall was observed.

Table 3.4 shows the occupant risk metrics derived from the simulation data. The values of the risk parameters are below the limiting values recommended in MASH. The simulated impact satisfied MASH criteria for Test 3-21. The height transition was sufficient to avoid hood snagging with the end of the tall wall.

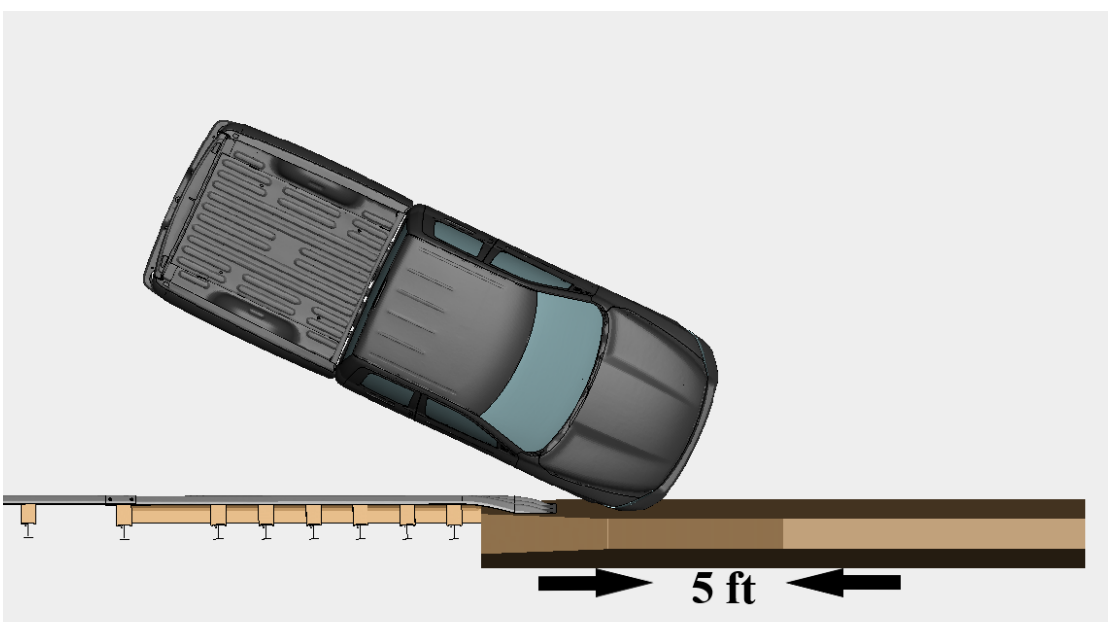
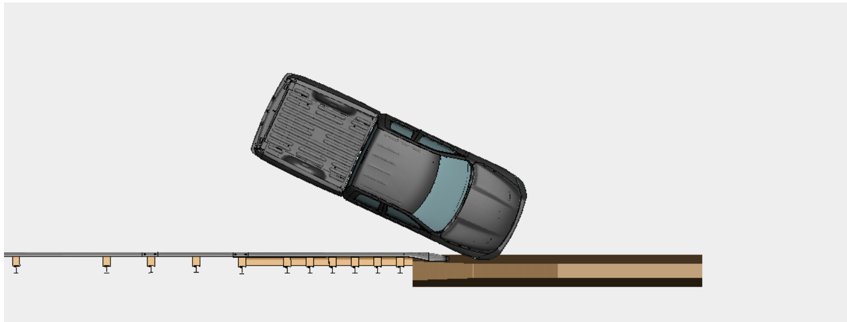
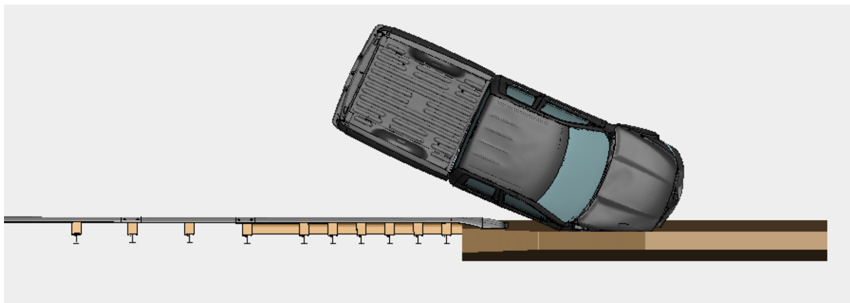


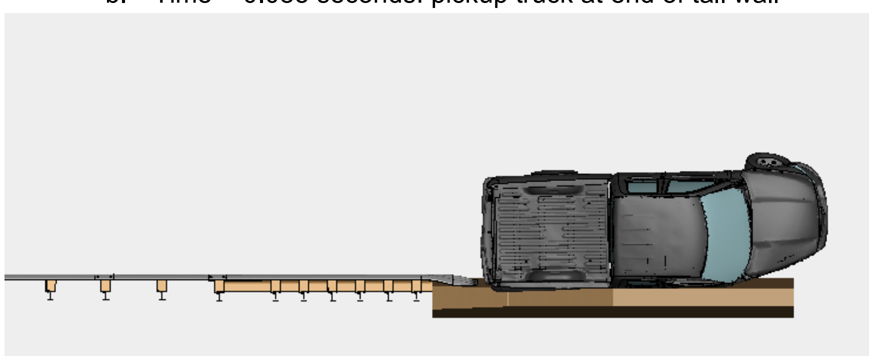
Figure 3.15. Impact Location of Pickup Truck with Extended Parapet Upstream of Tall Wall.



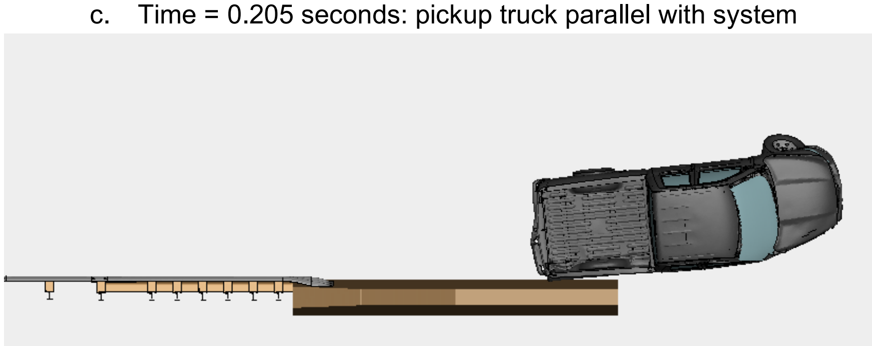
a. Time = 0.035 seconds: pickup truck impacts barrier



b. Time = 0.085 seconds: pickup truck at end of tall wall

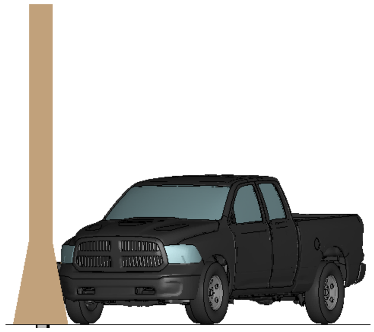


c. Time = 0.205 seconds: pickup truck parallel with system

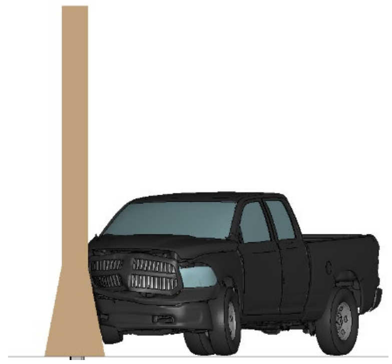


d. Time = 0.3550 seconds: pickup truck loses contact with system

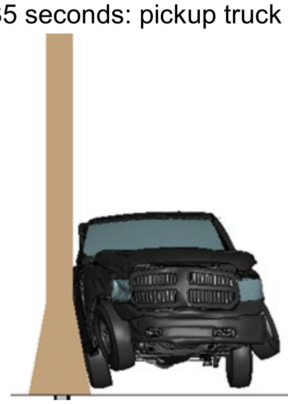
Figure 3.16. Sequential Images of Pickup Truck Simulation into Extended Parapet Upstream of Tall Wall—Overhead View.



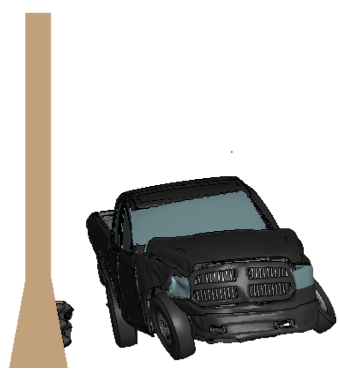
a. Time = 0.035 seconds: pickup truck impacts barrier



b. Time = 0.085 seconds: pickup truck at end of tall wall

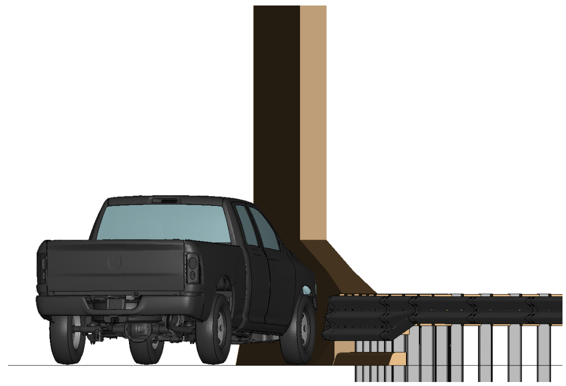


c. Time = 0.215 seconds: pickup truck parallel with system

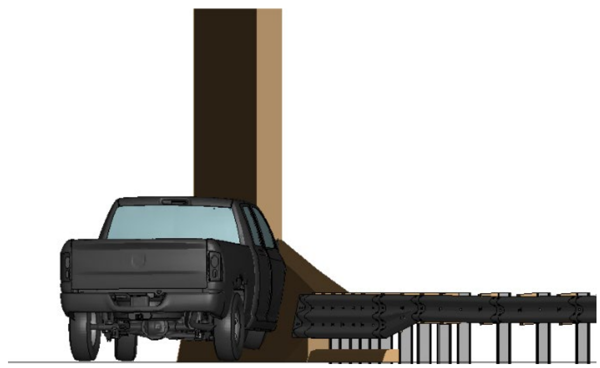


d. Time = 0.750 seconds: pickup truck after exiting system

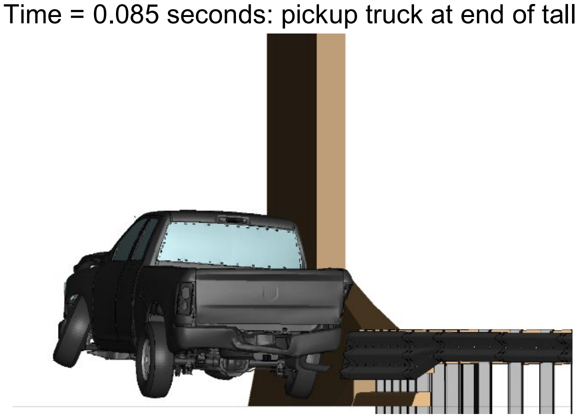
Figure 3.17. Sequential Images of Pickup Truck Simulation into Extended Parapet Upstream of Tall Wall—Front-End View.



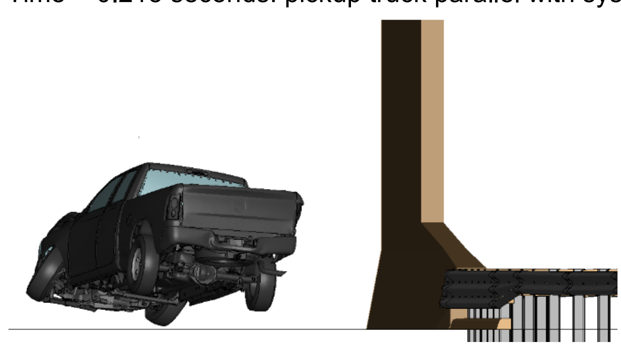
a. Time = 0.025 seconds: pickup truck impacts thrie beam



b. Time = 0.085 seconds: pickup truck at end of tall wall



c. Time = 0.215 seconds: pickup truck parallel with system



d. Time = 0.750 seconds: pickup truck after exiting system

Figure 3.18. Sequential Images of Pickup Truck Simulation into Extended Parapet Upstream of Tall Wall—Rear-End View.

Table 3.4. Occupant Risk Factors for Pickup Truck Simulation into Extended Parapet Upstream of Tall Wall.

Parameter	MASH Threshold	Simulation Result
OIV (ft/s)	40	28.0
RDA (g)	20.49	15.2
Yaw (deg)	NA	37.6
Pitch (deg)	75	6.8
Roll (deg)	75	11.1

Note: NA = not applicable.

Chapter 4. SUMMARY AND RECOMMENDATIONS

The objective of this project was to provide guidelines for attaching a MASH-compliant thrie-beam transition to rigid concrete barriers other than the barrier tested. TTI researchers conducted a survey of state Roadside Safety Pooled Fund members and reviewed their standard details to understand their current transition attachment practices. Various heights and shapes of transition parapets were identified, including vertical wall, F-shape, NJ-shape, and single-slope concrete barriers with and without flared ends. The project focused on attachment of thrie-beam transitions connected to a concrete barrier, which researchers found to be more common among the state members.

Researchers performed a literature review to identify key features and characteristics of parapet designs associated with MASH-compliant thrie-beam transition systems. Engineering evaluation and a limited computer simulation study were used to assess what features are needed to provide MASH compliance of the transitions when attached to other parapet types. Researchers considered barrier shape (or profile), barrier height, and barrier end taper.

The computer simulation effort considered attachment of a thrie-beam transition to a parapet with a tall wall above it. This might represent a scenario in which there is a sound wall, retaining wall, or tunnel entrance integral with the traffic barrier.

Following is general guidance for attaching thrie-beam transitions to concrete parapets other than what was tested. The details of the transition system should remain unchanged from the as-tested configurations unless noted below.

1. **Barrier Shape**—The most common rigid concrete barrier shapes to which transitions are attached include the F-shape, single slope, and vertical wall. When the thrie-beam transition rail is attached to a barrier with a sloped traffic face (i.e., F-shape or single slope), an adapter plate is sometimes used between the concrete barrier and thrie-beam end terminal connector to keep the axis of the thrie-beam transition rail aligned in a vertical plane. In one crash test study that evaluated direct attachment of a thrie-beam transition rail to the face of a single-slope concrete barrier, researchers provided justification showing that the single-slope profile is more critical than the F-shape in terms of vehicle stability due to a greater slope on the traffic face. In this test, the thrie-beam rail was flush against the traffic face of the concrete parapet without any offset. A vertical wall would also be less critical than the crash-tested single-slope parapet based on the same criteria. *If a MASH-compliant thrie-beam transition attached to a single-slope parapet is tested, it should be MASH compliant with F-shape or vertical wall parapets as well. If tested with an F-shape parapet, use of a vertical wall parapet should also be acceptable.*
2. **Height Transition**—When the top of the concrete transition parapet extends above the top of the thrie-beam transition rail, a height transition is used to reduce vehicle snagging severity with the top of the concrete parapet. Testing has shown that an inadequate height transition can result in unacceptable impact performance [8]. *A height transition should be used to mitigate vehicle snagging*

severity when the top of the concrete transition parapet extends above the height of the thrie-beam transition rail more than a couple of inches. The height transition should, at a minimum, provide a 5:1 linear taper on the top of the parapet. A 5-inch radius on the top corner of the transition parapet is an acceptable option when the parapet does not extend more than 5 inches above the top of the thrie-beam transition rail. Figure 4.1 shows an example of a 5-inch height transition radius for a 36-inch single-slope parapet that extends 5 inches above a 31-inch thrie-beam transition rail. This geometry was successfully crash tested in accordance with MASH Test 3-21 criteria [14]. Other transition systems have been successfully crash tested with a 5:1 straight taper for parapets extending up to 11 inches above the thrie-beam rail [10, 11]. The standardized transition parapet/buttress developed by MwRSF (see Figure 2.7) incorporates a 6:1 height transition [12]. In retrofit scenarios where a thrie-beam transition is being attached to an existing concrete parapet, the radius or height taper toe on the top of the concrete transition parapet can be saw cut if desired.

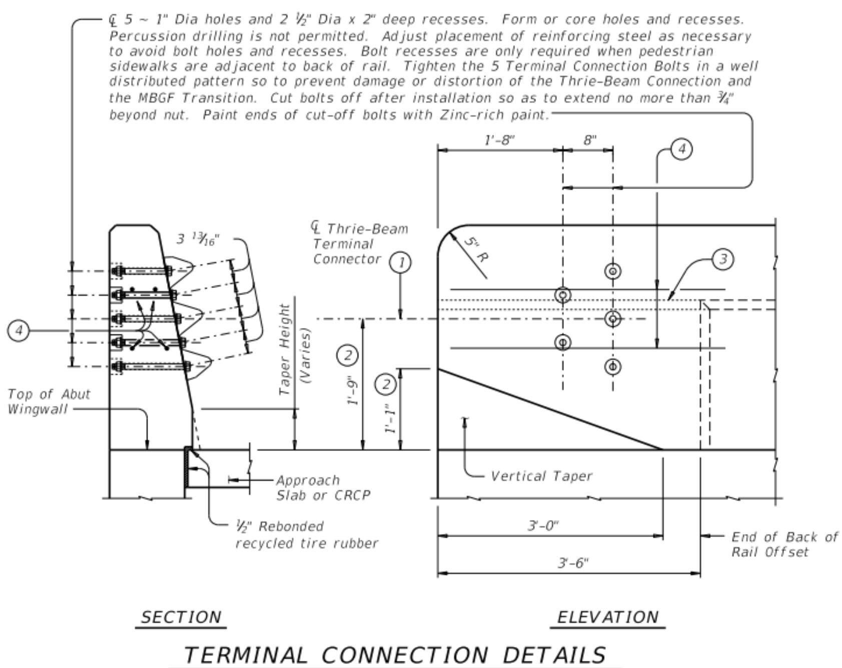


Figure 4.1. Single-Slope Traffic Rail Terminal Connection Detail.

3. **Tapering of Parapet Toe**—To meet impact performance evaluation criteria, designers use a stiffness transition to prevent severe vehicle snagging on the end of the rigid parapet beneath the thrie-beam transition rail. Severe snagging can lead to vehicle instability, high occupant risk values, and/or excessive occupant compartment deformation. Parapets with sloped profiles (e.g., F-shape and single slope) will have a greater projection and larger width at the base than a vertical wall parapet. The farther the toe of a parapet projects outwardly toward traffic, the greater the potential for an unacceptable level of snagging. *To mitigate vehicle snagging severity, the toe or bottom of a sloped concrete transition parapet should be tapered at the end of the parapet. The taper should, at a*

minimum, extend laterally to the back edge of the thrie-beam transition rail and vertically to the bottom edge of the thrie-beam transition rail. If a transition was tested on a parapet with a larger lateral taper, the same taper distance should be used on the alternate concrete transition parapet In retrofit scenarios where a thrie-beam transition is being attached to an existing concrete parapet, the toe of a sloped barrier profile can be saw cut if the anchorage reinforcement is not affected. Figure 4.1 and Figure 4.2 show parapet toe taper details for a single-slope barrier and F-shape, respectively, from TxDOT standards. Figure 2.7 provides the toe taper detail that MwRSF developed and integrated into its standardized transition parapet [12]. The detail provides an additional offset of 4½ inches from a vertical wall profile behind the thrie-beam transition rail, which eliminates the need for a curb or lower rubrail in the transition design.

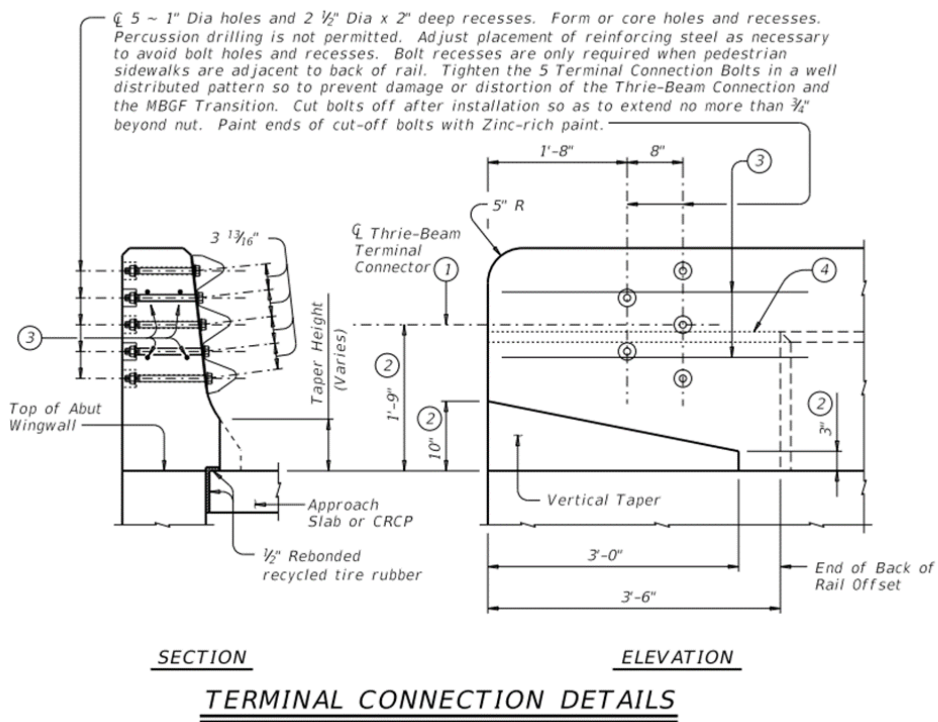


Figure 4.2. F-shape Terminal Connection Detail.

4. **Presence of Curb or Rubrail**—Some stiffness transition designs incorporate a rubrail or curb below the thrie-beam transition rail adjacent to the concrete transition parapet. Such design elements help limit snagging potential on the transition posts and parapet end. *If a MASH thrie-beam system is tested with a curb or rubrail adjacent to the concrete parapet, such elements must be retained when the transition is attached to a different parapet design.* Although curbs may have other functions from a drainage standpoint, they should be preserved in the design even if a site does not require the curb for drainage purposes. The benefit of a curb from an impact standpoint has been demonstrated in full-scale crash testing. When a thrie-beam transition that was successfully tested with a curb [14] was tested without the curb following MASH Test 3-21 impact conditions, the

test was unsuccessful due to rollover of the pickup truck [13]. As Figure 2.9 shows, a significant amount of tire snagging occurred on the end of the concrete transition parapet in the absence of the curb. A thrie-beam transition without a curb or rubrail was successfully tested to MASH criteria in combination with MwRSF's standardized transition buttress [12].

5. **Tall Wall above Parapet**—Some existing site scenarios may involve attachment of a stiffness approach transition to a tall wall feature such as a sound wall, retaining wall, or tunnel entrance above the traffic barrier. The presence of the tall wall can present a snagging concern for vehicles impacting the transition. Impact simulations performed under this project following MASH Test 3-21 conditions confirmed this snagging concern. Modification of the tall wall to provide an adequate height transition is likely impractical in most situations. Researchers used finite element computer simulation to explore the required length of a parapet extension that could be used to provide the needed height transition to the tall wall. A parapet length of 5 ft was insufficient, but a parapet extension of 10 ft satisfied MASH criteria, as presented in Chapter 3. *When attaching a MASH-compliant thrie-beam transition to a concrete parapet with a tall wall on top, engineers should provide a 10-ft-long concrete parapet extension in front of the existing parapet and wall with a 5:1 height transition along its length, as Figure 4.3 and Figure 4.4 depict. The parapet extension should be anchored to an engineered foundation for the desired test level.* The extended parapet could also be attached to the adjacent parapet as needed to achieve the desired capacity and continuity. In Figure 4.4, the bottom portion is the traffic barrier that matches the profile of the existing system, and the upper portion is a height transition. The simulations were performed using a single-slope parapet extension with a vertical-faced height transition on top. The parapet shape can vary using the recommended guidelines provided herein, and the offset and profile of the height transition can be adjusted to match the downstream tall wall.

In summary, researchers used a literature review, engineering experience and judgment, and computer simulation to provide general guidance for attachment of MASH-compliant stiffness transitions to parapets other than the type tested with the transition system. This report provides recommendations for incorporating toe tapers and height transitions depending on the nature of the parapet being used. The tested transition details, including the use of rubrails or curb features, should be retained unless otherwise addressed herein.

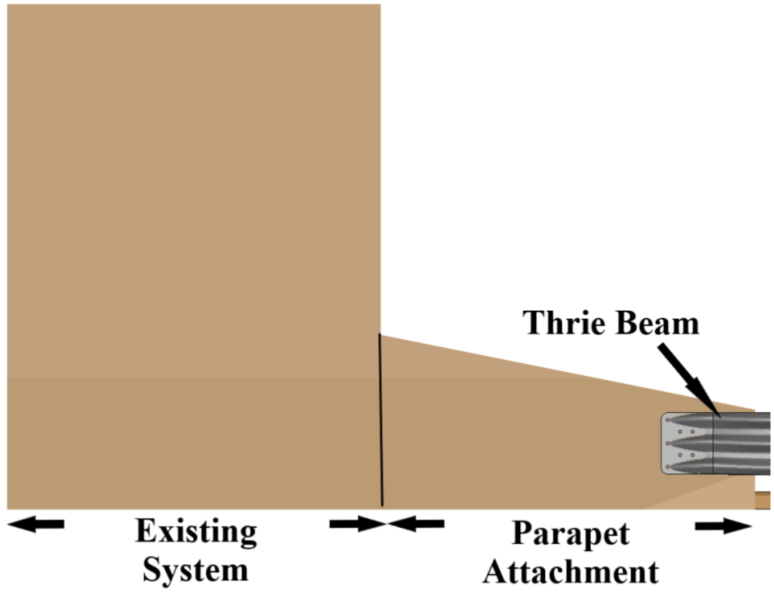


Figure 4.3. Extended Transition Parapet Upstream of Tall Wall.

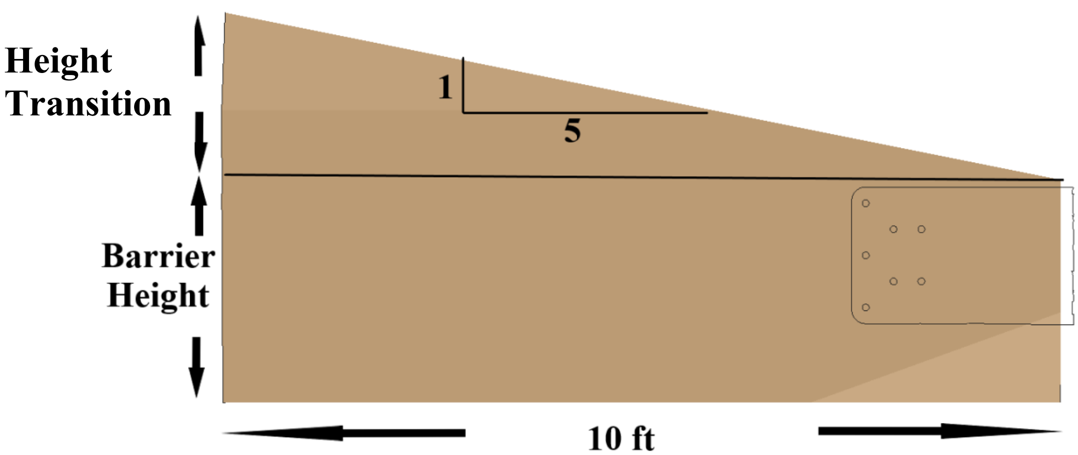


Figure 4.4. Extended Parapet Geometry.

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