



MASH EVALUATION OF TxDOT ROADSIDE SAFETY FEATURES— PHASE III



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16. Abstract <p>In 2009, the American Association of State Highway and Transportation Officials (AASHTO) published the <i>Manual for Assessing Safety Hardware (MASH)</i>, which supersedes the previous crash test and evaluation guidelines. A <i>MASH</i> implementation agreement was jointly developed and adopted by the Federal Highway Administration and AASHTO. It establishes implementation dates for different categories of roadside safety features.</p> <p>Texas Department of Transportation Bridge, Design, Maintenance, and Traffic Operations Divisions reviewed their standards for roadside safety devices and identified those devices that require testing and evaluation to assess <i>MASH</i> compliance. Under this project, roadside safety systems used in Texas will be crash-tested in accordance with <i>MASH</i> criteria in three phases over a 3-year period.</p> <p>A total of 10 devices were tested and evaluated during Phase I. In Phase II, an additional 14 devices were tested and evaluated. In Phase III, which is the subject of this report, an additional 14 devices were tested and evaluated.</p> <p>This report documents the crash testing and evaluation of these devices in accordance with <i>MASH</i> criteria. The critical configurations were identified and critical tests performed to assess <i>MASH</i> compliance.</p>					
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PHASE III**

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT.

This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Roger P. Bligh, P.E. #78550.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade of manufacturers' names appear herein solely because they are considered essential to the object of this report.

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The full-scale crash tests reported herein were performed at the Texas A&M Transportation Institute (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 tests were performed according to TTI Proving Ground quality procedures, and according to the *MASH* guidelines and standards. The results reported herein apply only to the articles being tested.

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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

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CHAPTER 1: INTRODUCTION

Since the 1940s, the United States has been crash-testing highway safety appurtenances. National guidelines for testing roadside appurtenances originated in 1962. Guidelines for testing and evaluating the impact performance of roadside safety features are periodically updated to stay current with improvements in technology and changes in the vehicle fleet and impact conditions. In 2009, the American Association of State Highway and Transportation Officials (AASHTO) published the *Manual for Assessing Safety Hardware (MASH)*, which supersedes the previous crash test and evaluation guidelines (1). Changes incorporated into *MASH* include new design test vehicles, revised test matrices, and revised impact conditions.

A *MASH* implementation agreement was jointly developed and adopted by the Federal Highway Administration (FHWA) and AASHTO. The agreement establishes various implementation dates for different categories of roadside safety features. On projects let after the specified dates, only *MASH*-compliant hardware is eligible for new installations on the National Highway System.

In response to the implementation requirements, the Texas Department of Transportation (TxDOT) Bridge, Design, Maintenance, and Traffic Operations Divisions reviewed their standards for roadside safety devices and identified those devices that require testing and evaluation to assess *MASH* compliance. Under this project, 33 roadside safety systems will be crash-tested in accordance with *MASH* criteria in three phases over a 3-year period.

The Texas A&M Transportation Institute (TTI) crash-tested and evaluated 10 devices in Phase I, which included the following:

- 36-inch vertical parapet bridge rail.
- 1-inch asphalt concrete pavement lateral support for concrete median barrier.
- Pinning pattern for precast concrete barriers on concrete.
- Single and dual embedded wood post sign support systems.
- Pedestal pole with flashing beacons with and without solar assembly.
- Multi-mailbox system on TxDOT Type 1 foundation and thin-walled galvanized tube support.
- Double mailbox system on TxDOT Type 2 foundation and thin-walled galvanized tubing.
- Double mailbox system on TxDOT Type 3 foundation and winged channel support.

In Phase II, 14 devices were crash-tested and evaluated. These included the following:

- C402 bridge rail.
- C412 bridge rail.
- C411 bridge rail.
- T1W bridge rail.
- Guardrail with round wood posts.

- Concrete barrier at light post.
- Single-post perforated square metal tube skid.
- Mailbox Type 4 foundation (single)—recycled rubber post.
- Mailbox Type 4 foundation (double)—thin-walled white post.
- Mailbox Type 4 foundation (multi)—Shurtite Multi Hanger.
- Mailbox Type 5 foundation (single)—wood post.
- Dual post wood skid.
- Guardrail steel posts in rocky terrain.
- Round wood posts in rocky terrain.

An additional 14 devices were crash-tested and evaluated in Phase III. These included the following:

- C1W bridge rail.
- Modified C66 bridge rail.
- Low-profile barrier.
- Low-profile-to-F-shape transition.
- Thrie-beam transition.
- Wood skid sign.
- Embedded Unistrut[®] sign.
- Burn ban slip base sign.
- Burn ban socket sign.
- Mailbox Type 6 foundation (single) on a plastic drum.
- Mailbox Type 2 foundation (single)—extra-large.
- Mailbox Type 2 foundation (single)—lockable
- Mow strip with wood posts.
- Type III barricade.

TxDOT standards may include multiple configurations or variations of a device to accommodate different design considerations or needs. TTI researchers developed the test plan for each device based on consideration of critical or worst-case configuration. If a critical configuration is successfully crash-tested, a less critical configuration of the device would also be considered *MASH* compliant. This approach reduces the required number of tests to achieve *MASH* compliance. The following chapters of this report provide details of the *MASH* testing of the different roadside safety systems evaluated under Phase III.

CHAPTER 2: TXDOT C1W BRIDGE RAIL

2.1 BACKGROUND

The C1W bridge rail is a variation of a rail initially developed by the Wyoming Department of Transportation. The bridge rail is a 42-inch-tall combination rail that consists of four rectangular tubular steel rail elements attached to fabricated steel posts mounted on a 9-inch-tall concrete curb. The bridge rail is designed to accommodate both vehicle and pedestrian traffic. TxDOT elected to evaluate the impact performance of the C1W bridge rail for *MASH* TL-4.

Under Phase II of this project, the impact performance of the T1W bridge rail was evaluated using the full *MASH* TL-3 test matrix (2). The T1W bridge rail is a 32-inch-tall rail that consists of two rectangular tubular steel rail elements attached to fabricated steel posts mounted on a 9-inch-tall concrete curb. The rail geometrics of the T1W bridge rail are considered more critical than the C1W. The rail elements, post details, and curb details used in the T1W are similar to those in the C1W bridge rail. The curb height and post setback distance are equivalent between the two systems. The upper rail element in the T1W is at the same mounting height as the third rail of the C1W. The lower rail element of the T1W, which is mounted at a height of 20 inches to the top of the rail, is replaced by two rail elements at mounting heights of 16¾ inches and 24½ inches in the C1W. Thus, the C1W provides additional rail contact surface area and reduced clear opening between rail elements, both of which reduce the potential for vehicle snagging or high vehicle decelerations. Further, review of the T1W tests did not indicate potential for head contact on the taller C1W bridge rail. Therefore, based on the successful testing of the T1W bridge rail, *MASH* Test 4-10 with the passenger car and Test 4-11 with the pickup truck were considered unnecessary for evaluation of the C1W. Only the structural adequacy test (*MASH* Test 4-12) was performed to evaluate the *MASH* compliance of the C1W bridge rail.

2.2 SYSTEM DETAILS

2.2.1 Test Article and Installation Details

The TxDOT C1W test installation consisted of four rectangular tubular steel rail elements attached to fabricated steel posts mounted on a concrete curb that was cast on an 8-inch-thick reinforced cantilevered concrete deck. The curb was 9 inches tall and 14 inches wide, and had embedded anchor bolts for attachment of the steel posts. The posts were spaced on 9-ft centers. The total height of the rail was 42 inches above the deck.

Two joints extended through both the curb and deck, and a third joint extended only through the curb. The most upstream of the three joints, which extended through the curb and deck, was used for *MASH* Test 4-12 to evaluate the structural adequacy of the C1W bridge rail. The second joint that extended through both the parapet and deck and the third joint that extended through the curb only were used in the previous evaluation of the T1W bridge rail for *MASH* Test 3-11 and Test 3-10, respectively (1).

Figure 2.1 presents overall information on the C1W bridge rail, and Figure 2.2 provides photographs of the installation. Appendix A.1 provides further details of the C1W bridge rail.



Figure 2.2. C1W Bridge Rail prior to Testing.

2.2.2 Material Specifications

Appendix A.2 provides material certification documents for the materials used to install/construct the C1W bridge rail.

The specified minimum unconfined compressive strength of the concrete was 4000 psi for TxDOT Class S concrete. The compressive strength of all of the concrete used in the curb and bridge deck measured an average of 6469 psi on October 1, 2018.

2.3 MASH TEST 4-12 (TEST NO. 469469-1)

2.3.1 Test Designation and Actual Impact Conditions

MASH Test 4-12 involves a 10000S vehicle weighing 22,046 lb \pm 660 lb impacting the critical impact points (CIPs) of the C1W bridge rail at an impact speed of 56 mi/h \pm 2.5 mi/h and an angle of 15° \pm 1.5°. The CIP for *MASH* Test 4-12 on the C1W bridge rail was 5.0 ft \pm 1 ft upstream of the joint in the deck and curb between posts 4 and 5.

The 2011 International 4300 box truck used in the test weighed 22,220 lb, and the actual impact speed and angle were 56 mi/h and 14°, respectively. The actual impact point was 5.3 ft upstream of the joint in the deck and curb between posts 4 and 5. Minimum target impact severity (IS) was 142 kip-ft, and actual IS was 136 kip-ft. Although the IS was 4% below the recommended value, the speed and impact angle were individually within their tolerance ranges recommended in *MASH*. Further, the Single Unit Truck (SUT) was contained by the test article in a very stable manner with a maximum roll angle of only 23°, and the resulting occupant compartment deformation was only 45% of the maximum allowed intrusion (at the floor pan). Based on the observed impact performance of the barrier, the behavior of the SUT, and the amount of room left within the *MASH* evaluation criteria, a retest was not deemed necessary.

2.3.2 Weather Conditions

The test was performed on the morning of October 17, 2018. Weather conditions at the time of testing were as follows: wind speed: 5 mi/h; wind direction: 30° with respect to the vehicle (vehicle was traveling in a north, northwesterly direction); temperature: 61°F; relative humidity: 94 percent.

2.3.3 Test Vehicle

Figure 2.3 and Figure 2.4 show the 2011 International 4300 box truck that was used for the crash test. The vehicle's test inertia weight was 22,220 lb, and its gross static weight was 22,220 lb. The height to the lower edge of the vehicle bumper was 19 inches, and height to the upper edge of the bumper was 34 inches. Table A.1 and Table A.2 in Appendix A.3.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 2.3. C1W Bridge Rail/Test Vehicle Geometrics for Test No. 469469-1.



Figure 2.4. Test Vehicle before Test No. 469469-1.

2.3.4 Test Description

Table 2.1 lists events that occurred during Test No. 469469-1. Figure A.1 and Figure A.2 in Appendix A.3.2 present sequential photographs during the test.

Table 2.1. Events during Test No. 469469-1.

Time	Events
0.000	Vehicle contacts barrier
0.076	Vehicle begins to redirect and deflect away from barrier
0.116	Front right tire leaves pavement
0.237	Rear left side of box frame contacts top rail
0.241	Rear right tires leave pavement
0.248	Vehicle is parallel with barrier
0.300	Barrier is at maximum dynamic deflection
0.454	Vehicle exits barrier
0.715	Right front tire makes contact with pavement
1.234	Left front tire makes secondary contact with curb and bottom three rails

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 65.6 ft downstream from impact for heavy vehicles). The 10000S vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle yawed counterclockwise and came to rest 213 ft downstream of the impact.

2.3.5 Damage to Test Installation

Figure 2.5 shows the damage to the C1W bridge rail. The bridge rails were deformed at the location of impact. The concrete was fractured around posts 4, 5, and 6. Post 5 was leaning back 3.1° from vertical. Post 4 was leaning back toward the protected side 5.9° from vertical and was fractured at the weld where the vertical plates are connected to the base plate. There was a secondary contact at post 14 to the end of the bridge rail. No damage was noticed, other than black marks from the tire. Working width was 4 ft, and the height of the working width was 13.1 ft. Maximum dynamic deflection during the test was 0.9 ft, and maximum permanent deformation was 0.3 ft.



Figure 2.5. C1W Bridge Rail after Test No. 469469-1.

2.3.6 Damage to Test Vehicle

Figure 2.6 and Figure 2.7 show the damage sustained by the vehicle. The front bumper, hood, left head light, left front tire and rim, left front spring and U-bolts, left side step, left corner of floor pan, left front corner of box, and left rear outer tire and rim were damaged. Maximum exterior crush to the vehicle was 14.0 inches in the front left corner. Maximum occupant compartment deformation was 5.5 inches in the front left corner of the floor pan. Table A.3 in Appendix A.3.1 provides details on the damage to the test vehicle.



Figure 2.6. Test Vehicle after Test No. 469469-1.



Figure 2.7. Interior of Test Vehicle for Test No. 469469-1.

2.3.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and are shown in Table 2.2. Figure 2.8 summarizes these data and other pertinent information from the test. Figure A.3 in Appendix A.3.3 shows the vehicle angular displacements, and Figure A.4 through Figure A.6 in Appendix A.3.4 show accelerations versus time traces.

Table 2.2. Occupant Risk Factors for Test No. 469469-1.

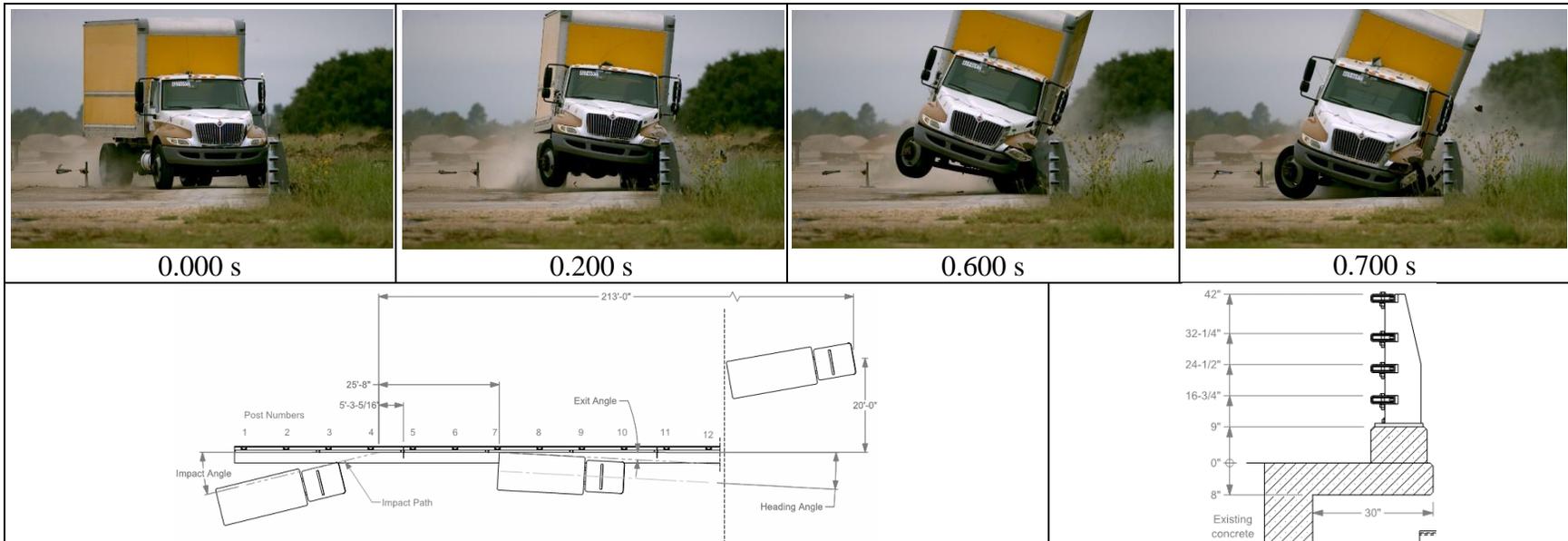
Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV) Longitudinal Lateral	ft/s	at 0.1962 seconds on left side of interior
	6.2	
	13.1	
Occupant Ridedown Accelerations Longitudinal Lateral	g	
	1.6	(0.3084–0.3184 seconds)
	9.6	(0.2454–0.2554 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.1908 seconds on left side of interior
	4.5	
Acceleration Severity Index (ASI)	0.68	(0.3254–0.3754 seconds)
Maximum 50-ms Moving Average Longitudinal Lateral Vertical	g	
	-1.4	(0.0764–0.1264 seconds)
	5.6	(0.2958–0.3458 seconds)
	1.8	(0.4217–0.4717 seconds)
Maximum Roll, Pitch, and Yaw Angles Roll Pitch Yaw	Degrees	
	23	(0.7419 seconds)
	7	(0.7398 seconds)
	18	(0.4755 seconds)

2.3.8 Assessment of Results

An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 4-12 is provided in Table 2.3.

2.4 CONCLUSIONS

The C1W bridge rail performed acceptably for *MASH* Test 4-12.



General Information

Test Agency Texas A&M Transportation Institute (TTI)
 Test Standard Test No. *MASH* Test 4-12
 TTI Test No. 469469-1
 Test Date 2018-10-17

Test Article

Type Longitudinal barrier—bridge rail
 Name TxDOT C1W bridge rail
 Installation Length 139 ft
 Material or Key Elements Concrete deck 8 inches thick with curb 9 inches tall x 14 inches wide with fabricated steel posts spaced at 9 ft supporting four steel rails. Top at 42 inches.

Soil Type and Condition

Concrete deck, damp

Test Vehicle

Type/Designation 10000S
 Make and Model 2011 International 4300, box truck
 Curb 14,190 lb
 Test Inertial 22,220 lb
 Dummy No dummy
 Gross Static 22,220 lb

Impact Conditions

Speed 56 mi/h
 Angle 14°
 Location/Orientation 5.3 ft upstream of the joint in the deck/curb between posts 4 and 5

Impact Severity

136.3 kip-ft

Exit Conditions

Speed 53 mi/h
 Exit Trajectory/Heading 3.4°/3.1°

Occupant Risk Values

Longitudinal OIV 6.2 ft/s
 Lateral OIV 13.1 ft/s
 Longitudinal Ridedown 1.6 g
 Lateral Ridedown 9.6 g
 THIV 4.5 m/s
 ASI 0.68
 Max. 0.050-s Average
 Longitudinal -1.4 g
 Lateral 5.6 g
 Vertical 1.8 g

Post-Impact Trajectory

Stopping Distance 213 ft downstream 20 ft to field side

Vehicle Stability

Maximum Yaw Angle 18°
 Maximum Pitch Angle 7°
 Maximum Roll Angle 23°
 Vehicle Snagging Slight
 Vehicle Pocketing No

Test Article Deflections

Dynamic 11.1 inches
 Permanent 3.8 inches
 Working Width 48.1 inches
 Working Width Height 157 inches

Vehicle Damage

VDS NA
 CDC 11FLEW4
 Max. Exterior Deformation 14.0 inches
 OCDI NA
 Max. Occupant Compartment Deformation 5.5 inches

Figure 2.8. Summary of Results for MASH Test 4-12 on the C1W Bridge Rail.

Table 2.3. Performance Evaluation Summary for MASH Test 4-12 on the C1W Bridge Rail.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-1

Test Date: 2018-10-17

MASH Test Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> A. <i>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.</i>	The TxDOT C1W bridge rail redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 11.1 inches.	Pass
<u>Occupant Risk</u> D. <i>Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i>	No detached elements, fragments, or other debris from the test article were present to penetrate or show potential for penetrating the occupant compartment or to present hazard to others in the area.	Pass
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</i>	Maximum occupant compartment deformation was 5.5 inches at the front left floor pan.	Pass
G. <i>It is preferable, although not essential, that the vehicle remain upright during and after collision.</i>	The 10000S vehicle remained upright during and after the collision event. Maximum roll was 23°.	Pass
<u>Vehicle Trajectory</u> For redirective devices, it is preferable that the vehicle be smoothly redirected and leave the barrier within the “exit box” criteria (not less than 65.6 ft for the 10000S vehicle), and should be documented.	The 10000S vehicle exited within the exit box criteria.	Documentation only

CHAPTER 3: TXDOT MODIFIED C66 BRIDGE RAIL

3.1 BACKGROUND

The T66 bridge rail is a variation of a rail initially developed by the California Department of Transportation. The bridge rail is a concrete beam-and-post system mounted on a 9-inch curb. The 15-inch-wide concrete posts are spaced at 6 ft 6 inches center to center. A 12-inch by 12-inch concrete beam is mounted at a height of 32 inches and offset 4 inches from the traffic face of the posts in line with the curb.

The C66 rail is a combination version of the T66 rail that is designed to accommodate both vehicle and pedestrian traffic. The C66 rail differs from the T66 rail in two ways. First, a 8-inch-tall steel rail element is attached to the top of the posts to achieve a total overall height of 42 inches to meet pedestrian requirements. The lateral position of the steel rail element is 10 inches from the traffic face of the concrete beam. The second variation is the addition of a steel pipe between posts centered in the clear opening between the bottom of the concrete beam and top of the curb. This pipe is also set back 10 inches from the traffic face of the concrete beam and curb.

The test installation was constructed in a manner to evaluate the *MASH* compliance of both the T66 and C66 bridge rail systems. The C66 steel rail element was incorporated into the test installation to evaluate any potential occupant or vehicle interaction. Since the lower pipe section could potentially reduce the severity of wheel snagging on the concrete posts, the lower pipe was removed from the test installation. If the testing of the Modified C66 rail (with the lower pipe removed) is successful, both the C66 and T66 bridge rail systems would be considered *MASH* compliant.

The Modified C66 bridge rail was tested and evaluated in accordance with *MASH* TL-3 requirements. The full *MASH* TL-3 test matrix was conducted on this rail system to fully evaluate vehicle-snagging potential on the concrete posts or any occupant or vehicle contact with the steel steel rail element. This shall consist of test designations 3-10 (small passenger car) and 3-11 (pickup truck).

3.2 SYSTEM DETAILS

3.2.1 Test Article and Installation Details

The Modified C66 bridge rail test installation was 74 ft 4½ inches long and consisted of a reinforced cantilevered concrete deck supporting a reinforced concrete beam-and-post bridge rail mounted on a 9-inch-tall reinforced concrete curb. The concrete deck was 30 inches wide by 8 inches thick. The curb was 9 inches tall and 17½ inches wide. Reinforced concrete posts measuring 12 inches by 15 inches were spaced on 6-ft-6-inch centers. A 12-inch by 12-inch longitudinal reinforced concrete beam was integrally cast with the posts such that the traffic face of the beam was flush with the traffic side face of the curb. The traffic face of the concrete posts was inset 4 inches from the traffic face of the beam and curb, and the top of the concrete posts extended 2 inches above the top of the beam. The top of the rail was 32 inches above the deck surface. A 2⅞-inch-diameter steel steel rail element pipe assembly was attached to the top of each post, and the top of the steel rail element was 42 inches above the deck. Two ¾-inch-wide

joints were placed through the concrete beam, curb, and deck. A concrete post was placed on each side of the joints.

Figure 3.1 presents the overall information on the Modified C66 bridge rail, and Figure 3.2 provides photographs of the installation. Appendix B.1 provides further details of the Modified C66 bridge rail.

3.2.2 Material Specifications

The minimum compressive strength of the TxDOT Class S concrete specified for the bridge deck, curb, posts, and beam was 4000 psi. The bridge deck and support wall were cast on September 27, 2018. The average compressive strength of the two batches of concrete used in the deck and wall measured 5900 psi on October 31, 2018 (at 34 days). The entire curb was cast on October 2, 2018, and its average compressive strength measured 4695 psi on October 31, 2018 (at 29 days). The posts and beam were cast on October 4, 2018, and their average compressive strength measured 5185 psi on October 31, 2018 (at 27 days). Appendix B.2 provides the concrete strength test results for the bridge rail test installation.

Reinforcement of the bridge deck was comprised of ASTM A615 Grade 60 rebar with a specified minimum yield strength of 60 ksi. Appendix B.2 contains mill certification sheets and other certification documents for the materials used in the bridge deck test installation.

3.3 MASH TEST 3-11 (TEST NO. 469469-2-1)

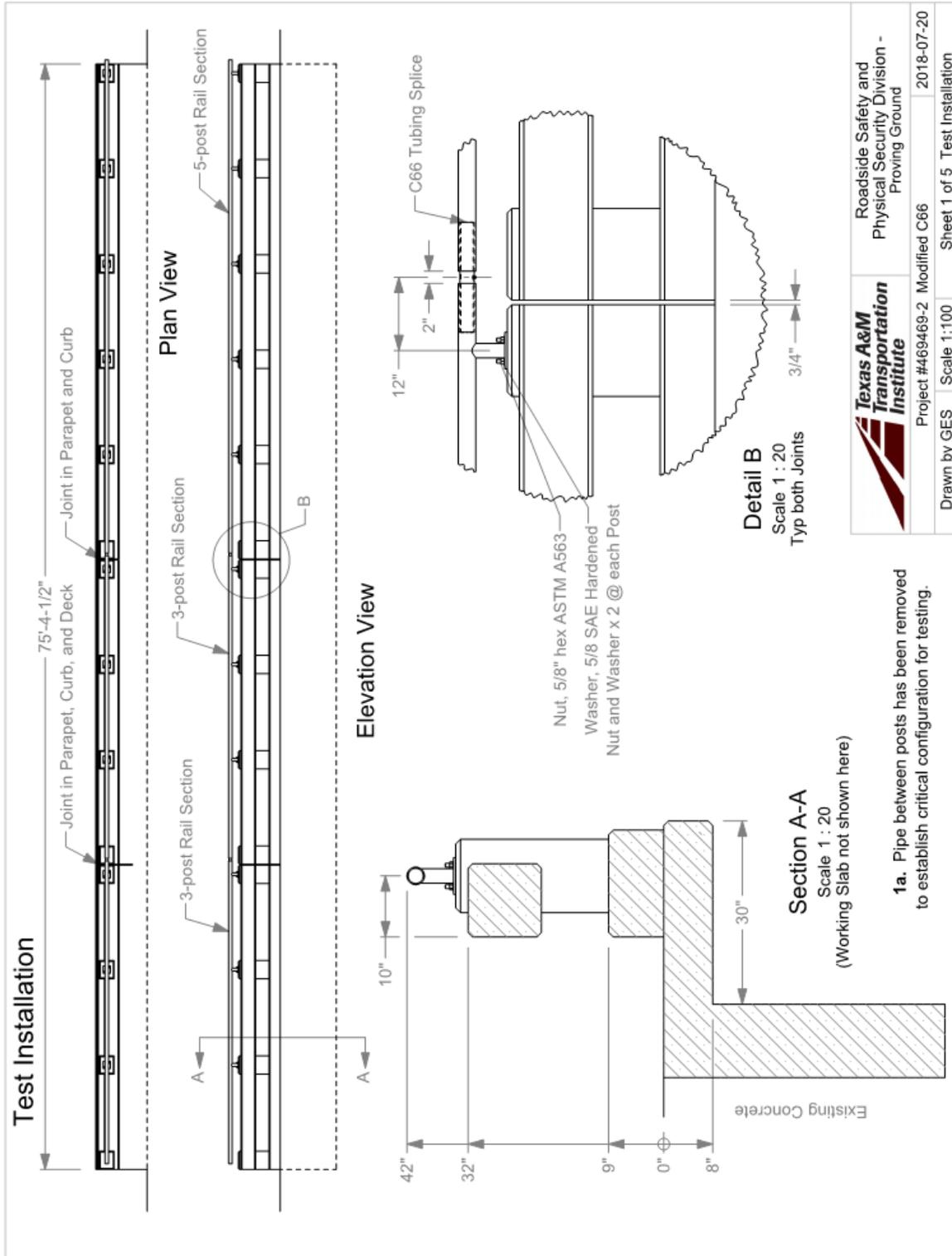
3.3.1 Test Designation and Actual Impact Conditions

MASH Test 3-11 involves a 2700P vehicle weighing 5000 lb \pm 110 lb impacting the CIP of the Modified C66 bridge rail at a speed of 62 mi/h \pm 2.5 mi/h and an angle of 25° \pm 1.5°. The CIP for *MASH* Test 3-11 on the Modified C66 bridge rail was 4.3 ft upstream of the joint in the deck, curb, and beam between posts 4 and 5.

The 2012 RAM 1500 used in the test weighed 5014 lb, and the actual impact speed and angle were 61.8 mi/h and 24.3°, respectively. The actual impact point was 4.1 ft upstream of the joint in the deck, curb, and beam between posts 4 and 5. Minimum target IS was 106 kip-ft, and actual IS was 108.4 kip-ft.

3.3.2 Weather Conditions

The test was performed on the morning of October 31, 2018. Weather conditions at the time of testing were as follows: wind speed: 10 mi/h; wind direction: 163° with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 76°F; relative humidity: 93 percent.



Roadside Safety and
Physical Security Division -
Proving Ground

Project #469469-2 Modified C66
2018-07-20

Drawn by GES Scale 1:100 Sheet 1 of 5 Test Installation

1a. Pipe between posts has been removed to establish critical configuration for testing.

Figure 3.1. Overall Details of the Modified C66 Bridge Rail.



Figure 3.2. Modified C66 Bridge Rail prior to Testing.

3.3.3 Test Vehicle

Figure 3.3 and Figure 3.4 show the 2012 RAM 1500 that was used for the crash test. The vehicle's test inertia weight was 5014 lb, and its gross static weight was 5179 lb. The height to the lower edge of the vehicle bumper was 11.8 inches, and the height to the upper edge of the bumper was 27 inches. The height to the vehicle's center of gravity was 28 inches. Table B.1 and Table B.2 in Appendix B.3.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 3.3. Modified C66 Bridge Rail/Test Vehicle Geometrics for Test No. 469469-2-1.



Figure 3.4. Test Vehicle before Test No. 469469-2-1.

3.3.4 Test Description

Table 3.1 lists events that occurred during Test No. 469469-2-1. Figure B.1 and Figure B.2 in Appendix B.3.2 present sequential photographs during the test.

Table 3.1. Events during Test No. 469469-2-1.

Time	Events
0.000	Vehicle contacts barrier
0.044	Vehicle begins to redirect
0.146	Left front tire lifts off pavement
0.157	Left rear tire lifts off pavement
0.208	Vehicle is parallel with barrier
0.245	Right rear bumper contacts barrier
0.392	Left front tire makes contact with pavement
0.416	Vehicle exits the barrier at 46.3 mi/h, heading 8.7° from barrier with a trajectory of 3.4° from barrier

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for cars and pickups). The 2270P vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle yawed counterclockwise and came to rest 185 ft downstream of the impact point and 5 ft toward traffic lanes.

3.3.5 Damage to Test Installation

Figure 3.5 shows the damage to the Modified C66 bridge rail. Some of the edges of the concrete at the joint between posts 4 and 5 were damaged and missing a small amount of material. No further damage to the bridge rail was noted. Working width was 20.5 inches, and the height of the working width was 58 inches. Maximum dynamic deflection during the test was 1.1 inches for the steel rail element on top of the concrete parapet. There was no measurable dynamic deflection of the concrete parapet. There was no measurable permanent deflection in either the concrete parapet or the steel rail element.



Figure 3.5. Modified C66 Bridge Rail after Test No. 469469-2-1.

3.3.6 Damage to Test Vehicle

Figure 3.6 and Figure 3.7 show the damage sustained by the vehicle. The front bumper, hood, radiator and support, left front fender, left front tire and rim, left frame rail, left upper and lower A-arms, left front floor pan and kick panel, left front door and glass and left rear door, left cab corner, left rear fender, and left rear tire and rim were damaged. Maximum exterior crush to the vehicle was 14.0 inches in the side plane at the left front corner at bumper height. Maximum occupant compartment deformation was 2.0 inches in the left side firewall area. Table B.3 and Table B.4 in Appendix B.3.1 provide the exterior crush and occupant compartment measurements of the vehicle.



Figure 3.6. Test Vehicle after Test No. 469469-2-1.



**Figure 3.7. Interior of Test Vehicle for Test No. 469469-2-1
(before Test on Left; after Test on Right).**

3.3.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 3.2. Figure 3.8 summarizes these data and other pertinent information from the test. Figure B.3 in Appendix B.3.3 shows the vehicle angular displacements, and Figure B.4 through Figure B.6 in Appendix B.3.4 show acceleration versus time traces.

Table 3.2. Occupant Risk Factors for Test No. 469469-2-1.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV) Longitudinal Lateral	ft/s	at 0.1029 seconds on left side of interior
	22.3	
	23.6	
Occupant Ridedown Accelerations (g's) Longitudinal Lateral		
	4.1	(0.2233–0.2333 seconds)
	7.8	(0.2236–0.2336 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.0997 seconds on left side of interior
	10	
Acceleration Severity Index (ASI)	1.81	(0.0594–0.1094 seconds)
Maximum 50-ms Moving Average (g's) Longitudinal Lateral Vertical		
	-11.8	(0.0340–0.0840 seconds)
	13.3	(0.0367–0.0867 seconds)
	4	(0.0787–0.1287 seconds)
Maximum Roll, Pitch, and Yaw Angles Roll (degrees) Pitch (degrees) Yaw (degrees)		
	12	(0.4178 seconds)
	7	(0.4409 seconds)
	39	(0.7687 seconds)

3.3.8 Assessment of Results

An assessment of the tests based on the applicable safety evaluation criteria for *MASH* Test 3-11 is provided in Table 3.3.

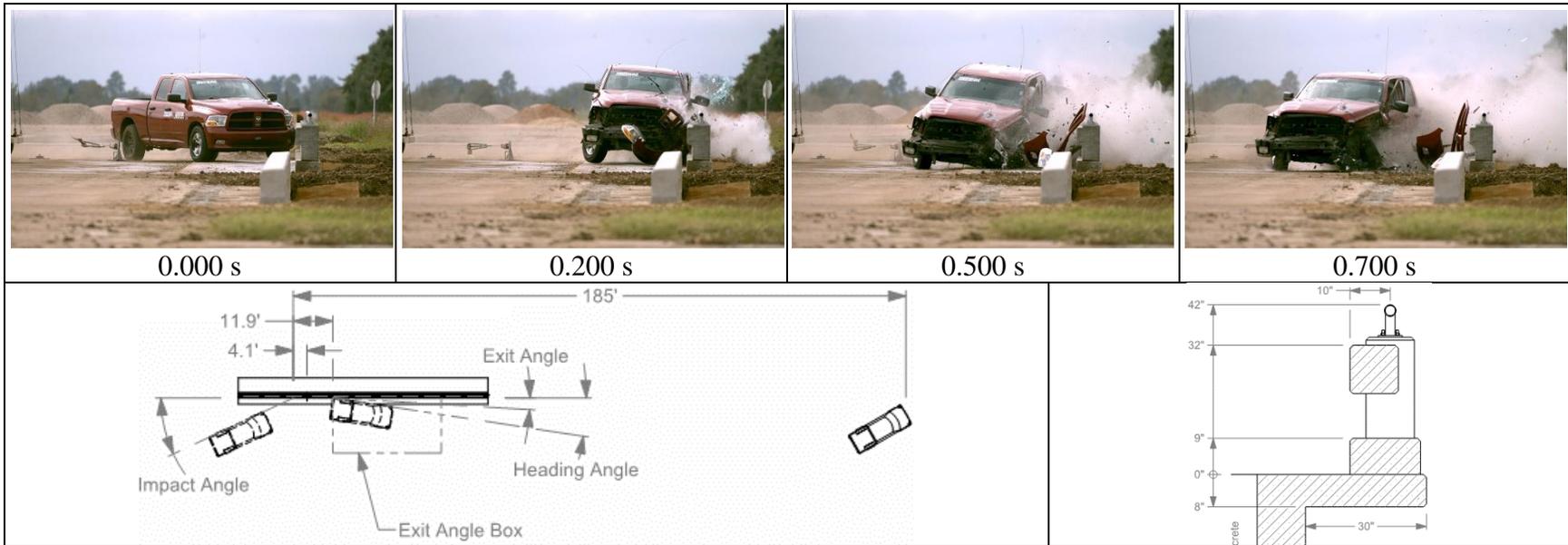
3.4 MASH TEST 3-10 (TEST NO. 469469-2-2)

3.4.1 Test Designation and Actual Impact Conditions

MASH Test 3-10 involves an 1100C vehicle weighing 2420 lb \pm 55 lb impacting the CIP of the Modified C66 bridge rail at an impact speed of 62 mi/h \pm 2.5 mi/h and an angle of 25° \pm 1.5°. The CIP for *MASH* Test 3-10 on the Modified C66 bridge rail was 3.6 ft upstream of the joint in the deck, curb, and beam between posts 8 and 9.

The 2011 Kia Rio¹ used in the test weighed 2448 lb, and the actual impact speed and angle were 63.0 mi/h and 24.9°, respectively. The actual impact point was 4.0 ft upstream of the joint in the deck, curb, and beam between posts 8 and 9. Minimum target impact severity was 51 kip-ft, and actual IS was 57.6 kip-ft.

¹ The 2009 model vehicle used is older than the 6-year age noted in *MASH*, and was selected based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2009 model vehicle met the *MASH* requirements.



General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-11
TTI Test No.	469469-2-1
Test Date	2018-10-31

Test Article

Type.....	Longitudinal barrier—bridge rail
Name	TxDOT Modified C66 bridge rail
Installation Length.....	75 ft 4-1/2 inches
Material or Key Elements	32-inch-tall concrete beam-and-post rail mounted on 9-inch-tall curb attached to 8-inch-thick cantilever deck; concrete posts spaced at 6.5 ft; metal steel rail element attached to concrete posts at height of 42 inches
Soil Type and Condition	Concrete deck, damp

Test Vehicle

Type/Designation	2270P
Make and Model	2012 RAM 1500
Curb.....	5025 lb
Test Inertial.....	5014 lb
Dummy	165 lb
Gross Static	5179 lb

Impact Conditions

Speed	61.8 mi/h
Angle	24.3°
Location/Orientation	4.1 ft upstream of the joint in the deck/curb between posts 4 and 5
Impact Severity	108.4 kip-ft

Exit Conditions

Speed	46.3 mi/h
Exit Trajectory/Heading	3.4°/8.7°

Occupant Risk Values

Longitudinal OIV.....	22.3 ft/s
Lateral OIV.....	23.6 ft/s
Longitudinal Ridedown	4.1 g
Lateral Ridedown	7.8 g
THIV	10 m/s
ASI.....	1.81
Max. 0.050-s Average	
Longitudinal.....	-11.8 g
Lateral.....	13.3 g
Vertical.....	4 g

Post-Impact Trajectory

Stopping Distance	185 ft
-------------------------	--------

Vehicle Stability

Maximum Yaw Angle.....	39°
Maximum Pitch Angle....	7°
Maximum Roll Angle	12°
Vehicle Snagging	Slight
Vehicle Pocketing.....	No

Test Article Deflections

Dynamic.....	1.1 inches
Permanent	None
Working Width.....	20.5 inches
Working Width Height....	58 inches

Vehicle Damage

VDS	10-LFQ-5
CDC	10FLEW4
Max. Exterior Deformation	14 inches
OCDI.....	LF0011000
Max. Occupant Compartment Deformation	2 inches

Figure 3.8. Summary of Results for MASH Test 3-11 on the Modified C66 Bridge Rail.

Table 3.3. Performance Evaluation Summary for MASH Test 3-11 on the Modified C66 Bridge Rail.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-2-1

Test Date: 2018-10-31

MASH Test 3-11 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> A. <i>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.</i>	The TxDOT Modified C66 bridge rail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 1.1 inches in the metal steel rail element.	Pass
<u>Occupant Risk</u> D. <i>Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i> <i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</i>	No detached elements, fragments, or other debris from the test article were present to penetrate or show potential for penetrating the occupant compartment or to present hazard to others in the area. Maximum reduction of space in the occupant compartment was 2.0 inch in the driver side floor pan and kick panel areas.	Pass
F. <i>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 2270P vehicle remained upright during and after the collision event. Maximum roll was 12°, and maximum pitch was 7°.	Pass
H. <i>Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.</i>	Longitudinal OIV was 22.3 ft/s, and lateral OIV was 23.6 ft/s.	Pass
I. <i>Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.</i>	Maximum longitudinal 10-ms occupant ridedown acceleration was 4.1 g, and maximum lateral 10-ms occupant ridedown acceleration was 7.8 g.	Pass
<u>Vehicle Trajectory</u> For redirective devices, it is preferable that the vehicle be smoothly redirected and leave the barrier within the “exit box” criteria (not less than 32.8 ft for the 1100C and 2270P vehicles), and should be documented.	The 2270P vehicle exited within the exit box criteria.	Documentation only

3.4.2 Weather Conditions

The test was performed on the morning of November 28, 2018. Weather conditions at the time of testing were as follows: wind speed: 9 mi/h; wind direction: 176° with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 62°F; relative humidity: 75 percent.

3.4.3 Test Vehicle

Figure 3.9 and Figure 3.10 show the 2011 Kia Rio that was used for the crash test. The vehicle's test inertia weight was 2448 lb, and its gross static weight was 2613 lb. The height to the lower edge of the vehicle bumper was 7.8 inches, and the height to the upper edge of the bumper was 21.5 inches. Table B.5. and Table B.6. in Appendix B.4.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 3.9. Modified C66 Bridge Rail/Test Vehicle Geometrics for Test No. 469469-2-2.



Figure 3.10. Test Vehicle before Test No. 469469-2-2.

3.4.4 Test Description

Table 3.4 lists events that occurred during Test No. 469469-2-2. Figure B.7 and Figure B.8 in Appendix B.4.2 present sequential photographs during the test.

Table 3.4. Events during Test No. 469469-2-2.

Time	Events
0.000	Vehicle contacts barrier
0.031	Vehicle begins to redirect
0.076	Right rear tire lifts off pavement
0.179	Vehicle is parallel with barrier
0.191	Left rear bumper contacts barrier
0.293	Vehicle exits the barrier at 49.4 mi/h, heading 10.1° from barrier and a trajectory of 4.7° from barrier

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for cars and pickups). The 1100C vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle yawed counterclockwise and came to rest 184 ft downstream of the impact point and 4 ft behind the barrier.

3.4.5 Damage to Test Installation

Figure 3.11 shows the damage to the Modified C66 bridge rail. Some of the edges of the concrete at the joint between posts 8 and 9 were damaged and missing a small amount of material. No further damage to the bridge rail was noted. Working width was 16 inches, and the height of the working width was 32 inches. There was no measurable dynamic or permanent deflection in either the concrete parapet or the steel rail element.



Figure 3.11. Modified C66 Bridge Rail after Test No. 469469-2-2.

3.4.6 Damage to Test Vehicle

Figure 3.12 and Figure 3.13 show the damage sustained by the vehicle. The front bumper, hood, radiator and support, left front head light, left front fender, left front strut and tower, left front tire and rim, left A post, windshield, left front floor pan, left front and rear door, left rear fender, rear bumper, and roof were damaged. Maximum exterior crush to the vehicle was 12.0 inches in the side plane at the left front corner above front bumper height. Maximum occupant compartment deformation was 2.0 inches for the interior height. Table B.6 and Table B.7 in Appendix B.4.1 provide exterior crush and occupant compartment measurements.



Figure 3.12. Test Vehicle after Test No. 469469-2-2.



Figure 3.13. Interior of Test Vehicle after Test No. 469469-2-2.

3.4.7 Occupant Risk Factors

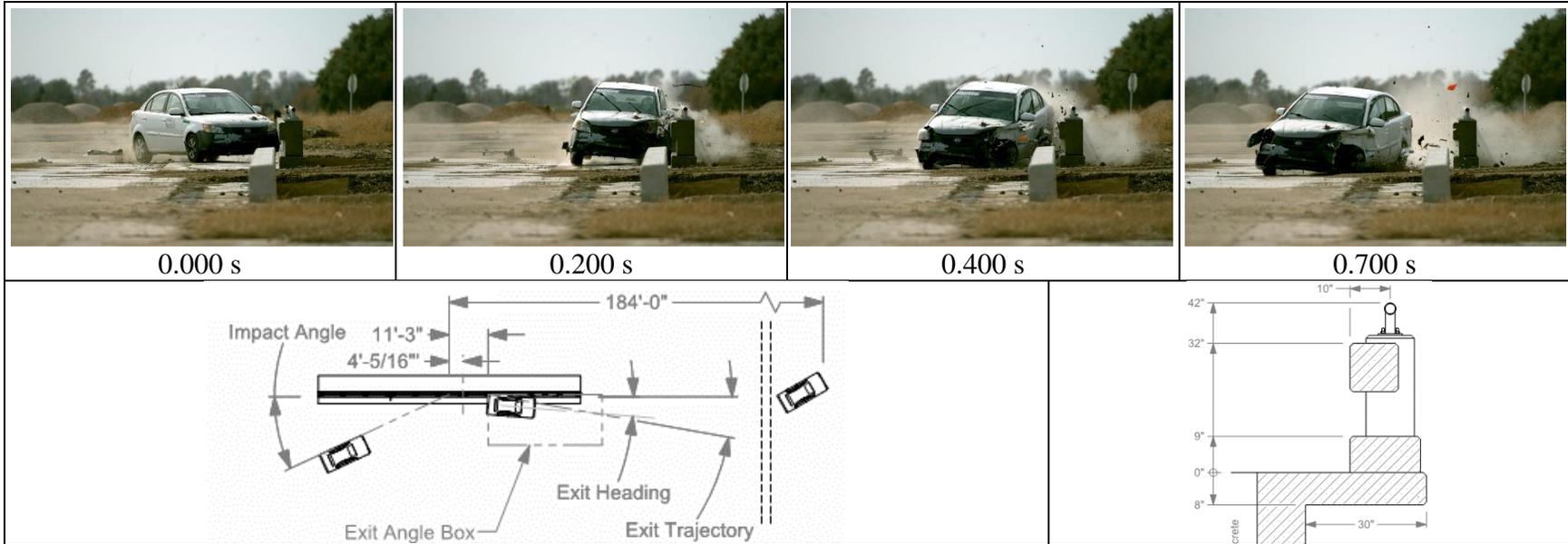
Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 3.5. Figure 3.14 summarizes these data and other pertinent information from the test. Figure B.9 in Appendix B.4.3 shows the vehicle angular displacements, and Figure B.10 through Figure B.12 in Appendix B.4.4 show acceleration versus time traces.

Table 3.5. Occupant Risk Factors for Test No. 469469-2-2.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV) Longitudinal Lateral	ft/s	at 0.0703 seconds on left side of interior
	28.5	
	33.1	
Occupant Ridedown Accelerations (g's) Longitudinal Lateral		
	3.7	(0.5879–0.5979 seconds)
	6.7	(0.2163–0.2263 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.0686 seconds on left side of interior
	13.2	
Acceleration Severity Index (ASI)	2.92	(0.0433–0.0933 seconds)
Maximum 50-ms Moving Average (g's) Longitudinal Lateral Vertical		
	-16.2	(0.0127–0.0627 seconds)
	20.2	(0.0118–0.0618 seconds)
	-3.4	(0.0081–0.0581 seconds)
Maximum Roll, Pitch, and Yaw Angles Roll Pitch Yaw	Degrees	
	18	(1.5000 seconds)
	14	(1.5000 seconds)
	43	(0.5956 seconds)

3.4.8 Assessment of Results

An assessment of the tests based on the applicable safety evaluation criteria for *MASH* Test 3-10 is provided in Table 3.6.



General Information		Impact Conditions		Post-Impact Trajectory	
Test Agency	Texas A&M Transportation Institute (TTI)	Speed	63.0 mi/h	Stopping Distance	184 ft and 4 ft toward field
Test Standard Test No.	MASH Test 3-10	Angle	24.9°	Vehicle Stability	
TTI Test No.	469469-2-2	Location/Orientation	4.0 ft upstream of the joint in the deck/curb between posts 8 and 9	Maximum Yaw Angle.....	43°
Test Date	2018-11-28	Impact Severity	57.6 kip*ft	Maximum Pitch Angle....	14°
Test Article		Exit Conditions		Maximum Roll Angle	18°
Type.....	Longitudinal barrier—bridge rail	Speed	49.4 mi/h	Vehicle Snagging	Slight
Name	TxDOT Modified C66 bridge rail	Exit Trajectory/Heading	4.7°/10.1°	Vehicle Pocketing.....	No
Installation Length.....	75 ft 4-1/2 inches	Occupant Risk Values		Test Article Deflections	
Material or Key Elements	32-inch-tall concrete beam-and-post rail mounted on 9-inch-tall curb attached to 8-inch-thick cantilever deck; concrete posts spaced at 6.5 ft; metal steel rail element attached to concrete posts at height of 42 inches	Longitudinal OIV.....	28.5 ft/s	Dynamic.....	None detected
		Lateral OIV.....	33.1 ft/s	Permanent	none
		Longitudinal Ridedown	3.7 g	Working Width.....	16 inches
		Lateral Ridedown	6.7 g	Working Width Height....	32 inches
		THIV	13.2 m/s	Vehicle Damage	
		ASI	2.92	VDS	NA
Soil Type and Condition	Concrete deck, damp	Max. 0.050-s Average		CDC	11FLEW4
Test Vehicle		Longitudinal.....	-16.2 g	Max. Exterior Deformation	12.0 inches
Type/Designation	1100C	Lateral.....	20.2 g	OCDI.....	NA
Make and Model	2011 Kia Rio	Vertical.....	-3.4 g	Max. Occupant Compartment	
Curb.....	2458 lb			Deformation	2.0 inches
Test Inertial.....	2448 lb				
Dummy	165 lb				
Gross Static	2613 lb				

Figure 3.14. Summary of Results for MASH Test 3-10 on the Modified C66 Bridge Rail.

Table 3.6. Performance Evaluation Summary for MASH Test 3-10 on the Modified C66 Bridge Rail.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-2-2

Test Date: 2018-11-28

MASH Test 3-10 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> A. <i>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.</i>	The TxDOT Modified C66 bridge rail contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. There was no measurable dynamic deflection during the test.	Pass
<u>Occupant Risk</u> D. <i>Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i> <i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</i>	No detached elements, fragments, or other debris from the test article were present to penetrate or show potential for penetrating the occupant compartment or to present hazard to others in the area. Maximum reduction of space in the occupant compartment was 2.0 inches between the floor and roof.	Pass
F. <i>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 1100C vehicle remained upright during and after the collision event. Maximum roll was 18°, and maximum pitch was 14°.	Pass
H. <i>Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.</i>	Longitudinal OIV was 28.5 ft/s, and lateral OIV was 33.1 ft/s.	Pass
I. <i>Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.</i>	Maximum longitudinal 10-ms occupant ridedown acceleration was 3.7 g, and maximum lateral 10-ms occupant ridedown acceleration was 6.7 g.	Pass
<u>Vehicle Trajectory</u> For redirective devices, it is preferable that the vehicle be smoothly redirected and leave the barrier within the “exit box” criteria (not less than 32.8 ft for the 1100C and 2270P vehicles), and should be documented.	The 1100C vehicle exited within the exit box criteria.	Documentation only

3.5 CONCLUSIONS

The TxDOT Modified C66 bridge rail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underide, or override the installation. Maximum dynamic deflection during the test was 1.1 inches at the steel rail element, and there was no measurable permanent deformation. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 2.0 inches in the driver side floor pan and kick panel areas. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 12° and 7°, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The 2270P vehicle exited within the exit box criteria.

The TxDOT Modified C66 bridge rail contained and redirected the 1100C vehicle. The vehicle did not penetrate, underide, or override the installation. There was no measurable dynamic or permanent deformation. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 2 inches between the floor and roof. The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 18° and 14°, respectively. Occupant risk factors were within the acceptable limits specified in *MASH*. The 1100C vehicle exited within the exit box criteria.

The TxDOT Modified C66 bridge rail performed acceptably according to *MASH* TL-3 evaluation criteria as shown in Table 3.7.

Table 3.7. Assessment Summary for *MASH* TL-3 Tests on TxDOT Modified C66 Bridge Rail.

Evaluation Factors	Evaluation Criteria	Test No. 469469-2-1	Test No. 469469-2-2
Structural Adequacy	A	S	S
Occupant Risk	D	S	S
	F	S	S
	H	S	S
	I	S	S
	Test No.	<i>MASH</i> Test 3-11	<i>MASH</i> Test 3-10
	Pass/Fail	Pass	Pass

S = Satisfactory
U = Unsatisfactory

CHAPTER 4: TXDOT LOW-PROFILE BARRIER

4.1 BACKGROUND

Details of the low-profile precast concrete barrier are found in TxDOT standard detail LCPB-13. This 20-inch-tall barrier provides improved sight distance for turning maneuvers within low-speed work zone areas. A negative slope on the face of the barrier helps improve vehicle stability during a vehicle impact.

The full *MASH* test matrix was performed on the low-profile barrier to assess vehicle stability, occupant risk, and dynamic deflection. The TL-2 matrix included Test 2-10 with the small passenger car and Test 2-11 with the pickup truck. The target CIPs selected for the tests were determined according to information provided in *MASH* Section 2.3.2, Table 2-7.

4.2 SYSTEM DETAILS

4.2.1 Test Article and Installation Details

The low-profile barrier test installation was approximately 200 ft long. It consisted of 10 precast reinforced concrete barriers that were each 20 ft long and 20 inches tall. The width at the base of the barrier sections was 26 inches and flared out to 28 inches at the top. Adjacent segments were connected with two threaded rods that were inserted into a trough and passed through holes cast into the ends of each segment. Each threaded rod was secured with a plate washer, flat washer, and nut on each end.

Eight of the barriers (numbers 2 through 9) were newly constructed for these tests by a TxDOT-approved contractor. The two end segments (numbers 1 and 10) used to complete the installation were taken from existing TTI inventory.

Figure 4.1 presents overall information on the low-profile barrier, and Figure 4.2 provides photographs of the installation. Appendix C.1 provides further details of the low-profile barrier.

4.2.2 Material Specifications

Appendix C.2 provides material certification documents and information on the concrete used to install/construct the low-profile barrier.

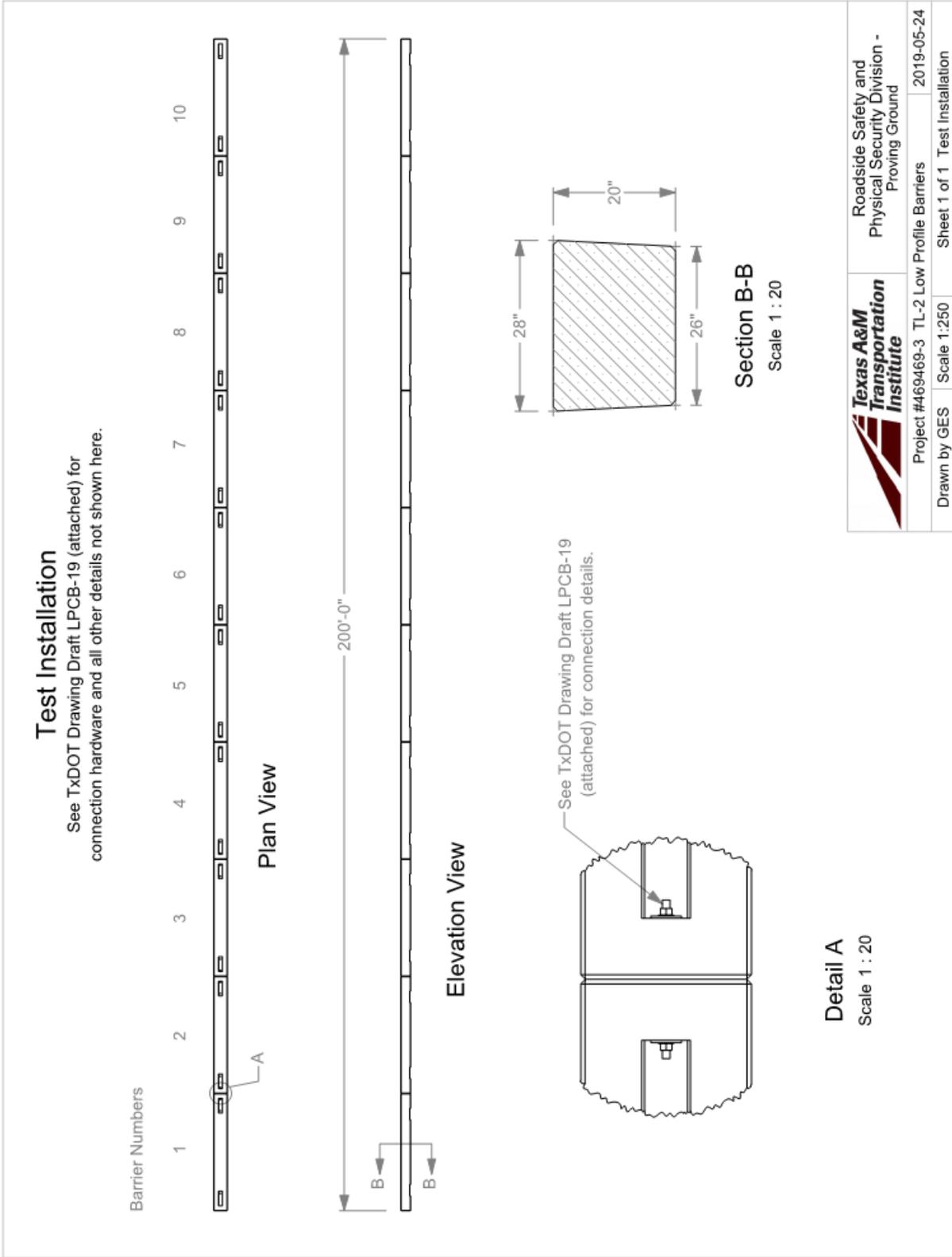


Figure 4.1. Overall Details of the Low-Profile Barrier.



Figure 4.2. Low-Profile Barrier prior to Testing.

4.3 MASH TEST 2-11 (TEST NO. 469469-3-2)

4.3.1 Test Designation and Actual Impact Conditions

MASH Test 2-11 involves a 2700P vehicle weighing 5000 lb \pm 110 lb impacting the CIP of the low-profile barrier at an impact speed of 44 mi/h \pm 2.5 mi/h and an angle of 25° \pm 1.5°. The CIP for *MASH* Test 2-11 on the low-profile barrier was 2.6 ft upstream of the joint between segments 5 and 6.

The 2015 RAM 1500 used in the test weighed 5011 lb, and the actual impact speed and angle were 44.4 mi/h and 25.1°, respectively. The actual impact point was 2.9 ft upstream of the joint between segments 5 and 6. Minimum target impact severity was 52 kip-ft, and actual IS was 59.4 kip-ft.

4.3.2 Weather Conditions

The test was performed on the morning of June 6, 2019. Weather conditions at the time of testing were as follows: wind speed: 5 mi/h; wind direction: 315° with respect to the vehicle (vehicle was traveling at a magnetic heading of 0°); temperature: 79°F; relative humidity: 82 percent.

4.3.3 Test Vehicle

Figure 4.3 and Figure 4.4 show the 2015 RAM 1500 that was used for the crash test. The vehicle's test inertia weight was 5011 lb, and its gross static weight was 5011 lb. The height to the lower edge of the vehicle bumper was 11.8 inches, and height to the upper edge of the bumper was 27 inches. The height to the vehicle's center of gravity was 28.4 inches. Table C.1 and Table C.2 in Appendix C.3.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 4.3. Low-Profile Barrier/Test Vehicle Geometrics for Test No. 469469-3-2.



Figure 4.4. Test Vehicle before Test No. 469469-3-2.

4.3.4 Test Description

Table 4.1 lists events that occurred during Test No. 469469-3-2. Figure C.1 and Figure C.2 in Appendix C.3.2 present sequential photographs during the test.

Table 4.1. Events during Test No. 469469-3-2.

Time	Events
0.000	Vehicle contacts barrier
0.080	Vehicle begins to redirect
0.100	Right front tire leaves pavement
0.138	Right rear tire leaves pavement
0.301	Vehicle is parallel with barrier
0.333	Rear left bumper corner makes contact with barrier
0.578	Vehicle exits barrier at 34.4 mi/h at a trajectory angle of 10.6° and a heading angle of 3.2°
0.684	Right front makes contact with pavement
1.455	Secondary impact with front left bumper of vehicle and low-profile barrier

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for cars and pickups). The 2270P vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle yawed counterclockwise and came to rest 120 ft downstream of the point of impact and 2 ft behind the traffic side of the barrier facing approximately 2° to the left. Brakes were not applied.

4.3.5 Damage to Test Installation

Figure 4.5 shows the damage to the low-profile barrier. The field side top corners were broken for a distance ranging from 10 to 18 inches on the downstream end of barrier segments 4, 5, and 7. There was minor cosmetic damage on the traffic side of barrier segments 5 and 6 near the joint. Table 4.2 shows the permanent field side displacement measured at the joints between segments.

Working width² was 36.6 inches, and the height of maximum working width was 20 inches. Maximum dynamic deflection during the test was 8.6 inches, and the maximum permanent deflection was 8.5 inches.

² Working width is defined as the distance between the traffic face of the barrier before impact and the maximum lateral position of any major part of the barrier or the vehicle after impact.

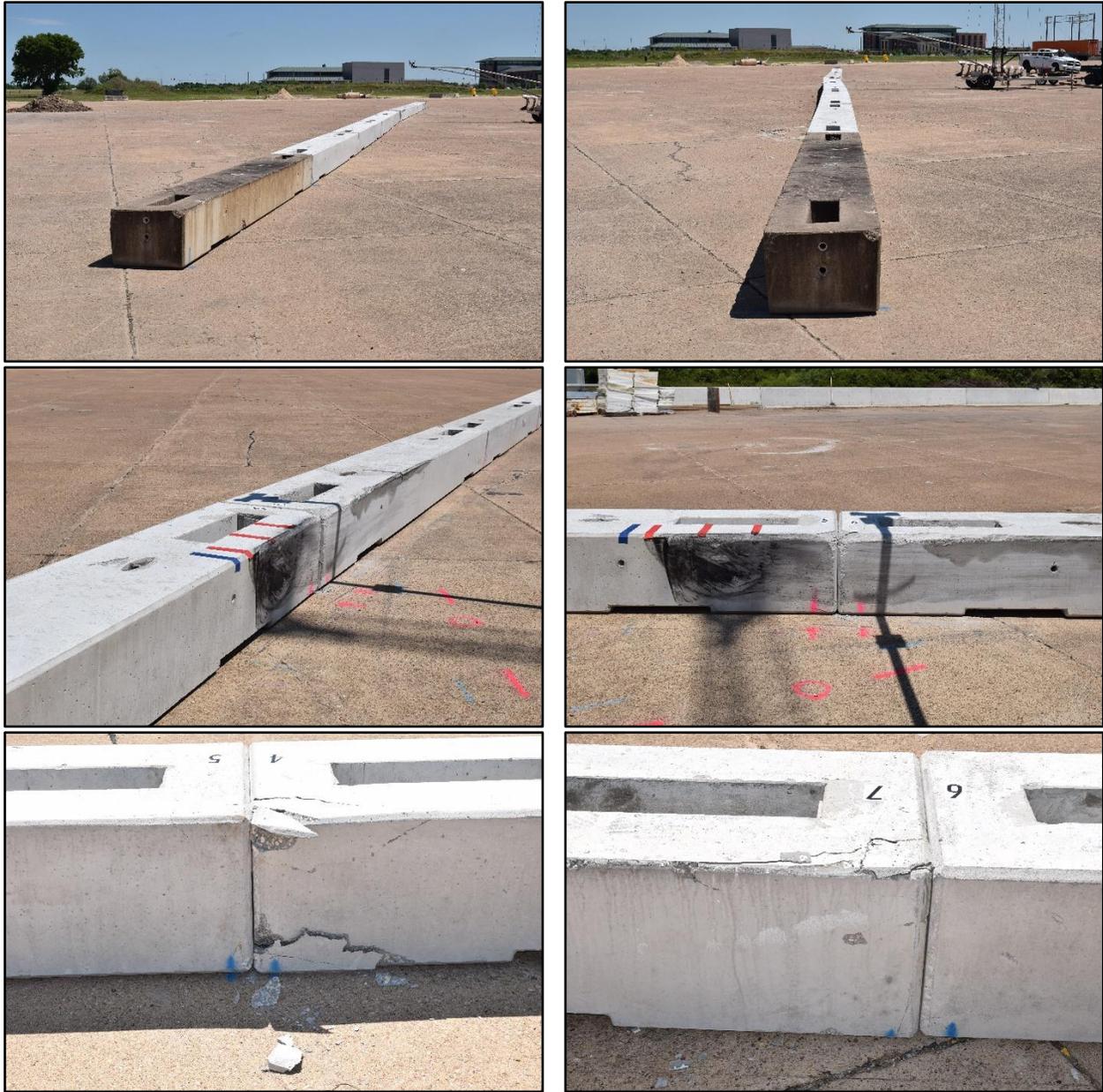


Figure 4.5. Low-Profile Barrier after Test No. 469469-3-2.

Table 4.2. Measured Displacement of Barrier, Test No. 469469-3-2.

Location	Displacement (Inches)
Joint 4-5	4
Joint 5-6	8.5
Joint 6-7	5.5
Joint 7-8	1

4.3.6 Damage to Test Vehicle

Figure 4.6 and Figure 4.7 show the damage sustained by the vehicle. The front bumper, left front fender, left front tire and rim, left front door, left rear door, left rear door, left cab corner, left rear fender, left rear rim, and rear bumper were damaged. Maximum exterior crush to the vehicle was 2 inches in the side plane at the left front corner at bumper height. There was no observed occupant compartment deformation. Table C.3 and Table C.4 in Appendix C.3.1 provide exterior crush and occupant compartment measurements.



Figure 4.6. Test Vehicle after Test No. 469469-3-2.



Figure 4.7. Interior of Test Vehicle for Test No. 469469-3-2 (before Test on Left; after Test on Right).

4.3.7 Occupant Risk Factors

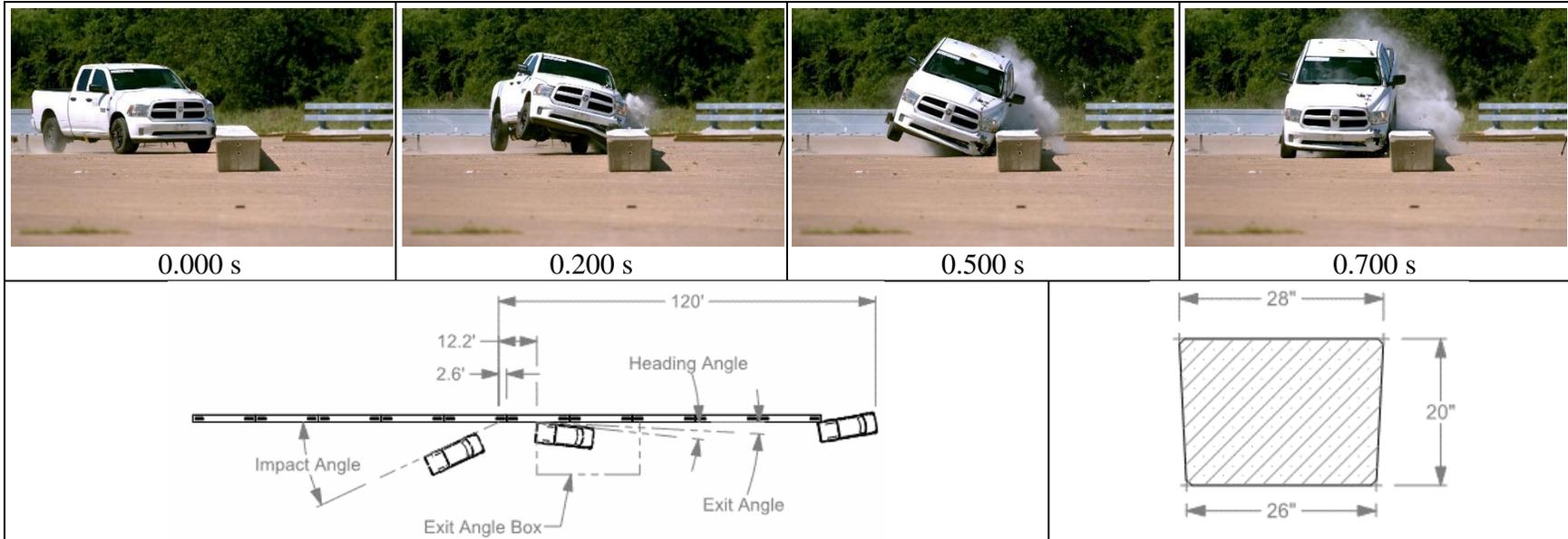
Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 4.3. Figure 4.8 summarizes these data and other pertinent information from the test. Figure C.3 in Appendix C.3.3 shows the vehicle angular displacements, and Figure C.4 through Figure C.6 in Appendix C.3.4 show acceleration versus time traces.

Table 4.3. Occupant Risk Factors for Test No. 469469-3-2.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV) Longitudinal Lateral	ft/s	at 0.1298 seconds on left side of interior
	15.1	
	16.1	
Occupant Ridedown Accelerations (g's) Longitudinal Lateral		
	2.6	(0.8807–0.8907 seconds)
	5.6	(0.3473–0.3573 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.1252 seconds on left side of interior
	6.7	
Acceleration Severity Index (ASI)	1.1	(0.0690–0.1190 seconds)
Maximum 50-ms Moving Average (g's) Longitudinal Lateral Vertical		
	-7.3	(0.0405–0.0905 seconds)
	7.9	(0.0446–0.0946 seconds)
	-2	(0.0301–0.0801 seconds)
Maximum Roll, Pitch, and Yaw Angles Roll Pitch Yaw	Degrees	
	22	(0.4391 seconds)
	10	(0.7849 seconds)
	31	(0.4870 seconds)

4.3.8 Assessment of Results

An assessment of the tests based on the applicable safety evaluation criteria for *MASH* Test 2-11 is provided in Table 4.4.



General Information		Impact Conditions		Post-Impact Trajectory	
Test Agency	Texas A&M Transportation Institute (TTI)	Speed	44.4 mi/h	Stopping Distance	120 ft downstrm; 2 ft twd field side
Test Standard Test No.	MASH Test 2-11	Angle	25.1°		
TTI Test No.	469469-3-2	Location/Orientation	2.9 ft upstream of the joint between segments 5 and 6	Vehicle Stability	
Test Date	2019-06-06			Maximum Yaw Angle.....	31°
Test Article		Impact Severity	59.4 kip-ft	Maximum Pitch Angle....	10°
Type.....	Longitudinal barrier—low profile	Exit Conditions		Maximum Roll Angle	22°
Name	TxDOT low-profile barrier	Speed	34.4 mi/h	Vehicle Snagging	No
Installation Length.....	200 ft	Exit Trajectory/Heading	10.6°/3.2°	Vehicle Pocketing.....	No
Material or Key Elements	Precast concrete barrier segments connected with two threaded rods	Occupant Risk Values		Test Article Deflections	
	Concrete deck, damp	Longitudinal OIV.....	15.1 ft/s	Dynamic.....	8.6 inches
Soil Type and Condition		Lateral OIV.....	16.1 ft/s	Permanent	8.5
Test Vehicle		Longitudinal Ridedown	2.6 g	Working Width.....	36.6 inches
Type/Designation	2270P	Lateral Ridedown	5.6 g	Working Width Height....	20 inches
Make and Model	2015 RAM 1500	THIV	6.7 m/s	Vehicle Damage	
Curb.....	4967 lb	ASI.....	1.1	VDS	10-LFQ-2
Test Inertial.....	5011 lb	Max. 0.050-s Average		CDC	10FLEW2
Dummy	No dummy	Longitudinal.....	-7.3 g	Max. Exterior Deformation	2 inches
Gross Static	5011 lb	Lateral.....	7.9 g	OCDI.....	LF0000000
		Vertical.....	-2 g	Max. Occupant Compartment Deformation	0 inches

Figure 4.8. Summary of Results for MASH Test 2-11 on the Low-Profile Barrier.

Table 4.4. Performance Evaluation Summary for MASH Test 2-11 on the Low-Profile Barrier.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-3-2

Test Date: 2019-06-06

MASH Test 2-11 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> A. <i>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.</i>	The TxDOT low-profile barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 8.6 inches.	Pass
<u>Occupant Risk</u> D. <i>Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i> <i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</i>	No detached elements, fragments, or other debris from the test article were present to penetrate or show potential for penetrating the occupant compartment or to present hazard to others in the area. No occupant compartment deformation or intrusion was observed.	Pass
F. <i>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 2270P vehicle remained upright during and after the collision event. Maximum roll was 22°, and maximum pitch was 10°.	Pass
H. <i>Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.</i>	Longitudinal OIV was 15.1 ft/s, and lateral OIV was 16.1 ft/s.	Pass
I. <i>Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.</i>	Maximum longitudinal 10-ms occupant ridedown acceleration was 2.6 g, and maximum lateral 10-ms occupant ridedown acceleration was 5.6 g.	Pass

4.4 MASH TEST 2-10 (TEST NO. 469469-3-1)

4.4.1 Test Designation and Actual Impact Conditions

MASH Test 2-10 involves a 1100C vehicle weighing 2420 lb \pm 55 lb impacting the CIP of the low-profile barrier at an impact speed of 44 mi/h \pm 2.5 mi/h and an angle of 25° \pm 1.5°. The CIP for *MASH* Test 2-10 on the low-profile barrier was 3.3 ft upstream of the joint between segments 5 and 6.

The 2009 Kia Rio³ used in the test weighed 2440 lb, and the actual impact speed and angle were 44.0 mi/h and 25.1°, respectively. The actual impact point was 3.6 ft upstream of the joint between segments 5 and 6. Minimum target impact severity was 25 kip-ft, and actual IS was 29 kip-ft.

4.4.2 Weather Conditions

The test was performed on the morning of June 14, 2019. Weather conditions at the time of testing were as follows: wind speed: 11 mi/h; wind direction: 187° with respect to the vehicle (vehicle was traveling at a magnetic heading of 0°); temperature: 84°F; relative humidity: 73 percent.

4.4.3 Test Vehicle

Figure 4.9 and Figure 4.10 show the 2009 Kia Rio that was used for the crash test. The vehicle's test inertia weight was 2440 lb, and its gross static weight was 2605 lb. The height to the lower edge of the vehicle bumper was 7.8 inches, and height to the upper edge of the bumper was 21.5 inches. Table C.5 in Appendix C.4.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

³ The 2009 model vehicle used is older than the 6-year age noted in *MASH* and was selected based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2009 model vehicle met the *MASH* requirements.



Figure 4.9. Low-Profile Barrier/Test Vehicle Geometrics for Test No. 469469-3-1.



Figure 4.10. Test Vehicle before Test No. 469469-3-1.

4.4.4 Test Description

Table 4.5 lists events that occurred during Test No. 469469-3-1. Figure C.7 and Figure C.8 in Appendix C.4.2 present sequential photographs during the test.

Table 4.5. Events during Test No. 469469-3-1.

Time	Events
0.000	Vehicle contacts barrier
0.051	Vehicle begins to redirect
0.231	Vehicle is parallel with barrier
0.253	Left rear bumper makes contact with barrier
0.263	Maximum dynamic barrier deflection of 4.9 inches
0.455	Vehicle exits barrier at 30.6 mi/h at a trajectory angle of 9.4° and a heading angle of 7.2°

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for cars and pickups). The 1100C vehicle exited within the exit box criteria defined in *MASH*. After loss of contact

with the barrier, the vehicle yawed counterclockwise and came to rest 128 ft downstream of the point of impact and 13 ft on the traffic side of the barrier. Brakes were not applied.

4.4.5 Damage to Test Installation

Figure 4.11 shows the damage to the low-profile barrier. There was concrete spalling, approximately 1½ inches wide and 16 inches long, and cracks on the traffic face upstream end top edge of barrier 6. Table 4.6 shows the permanent field side displacement measured at the joints between segments.

Table 4.6. Measured Displacement of Barrier, Test No. 469469-3-1.

Location	Displacement (Inches)
Joint 4-5	2
Joint 5-6	4.3
Joint 6-7	1

Working width⁴ was 32.9 inches, and the height of maximum working width was 20 inches. Maximum dynamic deflection during the test was 4.9 inches, and maximum permanent deflection was 4.3 inches.

⁴ Working width is defined as the distance between the traffic face of the barrier before impact and the maximum lateral position of any major part of the barrier or the vehicle after impact.

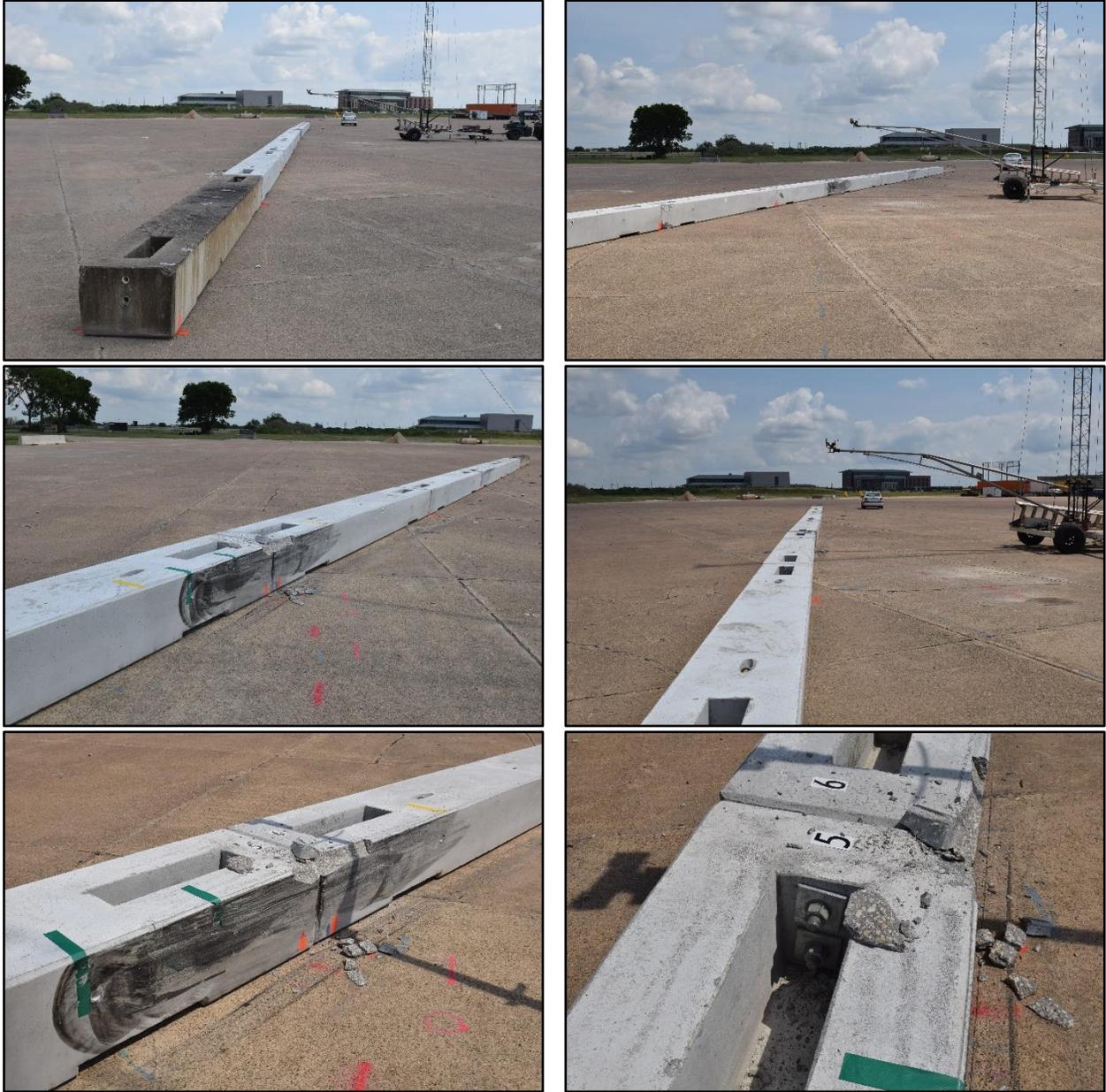


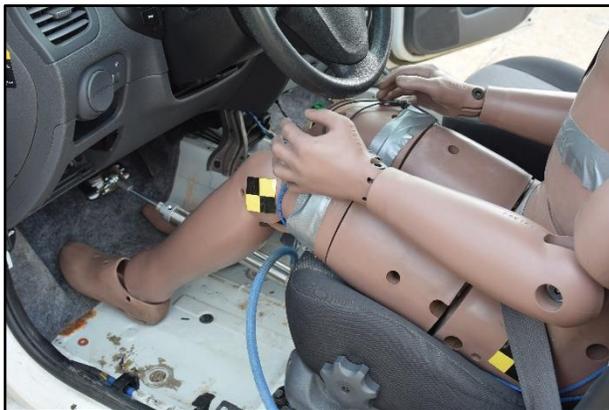
Figure 4.11. Low-Profile Barrier after Test No. 469469-3-1.

4.4.6 Damage to Test Vehicle

Figure 4.12 and Figure 4.13 show the damage sustained by the vehicle. The front bumper, left front tire and rim, left rear door, left front fender, rear bumper, and left rear fender were damaged. Maximum exterior crush to the vehicle was 6 inches in the side plane at the left front corner at bumper height. There was no observed occupant compartment deformation. Table C.6 and Table C.7 in Appendix C.4.1 provide exterior crush and occupant compartment measurements.



Figure 4.12. Test Vehicle after Test No. 469469-3-1.



**Figure 4.13. Interior of Test Vehicle for Test No. 469469-3-1
(before Test on Left; after Test on Right).**

4.4.7 Occupant Risk Factors

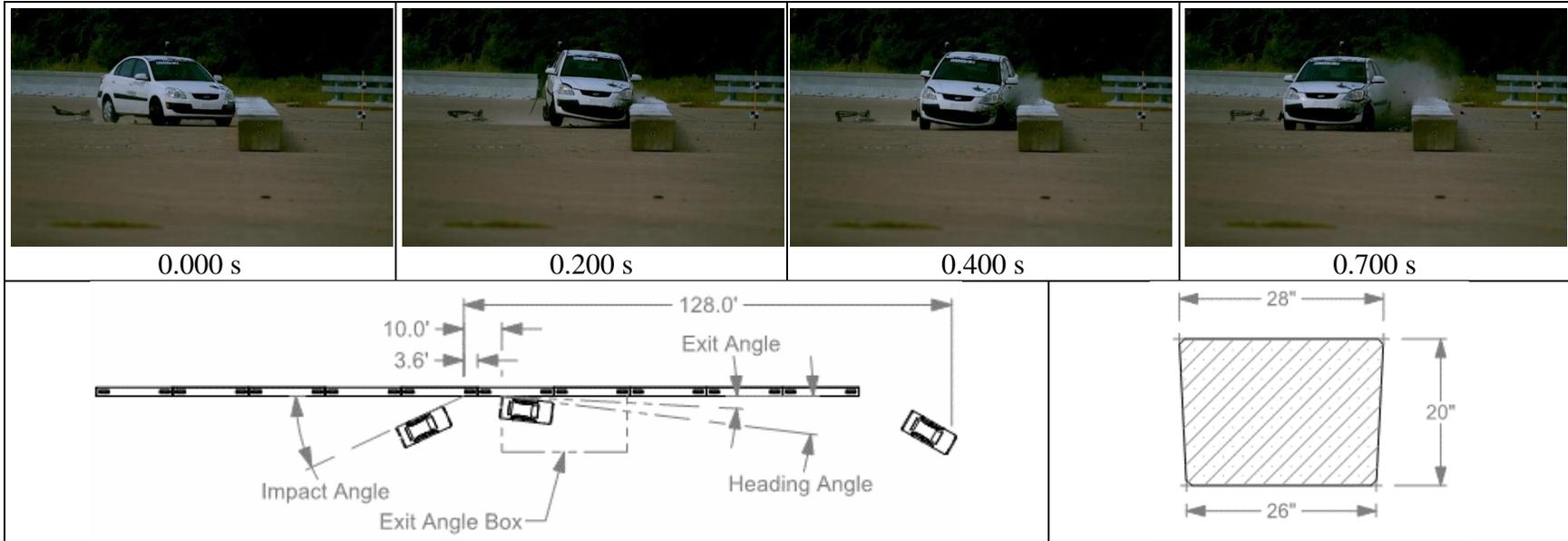
Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 4.7. Figure 4.14 summarizes these data and other pertinent information from the test. Figure C.9 in Appendix C.4.3 shows the vehicle angular displacements, and Figure C.10 through Figure C.12 in Appendix C.4.4 show acceleration versus time traces.

Table 4.7. Occupant Risk Factors for Test No. 469469-3-1.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV) Longitudinal Lateral	ft/s	at 0.0993 seconds on left side of interior
	14.4	
	17.4	
Occupant Ridedown Accelerations (g's) Longitudinal Lateral		
	2.9	(0.1044–0.1144 seconds)
	7.9	(0.2652–0.2752 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.0958 seconds on left side of interior
	6.8	
Acceleration Severity Index (ASI)	1.4	(0.0433–0.0933 seconds)
Maximum 50-ms Moving Average (g's) Longitudinal Lateral Vertical		
	-6.9	(0.0239–0.0739 seconds)
	10.3	(0.0136–0.0636 seconds)
	-1.9	(0.0447–0.0947 seconds)
Maximum Roll, Pitch, and Yaw Angles Roll Pitch Yaw	Degrees	
	6	(1.9864 seconds)
	3	(0.3690 seconds)
	32	(0.8730 seconds)

4.4.8 Assessment of Results

An assessment of the tests based on the applicable safety evaluation criteria for *MASH* Test 2-10 is provided in Table 4.8.



<p>General Information</p> <p>Test Agency Texas A&M Transportation Institute (TTI)</p> <p>Test Standard Test No. <i>MASH</i> Test 2-10</p> <p>TTI Test No. 469469-3-1</p> <p>Test Date 2019-06-14</p> <p>Test Article</p> <p>Type..... Longitudinal barrier—low profile</p> <p>Name TxDOT low-profile barrier</p> <p>Installation Length..... 200 ft</p> <p>Material or Key Elements Precast concrete barrier segments connected with two threaded rods</p> <p>Concrete deck, damp</p> <p>Soil Type and Condition</p> <p>Test Vehicle</p> <p>Type/Designation 1100C</p> <p>Make and Model 2009 Kia Rio</p> <p>Curb..... 2451 lb</p> <p>Test Inertial 2440 lb</p> <p>Dummy 165 lb</p> <p>Gross Static 2605 lb</p>	<p>Impact Conditions</p> <p>Speed 44 mi/h</p> <p>Angle 25.1°</p> <p>Location/Orientation 3.6 ft upstream of the joint between segments 5 and 6</p> <p>Impact Severity..... 29 kip*ft</p> <p>Exit Conditions</p> <p>Speed 30.6 mi/h</p> <p>Exit Trajectory/Heading 9.4°/7.2°</p> <p>Occupant Risk Values</p> <p>Longitudinal OIV..... 14.4 ft/s</p> <p>Lateral OIV..... 17.4 ft/s</p> <p>Longitudinal Ridedown 2.9 g</p> <p>Lateral Ridedown 7.9 g</p> <p>THIV 6.8 m/s</p> <p>ASI 1.4</p> <p>Max. 0.050-s Average</p> <p>Longitudinal..... -6.9 g</p> <p>Lateral..... 10.3 g</p> <p>Vertical..... -1.9 g</p>	<p>Post-Impact Trajectory</p> <p>Stopping Distance 128 ft downstrm; 13 ft twd traffic</p> <p>Vehicle Stability</p> <p>Maximum Yaw Angle..... 32°</p> <p>Maximum Pitch Angle.... 3°</p> <p>Maximum Roll Angle 6°</p> <p>Vehicle Snagging No</p> <p>Vehicle Pocketing..... No</p> <p>Test Article Deflections</p> <p>Dynamic..... 4.9 inches</p> <p>Permanent 4.3 inches</p> <p>Working Width..... 32.9 inches</p> <p>Working Width Height.... 20 inches</p> <p>Vehicle Damage</p> <p>VDS 10-LFQ-2</p> <p>CDC 10FLEW2</p> <p>Max. Exterior Deformation 6 inches</p> <p>OCDI..... LF0000000</p> <p>Max. Occupant Compartment Deformation 0 inches</p>
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Figure 4.14. Summary of Results for *MASH* Test 2-10 on the Low-Profile Barrier.

Table 4.8. Performance Evaluation Summary for MASH Test 2-10 on the Low-Profile Barrier.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-3-1

Test Date: 2019-06-14

MASH Test 2-10 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> A. <i>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.</i>	The TxDOT low-profile barrier contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 4.9 inches.	Pass
<u>Occupant Risk</u> D. <i>Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i> <i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</i>	No detached elements, fragments, or other debris from the test article were present to penetrate or show potential for penetrating the occupant compartment or to present hazard to others in the area. No occupant compartment deformation or intrusion was observed.	Pass
F. <i>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 1100C vehicle remained upright during and after the collision event. Maximum roll was 6°, and maximum pitch was 3°.	Pass
H. <i>Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.</i>	Longitudinal OIV was 14.4 ft/s, and lateral OIV was 17.4 ft/s.	Pass
I. <i>Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.</i>	Maximum longitudinal 10-ms occupant ridedown acceleration was 2.9 g, and maximum lateral 10-ms occupant ridedown acceleration was 7.9 g.	Pass

4.5 CONCLUSIONS

The TxDOT low-profile barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underide, or override the installation. Maximum dynamic deflection during the test was 8.6 inches, and maximum permanent deformation was 8.5 inches. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. There was no observed occupant compartment deformation. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 22° and 10°, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The 2270P vehicle exited within the exit box criteria.

The TxDOT low-profile barrier contained and redirected the 1100C vehicle. The vehicle did not penetrate, underide, or override the installation. Maximum dynamic deflection during the test was 4.9 inches, and maximum permanent deformation was 4.3 inches. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. There was no observed occupant compartment deformation. The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 6° and 3°, respectively. Occupant risk factors were within the allowable limits specified in *MASH*. The 1100C vehicle exited within the exit box criteria.

The TxDOT low-profile barrier performed acceptably according to *MASH* TL-2 evaluation criteria as shown in Table 4.9.

Table 4.9. Assessment Summary for *MASH* TL-2 Tests on TxDOT Low-Profile Barrier.

Evaluation Factors	Evaluation Criteria	Test No. 469469-3-2	Test No. 469469-3-1
Structural Adequacy	A	S	S
Occupant Risk	D	S	S
	F	S	S
	H	S	S
	I	S	S
	Test No.	<i>MASH</i> Test 2-11	<i>MASH</i> Test 2-10
	Pass/Fail	Pass	Pass

S = Satisfactory

U = Unsatisfactory

N/A = Not applicable

CHAPTER 5: TXDOT LOW-PROFILE-TO-F-SHAPE TRANSITION

5.1 BACKGROUND

This transition barrier segment is used to connect the 20-inch-tall low-profile barrier (LPCB-13) to the 32-inch-tall F-shape portable concrete barrier (CSB[1]-10). The low-profile barrier is a TL-2 system intended for use on lower-speed roadways, whereas the F-shape barrier is a TL-3 system suitable for use on high-speed roadways.

The transition is used when a segment of highway is transitioning from a low-speed to a high-speed section. Since the transition barrier segment is attached to the low-profile barrier on one end, it was considered appropriate to test and evaluate the transition segment using the same test level used for the low-profile barrier. This is analogous to testing a guardrail-to-bridge-rail transition to the same level as the approach guardrail, as opposed to the higher level of the bridge rail. Once the transition to a standard barrier height has been made, the roadway speed limits can be adjusted to those that are consistent with the taller TL-3 F-shape barrier.

Previous research under which the low-profile-to-F-shape transition was developed and tested was reviewed to help determine recommended tests for establishing *MASH* compliance and the critical impact points for those tests (3). Travel from both directions (i.e., F-shape to low profile and low profile to F-shape) was considered. The previous testing under National Cooperative Highway Research Program (NCHRP) Report 350 demonstrated that the pickup truck was much more stable traveling from the F-shape barrier to the low-profile barrier than in the opposite direction (3). Additionally, previous impact simulations with the 820C passenger car under NCHRP Report 350 impact conditions showed that the small car was very stable when impacting from both directions of the transition section, but traveling from the F-shape barrier toward the low-profile barrier was more critical.

It was determined that two tests should be performed to verify the impact performance of the low-profile-to-F-shape transition under *MASH* criteria. Test 2-20 with the small passenger car was performed with the vehicle traveling from the F-shape barrier toward the low-profile barrier. Although previous simulations indicated stable performance, the impact angle for Test 2-20 increased from 20° under NCHRP Report 350 to 25° under *MASH*. Therefore, since the increase in impact angle could aggravate vehicle stability, Test 2-20 was performed in the critical direction of travel. Test 2-21 with the pickup truck was performed with the vehicle traveling from the low-profile barrier toward the F-shape barrier. This was the critical direction of travel based on the previous crash testing.

5.2 SYSTEM DETAILS

5.2.1 Test Article and Installation Details

Low-profile-to-F-shape transition installation consisted of five 20-ft-long low-profile barriers, one 10-ft-long transition section, and three 30-ft-long F-shape precast reinforced concrete barrier segments set end to end. The barriers were placed freestanding (not attached or anchored) on a concrete surface.

The low-profile barrier segments were 20 inches tall, 28 inches wide at the top, and 26 inches wide at the bottom. They were connected to each other and to the transition section using two 1¼-inch-diameter steel rods with a plate washer, flat washer, and nut on each end. These steel rods were inserted into a trough and passed through holes cast into the ends of the low-profile barrier and transition sections.

The F-shape barrier segments were 32 inches tall, 9½ inches wide at the top, and 24 inches wide at the bottom. The F-shape barrier segment placed adjacent to the transition section was connected to the transition section using a cross-bolt connection consisting of two 7/8-inch-diameter rods with a plate washer, flat washer, and nut on each end. The rods passed through holes cast in the ends of the barrier segments at two different elevations forming an X in plan view and terminated in recesses cast into the sides of the barriers. This F-shape barrier section had a bent plate connection on the other end opposite the transition section. The portion of the plate that protruded from the end of the barrier had a J-shape that interlocked with a corresponding J-shaped bent plate on the adjacent F-shape barrier. The other two F-shape barriers had the J-shaped bent plate connection on each end.

The transition barrier segment transitioned from a 20-inch-tall low-profile barrier section on one end to a 32-inch-tall F-shape profile on the other end. The height and shape transitioned to the F-shape profile over a distance of 7.5 ft. The last 2.5 ft of the transition section had an F-shape profile to accommodate the cross-bolt connection to the adjacent F-shape barrier segment. The transition section had two 3-inch-tall by 24-inch-long drainage scuppers cast into the bottom 2 ft from each end.

Figure 5.1 presents overall information on the low-profile-to-F-shape transition, and Figure 5.2 provides photographs of the installation. Appendix D.1 provides further details of the low-profile-to-F-shape transition.

5.2.2 Material Specifications

The minimum compressive strength of the TxDOT Class C concrete specified for the transition section was 3600 psi. The transition barrier segment was cast on June 28, 2019. The average compressive strength of the single batch of concrete used in the transition measured 6213 psi on July 29, 2019 (at 31 days). An existing low-profile barrier segment was cored on August 2, 2019, and its compressive strength measured 8170 psi.

Reinforcement of the transition barrier segment was comprised of Grade 60 rebar with a specified minimum yield strength of 60 ksi.

Appendix D.2 provides material certification documents and information on the concrete used to install/construct a low-profile-to-F-shape transition.

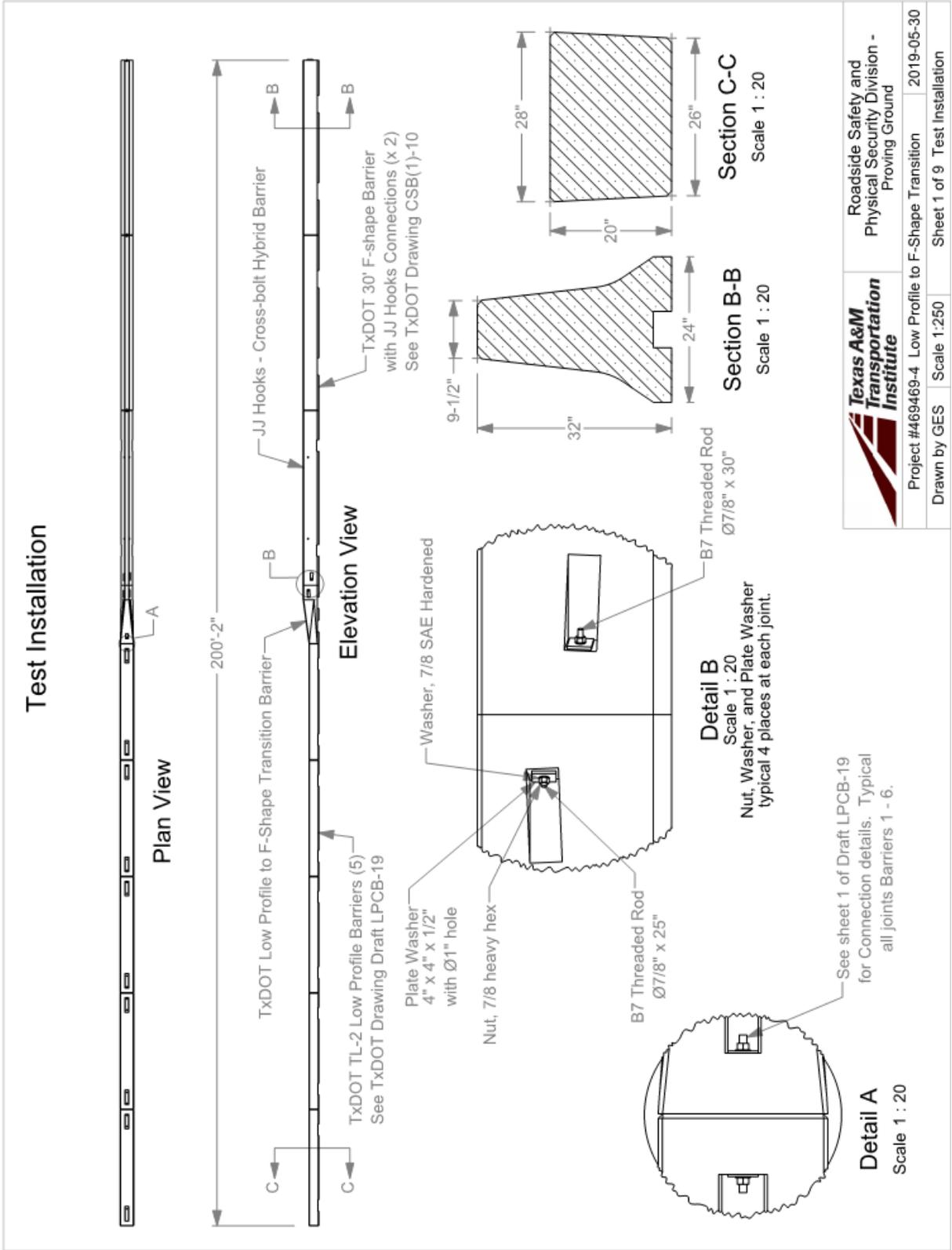


Figure 5.1. Overall Details of Low-Profile-to-F-Shape Transition.



Figure 5.2. Low-Profile-to-F-Shape Transition prior to Testing.

5.3 MASH TEST 2-20 (TEST NO. 469469-4-1)

5.3.1 Test Designation and Actual Impact Conditions

MASH Test 2-20 involves a 1100C vehicle weighing 2420 lb \pm 55 lb impacting the CIP of a low-profile-to-F-shape transition at an impact speed of 44 mi/h \pm 2.5 mi/h and an angle of 25° \pm 1.5°. The CIP for *MASH* Test 2-20 on a low-profile-to-F-shape transition was 30 inches downstream of joint 3-4 (between the transition and F-shape barriers) as determined through previous finite element impact simulations (3).

The 2008 Kia Rio⁵ used in the test weighed 2420 lb, and the actual impact speed and angle were 45.3 mi/h and 24.6°, respectively. The actual impact point was 27.9 inches

⁵ The 2008 model vehicle used is older than the 6-year age noted in *MASH* and was selected based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2008 model vehicle met the *MASH* requirements.

downstream of joint 3-4. Minimum target impact severity was 25 kip-ft, and actual IS was 28.8 kip-ft.

5.3.2 Weather Conditions

The test was performed on the morning of July 29, 2019. Weather conditions at the time of testing were as follows: wind speed: 10 mi/h; wind direction: 18° with respect to the vehicle (vehicle was traveling at a magnetic heading of 205°); temperature: 88°F; relative humidity: 70 percent.

5.3.3 Test Vehicle

The 2008 Kia Rio shown in Figure 5.3 and Figure 5.4 was used for the crash test. The vehicle's test inertia weight was 2420 lb, and its gross static weight was 2585 lb. The height to the lower edge of the vehicle bumper was 7.75 inches, and height to the upper edge of the bumper was 21.5 inches. Table D.1 in Appendix D.3.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 5.3. Low-Profile-to-F-Shape Transition/Test Vehicle Geometrics for Test No. 469469-4-1.

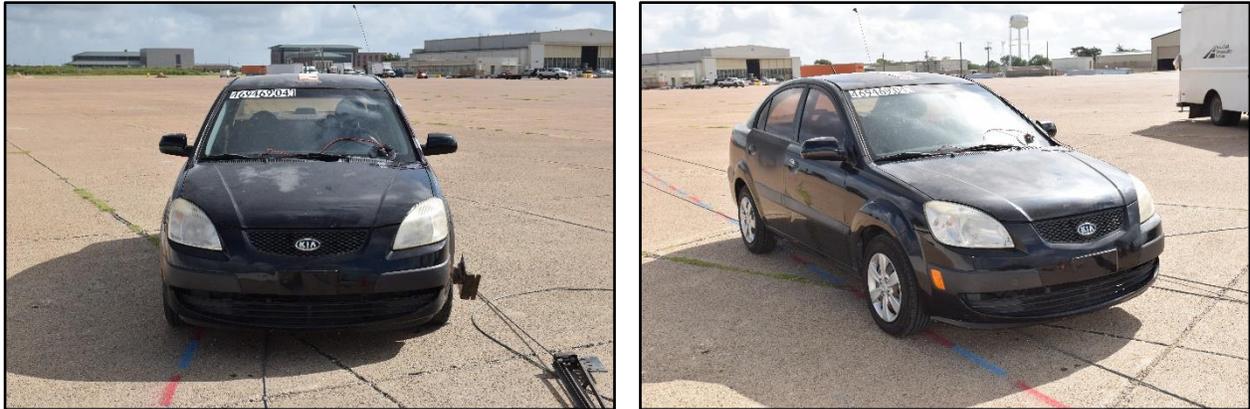


Figure 5.4. Test Vehicle before Test No. 469469-4-1.

5.3.4 Test Description

Table 5.1 lists events that occurred during Test No. 469469-4-1. Figure D.1 and Figure D.2 in Appendix D.3.2 present sequential photographs during the test.

Table 5.1. Events during Test No. 469469-4-1.

Time	Events
0.000	Vehicle contacts barrier
0.022	Vehicle begins to redirect
0.024	Transition barrier begins to displace toward field side
0.039	Transition barrier No. 4 begins to displace toward field side
0.062	Low-profile barrier No. 5 begins to displace toward field side
0.127	Front left tire leaves pavement
0.174	Vehicle is parallel with barrier
0.237	Right rear corner of vehicle impacts transition barrier
0.263	Rear left tire leaves pavement
0.383	Vehicle loses contact with barrier. Vehicle exits barrier at 37.1 mi/h at a trajectory angle of 9.8° and a heading angle of 15.3° from the barrier.
0.385	Right front tire makes contact with pavement
0.532	Left front tire makes contact with pavement

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for cars and pickups). The 1100C vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle yawed counterclockwise and came to rest 150 ft downstream of the point of impact and 75 ft behind the traffic side of the barrier facing approximately 45° to the left of downstream. Brakes were applied 3.1 second after impact.

5.3.5 Damage to Test Installation

Figure 5.5 shows the damage to the low-profile-to-F-shape transition system. The barriers were pushed toward the field side 8 inches at the joint between barriers 3 and 4, 6 inches at the joint between barriers 4 and 5, and 2 inches at the joint between barriers 5 and 6. There was an area of concrete damage 18 inches up from the bottom and 48 inches long on the traffic-side downstream end of barrier 3.

Working width⁶ was 36 inches, and the height of maximum working width was 0 inches (toe of the barrier). Maximum dynamic deflection during the test was 8 inches, and maximum permanent deflection was 8 inches.

⁶ Working width is defined as the distance between the traffic face of the barrier before impact and the maximum lateral position of any major part of the barrier or the vehicle after impact.

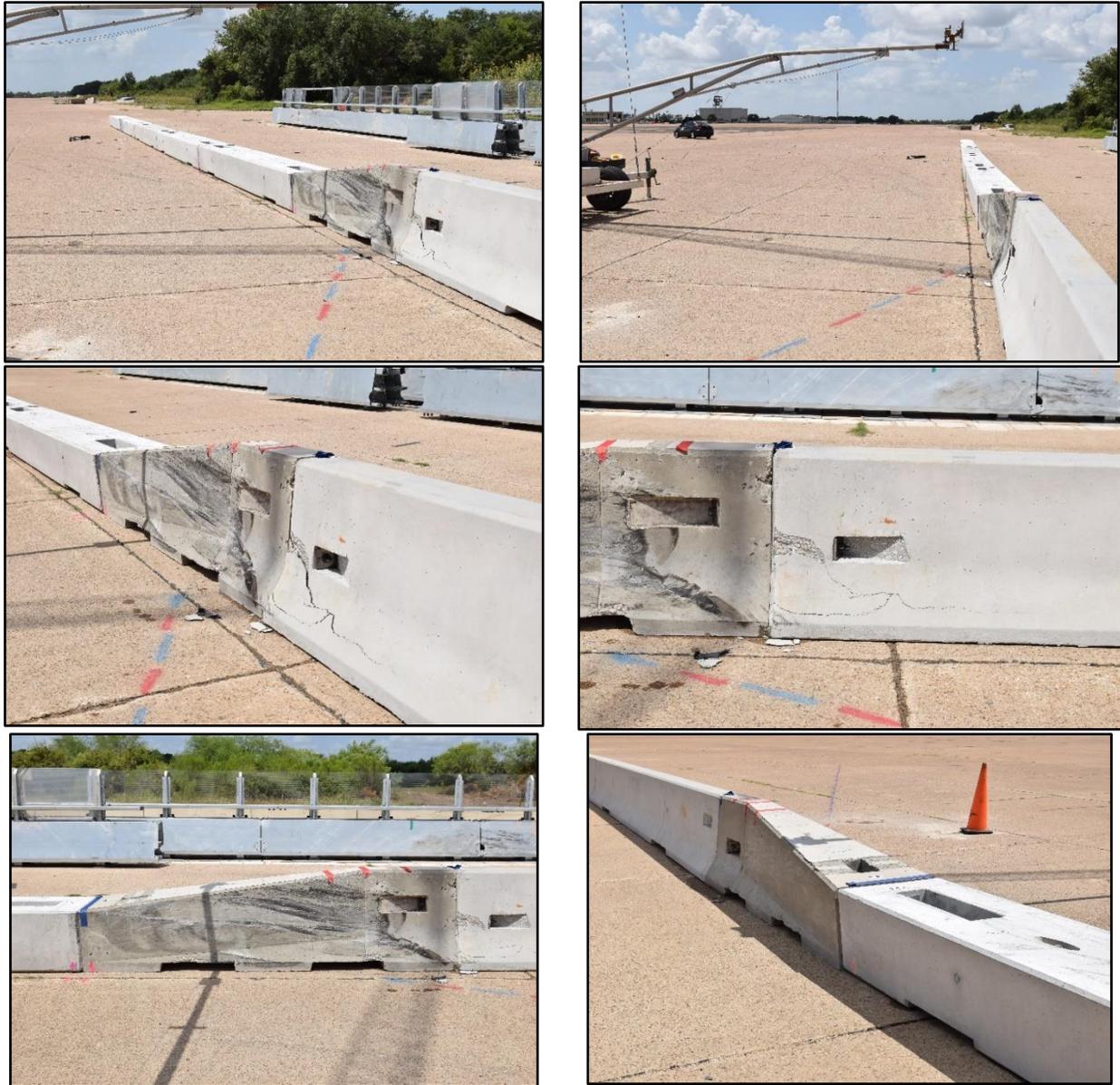


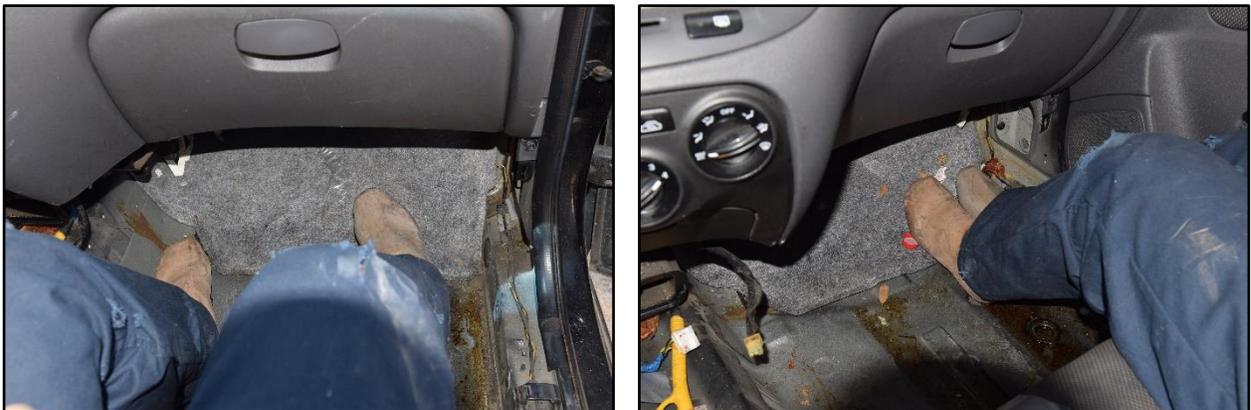
Figure 5.5. Low-Profile-to-F-Shape Transition after Test No. 469469-4-1.

5.3.6 Damage to Test Vehicle

Figure 5.6 and Figure 5.7 show the damage sustained by the vehicle. The front bumper, right front fender, right front tire and rim, right strut tower, right rear door, right head light, hood, right rear fender, right rear tire and rim, and rear bumper were damaged. Maximum exterior crush to the vehicle was 7 inches in the side plane at the right front corner at bumper height. There was no measurable occupant compartment deformation. Table D.2 and Table D.3 in Appendix D.3.1 provide exterior crush and occupant compartment measurements.



Figure 5.6. Test Vehicle after Test No. 469469-4-1.



**Figure 5.7. Interior of Test Vehicle for Test No. 469469-4-1
(before Test on Left; after Test on Right).**

5.3.7 Occupant Risk Factors

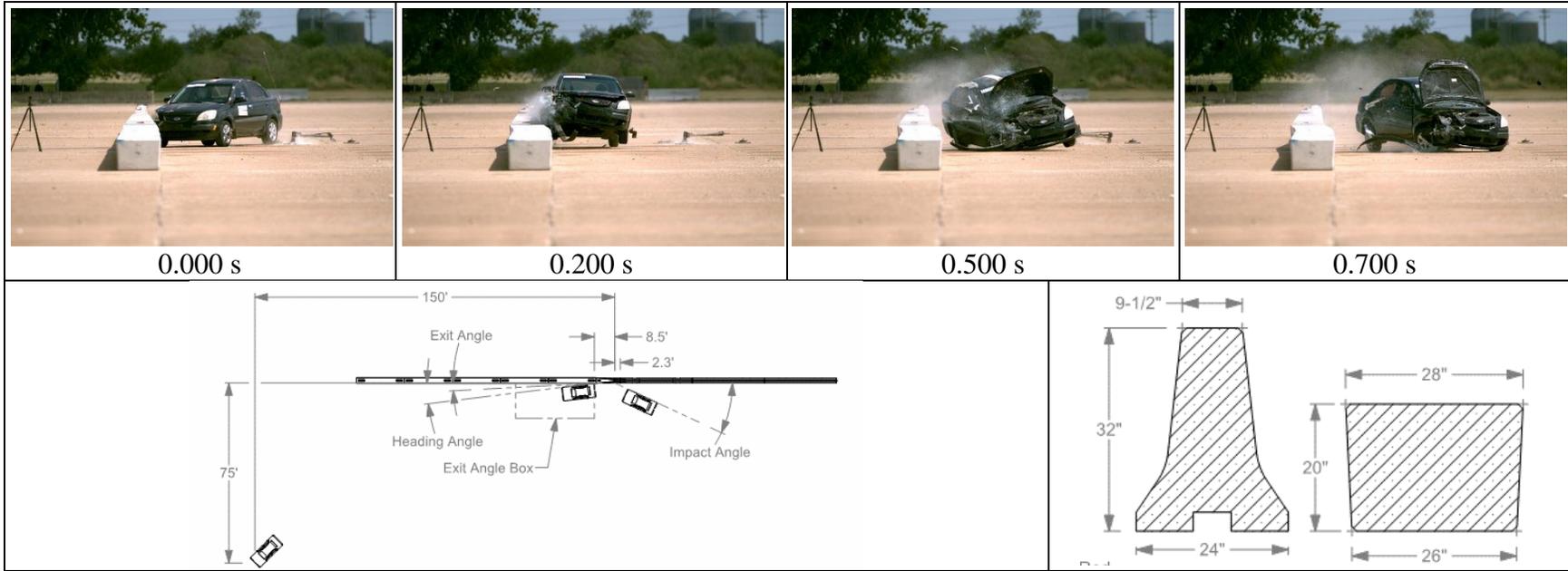
Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 5.2. Figure 5.8 summarizes these data and other pertinent information from the test. Figure D.3 in Appendix D.3.3 shows the vehicle angular displacements, and Figure D.4 through Figure D.6 in Appendix D.3.4 show acceleration versus time traces.

Table 5.2. Occupant Risk Factors for Test No. 469469-4-1.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV) Longitudinal Lateral	ft/s	at 0.0882 seconds on right side of interior
	15.4	
	23.6	
Occupant Ridedown Accelerations (g's) Longitudinal Lateral	ft/s²	
	2.1	(0.2382–0.2482 seconds)
	7.8	(0.2308–0.2408 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.0855 seconds on right side of interior
	8.6	
Acceleration Severity Index (ASI)	1.7	(0.0477–0.0977 seconds)
Maximum 50-ms Moving Average (g's) Longitudinal Lateral Vertical	ft/s²	
	-7.1	(0.0319–0.0819 seconds)
	-12.8	(0.0303–0.0803 seconds)
	-2.5	(0.0182–0.0682 seconds)
Maximum Roll, Pitch, and Yaw Angles Roll Pitch Yaw	Degrees	
	17	(0.4889 seconds)
	8	(1.1183 seconds)
	59	(2.0000 seconds)

5.3.8 Assessment of Results

An assessment of the tests based on the applicable safety evaluation criteria for *MASH* Test 2-20 is provided in Table 5.3.



General Information		Impact Conditions		Post-Impact Trajectory	
Test Agency	Texas A&M Transportation Institute (TTI)	Speed	45.3 mi/h	Stopping Distance	150 ft downstream; 75 ft toward traffic side
Test Standard Test No.	MASH Test 2-20	Angle	24.6°		
TTI Test No.	469469-4-1	Location/Orientation	27.9 inches downstream		
Test Date	2019-07-29		of joint 3-4		
Test Article		Impact Severity	28.8 kip-ft	Vehicle Stability	
Type	Longitudinal barrier—transition	Exit Conditions		Maximum Yaw Angle.....	59°
Name	TxDOT low-profile-to-F-shape transition	Speed	37.1 mi/h	Maximum Pitch Angle....	8°
Installation Length.....	200 ft 2 inches	Exit Trajectory/Heading	9.8°/15.3°	Maximum Roll Angle	17°
Material or Key Elements	10 ft concrete shape transition section between 5 low-profile barrier segments and 3 F-shape barrier segments	Occupant Risk Values		Vehicle Snagging	No
	Concrete deck, damp	Longitudinal OIV.....	15.4 ft/s	Vehicle Pocketing.....	No
Soil Type and Condition		Lateral OIV.....	23.6 ft/s	Test Article Deflections	
Test Vehicle		Longitudinal Ridedown	2.1 g	Dynamic	8 inches
Type/Designation	1100C	Lateral Ridedown	7.8 g	Permanent	8 inches
Make and Model	2008 Kia Rio	THIV	8.6 m/s	Working Width.....	36 inches
Curb.....	2461 lb	PHD	7.9 g	Working Width Height....	0 inches
Test Inertial	2420 lb	ASI	1.7	Vehicle Damage	
Dummy	165 lb, on impact side	Max. 0.050-s Average		VDS	10-RFQ-2
Gross Static	2585 lb	Longitudinal.....	-7.1 g	CDC	10RLEW2
		Lateral.....	-12.8 g	Max. Exterior Deformation	7 inches
		Vertical.....	-2.5 g	OCDI.....	LF0000000
				Max. Occupant Compartment Deformation	0 inches

Figure 5.8. Summary of Results for MASH Test 2-20 on Low-Profile-to-F-Shape Transition.

Table 5.3. Performance Evaluation Summary for MASH Test 2-20 on Low-Profile-to-F-Shape Transition.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-04-1

Test Date: 2019-07-29

MASH Test 2-10 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> A. <i>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.</i>	The TxDOT low-profile-to-F-shape transition contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 8 inches.	Pass
<u>Occupant Risk</u> D. <i>Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i> <i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</i>	No detached elements, fragments, or other debris from the test article were present to penetrate or show potential for penetrating the occupant compartment or to present hazard to others in the area. No occupant compartment deformation or intrusion was observed.	Pass
F. <i>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 1100C vehicle remained upright during and after the collision event. Maximum roll was 17°, and maximum pitch was 8°.	Pass
H. <i>Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.</i>	Longitudinal OIV was 15.4 ft/s, and lateral OIV was 23.6 ft/s.	Pass
I. <i>Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.</i>	Maximum longitudinal 10-ms occupant ridedown acceleration was 2.1 g, and maximum lateral 10-ms occupant ridedown acceleration was 7.8 g.	Pass
<u>Vehicle Trajectory</u> For redirective devices, it is preferable that the vehicle be smoothly redirected and leave the barrier within the “exit box” criteria (not less than 32.8 ft for the 1100C and 2270P vehicles), and should be documented.	The 1100C vehicle exited within the exit box criteria.	Documentation only

5.4 MASH TEST 2-21 (TEST NO. 469469-4-2)

5.4.1 Test Designation and Actual Impact Conditions

MASH Test 2-21 involves a 2270P vehicle weighing 5000 lb \pm 110 lb impacting the CIP of a low-profile-to-F-shape transition at an impact speed of 44 mi/h \pm 2.5 mi/h and an angle of 25° \pm 1.5°. The CIP for *MASH* Test 2-11 on the low-profile-to-F-shape transition was at the joint between segments 5 and 6 (between the low-profile barriers and the transition) as determined by previous finite element impact simulations (3).

The 2015 RAM 1500 used in the test weighed 5030 lb, and the actual impact speed and angle were 44.3 mi/h and 24.4°, respectively. The actual impact point was at the joint between segments 5 and 6. Minimum target impact severity was 52 kip-ft, and actual IS was 56.3 kip-ft.

5.4.2 Weather Conditions

The test was performed on the morning of August 1, 2019. Weather conditions at the time of testing were as follows: wind speed: 1 mi/h; wind direction: 155° with respect to the vehicle (vehicle was traveling at a magnetic heading of 335°); temperature: 89°F; relative humidity: 68 percent.

5.4.3 Test Vehicle

The 2015 RAM 1500 shown in Figure 5.9 and Figure 5.10 was used for the crash test. The vehicle's test inertia weight was 5030 lb, and its gross static weight was 5030 lb. The height to the lower edge of the vehicle bumper was 11.8 inches, and height to the upper edge of the bumper was 27 inches. The height to the vehicle's center of gravity was 28.9 inches. Table D.4 and Table D.5 in Appendix D.4.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 5.9. Low-Profile-to-F-Shape Transition/Test Vehicle Geometrics for Test No. 469469-4-2.



Figure 5.10. Test Vehicle before Test No. 469469-4-2.

5.4.4 Test Description

The 2015 RAM 1500, traveling at an impact speed of 56 mi/h, contacted the low-profile-to-F-shape transition at an impact angle of 24.4°. Table 5.4 lists events that occurred during Test No. 469469-4-2. Figure D.7 and Figure D.8 in Appendix D.4.2 present sequential photographs during the test.

Table 5.4. Events during Test No. 469469-4-2.

Time	Events
0.000	Vehicle contacts barrier
0.048	Vehicle begins to redirect
0.342	Vehicle is parallel with barrier
0.052	Transition and low-profile barrier begins to displace toward field side
0.075	F-shape barrier No. 7 begins to displace toward field side
0.101	Right front tire lifts off pavement
0.346	Left rear bumper impacts transition barrier
0.376	Right rear tire lifts off pavement
0.549	Vehicle loses contact with barrier. Vehicle exits at a speed of 35.5 mi/h, with a trajectory angle of 6.4° and a heading angle of 0.4° toward the barrier.
0.680	Right front tire makes contact with pavement
0.883	Right rear tire makes contact with pavement

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for cars and pickups). The 2270P vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle yawed counterclockwise and came to rest 150 ft downstream of the point of impact and 27 ft on the field side of the barrier. Brakes were applied 4.2 s after impact.

5.4.5 Damage to Test Installation

Figure 5.11 shows the damage to the low-profile-to-F-shape transition system. The barriers were pushed toward the field side 1 inch at the joint between barriers 4 and 5, 9 inches at the joint between barriers 5 and 6, and 14 inches at the joint between barriers 6 and 7. There was concrete damage to the upstream traffic faces of barriers 6 and 7, and the concrete face was spalled on the upstream end of the field side of barrier 5. Working width⁷ was 38.5 inches, and the height of maximum working width was 0 inches (at the toe of the barrier). Maximum dynamic deflection during the test was 14.5 inches, and the maximum permanent deflection was 14.0 inches.

⁷ Working width is defined as the distance between the traffic face of the barrier before impact and the maximum lateral position of any major part of the barrier or the vehicle after impact.

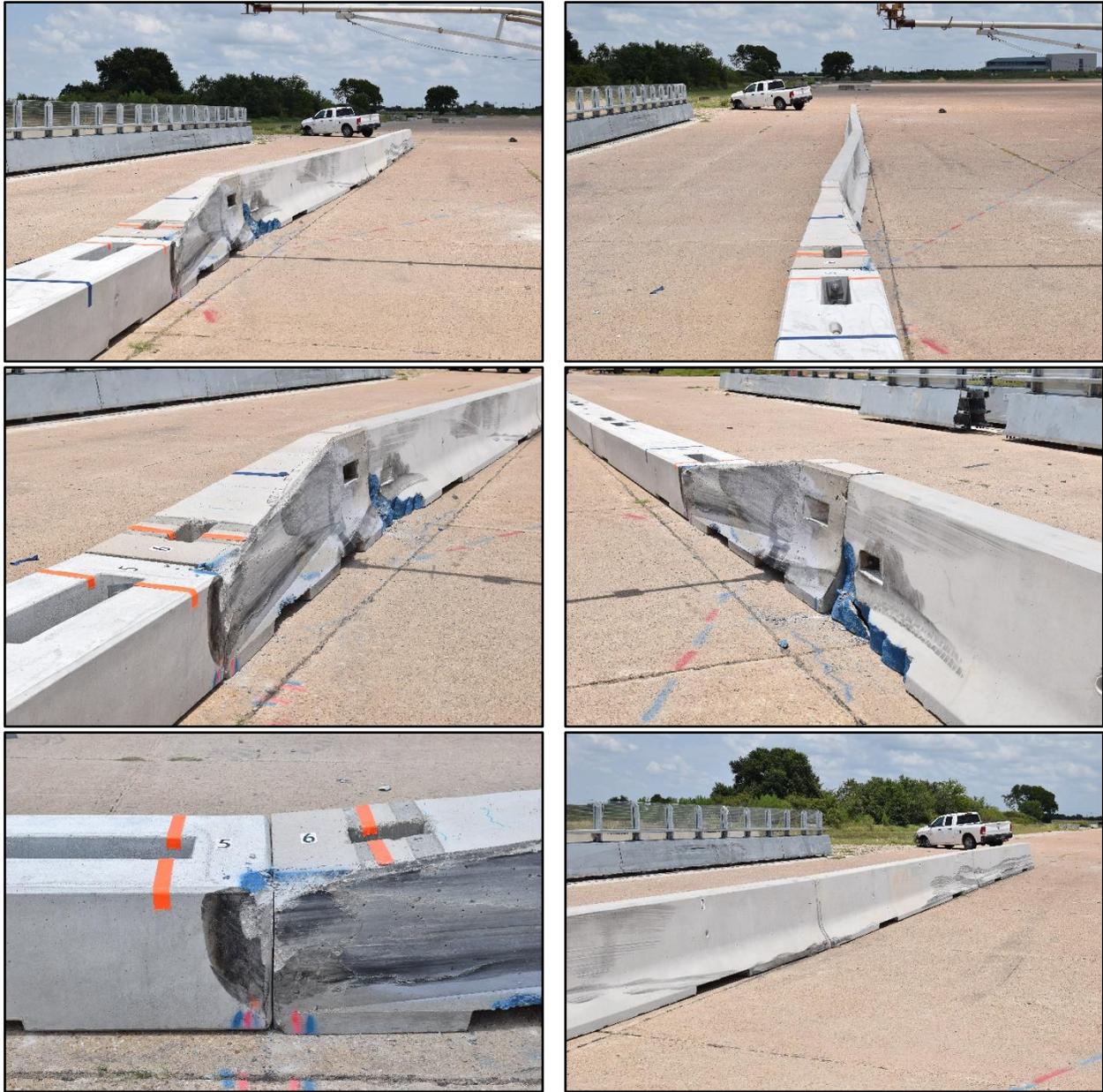


Figure 5.11. Low-Profile-to-F-Shape Transition after Test No. 469469-4-2.

5.4.6 Damage to Test Vehicle

Figure 5.12 and Figure 5.13 show the damage sustained by the vehicle. The front left bumper, left front tire and rim, left front door, left front fender, left headlight, and left front A-arm were damaged. Maximum exterior crush to the vehicle was 13 inches in the side plane at the left front corner at bumper height. There was no measurable occupant compartment deformation. Table D.6 and Table D.7 in Appendix D.4.1 provide exterior crush and occupant compartment measurements.



Figure 5.12. Test Vehicle after Test No. 469469-4-2.



**Figure 5.13. Interior of Test Vehicle for Test No. 469469-4-2
(before Test on Left; after Test on Right).**

5.4.7 Occupant Risk Factors

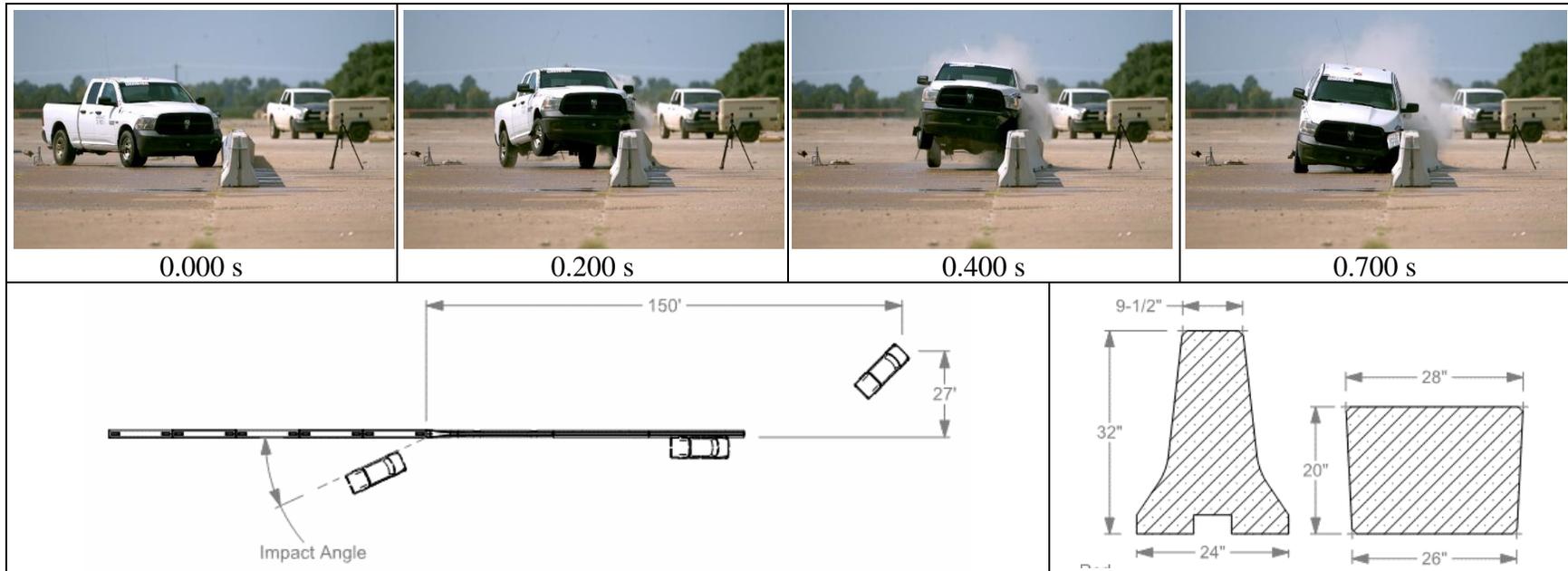
Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 5.5. Figure 5.14 summarizes these data and other pertinent information from the test. Figure D.9 in Appendix D.4.3 shows the vehicle angular displacements, and Figure D.10 through Figure D.12 in Appendix D.4.4 show acceleration versus time traces.

Table 5.5. Occupant Risk Factors for Test No. 469469-4-2.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV) Longitudinal Lateral	ft/s	at 0.1332 seconds on left side of interior
	12.8	
	14.1	
Occupant Ridedown Accelerations (g's) Longitudinal Lateral	ft/s²	
	2.0	(0.7312–0.7412 seconds)
	6.8	(0.3773–0.3873 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.1285 seconds on left side of interior
	5.8	
Acceleration Severity Index (ASI)	1.03	(0.0636–0.1136 seconds)
Maximum 50-ms Moving Average (g's) Longitudinal Lateral Vertical	ft/s²	
	-5.6	(0.0354–0.0854 seconds)
	7.2	(0.0441–0.0941 seconds)
	-3.5	(0.0499–0.0999 seconds)
Maximum Roll, Pitch, and Yaw Angles Roll Pitch Yaw	Degrees	
	7	(0.5262 seconds)
	7	(0.7546 seconds)
	26	(0.3909 seconds)

5.4.8 Assessment of Results

An assessment of the tests based on the applicable safety evaluation criteria for *MASH* Test 2-21 is provided in Table 5.6.



General Information

Test Agency..... Texas A&M Transportation Institute (TTI)
 Test Standard Test No. *MASH* Test 2-21
 TTI Test No. 469469-4-2
 Test Date..... 2019-08-01

Test Article

Type..... Longitudinal barrier—low profile
 Name TxDOT low-profile-to-F-shape transition
 Installation Length..... 200 ft
 Material or Key Elements 10 ft concrete shape transition section between 5 low-profile barrier segments and 3 F-shape barrier segments
 Soil Type and Condition Concrete deck, damp

Soil Type and Condition

Test Vehicle

Type/Designation 2270P
 Make and Model 2015 RAM 1500
 Curb..... 4944 lb
 Test Inertial 5030 lb
 Dummy No dummy
 Gross Static 5030 lb

Impact Conditions

Speed 44.3 mi/h
 Angle 24.4°
 Location/Orientation At the center of joints 5 and 6

Impact Severity.....

56.3 kip*ft

Exit Conditions

Speed 35.5 mi/h
 Exit Trajectory/Heading 6.3°/0.4°

Occupant Risk Values

Longitudinal OIV..... 12.8 ft/s
 Lateral OIV..... 14.1 ft/s
 Longitudinal Ridedown 2.0 g
 Lateral Ridedown 6.8 g
 THIV 5.8 km/h
 PHD 6.8 g
 ASI 1.03
 Max. 0.050-s Average
 Longitudinal..... -5.6 g
 Lateral..... 7.2 g
 Vertical..... -3.5 g

Post-Impact Trajectory

Stopping Distance 150 ft downstrm;
 27 ft on field side of barrier

Vehicle Stability

Maximum Yaw Angle..... 26°
 Maximum Pitch Angle.... 7°
 Maximum Roll Angle 7°
 Vehicle Snagging No
 Vehicle Pocketing..... No

Test Article Deflections

Dynamic..... 14.5 inches
 Permanent 14 inches
 Working Width..... 38.5 inches
 Working Width Height.... 0 inches

Vehicle Damage

VDS 10-LFQ-2
 CDC 10FLEW2
 Max. Exterior Deformation 6 inches
 OCDI..... LF0000000
 Max. Occupant Compartment Deformation 0 inches

Figure 5.14. Summary of Results for *MASH* Test 2-11 on Low-Profile-to-F-Shape Transition.

Table 5.6. Performance Evaluation Summary for MASH Test 2-21 on Low-Profile-to-F-Shape Transition.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-04-2

Test Date: 2019-08-01

MASH Test 2-11 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> A. <i>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.</i>	The TxDOT low-profile-to-F-shape transition contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 14.5 inches.	Pass
<u>Occupant Risk</u> D. <i>Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i> <i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</i>	No detached elements, fragments, or other debris from the test article were present to penetrate or show potential for penetrating the occupant compartment or to present hazard to others in the area. No occupant compartment deformation or intrusion was observed.	Pass
F. <i>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 2270P vehicle remained upright during and after the collision event. Maximum roll was 7°, and maximum pitch was 7°.	Pass
H. <i>Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.</i>	Longitudinal OIV was 12.8 ft/s, and lateral OIV was 14.1 ft/s.	Pass
I. <i>Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.</i>	Maximum longitudinal 10-ms occupant ridedown acceleration was 2.0 g, and maximum lateral 10-ms occupant ridedown acceleration was 6.8 g.	Pass
<u>Vehicle Trajectory</u> For redirective devices, it is preferable that the vehicle be smoothly redirected and leave the barrier within the “exit box” criteria (not less than 32.8 ft for the 1100C and 2270P vehicles), and should be documented.	The 2270P vehicle exited within the exit box criteria.	Documentation only

5.5 CONCLUSIONS

In Test 2-20, the TxDOT low-profile-to-F-shape transition contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 8 inches, and permanent deformation was 8 inches. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. There was no observed occupant compartment deformation. The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 17° and 8°, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The 1100C vehicle exited within the exit box criteria.

In Test 2-21, the TxDOT low-profile-to-F-shape transition contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 14.5 inches, and permanent deformation was 14 inches. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. There was no observed occupant compartment deformation. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 7° and 7°, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The 2270P vehicle exited within the exit box criteria.

The TxDOT low-profile-to-F-shape transition performed acceptably according to *MASH* TL-2 evaluation criteria as shown in Table 5.7.

Table 5.7. Assessment Summary for *MASH* TL-2 Tests on TxDOT Low-Profile-to-F-Shape Transition.

Evaluation Factors	Evaluation Criteria	Test No. 469469-4-1	Test No. 469469-4-2
Structural Adequacy	A	S	S
Occupant Risk	D	S	S
	F	S	S
	H	S	S
	I	S	S
	Test No.	<i>MASH</i> Test 2-20	<i>MASH</i> Test 2-21
	Pass/Fail	Pass	Pass

S = Satisfactory

U = Unsatisfactory

N/A = Not applicable

CHAPTER 6: TXDOT THRIE-BEAM TRANSITION TO CONCRETE BARRIER WITHOUT END SHOE BLOCK

6.1 BACKGROUND

When guardrail is used at a bridge approach, the stiffness of the more flexible metal beam guard fence is transitioned to the rigid concrete bridge parapet using a nested thrie-beam transition section with reduced post spacing. This thrie-beam transition section has been previously tested to *MASH* at both the upstream and downstream ends (4, 5). When the transition system was tested at the downstream end near its connection to a safety-shaped concrete parapet, a tapered steel block was positioned under the end shoe to keep it in a vertical plane.

The TxDOT variation of this transition, which is detailed in standard GF(31)TR, does not use the tapered blockout but rather twists the nested thrie beam and end shoe into the sloped barrier face. It was decided to test the downstream transition without the tapered end shoe block to determine if this configuration is *MASH* compliant.

The critical test for evaluating the need for the tapered end shoe block is *MASH* test designation 3-21 with the 2270P pickup truck. The stability of the pickup truck is most likely to be affected by the sloping thrie-beam rail adjacent to the bridge rail parapet. The standard detail sheet for the thrie-beam transition permits the use of three different post types: W6×8.5 steel posts, 7-inch-diameter round wood posts, and 6-inch by 8-inch rectangular wood posts. Researchers consider the W6×8.5 steel post to be the most critical condition for post snagging. Therefore, the steel post option was used in the full-scale crash test. By using the most critical post type, a successful result would also be applicable to the other post types permitted in the standard.

TxDOT bridge rail standards include two systems that have sloped faces that attach to the TL-3 thrie-beam transition. These are a 32-inch F-shape parapet (Type T551) and a 36-inch single slope traffic rail (SSTR). The SSTR has an 11° slope on the traffic face compared to a 6.5° 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 end shoe block. A successful result with the more critical SSTR would also be applicable to the T551 F-shape bridge rail.

6.2 SYSTEM DETAILS

6.2.1 Test Article and Installation Details

The bridge parapet constructed for the test was a 36-inch-tall SSTR. A 12.5-ft-long section of nested, 12-gauge thrie-beam rail was attached to the face of the SSTR using a 10-gauge thrie-beam terminal connector. The nested thrie-beam rail was twisted toward the sloped traffic face of the SSTR such that the terminal connector lay approximately flush with the surface of the parapet. The terminal connector was then attached to the parapet using five 7/8-inch A325 hex head through bolts.

The first post supporting the nested thrie-beam transition section was located 12¼ inches upstream from the end of the bridge rail end. The next five posts were spaced 18¾ inches center

to center. Each of these first six posts were 7-ft-long W6×8.5 steel posts embedded 52 inches below grade.

The nested thrie-beam rail was transitioned to a single 12-gauge W-beam rail over a distance of 6 ft 3 inches, using a 10-gauge, asymmetrically tapered transition section. The three posts positioned along this section of the transition were 6-ft-long W6×8.5 posts spaced at 37½ inches on center, which resulted in a post on each end and at midspan of the thrie-beam-to-W-beam transition piece. Routed wood blockouts nominally measuring 6 inches by 8 inches by 18 inches were used along the length of the thrie beam and the first two posts of the asymmetric transition section to offset the rail from the posts.

A 50-ft length of 31-inch-tall W-beam guardrail was attached to the upstream end of the asymmetric transition section. The guardrail consisted of a 12-gauge W-beam rail supported on 6-ft-long W6×8.5 steel posts spaced at 6 ft 3 inches. The W-beam rail was offset from the posts using routed wood blockouts nominally measuring 6 inches by 8 inches by 14 inches. The upstream end of the installation terminated with a TxDOT downstream anchor terminal.

A 12-foot-long section of 5¾-inch-tall reinforced concrete curb was constructed beneath the nested thrie-beam transition rail beginning at the end of the concrete parapet. The back of the curb was ½ inch from the traffic side face of the posts.

Figure 6.1 presents overall information on the thrie-beam transition without end shoe block, and Figure 6.2 provides photographs of the installation. Appendix E.1 provides further details of the thrie-beam transition without end shoe block.

6.2.2 Material Specifications

The minimum compressive strength of the TxDOT Class C concrete specified for the curb was 3600 psi. Part base of curb was cast on May 24, 2019. The average compressive strength of the single batch of concrete used in the base of the curb was 4091 psi on August 8, 2019 (at 76 days).

The minimum compressive strength of the TxDOT Class A concrete specified for the curb was 3000 psi. The curb segment was cast on May 29, 2019. The average compressive strength of the single batch of concrete used in the curb was 5601 psi on August 8, 2019 (at 71 days).

Appendix E.2 provides material certification documents and information on the materials used to install/construct the thrie-beam transition without end shoe block.

6.2.3 Soil Conditions

The test installation was installed in standard soil meeting Grading B of AASHTO standard specification M147-65(2004), “Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses.”

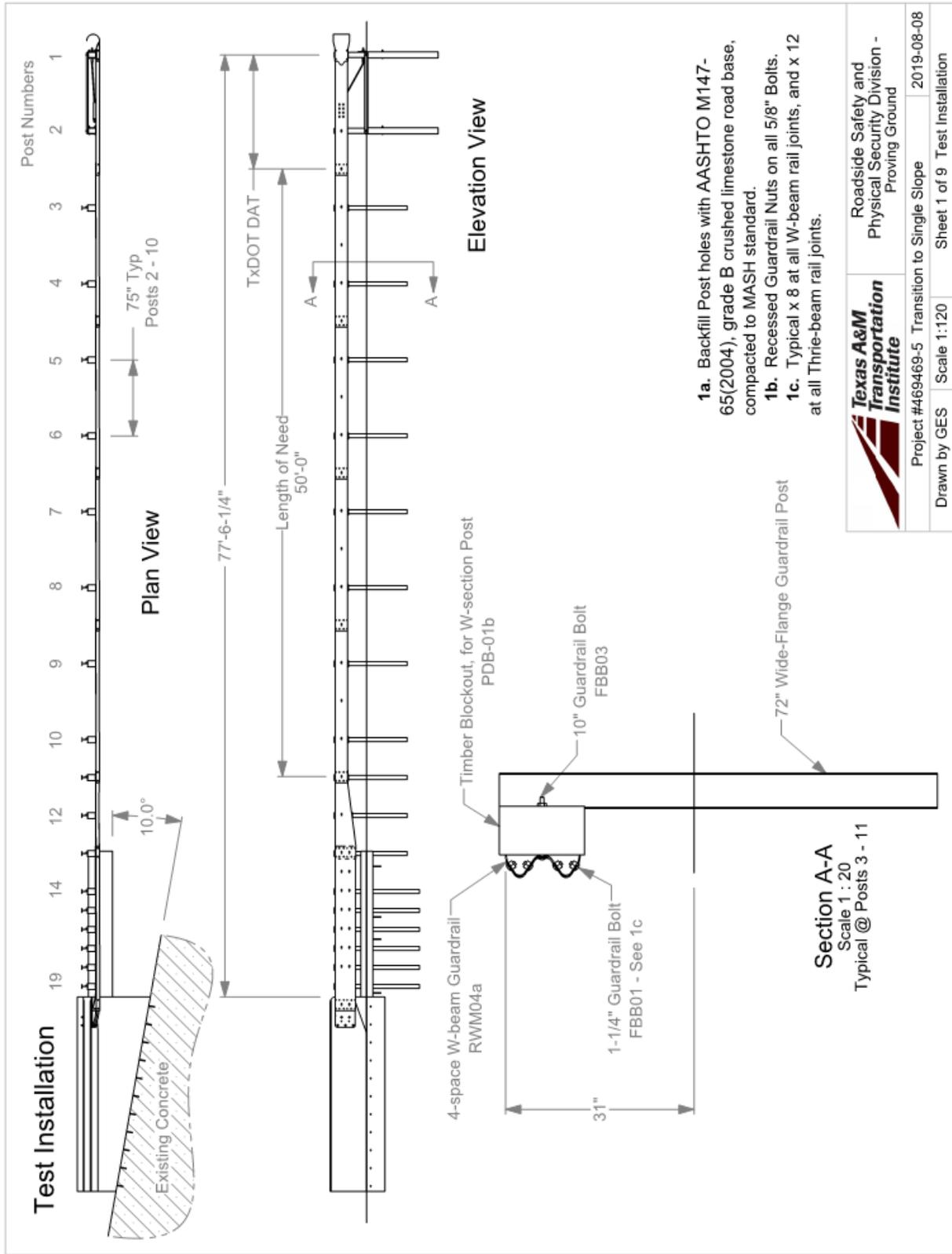


Figure 6.1. Overall Details of the Thrie-Beam Transition without End Shoe Block.



Figure 6.2. Thrie-Beam Transition without End Shoe Block prior to Testing.

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the guardrail system for full-scale crash testing, two 6-ft-long W6×16 posts were installed in the immediate vicinity of the guardrail system using the same fill materials and installation procedures used in the test installation and the standard dynamic test. Table E.1 in Appendix E.2 presents minimum soil strength properties established through the dynamic testing performed in accordance with *MASH* Appendix B.

As determined by the tests summarized in Appendix E.2, Table E.2, the minimum post loads required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, are 3940 lb, 5500 lb, and 6540 lb, respectively (90 percent of static load for the initial standard installation).

On the day of the first test, August 8, 2019, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 4040 lbf, 11627 lbf, and 13047 lbf, respectively. Table E.2 in Appendix E.2 shows that the strength of the backfill material in which the guardrail system was installed met the minimum *MASH* requirements.

6.3 MASH TEST 3-21 (TEST NO. 469469-5)

6.3.1 Test Designation and Actual Impact Conditions

MASH Test 3-21 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the CIP of the thrie-beam transition without end shoe block at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. The CIP for *MASH* Test 3-21 on the thrie-beam transition without end shoe block was 93 inches upstream of the end of the concrete barrier.

The 2013 RAM 1500 used in the test weighed 5038 lb, and the actual impact speed and angle were 62.3 mi/h and 25.1°. The actual impact point was 97.7 inches upstream of the end of the concrete barrier. Minimum target impact severity was 106 kip-ft, and actual IS was 118 kip-ft.

6.3.2 Weather Conditions

The test was performed on the morning of August 8, 2019. Weather conditions at the time of testing were as follows: wind speed: 6 mi/h; wind direction: 200° with respect to the vehicle (vehicle was traveling at a magnetic heading of 205°); temperature: 95°F; relative humidity: 56 percent.

6.3.3 Test Vehicle

The 2013 RAM 1500 shown in Figure 6.3 and Figure 6.4 was used for the crash test. The vehicle's test inertia weight was 5038 lb, and its gross static weight was 5038 lb. The height to the lower edge of the vehicle bumper was 11.8 inches, and height to the upper edge of the bumper was 27 inches. The height to the vehicle's center of gravity was 28.4 inches. Table E.3 and Table E.4 in Appendix E.3.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 6.3. Thrie-Beam Transition without End Shoe Block/Test Vehicle Geometrics for Test No. 469469-5.



Figure 6.4. Test Vehicle before Test No. 469469-5.

6.3.4 Test Description

Table 6.1 lists events that occurred during Test No. 469469-5. Figure E.1 and Figure E.2 in Appendix E.3.2 present sequential photographs during the test.

Table 6.1. Events during Test No. 469469-5.

Time	Events
0.000	Vehicle contacts rail
0.046	Vehicle begins to redirect
0.010	Post 14, 15, 16 and 17 begin to deflect toward field side
0.022	Post 18 and 19 begin to deflect toward field side
0.119	Front left tire leaves pavement
0.148	Rear left tire leaves pavement
0.193	Rear right bumper of truck impacts rail. Vehicle is parallel with rail.
0.288	Vehicle loses contact with the barrier; vehicle is traveling at 48.8 mi/h at a trajectory angle of 8.2° and a heading angle of 10.1°

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for cars and pickups). The 2270P vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle yawed counterclockwise and came to rest 241 ft downstream of the point of impact and 23 ft from the traffic side of the barrier. Brakes were applied at 2.1 seconds after impact.

6.3.5 Damage to Test Installation

Figure 6.5 shows the damage to the thrie-beam transition without end shoe block. There was a ½-inch gap between the curb and soil on the field side, and the rail was scuffed and deformed.

Working width⁸ was 18.5 inches, and the height of maximum working width was 48.8 inches (side mirror). Maximum dynamic deflection was 4.0 inches in the nested thrie-beam section. Maximum permanent deflection was ½ inch between posts 16 and 17.

⁸ Working width is defined as the distance between the traffic face of the barrier before impact and the maximum lateral position of any major part of the barrier or the vehicle after impact.



Figure 6.5. Thrie-Beam Transition without End Shoe Block after Test No. 469469-5.

6.3.6 Damage to Test Vehicle

Figure 6.6 and Figure 6.7 show the damage sustained by the vehicle. The front right bumper, hood, grill, radiator and supports, right front tire and rim, right front fender, right frame rail, right front upper and lower ball joints, right front upper and lower A-arms, front sway bar, right front door (8-inch gap at top), right front floor pan, right rear door, right cab corner, right rear fender, right rear rim, rear bumper, and right tail light were damaged. The windshield sustained stress cracks originating at the lower right and lower left corners. Maximum exterior crush to the vehicle was 10 inches at the front bumper at bumper height. The maximum occupant

compartment deformation was 4 inches at the lower right floor pan. Table E.5 and Table E.6 in Appendix E.3.1 provide exterior crush and occupant compartment measurements.



Figure 6.6. Test Vehicle after Test No. 469469-5.



Figure 6.7. Interior of Test Vehicle for Test No. 469469-5 (before Test on Left; after Test on Right).

6.3.7 Occupant Risk Factors

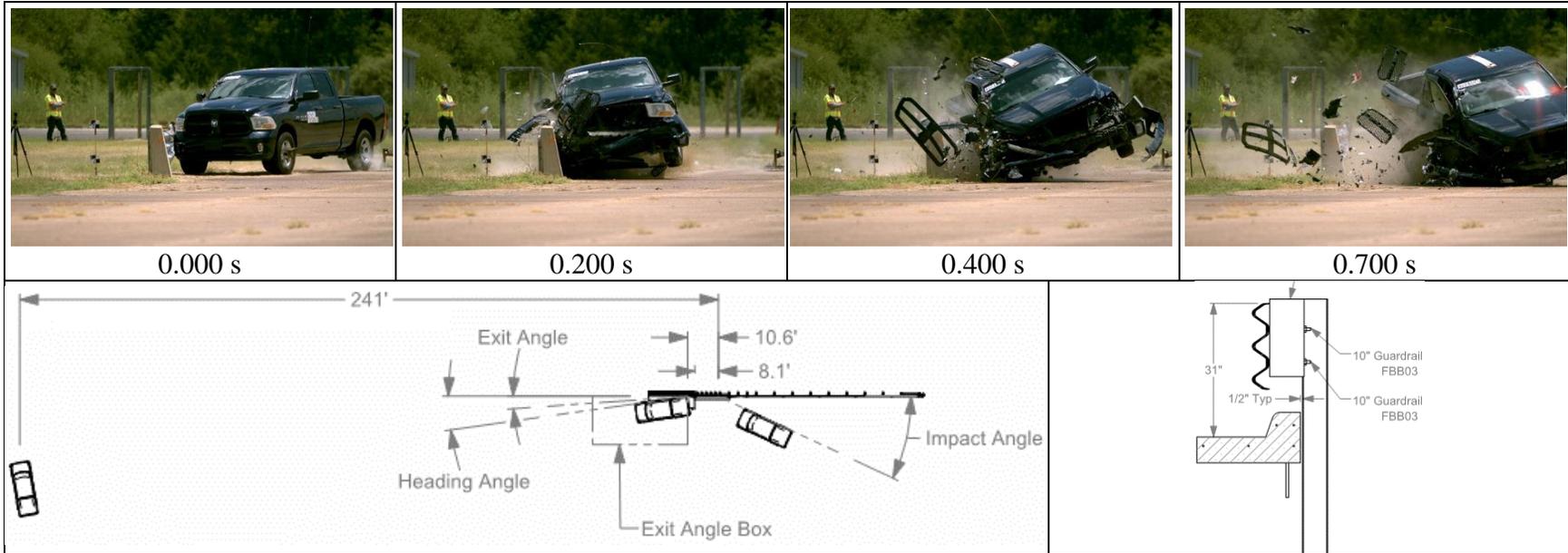
Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 6.2. Figure 6.8 summarizes these data and other pertinent information from the test. Figure E.3 in Appendix E.3.3 shows the vehicle angular displacements, and Figure E.4 through Figure E.6 in Appendix E.3.4 show acceleration versus time traces.

Table 6.2. Occupant Risk Factors for Test No. 469469-5.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV) Longitudinal Lateral	ft/s	at 0.1057 seconds on right side of interior
	20.3	
	26.2	
Occupant Ridedown Accelerations (g's) Longitudinal Lateral		
	6.6	(0.1057–0.1157 seconds)
	14.4	(0.2392–0.2492 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.1027 seconds on right side of interior
	9.9	
Post Head Deceleration (PHD) (g's)	14.6	(0.2391–0.2491 seconds)
Acceleration Severity Index (ASI)	1.4	(0.0811–0.1311 seconds)
Maximum 50-ms Moving Average (g's) Longitudinal Lateral Vertical		
	-8.7	(0.0357–0.0857 seconds)
	-11.2	(0.0569–0.1069 seconds)
	-3.8	(0.0204–0.0704 seconds)
Maximum Roll, Pitch, and Yaw Angles Roll Pitch Yaw	Degrees	
	24	(0.4866 seconds)
	7	(1.9988 seconds)
	47	(1.0026 seconds)

6.3.8 Assessment of Results

An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-21 is provided in Table 6.3.



<p>General Information</p> <p>Test Agency Texas A&M Transportation Institute (TTI) Test Standard Test No. MASH Test 3-21 TTI Test No. 469469-5 Test Date 2019-08-08</p> <p>Test Article</p> <p>Type Thrie-beam transition Name TxDOT thrie-beam transition without end shoe block Installation Length 93.5 ft Material or Key Elements 36-inch single slope concrete barrier, 12-ga. nested thrie-beam, 5/4-inch curb, 10-ga. asymmetric transition section, W6x8.5 steel posts</p> <p>Soil Type and Condition</p> <p>AASHTO M147-65(2004), Grading B soil (crushed limestone), damp</p> <p>Test Vehicle</p> <p>Type/Designation 2270P Make and Model 2013 RAM 1500 Curb 5011 lb Test Inertial 5038 lb Dummy No dummy Gross Static 5038 lb</p>		<p>Impact Conditions</p> <p>Speed 62.3 mi/h Angle 25.1° Location/Orientation At the center of joints 5 and 6</p> <p>Impact Severity 118 kip*ft</p> <p>Exit Conditions</p> <p>Speed 48.8 mi/h Exit Trajectory/Heading 8.2°/10.1°</p> <p>Occupant Risk Values</p> <p>Longitudinal OIV 20.3 ft/s Lateral OIV 26.2 ft/s Longitudinal Ridedown 6.6 g Lateral Ridedown 14.4 g THIV 35.6 km/h PHD 14.6 g ASI 1.38</p> <p>Max. 0.050-s Average</p> <p>Longitudinal -8.7 g Lateral -11.2 g Vertical -3.8 g</p>		<p>Post-Impact Trajectory</p> <p>Stopping Distance 241 ft downstrm; 23 ft on traffic side of barrier</p> <p>Vehicle Stability</p> <p>Maximum Yaw Angle 47° Maximum Pitch Angle 7° Maximum Roll Angle 24° Vehicle Snagging No Vehicle Pocketing No</p> <p>Test Article Deflections</p> <p>Dynamic 4.0 inches Permanent 0.5 inches Working Width 18.5 inches Working Width Height 48.8 inches</p> <p>Vehicle Damage</p> <p>VDS 10-RFQ-3 CDC 10FREW3 Max. Exterior Deformation 10 inches OCDI LF0121100 Max. Occupant Compartment Deformation 4 inches</p>	
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Figure 6.8. Summary of Results for MASH Test 3-21 on the Thrie-Beam Transition without End Shoe Block.

Table 6.3. Performance Evaluation Summary for MASH Test 3-21 on the Thrie-Beam Transition without End Shoe Block.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-05

Test Date: 2019-08-08

MASH Test 3-21 Evaluation Criteria	Test Results	Assessment
<p><u>Structural Adequacy</u></p> <p>A. <i>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.</i></p>	<p>The TxDOT thrie-beam transition without end shoe block contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 4.0 inches.</p>	<p>Pass</p>
<p><u>Occupant Risk</u></p> <p>D. <i>Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i></p> <hr/> <p><i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</i></p>	<p>No detached elements, fragments, or other debris from the test article were present to penetrate or show potential for penetrating the occupant compartment or to present hazard to others in the area.</p> <hr/> <p>4 inches of deformation in the floor pan.</p>	<p>Pass</p>
<p>F. <i>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i></p>	<p>The 2270P vehicle remained upright during and after the collision event. Maximum roll was 24°, and maximum pitch was 7°.</p>	<p>Pass</p>
<p>H. <i>Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.</i></p>	<p>Longitudinal OIV was 20.3 ft/s, and lateral OIV was 26.2 ft/s.</p>	<p>Pass</p>
<p>I. <i>Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.</i></p>	<p>Maximum longitudinal 10-ms occupant ridedown acceleration was 6.6 g, and maximum lateral 10-ms occupant ridedown acceleration was 14.4 g.</p>	<p>Pass</p>
<p><u>Vehicle Trajectory</u></p> <p>For redirective devices, it is preferable that the vehicle be smoothly redirected and leave the barrier within the “exit box” criteria (not less than 32.8 ft for the 1100C and 2270P vehicles), and should be documented.</p>	<p>The 2270P vehicle exited within the exit box criteria.</p>	<p>Documentation only</p>

6.4 CONCLUSIONS

The TxDOT thrie-beam transition without end shoe block contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 4.0 inches, and permanent deformation was ½ inch. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. The maximum occupant compartment deformation was 4 inches. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 24° and 7°, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The 2270P vehicle exited within the exit box criteria.

The TxDOT thrie-beam transition without end shoe block performed acceptably according to *MASH* Test 3-21 evaluation criteria as shown in Table 6.4.

Table 6.4. Assessment Summary for *MASH* Test 3-21 on TxDOT Thrie-Beam Transition without End Shoe Block.

Evaluation Factors	Evaluation Criteria	Test No. 469469-5
Structural Adequacy	A	S
	D	S
Occupant Risk	F	S
	H	S
	I	S
Test No.		<i>MASH</i> Test 3-21
Pass/Fail		Pass

S = Satisfactory

U = Unsatisfactory

N/A = Not applicable

CHAPTER 7: TXDOT SINGLE WOOD POST SKID-MOUNTED SIGN SUPPORT SYSTEM

7.1 BACKGROUND

The single wood post skid-mounted temporary sign support system uses a nominal 4-inch by 4-inch post and is designed for use with a maximum 12-sq-ft sign panel. Details can be found on TxDOT Barricade and Construction sheet BC(5)-14.

The *MASH* test matrix for work zone traffic control devices includes a high-speed test with a passenger car (Test 3-71) and pickup truck (Test 3-72) at both 0° and 90° impact orientations. The single wood post skid-mounted sign support system was previously tested with a small passenger car at high speed under NCHRP Report 350. Although the small passenger car design test vehicle has changed under *MASH*, its performance in frontal impacts with large skid-mounted sign support systems is not expected to differ appreciably. Therefore, only test designation 3-72 with the 2270P pickup truck is considered necessary for both the 0° and 90° impact orientations to assess *MASH* compliance.

MASH states that “lightweight free-standing features cannot cause sufficient velocity change to result in failure of the test under occupant risk criteria. Therefore, Tests 3-71 and 3-72 can be conducted without the instrumentation necessary for determining occupant risk whenever the test article has a total weight of 220 lb (100 kg) or less.”

7.2 SYSTEM DETAILS

7.2.1 Test Article and Installation Details

This test installation consisted of a 36-inch-square by 0.10-inch-thick aluminum sign panel secured to a nominal 4-inch by 4-inch wood support with two 3/8-inch-diameter through bolts. The panel had rounded corners and was mounted in a diamond orientation, with the bottom corner 84 inches above grade. The wood frame consisted of nominal 4-inch by 4-inch, 2-inch by 6-inch, and 2-inch by 4-inch lumber and assorted hardware. All lumber was treated southern yellow pine. All hex bolts were grade 5, and each had two USS flat washers, one lock washer, and one hex nut. Each lag screw had a USS flat washer under the head.

The installation was placed on an existing concrete apron but was not secured to it. The single wood post skid-mounted temporary sign support system was placed with the sign panel at 90° (parallel to the vehicle path). A 40-pound sandbag was placed on each end of the wood frame skid.

Figure 7.1 presents overall information on the single wood post skid-mounted sign, and Figure 7.2 provides photographs of the installation. Appendix F.1 provides further details of the single wood post skid-mounted sign.

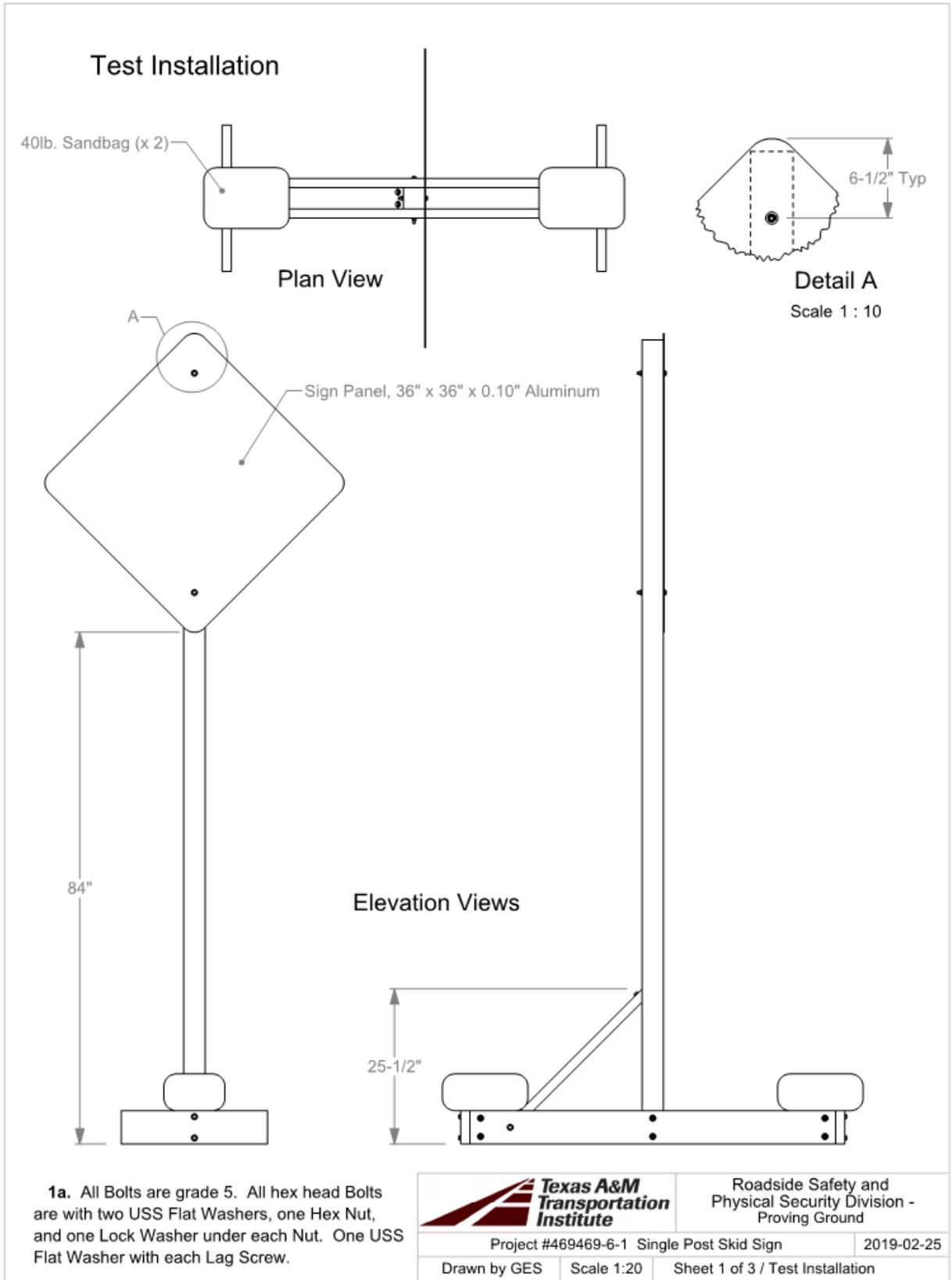


Figure 7.1. Overall Details of the Single Wood Post Skid-Mounted Sign.

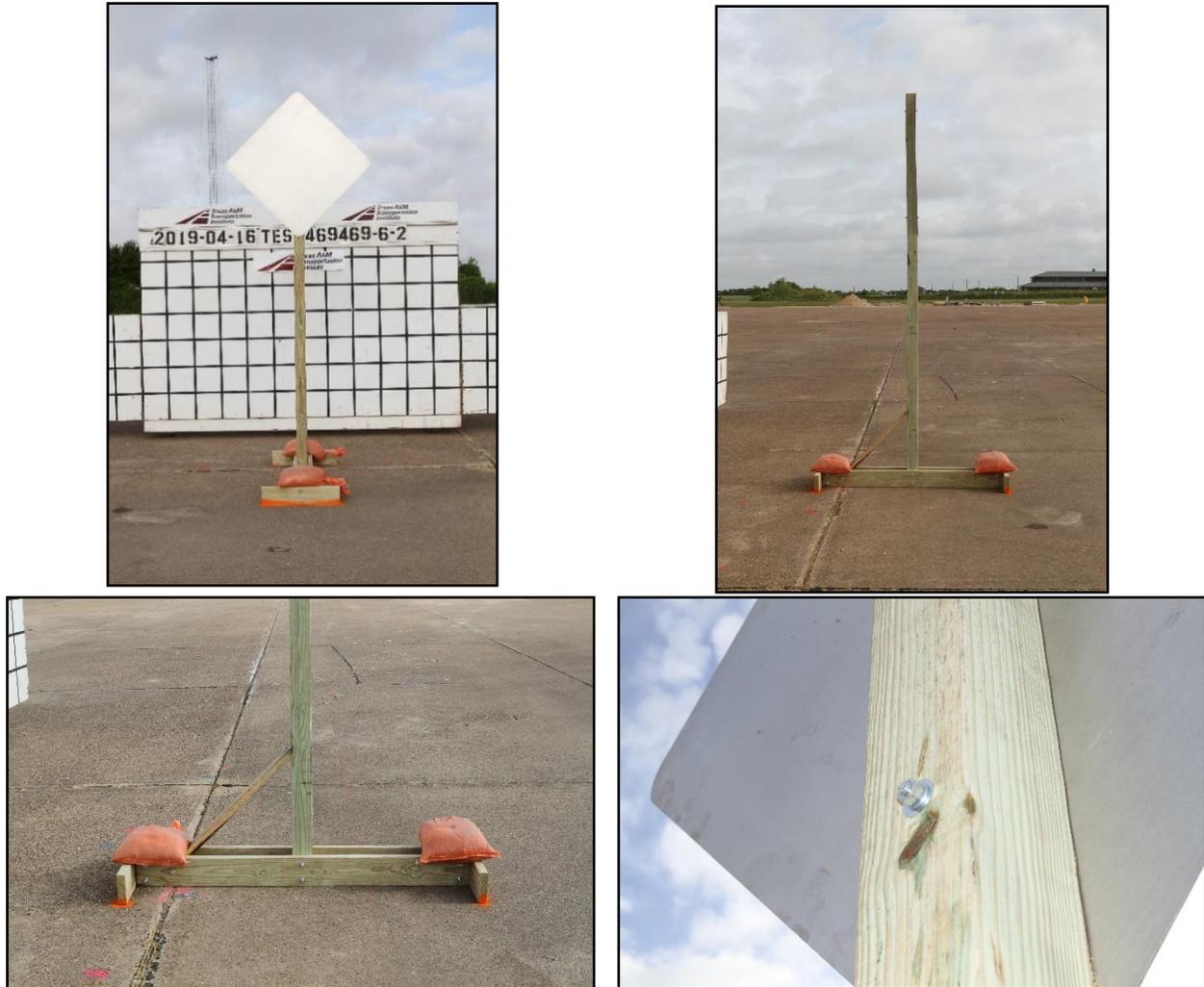


Figure 7.2. Single Wood Post Skid-Mounted Sign prior to Test No. 469469-06-02.

7.2.2 Material Specifications

Appendix F.2 provides material certification documents for the materials used to install/construct the single wood post skid-mounted sign.

7.3 MASH TEST 3-72 (TEST NO. 469469-06-02)

7.3.1 Test Designation and Actual Impact Conditions

MASH Test 3-72 involves a 2270P vehicle weighing 5000 lb \pm 110 lb impacting the CIP of the single wood post skid-mounted sign at an impact speed of 62 mi/h \pm 2.5 mi/h and an angle of 90° \pm 1.5°. The CIP for *MASH* Test 3-72 was the centerline of the support post aligned 12 inches off the centerline of the vehicle toward the driver's side.

The 2015 RAM 1500 used in the test weighed 5026 lb, and the actual impact speed and angle were 62.2 mi/h and 90°, respectively. Minimum target impact severity was 594 kip-ft, and actual IS was 650 kip-ft.

7.3.2 Weather Conditions

The test was performed on the morning of April 16, 2019. Weather conditions at the time of testing were as follows: wind speed: 10 mi/h; wind direction: 205° with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 70°F; relative humidity: 86 percent.

7.3.3 Test Vehicle

The 2015 RAM 1500 shown in Figure 7.3 and Figure 7.4 was used for the crash test. The vehicle's test inertia weight was 5026 lb, and its gross static weight was 5026 lb. The height to the lower edge of the vehicle bumper was 11.8 inches, and height to the upper edge of the bumper was 27 inches. The height to the vehicle's center of gravity was 28 inches. Table F.1 and Table F.2 in Appendix F.2.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 7.3. Single Wood Post Skid-Mounted Sign/Test Vehicle Geometrics for Test No. 469469-06-02.



Figure 7.4. Test Vehicle before Test No. 469469-06-02.

7.3.4 Test Description

The 2015 RAM 1500 was traveling at an impact speed of 62.2 mi/h when it contacted the support post 12 inches off centerline of the vehicle on the driver’s side, at an impact angle of 90°. Table 7.1 lists events that occurred during Test No. 469469-06-02. Figure F.1 and Figure F.2 in Appendix F.2.2 present sequential photographs during the test.

Table 7.1. Events during Test No. 469469-06-02.

Time	Events
0.000	Vehicle contacts sign support
0.002	Wood support post begins to fracture
0.015	Wood support post completely fractured and separated
0.031	Released wood support post and attached sign loses contact with vehicle
0.070	Corner of sign panel impacts upper windshield area near roof
0.134	Sign rotates off of vehicle roof

The 2270P vehicle came to rest 360 ft downstream and 10 ft to the left of the original impact position.

7.3.5 Damage to Test Installation

Figure 7.5 shows the damage to the single wood post skid-mounted sign. Components of the wood base fractured into multiple pieces that were scattered from the impact point to 50 ft downstream. The 4×4 wood support post fractured 24 inches above grade. The sign remained attached to the upper section of the fractured wood support post and came to rest 245 ft downstream and 50 ft to the left of the original impact position.



Figure 7.5. Single Wood Post Skid-Mounted Sign after Test No. 469469-06-02.

7.3.6 Damage to Test Vehicle

Figure 7.6 and Figure 7.7 show the damage sustained by the vehicle. There was a 7-inch by 12-inch by 1-inch-deep dent in the front bumper, a 4-inch by 2.5-inch by 0.3-inch-deep dent in the hood, and a 33-inch by 48-inch by 3.3-inch-deep dent in the roof. The windshield had a 48-inch by 8-inch by 2.8-inch-deep area of damage, and there was a 4-inch-long tear in the windshield laminate. The maximum exterior crush of the vehicle was 1 inch. Maximum occupant compartment deformation was 3.5 inches at the center of the roof. Table F.3 and Table F.4 in Appendix F.2.1 provide exterior crush and occupant compartment measurements.

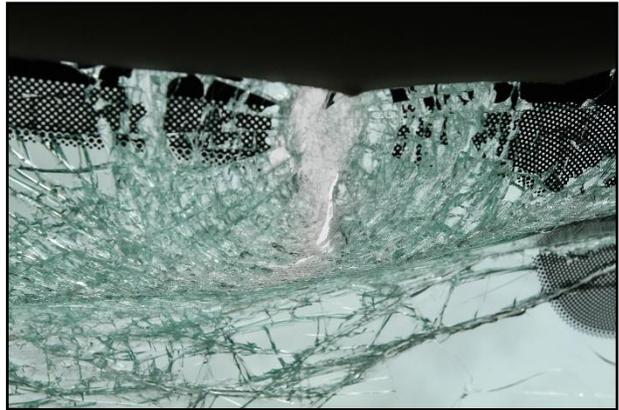


Figure 7.6. Test Vehicle after Test No. 469469-06-02.



Figure 7.7. Interior of Test Vehicle after Test No. 469469-06-02.

7.3.7 Occupant Risk Factors

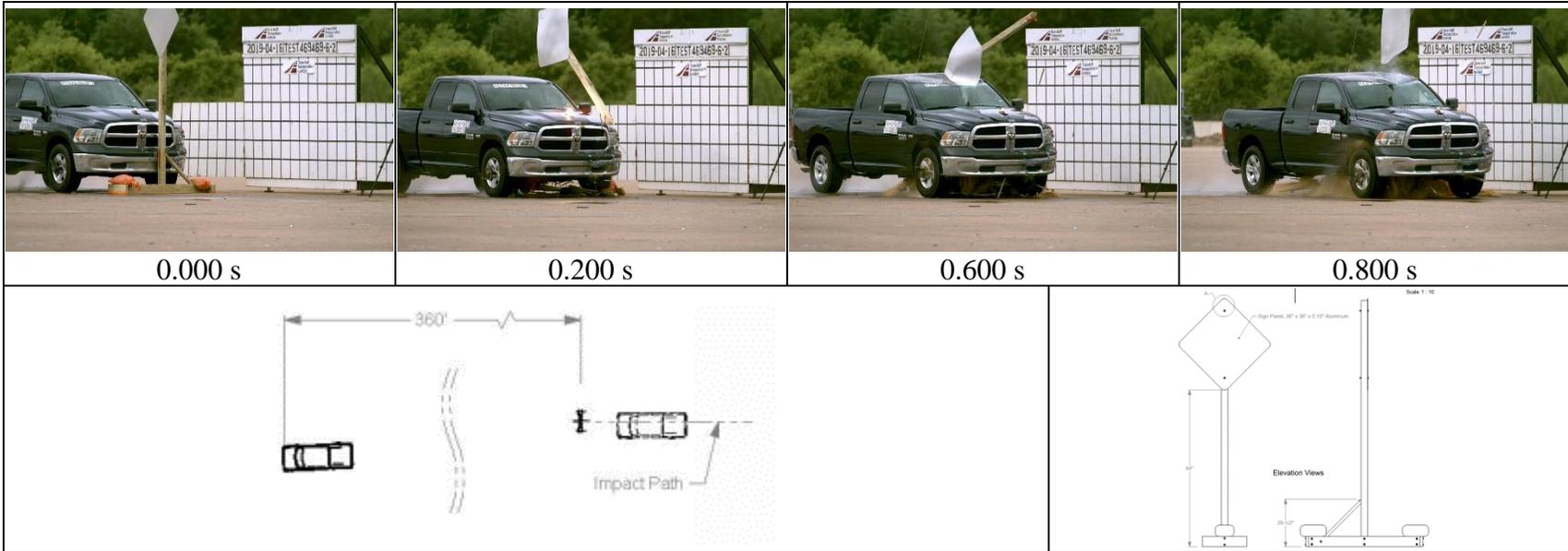
Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 7.2. Figure 7.8 summarizes these data and other pertinent information from the test. Figure F.3 in Appendix F.2.3 shows the vehicle angular displacements, and Figure F.4 through Figure F.6 in Appendix F.2.4 show acceleration versus time traces.

Table 7.2. Occupant Risk Factors for Test No. 469469-06-02.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)	ft/s	at 0.8294 seconds on right side of interior
Longitudinal	2.6	
Lateral	2.0	
Occupant Ridedown Accelerations (g's)		
Longitudinal	0.1	(1.4034–1.4134 seconds)
Lateral	0.3	(1.0431–1.0531 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.8062 seconds on right side of interior
	1	
Post Head Deceleration (PHD) (g's)	0.3	(1.0430–1.0530 seconds)
Acceleration Severity Index (ASI)	0.1	(0.0963–0.1463 seconds)
Maximum 50-ms Moving Average (g's)		
Longitudinal	-1	(0.0016–0.0516 seconds)
Lateral	-1	(0.1228–0.1728 seconds)
Vertical	1.1	(0.1463–0.1963 seconds)
Maximum Roll, Pitch, and Yaw Angles	Degrees	
Roll	2	(0.1963 seconds)
Pitch	1	(1.4978 seconds)
Yaw	3	(1.4989 seconds)

7.3.8 Assessment of Results

An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-72 is provided in Table 7.3.



General Information		Impact Conditions		Post-Impact Trajectory	
Test Agency	Texas A&M Transportation Institute (TTI)	Speed	62.2 mi/h	Stopping Distance	360 ft downstrm; 10 ft left
Test Standard Test No.	MASH Test 3-72	Angle	90°		
TTI Test No.	469469-06-02	Location/Orientation	Center of post aligned 12 inches off center of the vehicle toward the driver's side	Vehicle Stability	
Test Date	2019-4-16			Maximum Yaw Angle.....	3°
Test Article		Impact Severity	650 kip*ft	Maximum Pitch Angle....	1°
Type.....	Work zone sign	Exit Conditions		Maximum Roll Angle	2°
Name	TxDOT single wood post skid-mounted sign support	Speed	61.4 mi/h	Vehicle Snagging	No
Installation Length.....	n/a	Exit Trajectory/Heading	n/a	Vehicle Pocketing.....	n/a
Material or Key Elements	36-inch-square x 0.10-inch-thick aluminum sign mounted on 4x4 wood support at height of 84 inches: support attached to wood frame skid	Occupant Risk Values		Test Article Deflections	
Soil Type and Condition	Placed on dry concrete	Longitudinal OIV.....	2.6 ft/s	Dynamic.....	n/a
Test Vehicle		Lateral OIV.....	2.0 ft/s	Permanent	n/a
Type/Designation	2270P	Longitudinal Ridedown	0.1 g	Working Width.....	n/a
Make and Model	2015 RAM 1500	Lateral Ridedown	0.3 g	Working Width Height....	n/a
Curb.....	5026 lb	THIV	1.0 m/s	Vehicle Damage	
Test Inertial.....	5026 lb	PHD	0.3 g	VDS	12TRGN2
Dummy	No dummy	ASI	0.13	CDC	12FR1
Gross Static	5026 lb	Max. 0.050-s Average		Max. Exterior Deformation	1 inch
		Longitudinal.....	-1.0 g	OCDI.....	FS0100000
		Lateral.....	-1.0 g	Max. Occupant Compartment	
		Vertical.....	1.1 g	Deformation	3.5 inches (roof)

Figure 7.8. Summary of Results for MASH Test 3-72 on the Single Wood Post Skid-Mounted Sign.

Table 7.3. Performance Evaluation Summary for MASH Test 3-72 on the Single Wood Post Skid-Mounted Sign.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-06-02

Test Date: 2019-04-16

MASH Test 3-72 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
B. <i>The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</i>	The wood support post fractured and yielded to the 2270P vehicle as designed.	Pass
<u>Occupant Risk</u>		
D. <i>Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i>	The edge of the aluminum sign panel contacted and penetrated the top of the windshield, resulting in a 4-inch-long tear in its laminate.	Fail
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</i>	The occupant compartment deformation was 3.5 inches in the roof.	Pass
E. <i>Detached elements, fragments, or other debris from the test article, or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle</i>	No detached elements, fragments, or other debris from the test article or vehicle blocked the driver's vision	Pass
F. <i>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 2° and 1°, respectively.	Pass
H. <i>Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.</i>	Longitudinal OIV was 2.6 ft/s, and lateral OIV was 2.0 ft/s.	Pass
I. <i>The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>	Longitudinal occupant ridedown acceleration was 0.1 g, and lateral occupant ridedown was 0.3 g.	Pass
<u>Vehicle Trajectory</u>		
N. <i>Vehicle trajectory behind the test article is acceptable.</i>	The 2270P vehicle came to rest 360 ft behind and 10 ft left of the original position of the installation.	Pass

7.4 CONCLUSIONS

Upon impact, the wood support post fractured near bumper height. The upper portion of the fractured support with attached aluminum sign panel rotated toward the vehicle, and the corner of the sign panel contacted the windshield and caused a 4-inch-long tear in the laminate. Consequently, the single wood post skid-mounted sign support system failed to comply with *MASH* Test 3-72 criteria.

The TxDOT single wood post skid-mounted temporary sign support system did not perform acceptably according to *MASH* Test 3-72 evaluation criteria as shown in Table 7.4.

Table 7.4. Assessment Summary for *MASH* Test 3-72 on TxDOT Single Wood Post Skid-Mounted Temporary Sign Support System.

Evaluation Factors	Evaluation Criteria	Test No. 469469-06-02
Structural Adequacy	B	S
Occupant Risk	D	F
	E	S
	F	S
	H	S
	I	S
	N	S
Test No.		<i>MASH</i> Test 3-72
Pass/Fail		Fail

S = Satisfactory

U = Unsatisfactory

N/A = Not applicable

CHAPTER 8: TXDOT PERFORATED SQUARE STEEL TUBE SIGN SUPPORT

8.1 BACKGROUND

TxDOT uses perforated square steel tube (PSST) supports for ground-mounted temporary signs. Barricade and construction sheet BC(5)-14 and Section J “Signs and Sign Supports” of the Compliant Work Zone Traffic Control Device List provide three foundation options:

- Option 1 is direct embedment of the sign support.
- Option 2 involves insertion of the sign post into a larger size PSST anchor stub.
- Option 3 incorporates an 18-inch PSST reinforcing sleeve over the PSST anchor stub.

The PSST support functions by fracturing the post through the perforated holes that exist on each face of the square cross section. The most critical foundation option is Option 1, direct embedment. Option 2 and Option 3 both provide additional stiffening of the support post at the ground line, which helps facilitate fracture during an impact. However, field use of Option 2 is much more common than Option 1 because it permits the short anchor stub to be readily driven into the ground for installation of the PSST support. Therefore, efforts focused on evaluation of the anchor stub foundation options. If the testing demonstrates that the single PSST sign support in anchor stub (Option 2) meets *MASH* criteria, the less critical Option 3 foundation configuration with reinforced anchor stub can also be considered *MASH* compliant.

MASH Section 2.2.4.1 recognizes that sign support systems that are used near an intersection can be struck from virtually any direction. *MASH* Section 2.2.4.1 recommends that “In this case, testing should be conducted at both 90 degrees from the normal direction and at any orientation between 0 and 25 degrees that is deemed to represent the highest risk for the system to fail any of the recommended evaluation criteria. Features designed to be used along the outside of divided highways need only be evaluated for impact angles of 0 to 25 degrees.” Consequently, since these temporary signs are used at or near intersections, the recommended test matrix for evaluating the ground-mounted PSST sign support system includes *MASH* Test 3-61 with the 1100C passenger car and Test 3-62 with the 2270P pickup truck at both 0° and 90°.

The TxDOT standards permit the use of both 14-gauge and 12-gauge PSST supports of different sizes to accommodate different sign sizes. A single 2-inch by 14-gauge PSST support in an anchor stub was successfully tested in accordance with *MASH* criteria. Therefore, efforts under the current project focused on evaluation of 12-gauge PSST supports. Both foundation Option 2 (PSST support in anchor stub) and Option 3 (PSST support in reinforced anchor stub) were evaluated for a 2-inch, 12-gauge PSST support.

8.2 PSST SIGN SUPPORT IN ANCHOR STUB

8.2.1 Test Article and Installation Details

The PSST sign support in anchor stub system test assembly consisted of a 2-inch by 12-gauge PSST support post inserted 9 inches into a 2¼-inch by 12-gauge perforated square steel

anchor stub. The anchor tube was 34 inches long and embedded such that it protruded 2 inches above grade. The PSST support was secured inside the anchor stub using a $\frac{3}{8}$ -inch-diameter hex head bolt and hardware. The PSST support and anchor stub contained $\frac{7}{16}$ -inch-diameter holes spaced on 1-inch centers on all four faces. The anchor stub was installed in AASHTO M147-65(2004), Grading B soil (crushed limestone) that was compacted to meet *MASH* performance standards as demonstrated by a static post pull test (Appendix G.1.1).

A 36-inch by 36-inch by 0.100-inch-thick aluminum sign panel was mounted to the support post in a diamond orientation using two $\frac{3}{8}$ -inch-diameter hex head bolts and hardware, with the bottom corner located 84 inches above grade.

Figure 8.1 presents overall information on the PSST sign support in anchor stub system, and Figure 8.2 provides photographs of the test installation. Appendix G.1 provides further details of the PSST sign support in anchor stub system.

8.2.2 MASH Test 3-61 (Test No. 469469-07-02)

8.2.2.1 Test Designation and Actual Impact Conditions

MASH Test 3-61 involves a 1100C vehicle weighing 2420 lb \pm 55 lb impacting the PSST sign support in anchor stub system at an impact speed of 62 mi/h \pm 2.5 mi/h and an angle of 90° \pm 1.5°. The selected point of impact was the centerline of the PSST sign support in anchor stub system aligned 14 inches off the centerline of the vehicle toward the driver's side.

The 2011 Kia Rio⁹ used in the test weighed 2443 lb, and the actual impact speed and angle were 62.7 mi/h and 90°, respectively. Minimum target impact severity was 288 kip-ft, and actual IS was 321 kip-ft.

8.2.2.2 Weather Conditions

The test was performed on the afternoon of August 23, 2019. Weather conditions at the time of testing were as follows: wind speed: 3 mi/h; wind direction: 157° with respect to the vehicle (vehicle was traveling at a magnetic heading of 180°); temperature: 97°F; relative humidity: 52 percent.

⁹ The 2011 model vehicle used is older than the 6-year age noted in *MASH* and was selected based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2011 model vehicle met the *MASH* requirements.

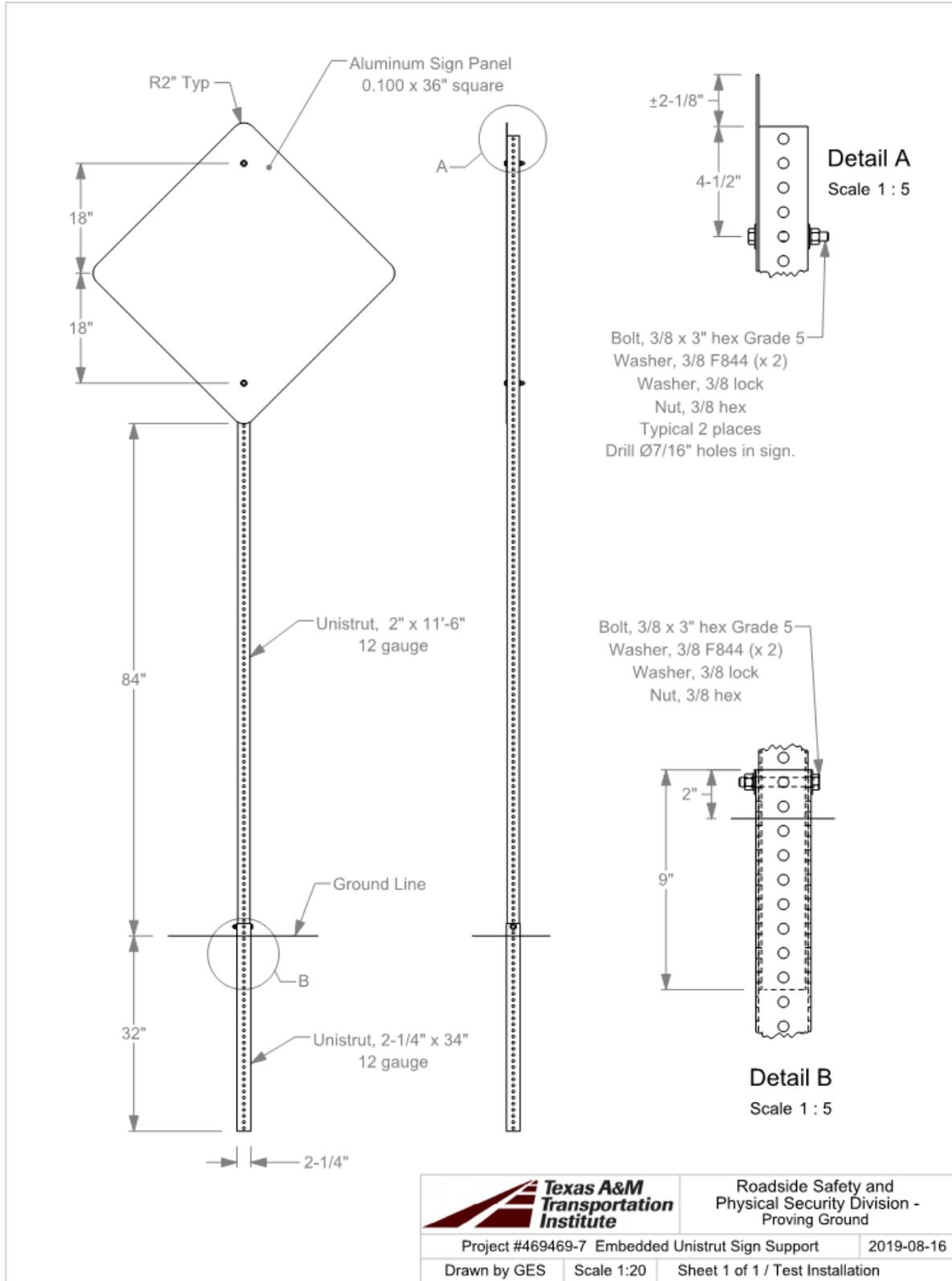


Figure 8.1. Overall Details of the PSST Sign Support in Anchor Stub System for Text No. 469469-7-2.

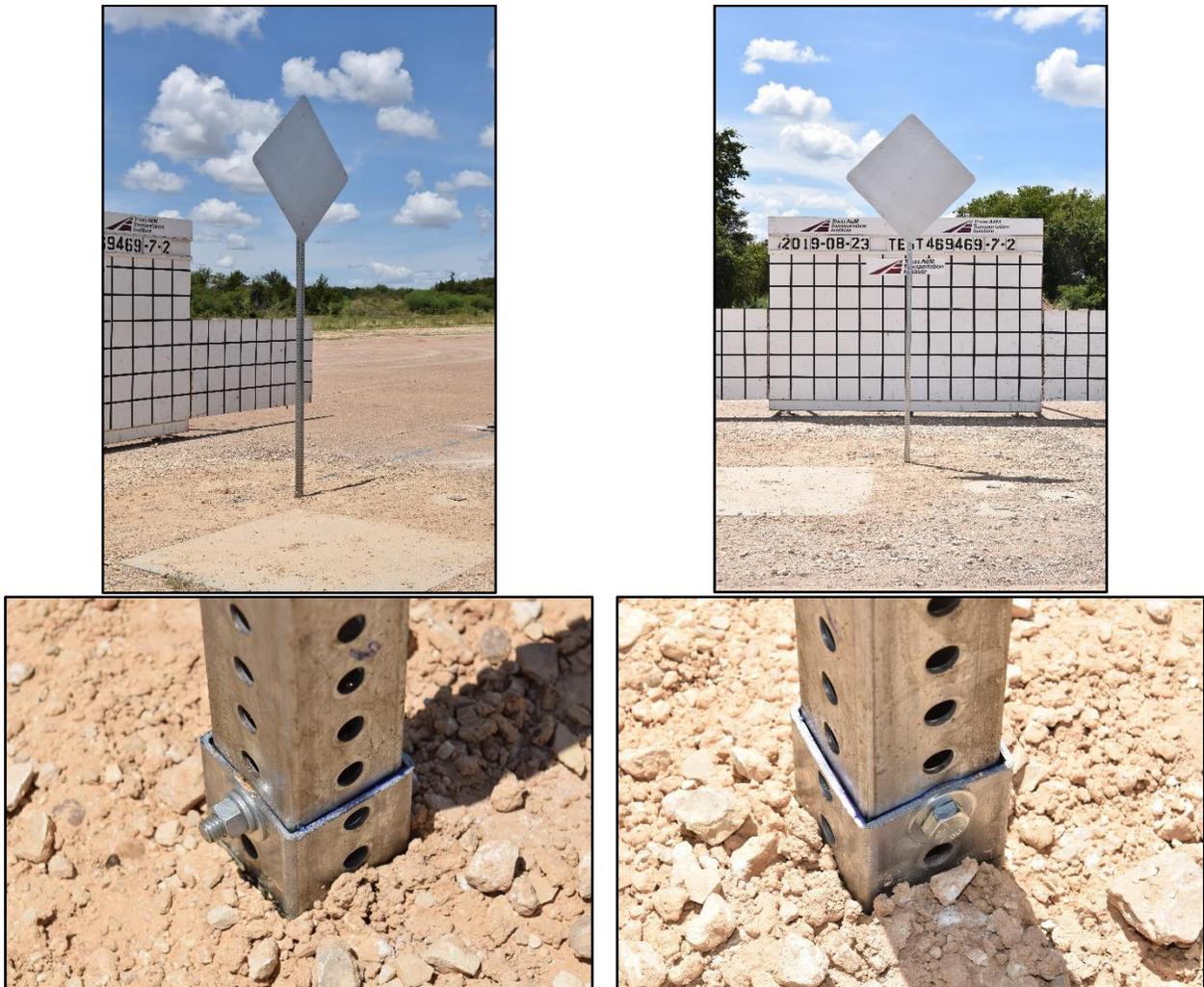


Figure 8.2. PSST Sign Support in Anchor Stub System prior to Test No. 469469-07-02.

8.2.2.3 Test Vehicle

The 2011 Kia Rio shown in Figure 8.3 and Figure 8.4 was used for the crash test. The vehicle's test inertia weight was 2443 lb, and its gross static weight was 2608 lb. The height to the lower edge of the vehicle bumper was 7.75 inches, and height to the upper edge of the bumper was 21.5 inches. Table G.3 in Appendix G.1.2 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 8.3. PSST Sign Support in Anchor Stub System Test Vehicle Geometrics for Test No. 469469-07-02.



Figure 8.4. Test Vehicle before Test No. 469469-07-02.

8.2.2.4 Test Description

Table 8.1 lists events that occurred during Test No. 469469-07-02. Figure G.1 in Appendix G.1.3 presents sequential photographs during the test.

Table 8.1. Events during Test No. 469469-07-02.

Time	Events
0.000	Vehicle contacts support post
0.011	Anchor stub begins to pull out of soil
0.043	Anchor stub fractures
0.059	Corner of sign makes contact with vehicle at roof and windshield interface
0.065	Corner of sign penetrates into occupant compartment
0.095	Sign at max penetration into occupant compartment

Brakes were applied 3.3 seconds after impact, and the vehicle came to rest 450 ft downstream of the initial point of impact and in line of the impact path.

8.2.2.5 Damage to Test Installation

Figure 8.5 shows the damage to the PSST sign support in anchor stub system. The anchor stub displaced 2½ inches rearward in the soil and fractured 9 inches below the top end as it was pulled out of the ground. The support post was bent 90° approximately 18 inches above grade. The sign panel remained attached to the post, and the assembly landed 240 ft downstream of the point of impact and in line with the impact path.



Figure 8.5. PSST Sign Support in Anchor Stub System after Test No. 469469-07-02.

8.2.2.6 Damage to Test Vehicle

Figure 8.6 and Figure 8.7 show the damage sustained by the vehicle. There was a dent 14 inches to the left of the vehicle centerline in the front bumper and hood. The windshield had a 44-inch by 31-inch by 13-inch-deep dent with a 6-inch by 24-inch cut in the laminate. The roof sustained a 41-inch by 27-inch by 12-inch-deep dent. There was also a 16-inch-long tear in the roof along the left seam line. There was no measurable exterior crush of the vehicle. The roof was pushed 11½ inches into the occupant compartment. Table G.4 and Table G.5 in Appendix G.1.2 provide exterior crush and occupant compartment measurements.

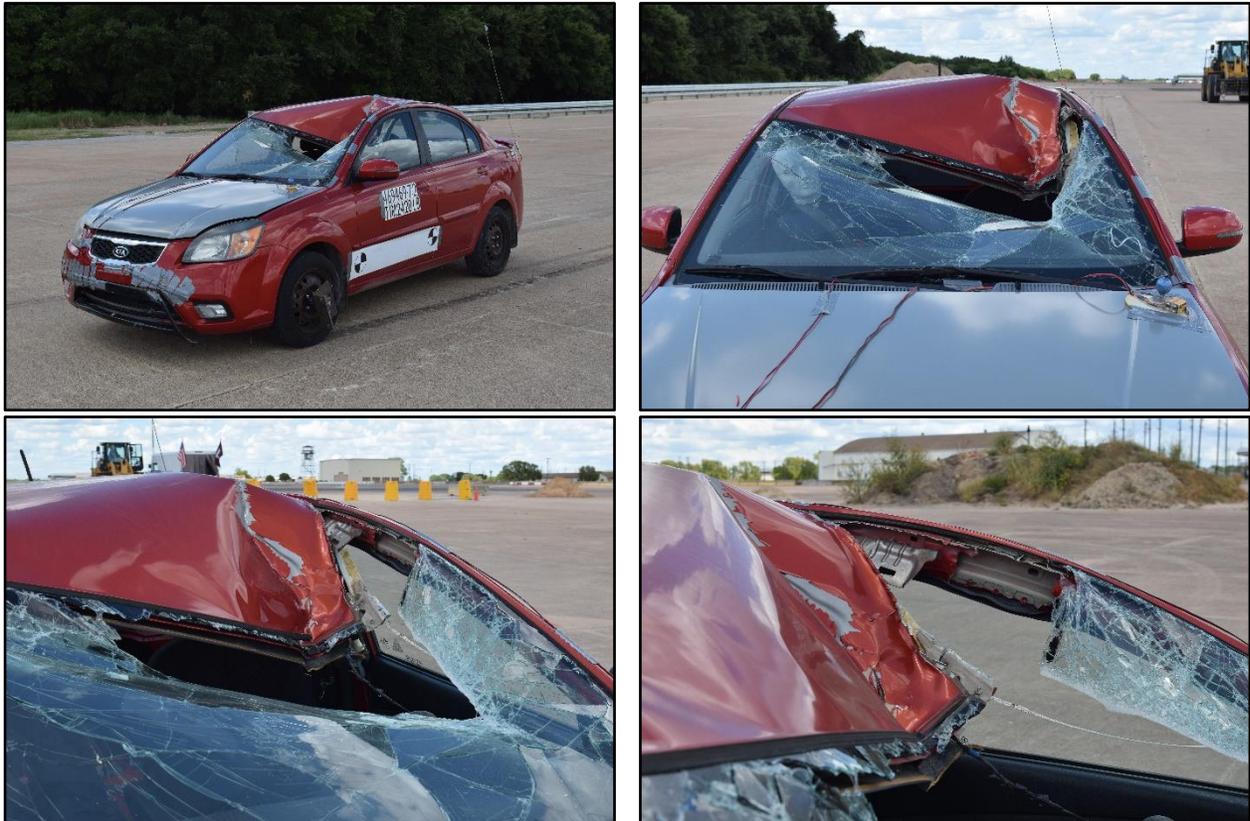


Figure 8.6. Test Vehicle after Test No. 469469-07-02.



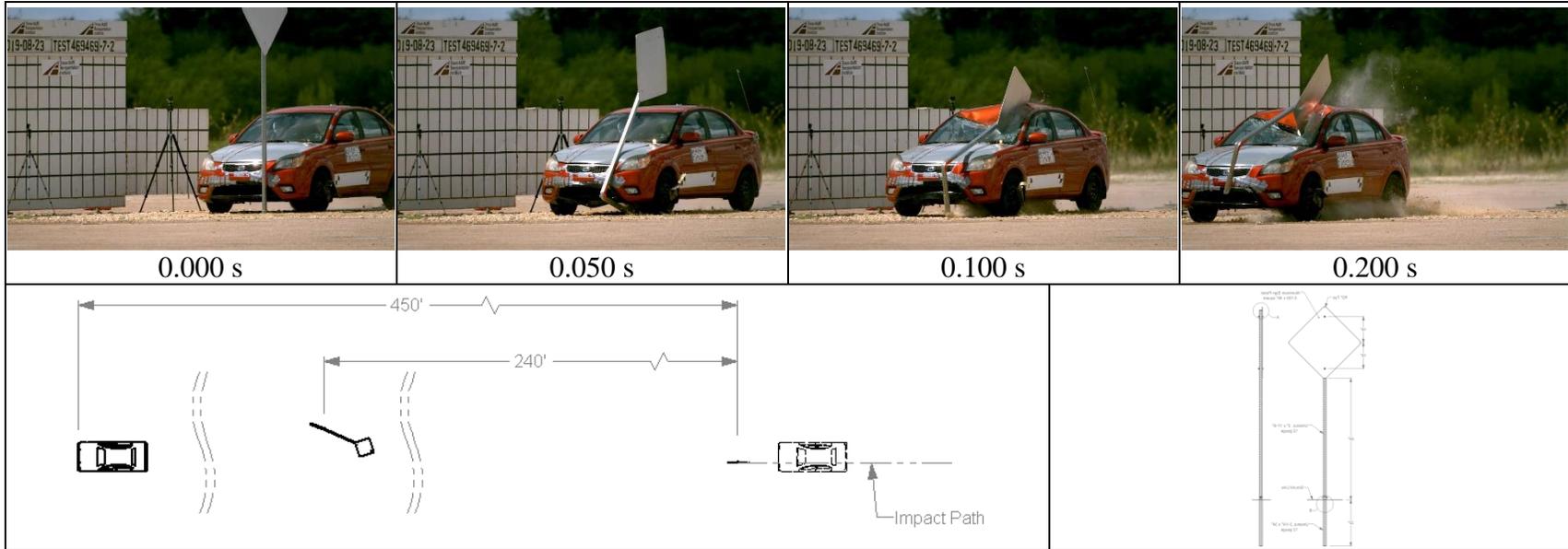
Figure 8.7. Interior of Test Vehicle after Test No. 469469-07-02.

8.2.2.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 8.2. Figure 8.8 summarizes these data and other pertinent information from the test. Figure G.3 in Appendix G.1.4 shows the vehicle angular displacements, and Figure G.4 through Figure G.6 in Appendix G.1.5 show acceleration versus time traces.

Table 8.2. Occupant Risk Factors for Test No. 469469-07-02.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)	ft/s	at 0.7037 seconds on front of interior
Longitudinal	3.0	
Lateral	0.0	
Occupant Ridedown Accelerations (g's)		
Longitudinal	0.8	(1.8902–1.9002 seconds)
Lateral	0.5	(0.8154–0.8254 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.6964 seconds on front of interior
	0.9	
Acceleration Severity Index (ASI)	0.1	(0.0133–0.0633 seconds)
Maximum 50-ms Moving Average (g's)		
Longitudinal	-1.4	(0.0016–0.0516 seconds)
Lateral	0.3	(0.6392–0.6892 seconds)
Vertical	0.9	(0.0476–0.0976 seconds)
Maximum Roll, Pitch, and Yaw Angles	Degrees	
Roll	2	(0.3695 seconds)
Pitch	2	(1.8772 seconds)
Yaw	2	(0.3055 seconds)



General Information		Impact Conditions		Post-Impact Trajectory	
Test Agency.....	Texas A&M Transportation Institute (TTI)	Speed	62.7 mi/h	Stopping Distance	450 ft, in line
Test Standard Test No.	MASH Test 3-61	Angle	0°	Vehicle Stability	
TTI Test No.....	469469-07-02	Location/Orientation	Center of post aligned	Maximum Yaw Angle.....	2°
Test Date.....	2019-08-23		14 inches off center of the vehicle toward the driver's side	Maximum Pitch Angle....	2°
Test Article		Impact Severity	321 kip*ft	Maximum Roll Angle	2°
Type.....	Sign support structure	Exit Conditions		Vehicle Snagging	No
Name	PSST sign support in anchor stub	Speed	n/a	Vehicle Pocketing.....	n/a
Installation Length.....	n/a	Exit Trajectory/Heading	n/a	Test Article Deflections	
Material or Key Elements	2-inch x 12-ga. PSST support inserted into 2¼ -inch x 12-ga. PSST anchor stub, 36-inch-square x 0.100-inch-thick aluminum sign at 84 inches above grade	Occupant Risk Values		Dynamic.....	n/a
Soil Type and Condition	Embedded in AASHTO M147-65(2004), Grading B soil (crushed limestone)	Longitudinal OIV.....	3.0 ft/s	Permanent	n/a
Test Vehicle		Lateral OIV.....	0.0 ft/s	Working Width.....	n/a
Type/Designation	1100C	Longitudinal Ridedown	0.8 g	Working Width Height....	n/a
Make and Model	2011 Kia Rio	Lateral Ridedown	0.5 g	Vehicle Damage	
Curb.....	2544 lb	THIV	0.9 m/s	VDS	12FL2
Test Inertial	2443 lb	ASI	0.13	CDC	12TLGN3
Dummy	165 lb	Max. 0.050-s Average		Max. Exterior Deformation	Non-measurable
Gross Static	2608 lb	Longitudinal.....	-1.4 g	OCDI.....	LF0300000
		Lateral.....	0.3 g	Max. Occupant Compartment Deformation	11.5 inches at roof
		Vertical.....	0.9 g		

Figure 8.8. Summary of Results for MASH Test 3-61 on the PSST Sign Support in Anchor Stub System.

8.2.2.8 *Assessment of Results*

An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-61 is provided in Table 8.3.

8.2.3 Conclusions

The anchor stub fractured as it was pulled out of the ground. After the anchor stub fractured, the sign panel and support rotated toward the vehicle and impacted the windshield and roof. The sign penetrated into the occupant compartment through the windshield and roof. Consequently, the PSST sign support in anchor stub system did not satisfy *MASH* criteria for breakaway support structures.

After the unsuccessful test of the PSST sign support in anchor stub system, it was decided to evaluate the impact performance of a 2-inch by 12-gauge PSST support post in a reinforced anchor stub. The reinforcing sleeve provides additional stiffening of the support post at the ground line, which should help facilitate fracture of the support post during an impact. Quicker fracture of the support post may change the trajectory of the released sign support system. The crash test performed on the PSST sign support in reinforced anchor stub system is described in the next section.

Table 8.3. Performance Evaluation Summary for MASH Test 3-61 on the PSST Sign Support in Anchor Stub System.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-07-02

Test Date: 2019-08-23

MASH Test 3-61 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
<i>B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</i>	The embedded Unistrut sign post support system yielded to the 1100C vehicle and fractured.	Pass
<u>Occupant Risk</u>		
<i>D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i>	After fracture of the anchor stub, the released sign support system rotated toward the vehicle and impacted the windshield and roof of the vehicle. The sign panel penetrated through the windshield and roof into the occupant compartment.	Fail
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</i>	There was a 24-inch-long cut in the windshield that connected to a 16-inch-long cut in the roof.	Fail
<i>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 2° and 2°, respectively.	Pass
<i>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.</i>	Longitudinal OIV was 3.0 ft/s, and lateral OIV was 0.0 ft/s.	Pass
<i>I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>	Longitudinal occupant ridedown acceleration was 0.8 g, and lateral occupant ridedown was 0.5 g.	Pass
<u>Vehicle Trajectory</u>		
<i>N. Vehicle trajectory behind the test article is acceptable.</i>	The 1100C vehicle came to rest 450 ft behind the original position of the installation.	Documentation only

8.3 PSST SIGN SUPPORT IN REINFORCED ANCHOR STUB

8.3.1 Test Article and Installation Details

The PSST sign support in reinforced anchor stub system test assembly consisted of a 2-inch by 12-gauge PSST support post inserted 12 inches into a reinforced anchor stub. The 2¼-inch by 12-gauge by 42-inch-long PSST anchor stub was embedded such that it protruded 2 inches above grade. A 2½-inch by 12-gauge by 18-inch-long PSST reinforcing sleeve was placed over and flush with the top of the anchor stub. The PSST support was secured inside the anchor stub using a 5/16-inch-diameter corner bolt and hardware. The PSST support, anchor stub, and reinforcing sleeve contained 7/16-inch-diameter holes spaced on 1-inch centers on all four faces. The anchor stub and reinforcing sleeve were installed in AASHTO M147-65(2004), Grading B soil (crushed limestone) that was compacted to meet *MASH* performance standards as demonstrated by a static post pull test (Appendix G.2.1).

A 36-inch by 36-inch by 0.100-inch-thick aluminum sign panel was mounted to the support post in a diamond orientation using two ¾-inch-diameter hex head bolts and hardware, with the bottom corner located 84 inches above grade.

Figure 8.9 presents overall information on the PSST sign support in reinforced anchor stub system, and Figure 8.10 provides photographs of the test installation. Appendix G.2 provides further details of the PSST sign support in reinforced anchor stub system.

8.3.2 MASH Test 3-61 (Test No. 469469-07-05)

8.3.2.1 Test Designation and Actual Impact Conditions

MASH Test 3-61 involves a 1100C vehicle weighing 2420 lb ±55 lb impacting the PSST sign support in anchor stub system at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 90° ±1.5°. The selected impact point was the centerline of the PSST sign support in anchor stub system aligned 14 inches off the centerline of the vehicle toward the driver's side.

The 2007 Kia Rio¹⁰ used in the test weighed 2450 lb, and the actual impact speed and angle were 61.3 mi/h and 90°, respectively. Minimum target impact severity was 288 kip-ft, and actual IS was 308 kip-ft.

8.3.2.2 Weather Conditions

The test was performed on the morning of August 29, 2019. Weather conditions at the time of testing were as follows: wind speed: 2 mi/h; wind direction: 225° with respect to the vehicle (vehicle was traveling at a magnetic heading of 180°); temperature: 86°F; relative humidity: 81 percent.

¹⁰ The 2007 model vehicle used is older than the 6-year age noted in *MASH* and was selected based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2007 model vehicle met the *MASH* requirements.

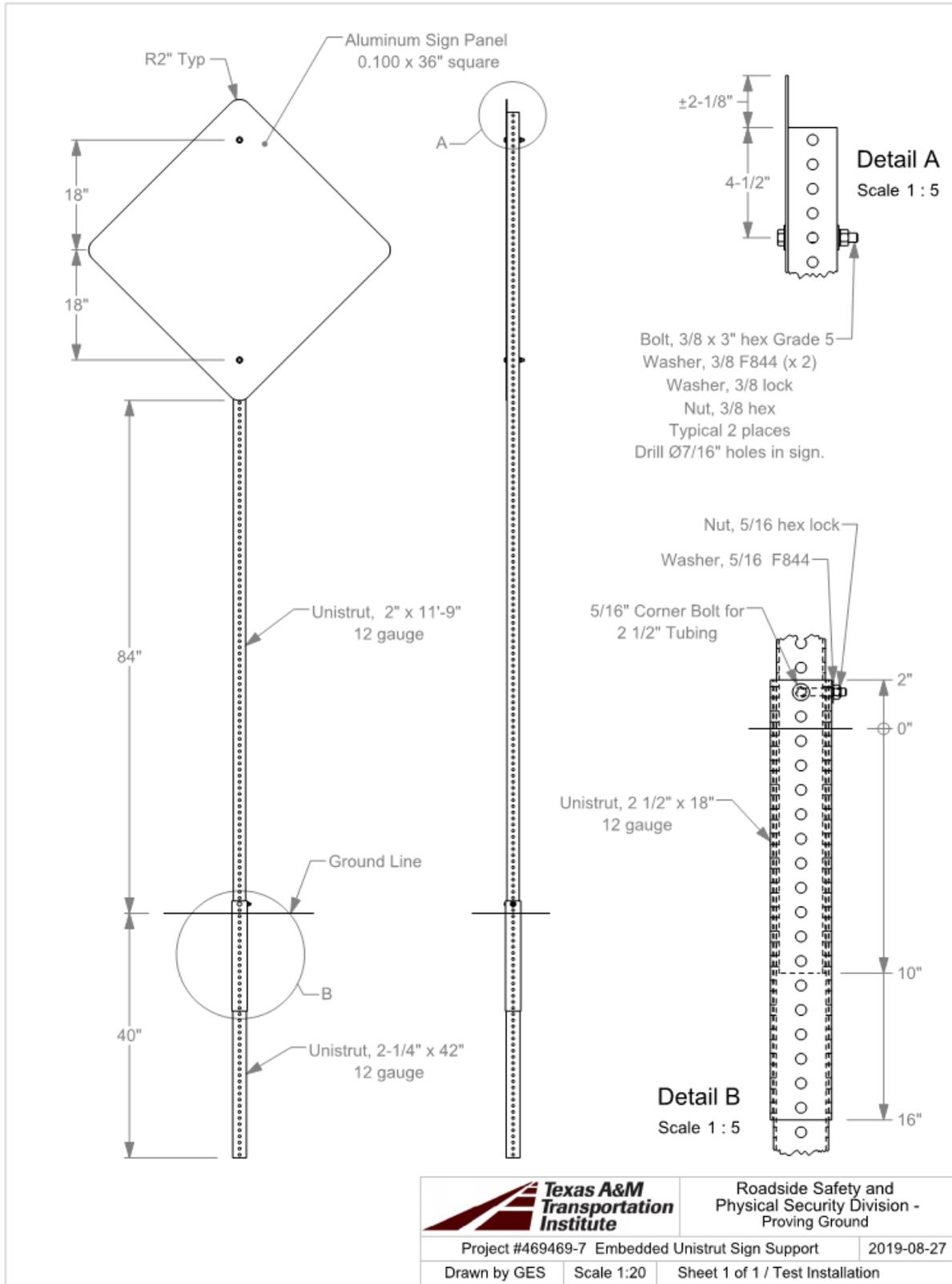


Figure 8.9. Overall Details of the PSST Sign Support in Anchor Stub System for Test No. 469469-7-5.

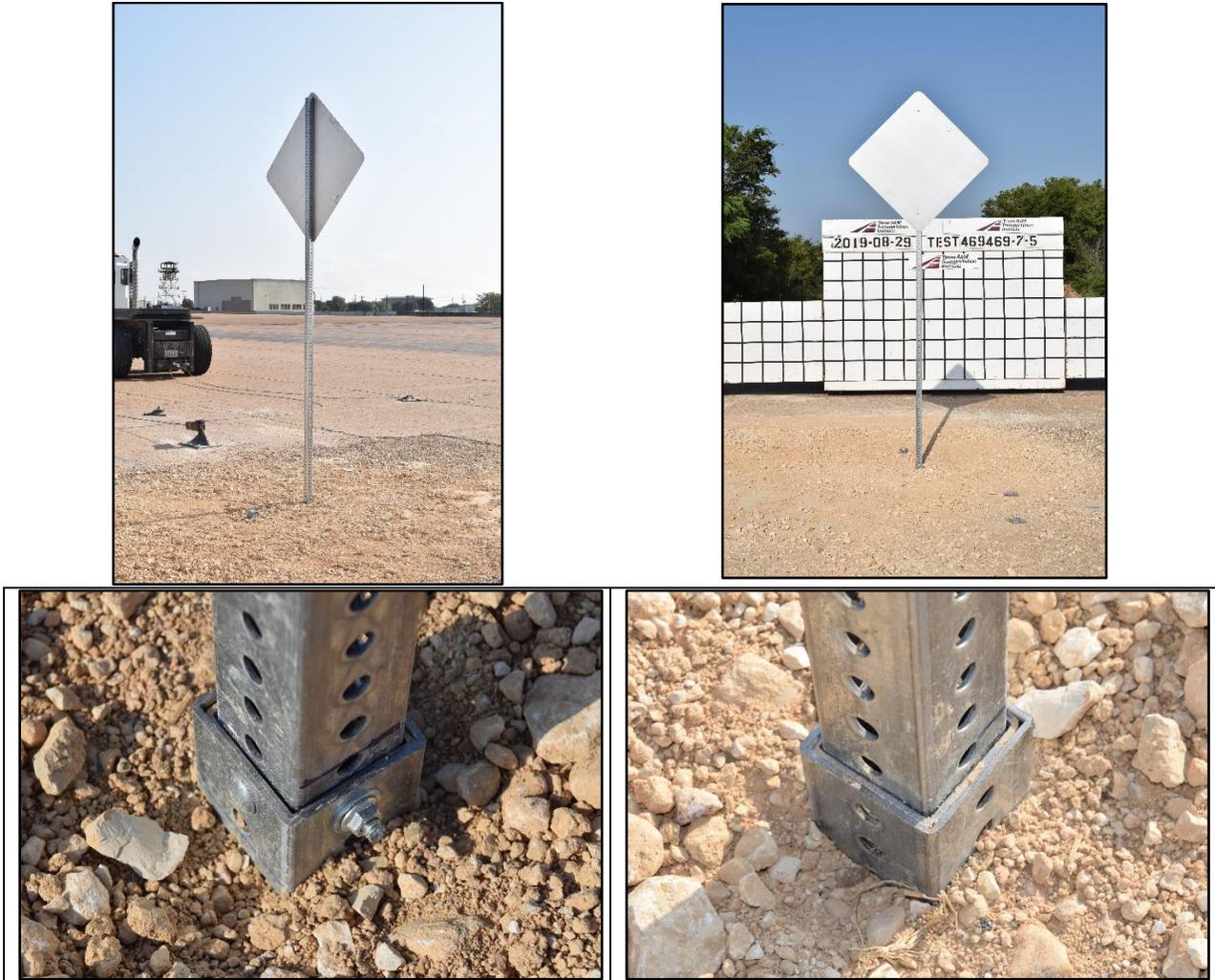


Figure 8.10. PSST Sign Support in Anchor Stub System prior to Test No. 469469-07-05.

8.3.2.3 Test Vehicle

The 2007 Kia Rio shown in Figure 8.11 and Figure 8.12 was used for the crash test. The vehicle's test inertia weight was 2450 lb, and its gross static weight was 2615 lb. The height to the lower edge of the vehicle bumper was 7.75 inches, and height to the upper edge of the bumper was 21.5 inches. Table G.8 in Appendix G.2.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 8.11. PSST Sign Support in Anchor Stub System Test Vehicle Geometrics for Test No. 469469-07-05.



Figure 8.12. Test Vehicle before Test No. 469469-07-05.

8.3.2.4 Test Description

Table 8.4 lists events that occurred during Test No. 469469-07-05. Figure G.7 in Appendix G.2.3 present sequential photographs during the test.

Table 8.4. Events during Test No. 469469-07-05.

Time	Events
0.000	Vehicle contacts support post
0.010	Support post begins to pull out of anchor stub
0.015	Support post fractures near grade
0.067	Corner of sign makes contact with roof
0.071	Corner of sign penetrates into occupant compartment
0.125	Sign at maximum penetration into occupant compartment

Brakes were applied 2.3 seconds after impact, and the vehicle came to rest 420 ft downstream of the point of impact and in line of the impact path.

8.3.2.5 Damage to Test Installation

Figure 8.13 shows the damage to the PSST sign support in anchor stub system. The soil was disturbed around the anchor stub and reinforcing sleeve. The corner bolt was fractured. The support post lifted about 2 inches out of the anchor stub and fractured approximately 4 inches above grade. The sign panel remained attached to the post, and the assembly landed 150 ft downstream of the point of impact and 13 ft to the left of the impact path.

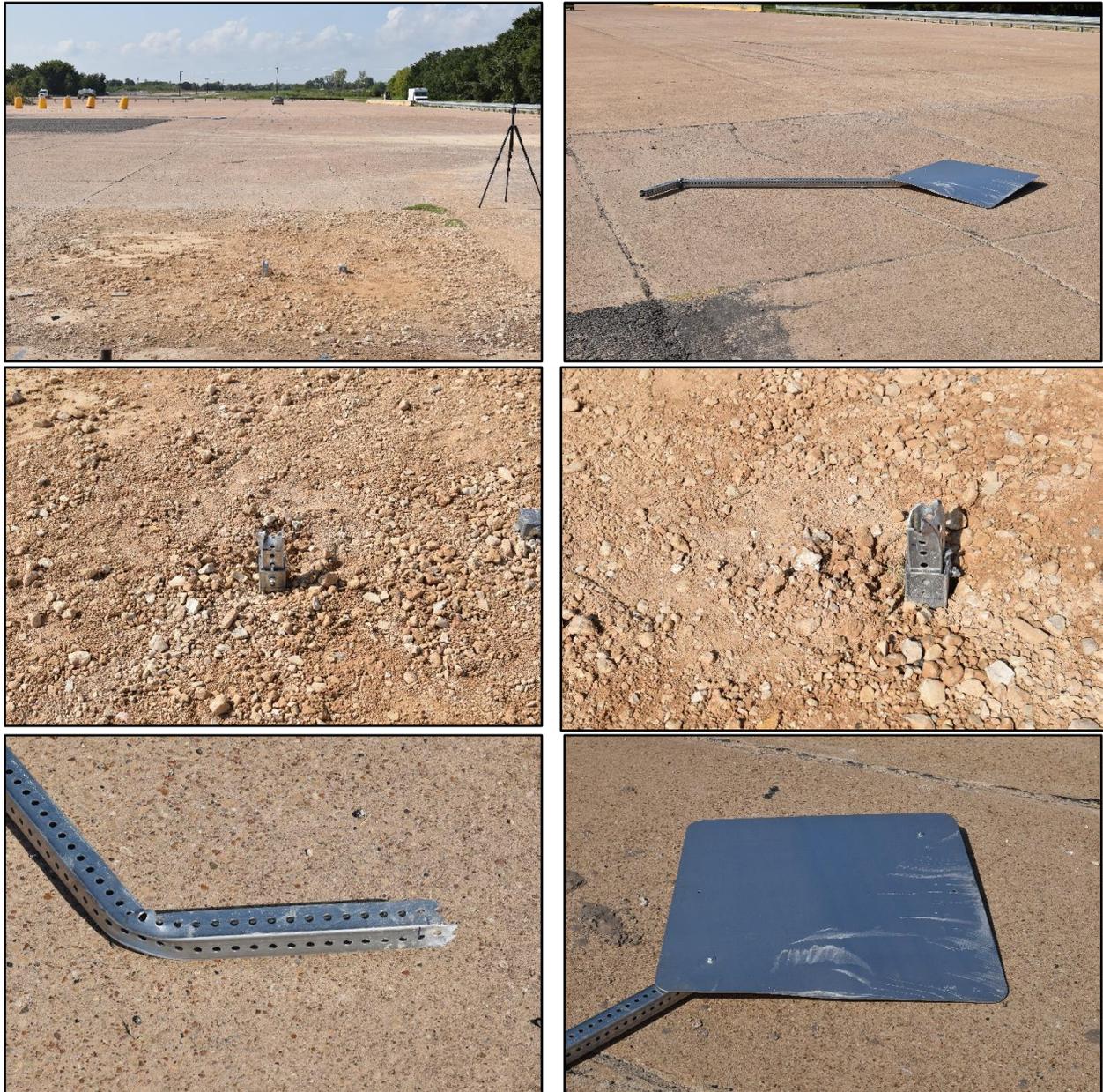


Figure 8.13. PSST Sign Support in Anchor Stub System after Test No. 469469-07-05.

8.3.2.6 Damage to Test Vehicle

Figure 8.14 and Figure 8.15 show the damage sustained by the vehicle. There was a dent located 14 inches to the left of the vehicle centerline in the front bumper and hood. The windshield was shattered in an area measuring 34 inches by 16 inches by 1 inch deep. The roof sustained a 4-inch-wide by 46½-inch-long cut. There was no measurable exterior crush of the vehicle. The deformation of the roof extended 11¼ inches into the occupant compartment. Table G.9 and Table G.10 in Appendix G.2.2 provide exterior crush and occupant compartment measurements.

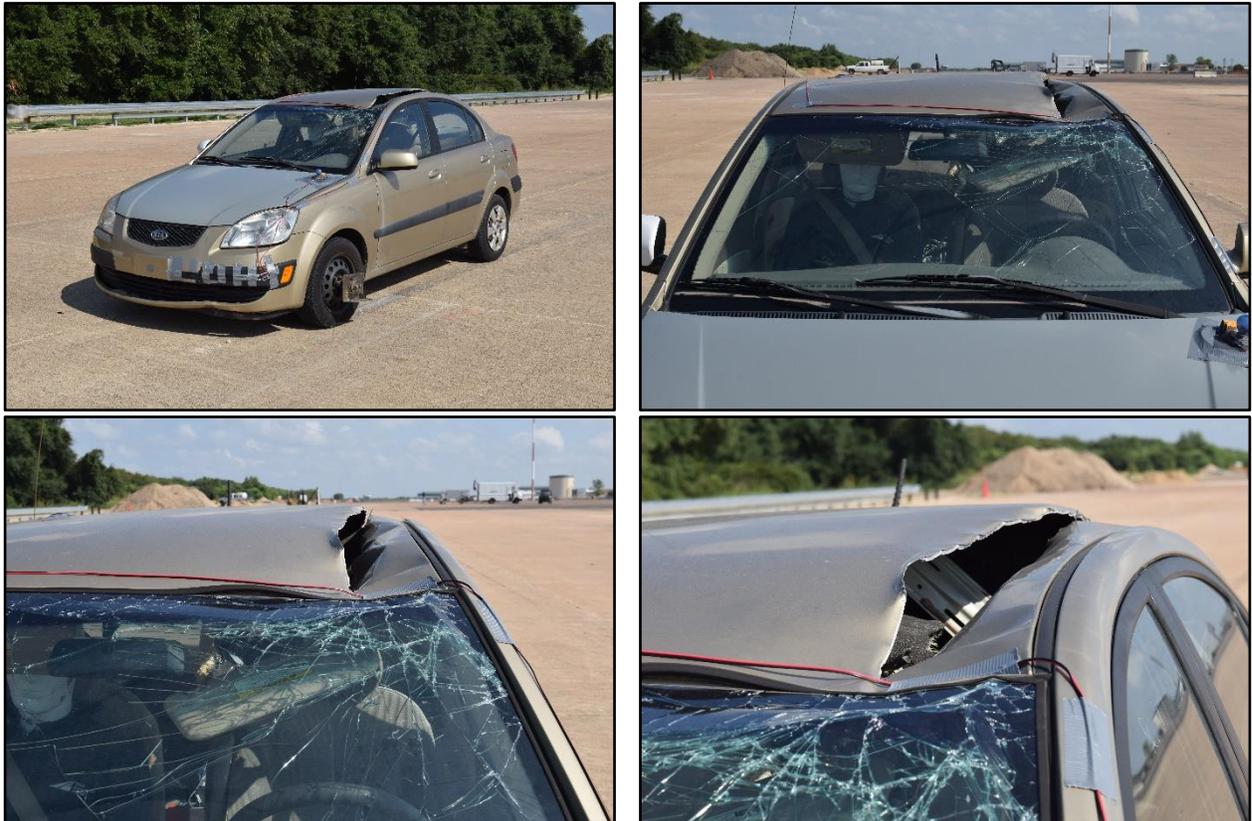


Figure 8.14. Test Vehicle after Test No. 469469-07-05.



Figure 8.15. Interior of Test Vehicle after Test No. 469469-07-05.

8.3.2.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 8.5. Figure 8.16 summarizes these data and other pertinent information from the test. Figure G.8 in Appendix G.2.4 shows the vehicle angular displacements, and Figure G.9 through Figure G.11 in Appendix G.2.5 show acceleration versus time traces.

Table 8.5. Occupant Risk Factors for Test No. 469469-07-05.

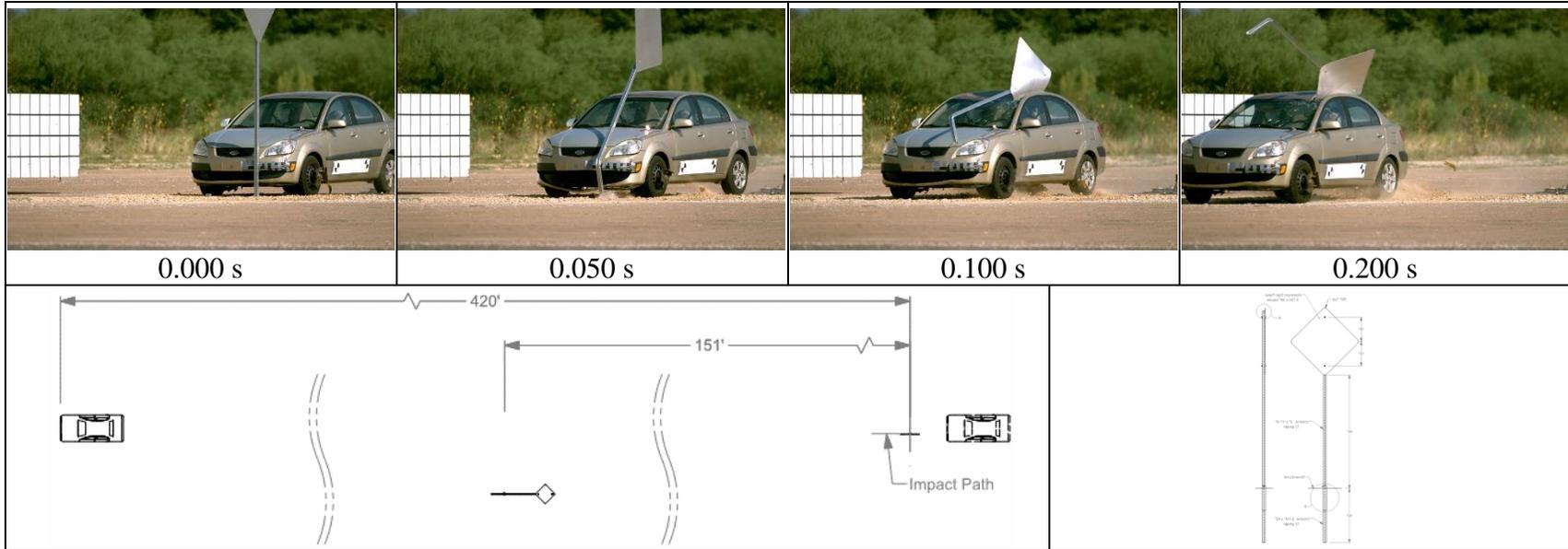
Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV) Longitudinal Lateral	ft/s	at 0.6523 seconds on right side of interior
	2.6	
	2.6	
Occupant Ridedown Accelerations (g's) Longitudinal Lateral		
	0.3	(0.7642–0.7742 seconds)
	0.4	(1.0180–1.0280 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.6539 seconds on right side of interior
	1.1	
Post Head Deceleration (PHD) (g's)	0.4	(1.0179–1.0279 seconds)
Acceleration Severity Index (ASI)	0.1	(0.0077–0.0577 seconds)
Maximum 50-ms Moving Average (g's) Longitudinal Lateral Vertical		
	-0.7	(0.0016–0.0516 seconds)
	-0.4	(0.1773–0.2273 seconds)
	0.8	(0.0383–0.0883 seconds)
Maximum Roll, Pitch, and Yaw Angles Roll Pitch Yaw	Degrees	
	2	(1.9996 seconds)
	1	(0.2145 seconds)
	2	(0.3164 seconds)

8.3.2.8 Assessment of Results

An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-61 is provided in Table 8.6.

8.3.3 Conclusions

The sign support fractured near the ground line as designed. After the support post fractured, the sign panel and support rotated toward the vehicle and impacted the windshield and roof. The sign penetrated through the roof into the occupant compartment, and the roof sustained 11¼ inches of deformation into the occupant compartment. Consequently, the PSST sign support in reinforced anchor stub system did not satisfy *MASH* criteria for breakaway support structures.



General Information		Impact Conditions		Post-Impact Trajectory	
Test Agency.....	Texas A&M Transportation Institute (TTI)	Speed	61.3 mi/h	Stopping Distance	420 ft, in line
Test Standard Test No.	MASH Test 3-61	Angle	0°	Vehicle Stability	
TTI Test No.....	469469-07-05	Location/Orientation	Center of post aligned	Maximum Yaw Angle.....	2°
Test Date	2019-08-29		14 inches off center of the vehicle toward the driver's side	Maximum Pitch Angle....	1°
Test Article			308 kip*ft	Maximum Roll Angle	2°
Type.....	Sign support structure	Impact Severity		Vehicle Snagging	No
Name	PSST sign support in reinforced anchor stub	Speed	n/a	Vehicle Pocketing.....	n/a
Installation Length.....	n/a	Exit Trajectory/Heading	n/a	Test Article Deflections	
Material or Key Elements	2-inch x 12-ga. PSST support inserted into 2¼ -inch x 12-ga. PSST anchor stub with 2¼ -inch x 12-ga. PSST reinforcing sleeve, 36-inch-square x 0.100-inch-thick aluminum sign at 84 inches above grade	Occupant Risk Values		Dynamic.....	n/a
	Embedded in AASHTO M147-65(2004), Grading B soil (crushed limestone)	Longitudinal OIV.....	2.6 ft/s	Permanent	n/a
Soil Type and Condition		Lateral OIV.....	2.6 ft/s	Working Width.....	n/a
		Longitudinal Ridedown	0.3 g	Working Width Height....	n/a
Test Vehicle		Lateral Ridedown	0.4 g	Vehicle Damage	
Type/Designation	1100C	THIV	1.1 m/s	VDS	12FL2
Make and Model	2007 Kia Rio	PHD	0.4 g	CDC	12TLGN3
Curb.....	2453 lb	ASI.....	0.1	Max. Exterior Deformation	Non-measurable
Test Inertial	2450 lb	Max. 0.050-s Average		OCDI.....	LF0300000
Dummy	165 lb	Longitudinal.....	-0.7 g	Max. Occupant Compartment Deformation	11¼ inches at roof
Gross Static	2615 lb	Lateral.....	-0.4 g		
		Vertical.....	0.8 g		

Figure 8.16. Summary of Results for MASH Test 3-61 on the PSST Sign Support in Anchor Stub System.

Table 8.6. Performance Evaluation Summary for MASH Test 3-61 on the PSST Sign Support in Anchor Stub System.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-07-05

Test Date: 2019-08-29

MASH Test 3-61 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
B. <i>The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</i>	The embedded Unistrut sign post support yielded to the 1100C vehicle and fractured as designed.	Pass
<u>Occupant Risk</u>		
D. <i>Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i>	After fracture of the support post, the released sign support system rotated toward the vehicle and impacted the windshield and roof of the vehicle. The sign panel penetrated through the roof into the occupant compartment.	Fail
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</i>	There was a 4-inch wide by 46½-inch-long cut in the roof and 11¼ inches of roof deformation.	Fail
F. <i>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 2° and 1°, respectively.	Pass
H. <i>Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.</i>	Longitudinal OIV was 2.6 ft/s, and lateral OIV was 2.6 ft/s.	Pass
I. <i>The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>	Longitudinal occupant ridedown acceleration was 0.3 g, and lateral occupant ridedown was 0.4 g.	Pass
<u>Vehicle Trajectory</u>		
N. <i>Vehicle trajectory behind the test article is acceptable.</i>	The 1100C vehicle came to rest 420 ft behind and 13 ft to left of the original position of the installation.	Pass

CHAPTER 9: TXDOT BURN BAN SIGN ON SLIP BASE SUPPORT

9.1 BACKGROUND

TxDOT permits counties to post advisory signs on the roadside to alert motorists when a burn ban is in effect. The current practice is to append the burn ban notification signs to existing sign support structures.

Two different sizes of burn ban signs fabricated from lightweight composite sheeting were appended to slip base sign supports and evaluated through full-scale crash testing under NCHRP Report 350 with the 820C vehicle (6). In the full-scale tests, secondary contact of the released sign support system with the roof of the impacting vehicle resulted in roof deformation ranging from 4.8 inches to 5.6 inches (7). Although these deformations were considered acceptable under NCHRP Report 350, they exceed the permissible roof deformation criteria of 4 inches in *MASH*. Additional testing of burn ban signs on slip base supports was therefore needed with both the 1100C passenger car and the 2270P pickup truck design vehicle that was added to the *MASH* test matrix for breakaway support structures. Since burn ban signs are deployed on support structures along the roadside and not at or near intersections, only evaluation at 0° was considered necessary.

The previous testing of the burn ban signs under NCHRP Report 350 showed that the observed roof deformation was largely attributed to the practice of using small signs on slip base supports rather than the appended lightweight burn ban signs (7). This led to further research that concluded the minimum sign area that should be used on a slip base support to meet *MASH* requirements for 0° impacts is 14 sq ft (8). Therefore, it was recommended to append the burn ban sign to a slip base sign support system that has a primary sign panel area of at least 14 sq ft.

Two different sizes of burn ban signs are used. The smaller 24-inch by 24-inch sign is intended to simply communicate that a burn ban is in effect. The larger 30-inch by 36-inch sign additionally indicates the name of the county when needed. The larger sign is the more critical of the two sizes. If testing of the 30-inch by 36-inch burn ban sign is satisfactory, the smaller 24-inch by 24-inch burn ban sign will also be considered *MASH* compliant.

9.2 SYSTEM DETAILS

9.2.1 Test Article and Installation Details

The test installation for evaluation of a burn ban sign on slip base support consisted of a 45-inch-square by 0.10-inch-thick aluminum sign mounted on a 2½-inch 10 BWG pipe support, with the lower edge of the primary sign located 84 inches above grade. A T-bracket was attached to the top of the 10 BWG pipe to help support the aluminum sign panel.

A second 30-inch-wide by 36-inch-tall by 0.080-inch-thick lightweight composite burn ban sign was mounted 3 inches below the primary sign. The composite burn ban sign panel was comprised of a thin sheet of high-density polyethylene plastic between aluminum sheets. This smaller sign was attached directly to the pipe support.

The bottom end of the 10 BWG pipe support was secured inside a cast slip base assembly using three set screws. The upper triangular slip base plate was secured to a matching lower plate

using three slip bolts tightened to a torque of 60 ft-lb. A keeper plate was positioned between the upper and lower slip plates. The lower triangular slip plate was attached to a pipe stub that was embedded in a 12-inch-diameter by 42-inch-deep unreinforced concrete footing.

Figure 9.1 presents overall information on the burn ban sign on slip base support, and Figure 9.2 provides photographs of the installation. Appendix H.1 provides further details of the burn ban sign on slip base support.

9.2.2 Material Specifications

Appendix H.2 provides material certification documents for the materials used to install/construct the burn ban sign on slip base support.

9.3 MASH TEST 3-61 (TEST NO. 469469-08-01)

9.3.1 Test Designation and Actual Impact Conditions

MASH Test 3-61 involves a 1100C vehicle weighing 2420 lb \pm 55 lb impacting the CIP of the burn ban sign with slip base at an impact speed of 62 mi/h \pm 2.5 mi/h and an angle of 0° \pm 1.5°. The centerline of the support post was aligned 13 inches off the centerline of the vehicle toward the driver's side.

The 2007 Kia Rio used in the test weighed 2418 lb, and the actual impact speed and angle were 62.9 mi/h and 0°, respectively. Minimum target IS was 288 kip-ft, and actual IS was 320 kip-ft.

9.3.2 Weather Conditions

The test was performed on the morning of April 26, 2019. Weather conditions at the time of testing were as follows: wind speed: 4 mi/h; wind direction: 30° with respect to the vehicle (vehicle was traveling in a southerly direction); temperature: 73°F; relative humidity: 71 percent.

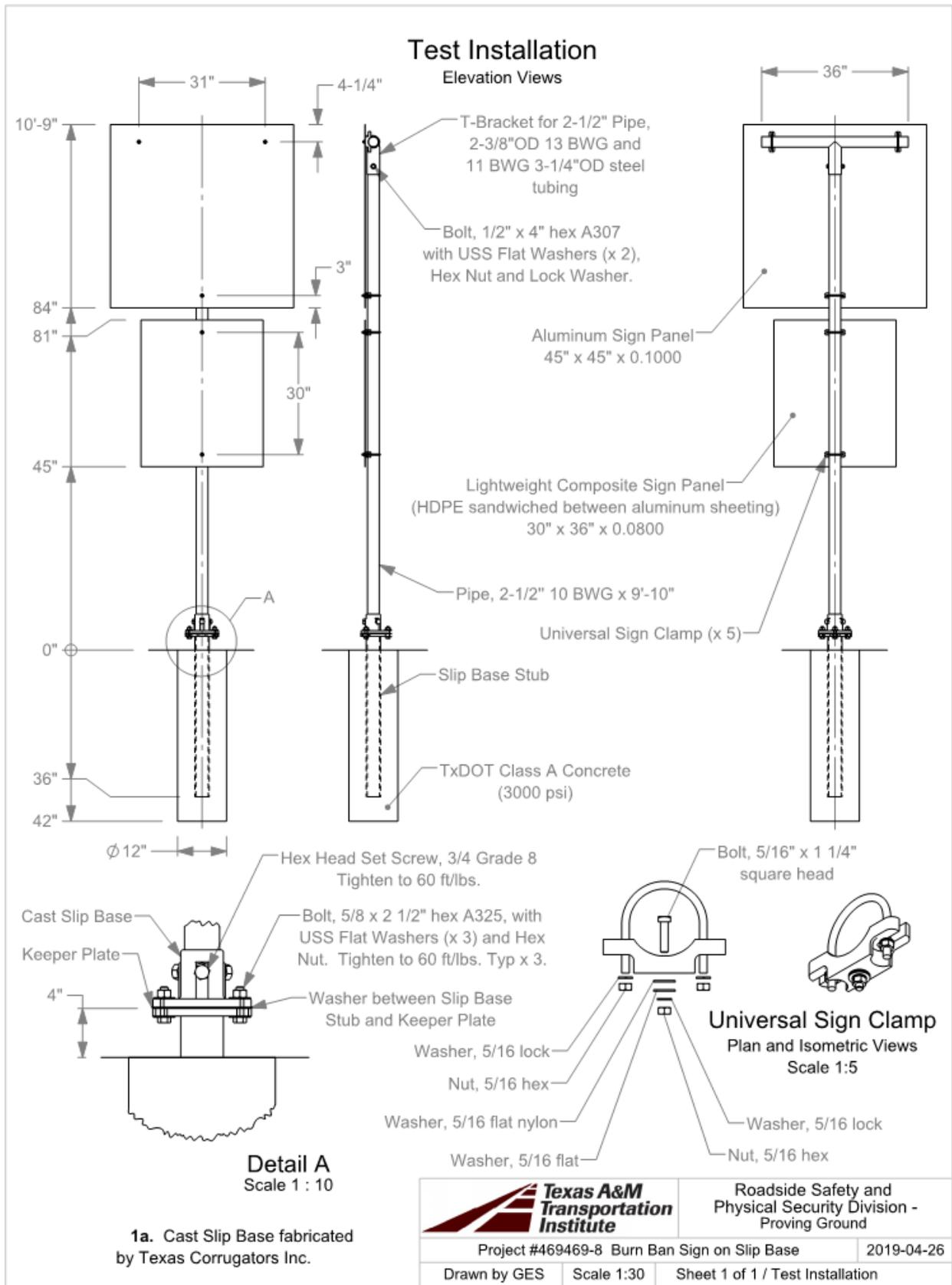


Figure 9.1. Overall Details of the Burn Ban Sign on Slip Base Support.



Figure 9.2. Burn Ban Sign on Slip Base Support prior to Test No. 469469-08-01.

9.3.3 Test Vehicle

The 2007 Kia Rio shown in Figure 9.3 and Figure 9.4 was used for the crash test. The vehicle's test inertia weight was 2418 lb, and its gross static weight was 2583 lb. The height to the lower edge of the vehicle bumper was 7.75 inches, and height to the upper edge of the bumper was 21.5 inches. Table H.1. and Table H.2. in Appendix H.3.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 9.3. Burn Ban Sign with Slip Base Test Vehicle Geometrics for Test No. 469469-08-01.



Figure 9.4. Test Vehicle before Test No. 469469-08-01.

9.3.4 Test Description

Table 9.1 lists events that occurred during Test No. 469469-08-01. Figure H.1 in Appendix H.3.2 presents sequential photographs during the test.

Table 9.1. Events during Test No. 469469-08-01.

Time	Events
0.000	Vehicle contacts support
0.003	Slip base begins to move
0.007	Slip base completely released
0.015	Composite burn ban sign released from support
0.040	Released sign support loses contact with bumper
0.067	Composite burn ban sign impacts windshield
0.157	Sign and support contact rear window and trunk of vehicle
0.199	Sign and support rotates off of vehicle

The sign support installation rotated over the 1100C vehicle, and the vehicle came to rest 400 ft downstream of the impact point and in line with the initial impact path.

9.3.5 Damage to Test Installation

Figure 9.5 shows the damage to the burn ban sign on slip base support. The slip base system activated as designed, and the stub and foundation were undisturbed. The lower burn ban sign released from the pipe support and came to rest 105 ft downstream and 20 ft right of the original location. The remaining components of the sign support system stayed together and came to rest 120 ft downstream and 8 ft right of the original location.



Figure 9.5. Burn Ban Sign with Slip Base Support after Test No. 469469-08-01.

9.3.6 Damage to Test Vehicle

Figure 9.6 and Figure 9.7 show the damage sustained by the vehicle. There was a 4-inch by 6-inch by 2.5-inch-deep dent in the front bumper and a 3-inch by 4-inch by 1-inch-deep dent in the hood, the trunk lid was dented, and the rear window was ejected. The maximum exterior crush of the vehicle was 2.5 inches at the front bumper. There was no measurable occupant compartment deformation. The package deck (shelf) under the rear window showed signs of penetration by the hardware that attached the sign to the support (Figure 9.6). Table H.2 and Table H.3 in Appendix H.3.1 provide exterior crush and occupant compartment measurements.



Figure 9.6. Test Vehicle after Test No. 469469-08-01.



Figure 9.7. Interior of Test Vehicle after Test No. 469469-08-01.

9.3.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 9.2. Figure 9.8 summarizes these data and other pertinent information from the test. Figure H.2 in Appendix H.3.3 shows the vehicle angular displacements, and Figure H.3 through Figure H.5 in Appendix H.3.4 show acceleration versus time traces.

Table 9.2. Occupant Risk Factors for Test No. 469469-08-01.

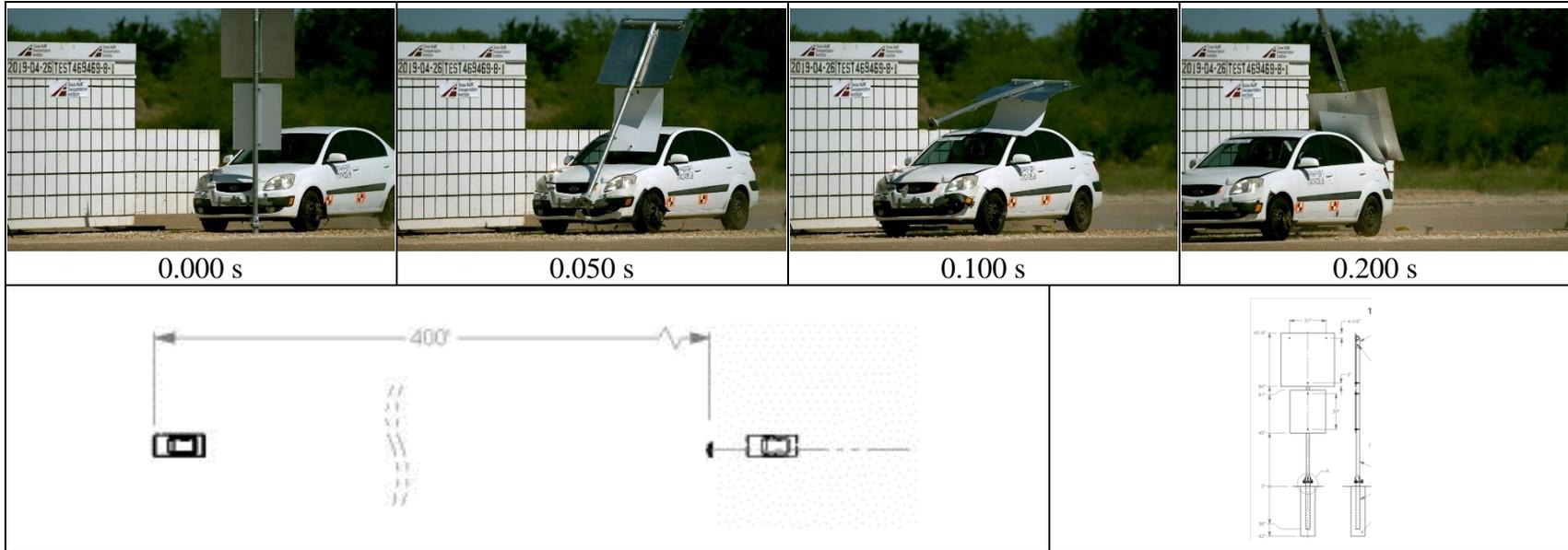
Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV) Longitudinal Lateral	ft/s	at 0.7746 seconds on right side of interior
	2.0	
	1.6	
Occupant Ridedown Accelerations (g's) Longitudinal Lateral		
	0.2	(1.2171–1.2271 seconds)
	0.4	(1.2025–1.2125 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.7744 seconds on right side of interior
	0.8	
Acceleration Severity Index (ASI)	0.1	(0.0033–0.0533 seconds)
Maximum 50-ms Moving Average (g's) Longitudinal Lateral Vertical		
	-0.8	(0.0011–0.0511 seconds)
	-0.4	(0.2527–0.3027 seconds)
	0.8	(0.1533–0.2033 seconds)
Maximum Roll, Pitch, and Yaw Angles Roll Pitch Yaw	Degrees	
	1	(0.5983 seconds)
	3	(1.5000 seconds)
	2	(0.3072 seconds)

9.3.8 Assessment of Results

An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-61 is provided in Table 9.3.

9.4 CONCLUSIONS

The burn ban sign on slip base support did not comply with *MASH* criteria. After release from the slip base, the sign support system rotated over the impacting vehicle, and the top of the sign panel and support contacted and penetrated the rear window.



<p>General Information Test Agency Texas A&M Transportation Institute (TTI) Test Standard Test No. <i>MASH</i> Test 3-61 TTI Test No. 469469-08-01 Test Date 2019-4-26</p> <p>Test Article Type..... Sign support structure Name Burn ban sign on slip base support Installation Length..... n/a Material or Key Elements Triangular, 3-bolt slip base, 10 BWG support pipe, 45-inch-square aluminum sign, 30x36-inch composite sign Concrete footing in compacted road base</p> <p>Soil Type and Condition Test Vehicle Type/Designation 1100C Make and Model 2007 Kia Rio Curb..... 2467 lb Test Inertial 2418 lb Dummy 165 lb Gross Static 2583 lb</p>	<p>Impact Conditions Speed 62.9 mi/h Angle 0° Location/Orientation Center of post aligned 13 inches off center of the vehicle toward the driver's side</p> <p>Impact Severity..... 320 kip*ft</p> <p>Exit Conditions Speed 62.9 mi/h Exit Trajectory/Heading n/a</p> <p>Occupant Risk Values Longitudinal OIV..... 2.0 ft/s Lateral OIV..... 1.6 ft/s Longitudinal Ridedown 0.2 g Lateral Ridedown 0.4 g THIV 0.8 m/s PHD 0.4 g ASI 0.11 Max. 0.050-s Average Longitudinal..... -0.8 g Lateral..... -0.4 g Vertical..... 0.8 g</p>	<p>Post-Impact Trajectory Stopping Distance 400 ft</p> <p>Vehicle Stability Maximum Yaw Angle..... 2° Maximum Pitch Angle.... 3° Maximum Roll Angle 1° Vehicle Snagging No Vehicle Pocketing..... n/a</p> <p>Test Article Deflections Dynamic..... n/a Permanent n/a Working Width..... n/a Working Width Height.... n/a</p> <p>Vehicle Damage VDS 12TRGN2 CDC 12FR1 Max. Exterior Deformation 2.5 inches (bumper) OCDI..... FS0100000 Max. Occupant Compartment Deformation None measurable</p>
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Figure 9.8. Summary of Results for *MASH* Test 3-61 on the Burn Ban Sign with Slip Base.

Table 9.3. Performance Evaluation Summary for MASH Test 3-61 on the Burn Ban Sign with Slip Base.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-08-01

Test Date: 2019-04-16

MASH Test 3-61 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
<i>B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</i>	The slip base activated and released as designed.	Pass
Occupant Risk		
<i>D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i>	The released sign support system rotated over the vehicle and contacted the rear window and trunk. The top portion of the aluminum sign panel penetrated beyond the rear window, leaving marks on the package deck (shelf) inside the occupant compartment. Thus, the sign panel penetrated the occupant compartment.	Fail
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</i>	There was no measurable occupant compartment deformation.	Pass
<i>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 1° and 3°, respectively.	Pass
<i>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.</i>	Longitudinal OIV was 2.0 ft/s, and lateral OIV was 1.6 ft/s.	Pass
<i>I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>	Longitudinal occupant ridedown acceleration was 0.2 g, and lateral occupant ridedown was 0.4 g.	Pass
Vehicle Trajectory		
<i>N. Vehicle trajectory behind the test article is acceptable.</i>	The 1100C vehicle came to rest 400 ft behind the original position of the installation.	Pass

CHAPTER 10: TXDOT BURN BAN SIGN ON WEDGE AND SOCKET SUPPORT

10.1 BACKGROUND

TxDOT permits counties to post advisory signs on the roadside to alert motorists when a burn ban is in effect. The current practice is to append the burn ban notification signs to existing sign support structures.

The initial implementation of this practice was limited to slip base sign support systems (7). TxDOT desires to expand this implementation to include thin-wall steel tubing supports secured in a wedge and socket foundation. Since burn ban signs are deployed on support structures along the roadside and not at or near intersections, only evaluation at 0° was considered necessary. Therefore, the recommendation was to evaluate the burn ban sign with both the 1100C passenger car and 2270P pickup truck at 0°.

Two different sizes of burn ban signs are used. The smaller 24-inch by 24-inch sign is intended to simply communicate that a burn ban is in effect. The larger 30-inch by 36-inch sign additionally indicates the name of the county when needed. Due to the capacity of the thin-wall steel tube support, the smaller 24-inch by 24-inch burn ban sign was evaluated.

10.2 SYSTEM DETAILS

10.2.1 Test Article and Installation Details

The TxDOT burn ban sign on wedge and socket support test installation consisted of two sign panels mounted on a nominal 2 $\frac{3}{8}$ -inch outer diameter by 0.095-inch wall galvanized steel tube support post (13 BWG pipe). The support post was inserted 12 inches into a steel tube socket that was embedded in a 12-inch-diameter by 30-inch-deep unreinforced concrete footer. The support post was secured inside the socket using a driven steel wedge.

The upper primary sign was a 38-inch-square by 0.100-inch-thick aluminum panel mounted with its bottom edge 84 inches above grade. A T-bracket was attached to the top of the 13 BWG pipe to help support the aluminum sign panel. The lower burn ban sign was a 24-inch-square by $\frac{1}{8}$ -inch (3-mm) thick composite panel that was mounted 3 inches below the primary sign. The composite burn ban sign panel was comprised of a thin sheet of high-density polyethylene plastic between thin aluminum sheets. The support post, two signs, and associated hardware weighed 53 lbs.

Figure 10.1 presents overall information on the burn ban sign on wedge and socket support, and Figure 10.2 provides photographs of the installation. Appendix I.1 provides further details of the burn ban sign on wedge and socket support.

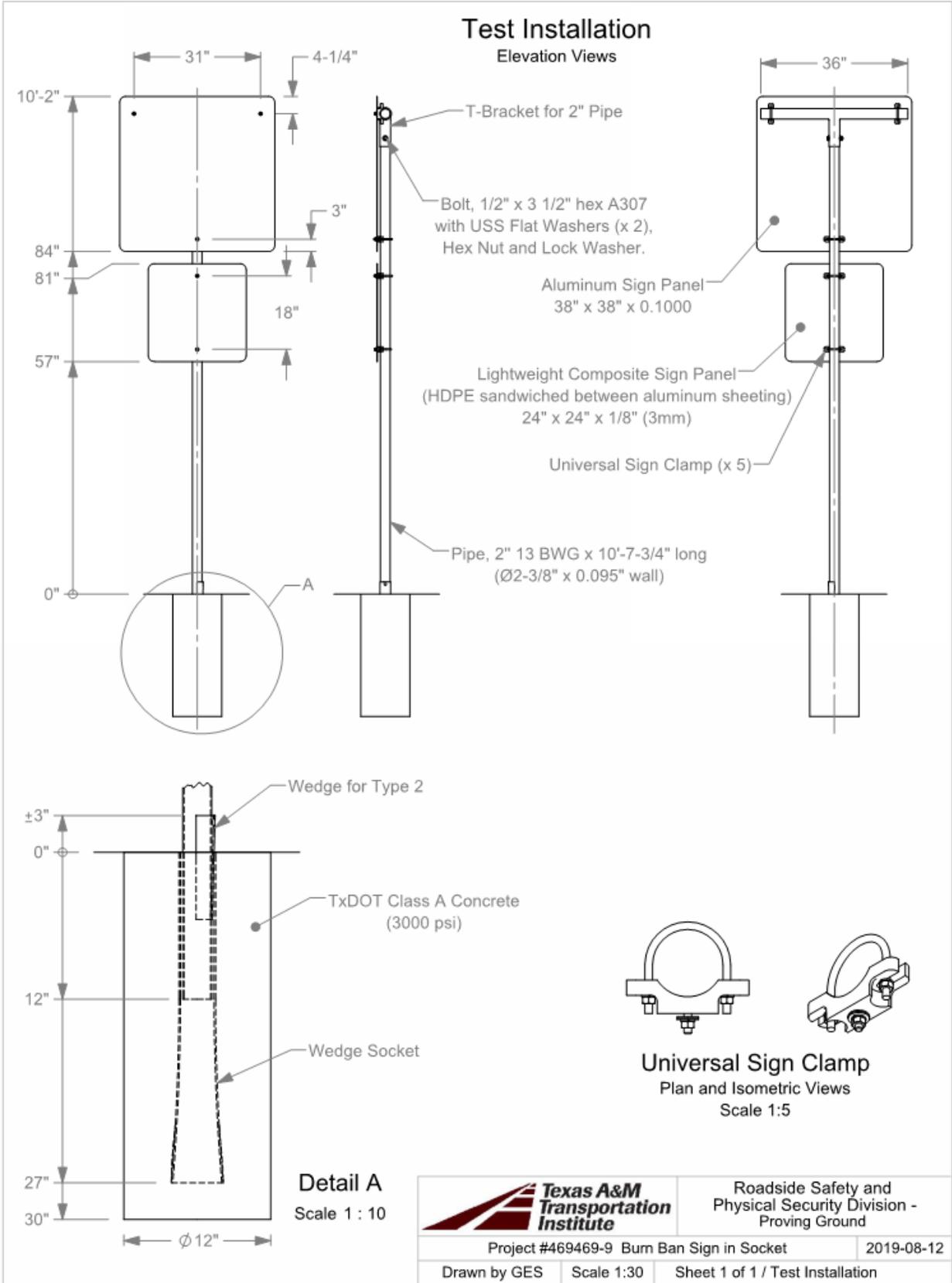


Figure 10.1. Overall Details of the Burn Ban Sign on Wedge and Socket Support.

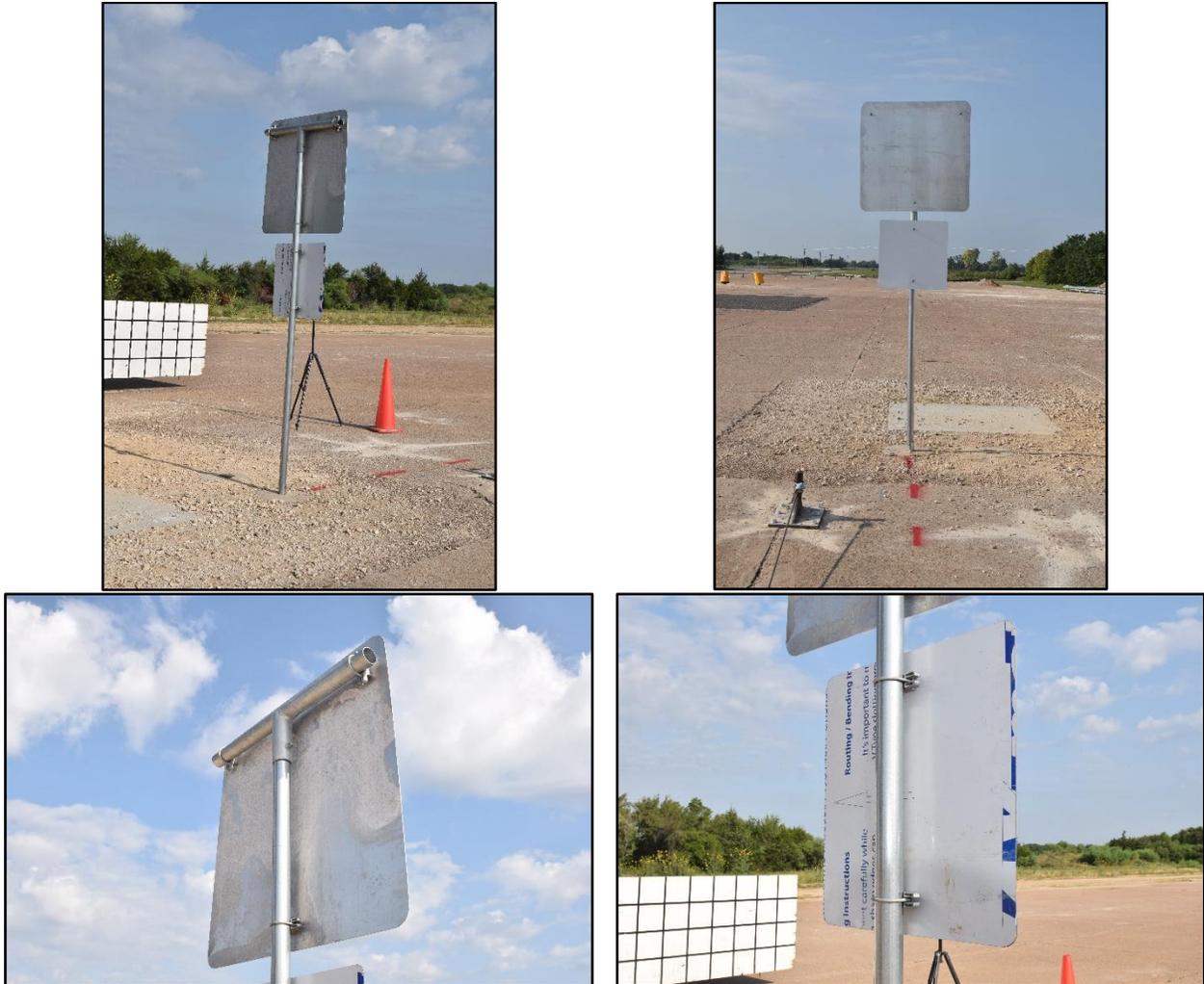


Figure 10.2. Burn Ban Sign on Wedge and Socket Support prior to Test No. 469469-09-01.

10.3 MASH TEST 3-61 (TEST NO. 469469-09-01)

10.3.1 Test Designation and Actual Impact Conditions

MASH Test 3-61 involves a 1100C vehicle weighing 2420 lb \pm 55 lb impacting the CIP of the burn ban sign on wedge and socket support at an impact speed of 62 mi/h \pm 2.5 mi/h and an angle of $0^\circ \pm 1.5^\circ$. The selected impact point was the centerline of the burn ban sign on wedge and socket support aligned 14 inches off the centerline of the vehicle toward the driver's side.

The 2008 Kia Rio used in the test weighed 2435 lb, and the actual impact speed and angle were 63.7 mi/h and 0° , respectively. Minimum target impact severity was 288 kip-ft, and actual IS was 330 kip-ft.

10.3.2 Weather Conditions

The test was performed on the morning of August 14, 2019. Weather conditions at the time of testing were as follows: wind speed: 4 mi/h; wind direction: 265° with respect to the vehicle (vehicle was traveling at a magnetic heading of 180°); temperature: 88°F; relative humidity: 76 percent.

10.3.3 Test Vehicle

Figure 10.3 and Figure 10.4 show the 2008 Kia Rio¹¹ that was used for the crash test. The vehicle's test inertia weight was 2435 lb, and its gross static weight was 2600 lb. The height to the lower edge of the vehicle bumper was 7.75 inches, and height to the upper edge of the bumper was 21.5 inches. Table I.1 in Appendix I.2.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 10.3. Burn Ban Sign on Wedge and Socket Support Test Vehicle Geometrics for Test No. 469469-09-01.

¹¹ The 2008 model vehicle used is older than the 6-year age noted in *MASH* and was selected based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2008 model vehicle met the *MASH* requirements.



Figure 10.4. Test Vehicle before Test No. 469469-09-01.

10.3.4 Test Description

Table 10.1 lists events that occurred during Test No. 469469-09-01. Figure I.1 in Appendix I.2.2 presents sequential photographs during the test.

Table 10.1. Events during Test No. 469469-09-01.

Time	Events
0.000	Vehicle contacts sign support
0.008	Sign support begins to pull out of socket
0.039	Lower burn ban sign on support makes contact with vehicle hood
0.062	Top primary sign on support impacts windshield

Brakes were applied 1.6 seconds after impact, and the vehicle came to rest 303 ft downstream and 4 ft left of the origin point of impact with the sign support system still in contact.

10.3.5 Damage to Test Installation

Figure 10.5 shows the damage to the burn ban sign on wedge and socket support. The support post partially pulled out of the socket and fractured 24 inches above the ground line. The lower portion remaining in the socket was bent over approximately 85° such that it was nearly parallel with the ground. Both sign panels remained attached to the upper portion of the fractured support post, and this assembly wrapped around the front of the test vehicle and remained intact with the vehicle until it came to a stop.



Figure 10.5. Burn Ban Sign on Wedge and Socket Support after Test No. 469469-09-01.

10.3.6 Damage to Test Vehicle

Figure 10.6 and Figure 10.7 show the damage sustained by the vehicle. There was a dent in the front bumper and a 24-inch by 34-inch by 4.25-inch-deep dent in the hood including two 0.25-inch round holes that were 7 inches apart. The left headlight, left side mirror, left A-pillar, and radiator support were damaged. The windshield had a 37-inch by 32-inch by 6-inch-deep indentation and two cuts/tears in the laminate, one 16 inches long and one 3 inches long. There was no measurable exterior crush of the vehicle. The windshield deformed 6 inches into the occupant compartment and had a large cut in it as explained previously. Table I.2 and Table I.3 in Appendix I.2.1 provide exterior crush and occupant compartment measurements.



Figure 10.6. Test Vehicle after Test No. 469469-09-01.



Figure 10.7. Interior of Test Vehicle after Test No. 469469-09-01.

10.3.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 10.2. Figure 10.8 summarizes these data and other pertinent information from the test. Figure I.2 in Appendix I.2.3 shows the vehicle

angular displacements, and Figure I.3 through Figure I.5 in Appendix I.2.4 show acceleration versus time traces.

Table 10.2. Occupant Risk Factors for Test No. 469469-09-01.

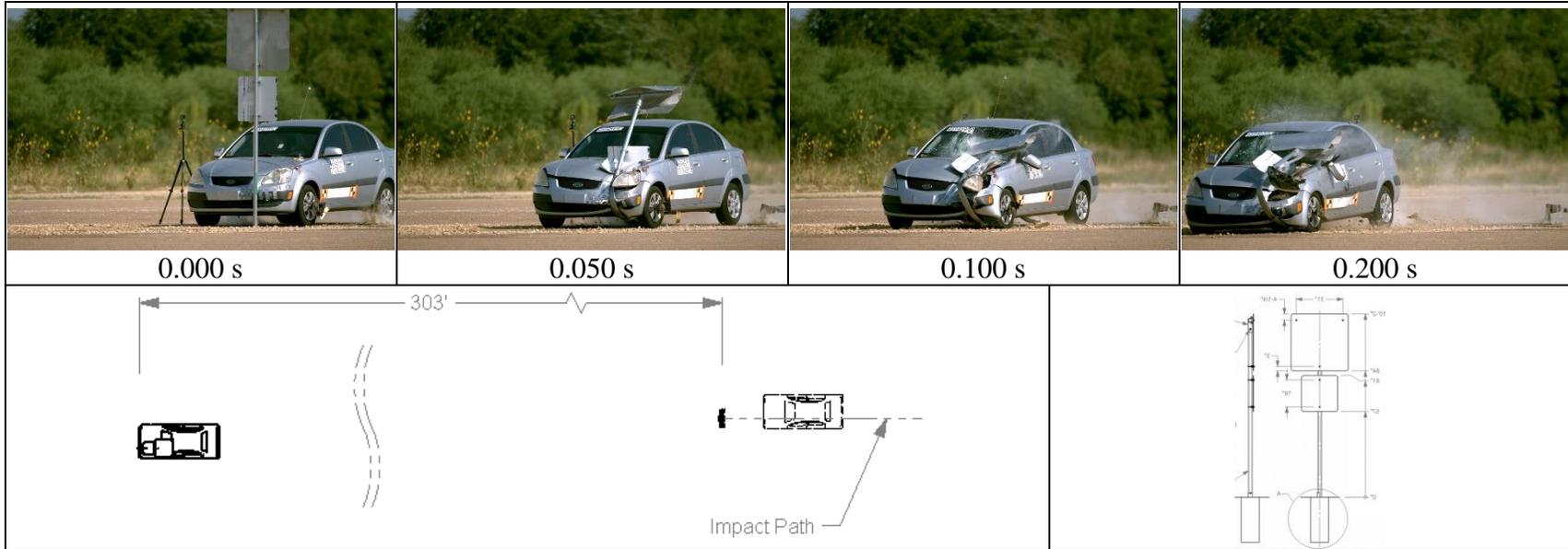
Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV) Longitudinal Lateral	ft/s	at 0.2671 seconds on front of interior
	8.5	
	1.0	
Occupant Ridedown Accelerations (g's) Longitudinal Lateral		
	0.4	(0.4735–0.4835 seconds)
	0.9	(0.3533–0.3633 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.2680 seconds on front of interior
	2.7	
Acceleration Severity Index (ASI)	0.35	(0.0408–0.0908 seconds)
Maximum 50-ms Moving Average (g's) Longitudinal Lateral Vertical		
	-4.4	(0.0123–0.0623 seconds)
	-1.1	(0.0710–0.1210 seconds)
	3.4	(0.0288–0.0788 seconds)
Maximum Roll, Pitch, and Yaw Angles Roll Pitch Yaw	Degrees	
	5	(0.2870 seconds)
	2	(0.1800 seconds)
	9	(0.4507 seconds)

10.3.8 Assessment of Results

An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-61 is provided in Table 10.3.

10.4 CONCLUSIONS

Upon impact with the burn ban sign on wedge and socket support, the support post initially began to pull out of its socket, but it subsequently fractured about 24 inches above grade. After fracture of the support post, the upper portion wrapped around the front of the vehicle, and the upper sign panel and support contacted and penetrated the windshield. Consequently, the burn ban sign on wedge and socket support did not meet *MASH* criteria.



<p>General Information Test Agency..... Texas A&M Transportation Institute (TTI) Test Standard Test No. <i>MASH</i> Test 3-61 TTI Test No..... 469469-09-01 Test Date..... 2019-8-14</p> <p>Test Article Type..... Sign support structure Name..... Burn ban sign on wedge and socket support Installation Length..... n/a Material or Key Elements 13 BWG steel pipe support secured in socket with steel wedge, 38-inch-square aluminum primary sign, 24-inch-square composite burn ban sign, steel hardware</p> <p>Soil Type and Condition Unreinforced concrete footer in compacted road base</p> <p>Test Vehicle Type/Designation 1100C Make and Model 2008 Kia Rio Curb..... 2459 lb Test Inertial..... 2435 lb Dummy 165 lb Gross Static 2600 lb</p>	<p>Impact Conditions Speed 63.7 mi/h Angle 0° Location/Orientation Center of post aligned 14 inches off center of the vehicle toward the driver's side</p> <p>Impact Severity..... 330 kip*ft</p> <p>Exit Conditions Speed n/a Exit Trajectory/Heading n/a</p> <p>Occupant Risk Values Longitudinal OIV..... 8.5 ft/s Lateral OIV..... 1.0 ft/s Longitudinal Ridedown 0.4 g Lateral Ridedown 0.9 g THIV 2.7 m/s PHD 0.9 g ASI..... 0.35 Max. 0.050-s Average Longitudinal..... -4.4 g Lateral..... -1.1 g Vertical..... 3.4 g</p>	<p>Post-Impact Trajectory Stopping Distance 303 ft, 4 ft left</p> <p>Vehicle Stability Maximum Yaw Angle..... 9° Maximum Pitch Angle.... 2° Maximum Roll Angle 5° Vehicle Snagging No Vehicle Pocketing..... n/a</p> <p>Test Article Deflections Dynamic..... n/a Permanent n/a Working Width..... n/a Working Width Height.... n/a</p> <p>Vehicle Damage VDS 12TLGN2 CDC 12FL1 Max. Exterior Deformation Non-measurable OCDI..... FS0000000 Max. Occupant Compartment Deformation 6 inches at windshield</p>
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Figure 10.8. Summary of Results for *MASH* Test 3-61 on the Burn Ban Sign on Wedge and Socket Support.

Table 10.3. Performance Evaluation Summary for MASH Test 3-61 on the Burn Ban Sign on Wedge and Socket Support.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-09-01

Test Date: 2019-04-16

MASH Test 3-61 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
<i>B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</i>	The burn ban sign on wedge and socket support yielded to the 1100C vehicle and fractured.	Pass
<u>Occupant Risk</u>		
<i>D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i>	After fracture of the support post, the upper portion wrapped around the front of the vehicle, and the upper sign panel and support contacted and penetrated the windshield. The sign panel penetrated the occupant compartment.	Fail
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</i>	There was a 6-inch-deep area of deformation and 16-inch-long tear in the windshield laminate.	Fail
<i>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 5° and 2°, respectively.	Pass
<i>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.</i>	Longitudinal OIV was 8.5 ft/s, and lateral OIV was 1.0 ft/s.	Pass
<i>I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>	Longitudinal occupant ridedown acceleration was 0.4 g, and lateral occupant ridedown was 0.9 g.	Pass
<u>Vehicle Trajectory</u>		
<i>N. Vehicle trajectory behind the test article is acceptable.</i>	The 1100C vehicle came to rest 303 ft behind the original position of the installation.	Pass

CHAPTER 11: TXDOT SINGLE TEMPORARY MAILBOX ON PLASTIC DRUM

11.1 BACKGROUND

The small passenger car is considered the critical design vehicle for evaluation of mailbox support systems based on the required mailbox mounting height. As shown in Figure 11.1, the mounting height regulated for mailboxes by the United States Postal Service places mailboxes at a height that makes interaction with the windshield of the pickup truck design vehicle improbable. The taller hood height and longer wrap-around distance (i.e., the distance from the ground, around the front end, and across the hood to the base of the windshield) of the 2270P pickup truck significantly decreases the probability of windshield impact and occupant compartment intrusion. Therefore, Test 3-62 with the pickup truck was considered unnecessary for the *MASH* evaluation of the TxDOT mailbox systems.

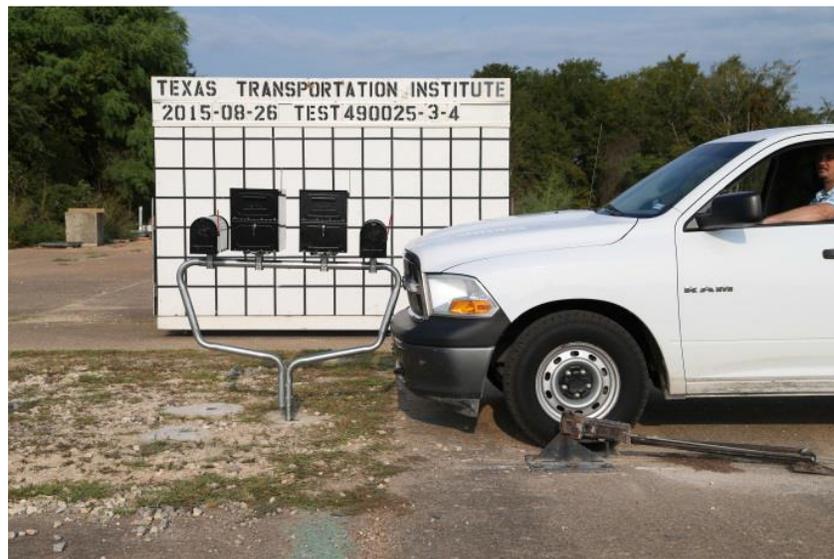


Figure 11.1. Mailbox Geometrics with 2270P Pickup Truck (9).

The *MASH* test matrix for breakaway supports includes two tests with the 1100C small passenger car: a low-speed test at 19 mi/h (Test 3-60) and a high-speed test at 62 mi/h (Test 3-61). In the low-speed small car test, *MASH* testing has shown that the mailbox support assembly will be pushed forward by the impacting vehicle (10). It is unlikely that the mailbox will separate from the support or that the support assembly will interact with the vehicle windshield during this lower impact severity test.

TTI researchers consider the most critical test for evaluation of mailbox systems to be *MASH* test designation 3-61, which involves the 1100C small passenger car impacting at high speed. This test evaluates both the structural adequacy of the mailbox connection hardware and any secondary contact and interaction between the mailbox support assembly and the vehicle, particularly the windshield. If the mailbox remains attached during this high-speed test, it is not expected to detach in the low-speed test.

Three different mailbox support systems were selected for *MASH* testing and evaluation during Phase III of the project. The details of these systems and the results of the crash testing are provided as follows.

11.2 SINGLE TEMPORARY MAILBOX ON PLASTIC DRUM (TYPE 6 FOUNDATION)

11.2.1 System Details

The test installation consisted of a No. 1-A medium size mailbox (Gibraltar Model #E1600B00) attached to the top of a “Lane Changer” plastic construction drum (Work Area Protection Corp Model# B500LC) using two 14-gauge steel angle brackets (DHT 2917). The bottom of the mailbox was mounted 42 inches above grade. The single temporary mailbox on a plastic drum was placed freestanding on compacted AASHTO M147-65(2004) Grade B crushed limestone road base. Details of this system are described in Maintenance Division standard MB-15(1) and Section K of the TxDOT Compliant Work Zone Traffic Control Device List.

Figure 11.2 presents overall information on the single temporary mailbox on a plastic drum, and Figure 11.3 provides photographs of the test installation. Further details are provided in Appendix J.1.1.

11.2.2 MASH Test 3-61 (Crash Test No. 469469-10-1)

11.2.2.1 Test Designation and Actual Impact Conditions

MASH Test 3-61 involves an 1100C vehicle weighing 2420 lb \pm 55 lb impacting the CIP of the single temporary mailbox on a plastic drum at an impact speed of 62 mi/h \pm 2.5 mi/h and an angle of 0° \pm 1.5°. The target impact point was the centerline of the mailbox aligned 14 inches toward the driver’s side from the centerline of the vehicle.

The 2011 Kia Rio used in the test weighed 2440 lb, and the actual impact speed and angle were 62.9 mi/h and 0°, respectively. The actual impact point on the vehicle was the centerline of the mailbox aligned with a point 14 inches toward the driver’s side from the centerline of the vehicle. Minimum target impact severity was 288 kip-ft, and actual IS was 323 kip-ft.

11.2.2.2 Weather Conditions

The test was performed on the morning of April 11, 2019. Weather conditions at the time of testing were as follows: wind speed: 8 mi/h; wind direction: 229° with respect to the vehicle (vehicle was traveling at a magnetic heading of 180°); temperature: 76°F; relative humidity: 75 percent.

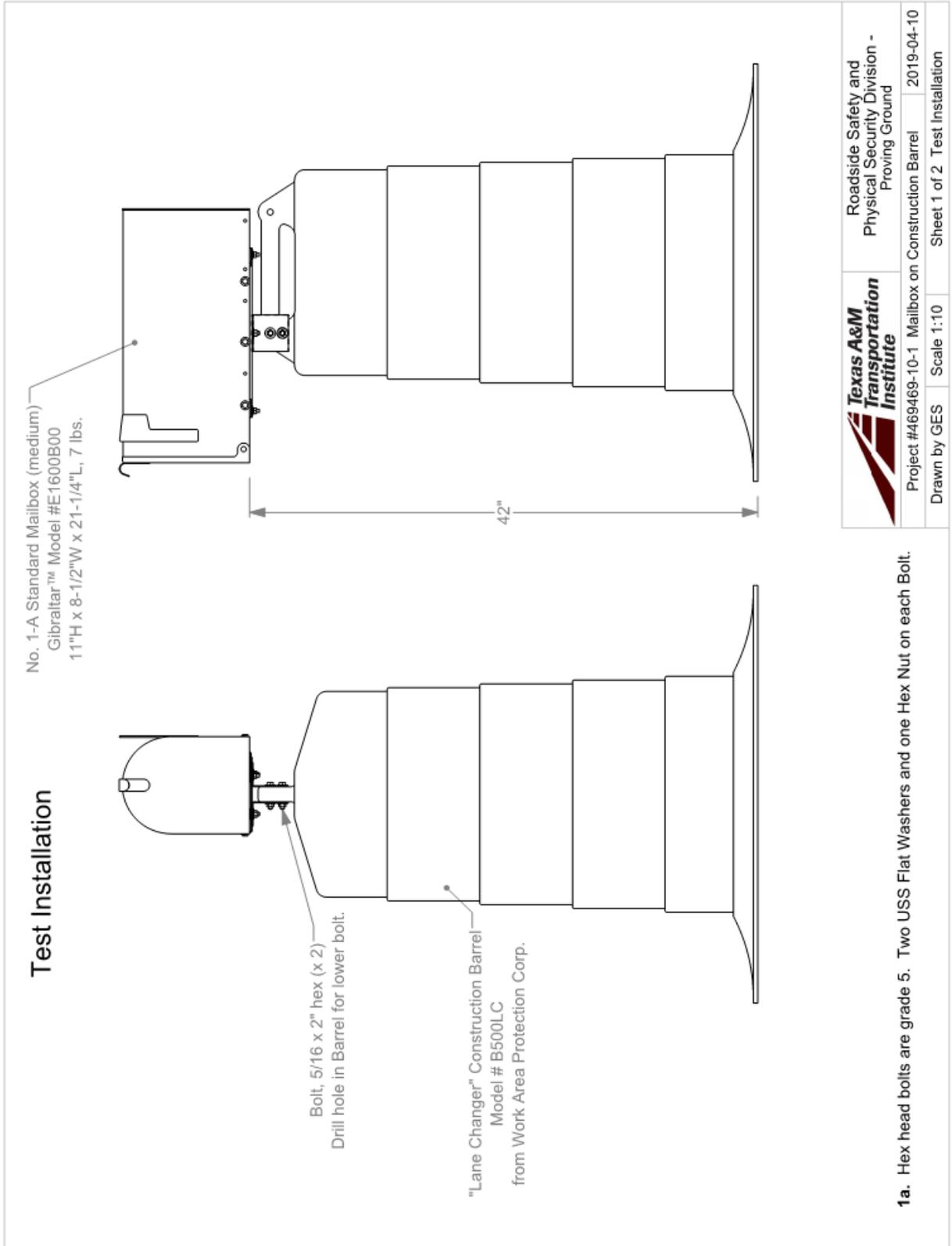


Figure 11.2. Overall Details of the Single Temporary Mailbox on Plastic Drum.



Figure 11.3. Single Temporary Mailbox on Plastic Drum prior to Testing.

11.2.2.3 Test Vehicle

The 2011 Kia Rio,¹² shown in Figure 11.4 and Figure 11.5, was used for the crash test. The vehicle's test inertia weight was 2440 lb, and its gross static weight was 2605 lb. The height to the lower edge of the vehicle bumper was 7.8 inches, and height to the upper edge of the bumper was 21.5 inches. Table J.1 in Appendix J.1.2 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

¹² The 2011 model vehicle used is older than the 6-year age noted in *MASH* and was selected based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2011 model vehicle met the *MASH* requirements.



Figure 11.4. Single Temporary Mailbox on Plastic Drum/Test Vehicle Geometrics for Test No. 469469-10-1.



Figure 11.5. Test Vehicle before Test No. 469469-10-1 (prior to Placement of the Dummy).

11.2.2.4 Test Description

The 2011 Kia Rio, traveling at an impact speed of 62.9 mi/h, contacted the single temporary mailbox on a plastic drum 14 inches toward the driver's side from the centerline of the vehicle (CIP) at an impact angle of 0°. Table 11.1 lists events that occurred during Test No. 469469-10-1. Figure J.1 in Appendix J.1.3 presents sequential photographs during the test.

Table 11.1. Events during Test No. 469469-10-1.

Time	Events
0.000	Vehicle contacts drum
0.025	Drum released from rubber ring base
0.034	Mailbox begins to impact vehicle hood
0.097	Drum and mailbox have rebounded off vehicle

Brakes were applied at 1.8 seconds after loss of contact with the single temporary mailbox on a plastic drum, and the vehicle came to rest 325 ft downstream and in line of the point of impact.

11.2.2.5 Damage to Test Installation

Figure 11.6 shows the damage to the single temporary mailbox on a plastic drum. The mailbox was deformed but still attached to the drum. The single temporary mailbox on a plastic drum assembly came to rest 90 ft downstream and 10 ft to the left of its original location.



Figure 11.6. Single Temporary Mailbox on Plastic Drum after Test No. 469469-10-1.

11.2.2.6 Damage to Test Vehicle

Figure 11.7 and Figure 11.8 show the damage sustained by the vehicle. The hood of the vehicle suffered an 8-inch by 20-inch by $\frac{3}{4}$ -inch-deep dent, and there were minor scuff marks on the bumper at the point of impact. There was neither measurable exterior crush nor interior deformation to the vehicle. Table J.2 and Table J.3 in Appendix J.1.2 provide further details.



Figure 11.7. Test Vehicle after Test No. 469469-10-1.



Figure 11.8. Interior of Test Vehicle for Test No. 469469-10-1.

11.2.2.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 11.2. Figure 11.9 summarizes these data and other pertinent information from the test. Figure J.2 in Appendix J.1.4 shows the vehicle angular displacements, and Figure J.3 through Figure J.5 in Appendix J.1.5 show acceleration versus time traces.

Table 11.2. Occupant Risk Factors for Test No. 469469-10-1.

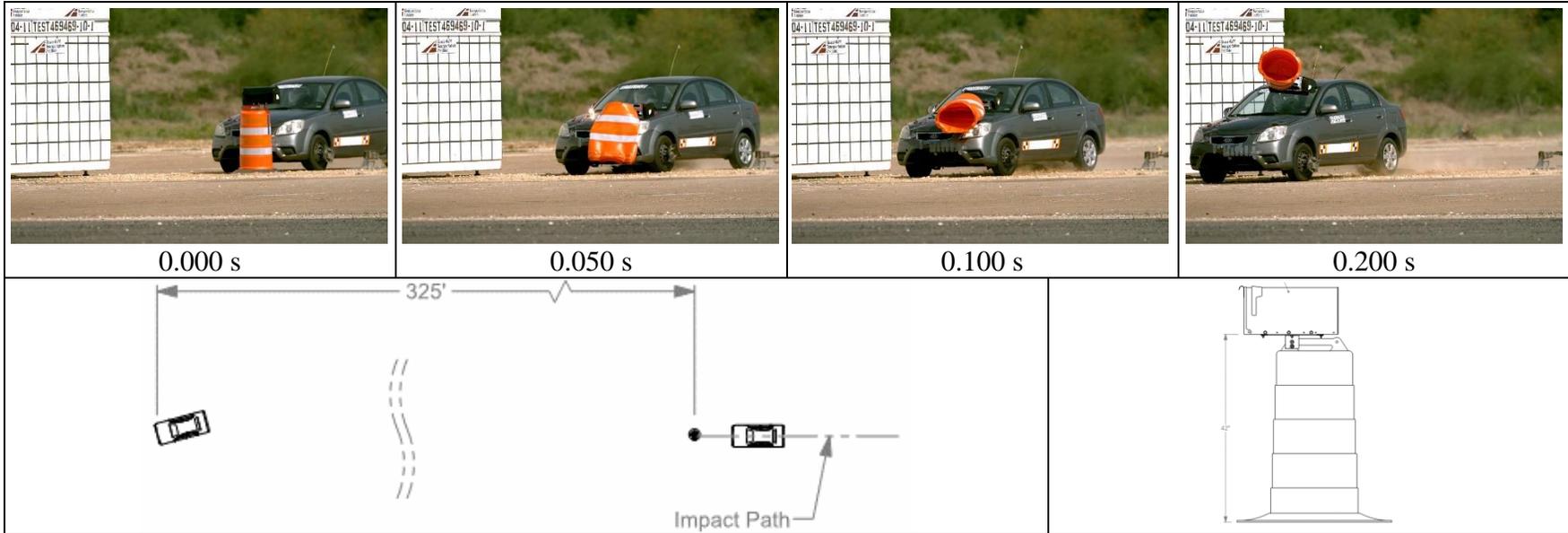
Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV) Longitudinal Lateral	ft/s	at 0.7988 seconds on left side of interior
	0.3	
	3.0	
Occupant Ridedown Accelerations (g's) Longitudinal Lateral		
	0.2	(1.3974–1.4074 seconds)
	0.4	(1.3319–1.3419 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.7940 seconds on left side of interior
	0.9	
Post Head Deceleration (PHD) (g's)	0.5	(1.3319–1.3419 seconds)
Acceleration Severity Index (ASI)	0.06	(0.0464–0.0964 seconds)
Maximum 50-ms Moving Average (g's) Longitudinal Lateral Vertical		
	-0.5	(0.0012–0.0512 seconds)
	0.3	(0.0186–0.0686 seconds)
	0.5	(0.0312–0.0812 seconds)
Maximum Roll, Pitch, and Yaw Angles Roll Pitch Yaw	Degrees	
	2	(1.4519 seconds)
	1	(0.2792 seconds)
	3	(1.4725 seconds)

11.2.2.8 Assessment of Results

An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-61 is provided in Table 11.3.

11.2.3 Conclusions

The TxDOT mailbox support and foundation (MB-15[1]) Type 6 temporary mailbox support on a plastic drum (single temporary mailbox on a plastic drum) performed acceptably for *MASH* Test 3-61.



General Information

Test Agency Texas A&M Transportation Institute (TTI)
 Test Standard Test No. *MASH* Test 3-61
 TTI Test No. 469469-10-1
 Test Date 2019-04-11

Test Article

Type..... Temporary mailbox
 Name Mailbox on "Lane Changer" construction drum
 Installation Length..... n/a
 Material or Key Elements Metal medium-size mailbox bolted to plastic drum

Soil Type and Condition

AASHTO M147-65(2004) Grade B crushed limestone road base

Test Vehicle

Type/Designation 1100C
 Make and Model 2011 Kia Rio
 Curb..... 2455 lb
 Test Inertial 2440 lb
 Dummy 165 lb
 Gross Static 2605 lb

Impact Conditions

Speed 62.9 mi/h
 Angle 0°
 Location/Orientation 14 inches off center of vehicle on driver's side with center of mailbox
 Impact Severity..... 323 kip*ft

Exit Conditions

Speed 60.0 mi/h
 Exit Trajectory/Heading 0°

Occupant Risk Values

Longitudinal OIV..... 0.3 ft/s
 Lateral OIV..... 3.0 ft/s
 Longitudinal Ridedown 0.2 g
 Lateral Ridedown 0.4 g
 THIV 3.3 km.h
 PHD 0.5 g
 ASI 0.06
 Max. 0.050-s Average
 Longitudinal..... -0.5g
 Lateral..... 0.3 g
 Vertical..... 0.5 g

Post-Impact Trajectory

Stopping Distance 325 ft

Vehicle Stability

Maximum Yaw Angle..... 3°
 Maximum Pitch Angle.... 1°
 Maximum Roll Angle 2°
 Vehicle Snagging No
 Vehicle Pocketing n/a

Test Article Deflections

Dynamic..... n/a
 Permanent n/a
 Working Width..... n/a
 Working Width Height.... n/a

Vehicle Damage

VDS n/a
 CDC n/a
 Max. Exterior Deformation None measurable
 OCDI n/a
 Max. Occupant Compartment Deformation None measurable

Figure 11.9. Summary of Results for *MASH* Test 3-61 on the Single Temporary Mailbox on Plastic Drum.

Table 11.3. Performance Evaluation Summary for MASH Test 3-61 on the Single Temporary Mailbox on Plastic Drum.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-10-1

Test Date: 2019-04-11

MASH Test 3-61 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
<i>B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</i>	The single temporary mailbox on a plastic drum yielded to the 1100C vehicle.	Pass
<u>Occupant Risk</u>		
<i>D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i>	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</i>	No occupant compartment deformation or intrusion occurred.	
<i>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 2° and 1°, respectively.	Pass
<i>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.</i>	Longitudinal OIV was 0.3 ft/s, and lateral OIV was 3.0 ft/s.	Pass
<i>I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>	Maximum longitudinal occupant ridedown acceleration was 0.2 g, and maximum lateral occupant ridedown acceleration was 0.4 g.	Pass
<u>Vehicle Trajectory</u>		
<i>N. Vehicle trajectory behind the test article is acceptable.</i>	The 1100C vehicle came to rest 325 ft behind the installation.	Pass

11.3 SINGLE CENTENNIAL MODEL MAILBOX ON TYPE 2 FOUNDATION

11.3.1 System Details

This system consisted of a single extra-large mailbox attached to a galvanized thin-wall steel tube support secured inside a 12-gauge galvanized anchor socket embedded in a concrete footing. The bottom (floor) of the mailbox was mounted 42 inches above grade. Details of this system are described in Maintenance Division standard MB-15(1).

The Centennial extra-large mailbox (Model #950020B) from Architectural Mailboxes had approximate dimensions of 11.9 inches tall by 14.2 inches wide by 18.3 inches deep and weighed 11.8 lb. Attachment of the mailbox to the post was accomplished using a mailbox bracket with an integral collar (DHT #161443). The bracket was secured to the bottom of the mailbox using four 5/16-inch-diameter by 1-inch-long SAE Grade 5 hex bolts, two 2-inch by 5/2-inch by 1/8-inch ASTM A36 plate washers, and associated hardware. The collar on the mailbox bracket was positioned over and secured to the top of the support post using a 5/16-inch-diameter by 3-inch-long SAE Grade 5 hex bolt with associated hardware.

The support post was a 2³/₈-inch-outside-diameter by 0.095-inch-thick galvanized thin-wall steel tube (DHT #143426). The support post was inserted approximately 8 inches into a 2³/₈-inch-outside-diameter by 0.095-inch-thick galvanized thin-wall steel tube socket (DHT #143434) and secured with a curved steel wedge plate (DHT #143433) on the impact side. The socket was embedded 27 inches deep and installed flush with the top of a TxDOT Type 2 non-reinforced concrete footer that measured approximately 12 inches in diameter by 30 inches deep.

Figure 11.10 presents overall information on the extra-large mailbox on thin-wall galvanized tube with Type 2 foundation, and Figure 11.11 provides photographs of the test installation. Further details are provided in Appendix J.2.1.

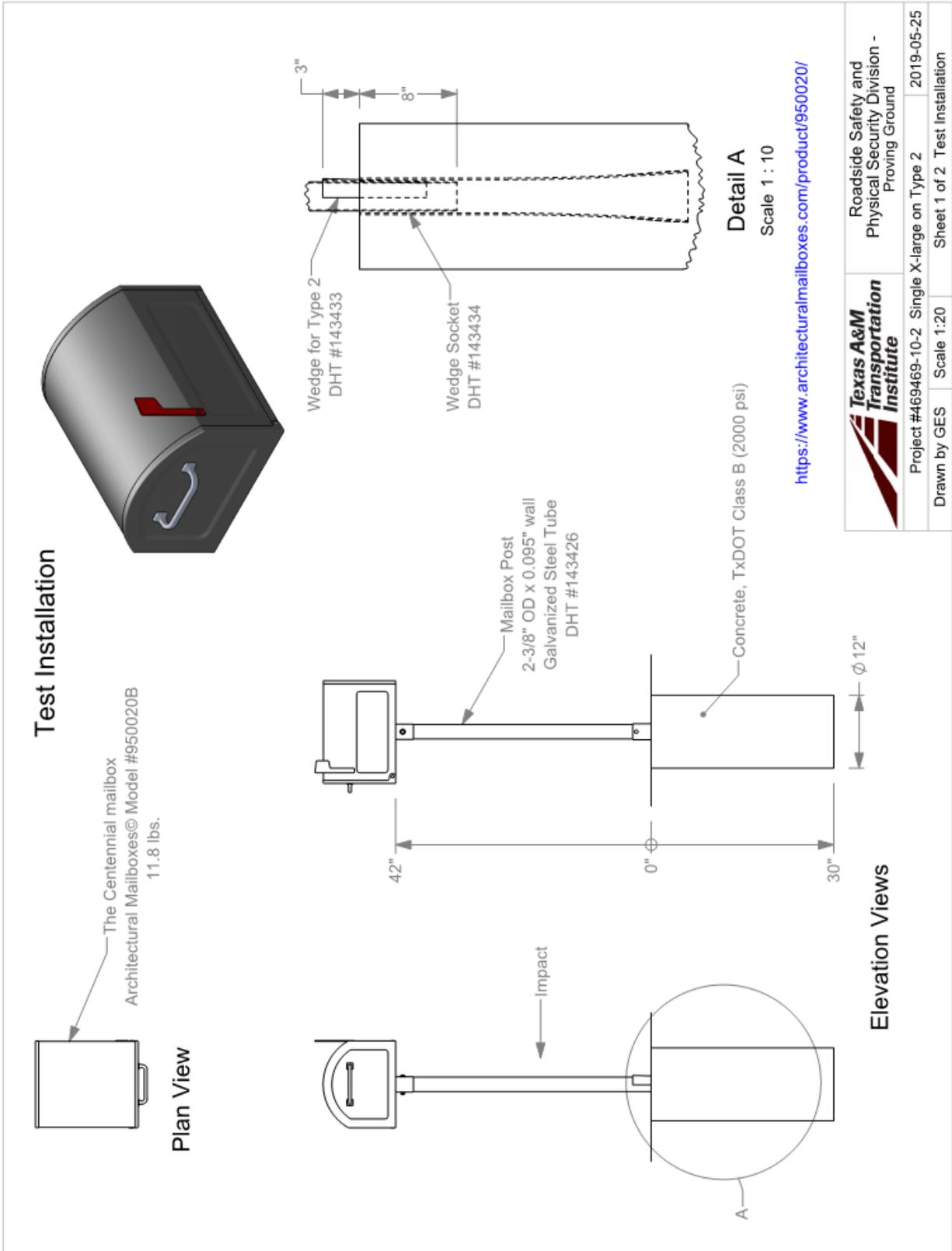


Figure 11.10. Overall Details of the Centennial Mailbox on Steel Tube Post.



Figure 11.11. Centennial Mailbox on Steel Tube Post prior to Testing.

11.3.2 MASH Test 3-61 (Crash Test No. 469469-10-2)

11.3.2.1 Test Designation and Actual Impact Conditions

MASH Test 3-61 involves a 1100C vehicle weighing 2420 lb \pm 55 lb impacting the Centennial model mailbox on Type 2 foundation at an impact speed of 62 mi/h \pm 2.5 mi/h and an angle of $0^\circ \pm 1.5^\circ$. The target impact point was the centerline of the mailbox support aligned 14 inches toward the driver's side from the centerline of the vehicle.

The 2011 Kia Rio used in the test weighed 2440 lb, and the actual impact speed and angle were 63.0 mi/h and 0° , respectively. The actual impact point of the mailbox support on the vehicle was 14 inches toward the driver's side from the centerline of the vehicle. Minimum target impact severity was 288 kip-ft, and actual IS was 324 kip-ft.

11.3.2.2 Weather Conditions

The test was performed on the morning of June 25, 2019. Weather conditions at the time of testing were as follows: wind speed: 3 mi/h; wind direction: 144° with respect to the vehicle (vehicle was traveling at a magnetic heading of 180°); temperature: 85°F ; relative humidity: 79 percent.

11.3.2.3 Test Vehicle

The 2011 Kia Rio,¹³ shown in Figure 11.12 and Figure 11.13, was used for the crash test. The vehicle's test inertia weight was 2440 lb, and its gross static weight was 2605 lb. The height to the lower edge of the vehicle bumper was 7.8 inches, and height to the upper edge of the bumper was 21.5 inches. Table J.5 in Appendix J.2.2 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 11.12. Extra-Large Mailbox on Thin-Wall Galvanized Tube with Type 2 Foundation/Test Vehicle Geometrics for Test No. 469469-10-2.



Figure 11.13. Test Vehicle before Test No. 469469-10-2 (prior to Installation of the Dummy).

¹³ The 2011 model vehicle used is older than the 6-year age noted in *MASH* and was selected based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2011 model vehicle met the *MASH* requirements.

11.3.2.4 Test Description

Table 11.4 lists events that occurred during Test No. 469469-10-2. Figure J.6 in Appendix J.2.3 present sequential photographs during the test.

Table 11.4. Events during Test No. 469469-10-2.

Time	Events
0.000	Vehicle contacts mailbox support
0.008	Mailbox support begins to pull out of base
0.015	Top of mailbox separates from bottom panel of mailbox
0.059	Mailbox support is still in base under car and flat on ground
0.028	Top of mailbox impacts hood of vehicle
0.144	Mailbox has rebounded off of windshield and post is under car

Brakes on the vehicle were applied 1.25 seconds after impact. The vehicle came to rest 265 ft downstream of and in line with the point of impact with the vehicle facing 45° counterclockwise.

11.3.2.5 Damage to Test Installation

Figure 11.14 shows the damage to the Centennial model mailbox on Type 2 foundation. The post pulled out of the socket 5 inches and then bent over flat against the soil/concrete. The mailbox was detached from the bracket and separated into four pieces that came to rest in an area ranging from 55 to 95 ft downstream of the point of impact and 5 ft left to 31 ft right of the travel path of the vehicle.

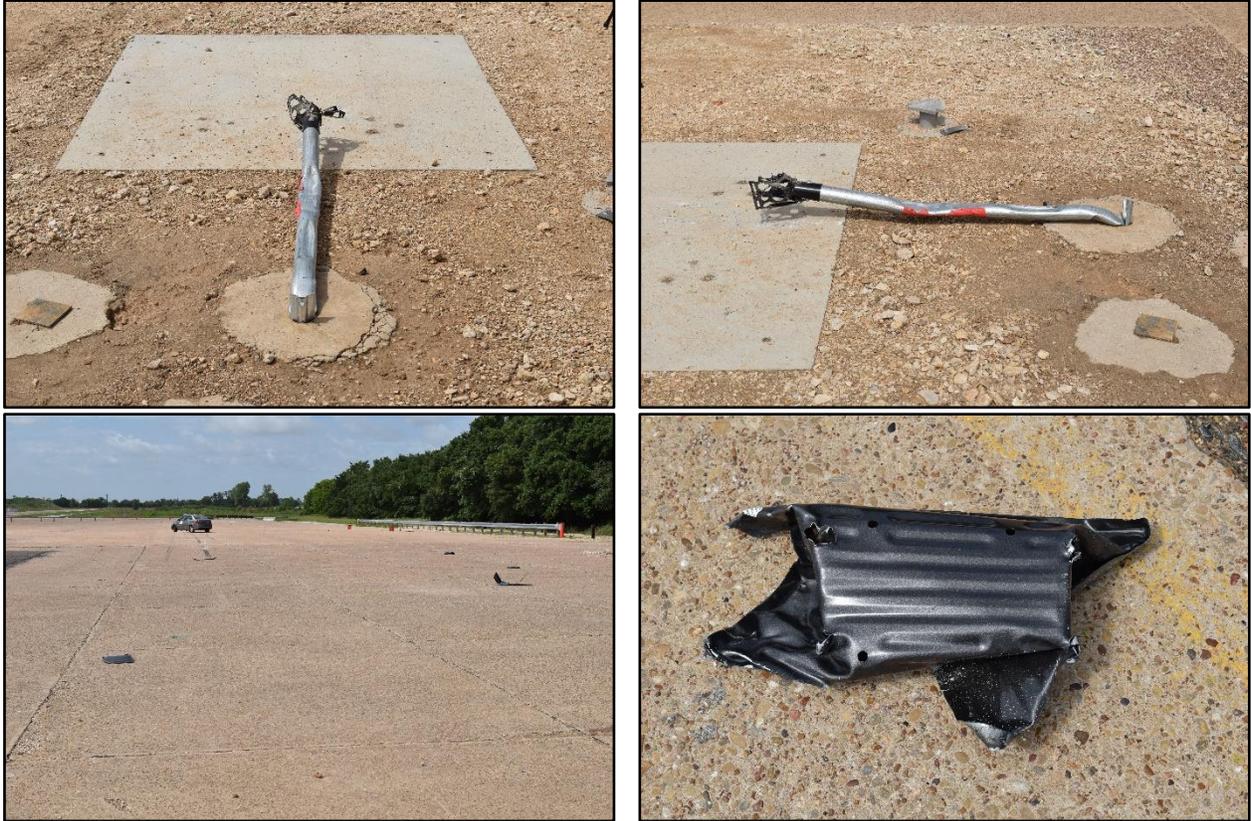


Figure 11.14. Extra-Large Mailbox on Thin-Wall Galvanized Tube with Type 2 Foundation after Test No. 469469-10-2.

11.3.2.6 Damage to Test Vehicle

Figure 11.15 and Figure 11.16 show the damage sustained by the vehicle. The right side of the bumper had a 3-inch dent, and the right side of the hood of the vehicle had a 29-inch by 31-inch by 1.3-inch-deep dent with 2.5-inch by 2-inch cuts. There was a small dent in the right A-pillar, and the bottom right of the windshield was fractured over an 8-inch by 8-inch area; however, there was no penetration of the windshield. There was a 3-inch dent in the bumper and no interior deformation to the vehicle. Table J.6 and Table J.7 in Appendix J.2.2 provide further details.



Figure 11.15. Test Vehicle after Test No. 469469-10-2.



Figure 11.16. Interior of Test Vehicle for Test No. 469469-10-2.

11.3.2.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 11.5. Figure 11.17 summarizes these data and other pertinent information from the test. Figure J.7 in Appendix J.2.4 shows the vehicle angular displacements, and Figure J.8 through Figure J.10 in Appendix J.2.5 show acceleration versus time traces.

Table 11.5. Occupant Risk Factors for Test No. 469469-10-2.

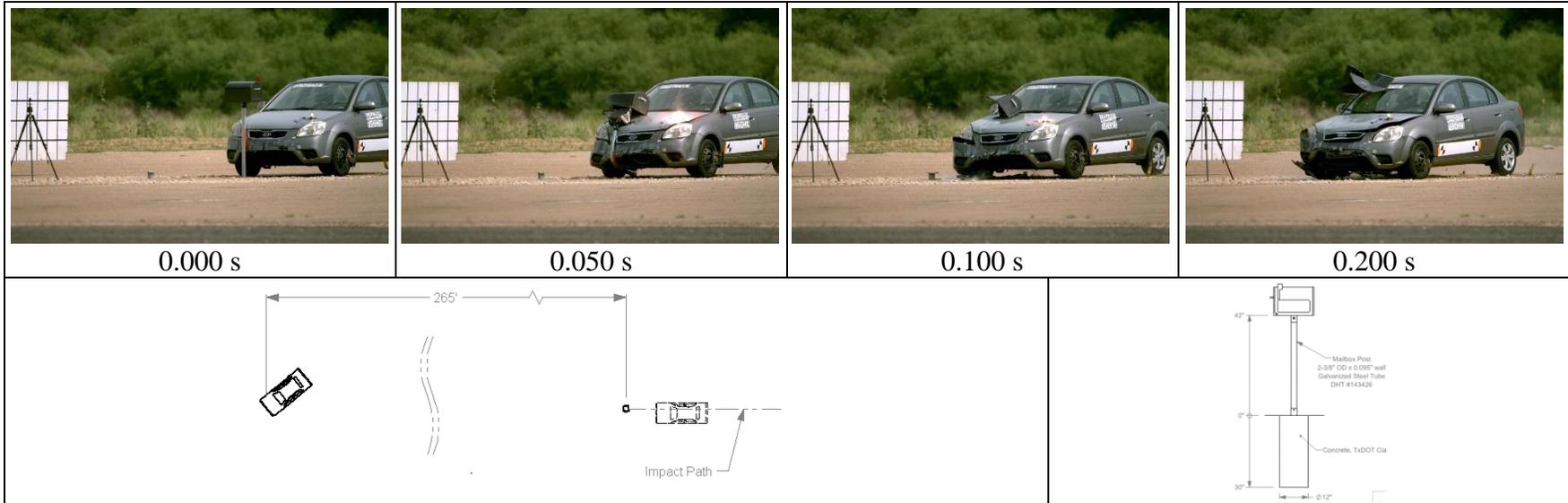
Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV) Longitudinal Lateral	ft/s	at 0.6071 seconds on left side of interior
	3.0	
	2.6	
Occupant Ridedown Accelerations (g's) Longitudinal Lateral		
	0.2	(0.7029–0.7129 seconds)
	0.4	(0.9324–0.9424 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.5996 seconds on left side of interior
	1.3	
Post Head Deceleration (PHD) (g's)	0.4	(0.9324–0.9424 seconds)
Acceleration Severity Index (ASI)	0.2	(0.0154–0.0654 seconds)
Maximum 50-ms Moving Average (g's) Longitudinal Lateral Vertical		
	-1.9	(0.0006–0.0506 seconds)
	0.5	(0.0606–0.1106 seconds)
	0.7	(0.0309–0.0809 seconds)
Maximum Roll, Pitch, and Yaw Angles Roll Pitch Yaw	Degrees	
	3	(1.0000 seconds)
	1	(0.1126 seconds)
	3	(0.3505 seconds)

11.3.2.8 Assessment of Results

An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-61 is provided in Table 11.6.

11.3.3 Conclusions

The Centennial model mailbox mounted on a 2 $\frac{3}{8}$ -inch OD by 0.095-inch wall galvanized steel tube post performed acceptably for *MASH* Test 3-61.



General Information

Test Agency..... Texas A&M Transportation Institute (TTI)
 Test Standard Test No. MASH Test 3-61
 TTI Test No..... 469469-10-2
 Test Date..... 2019-06-25

Test Article

Type..... Mailbox support
 Name..... Extra-large mailbox on thin-wall tube with Type 2 foundation
 Installation Length..... n/a
 Material or Key Elements Extra-large mailbox attached to 2 3/8-inch OD steel tube inserted into a steel anchor tube embedded in concrete footing and secured by a curved steel wedge

Soil Type and Condition

AASHTO M147-65(2004) Grade B crushed limestone road base

Test Vehicle

Type/Designation..... 1100C
 Make and Model..... 2011 Kia Rio
 Curb..... 2455 lb
 Test Inertial..... 2440 lb
 Dummy..... 165 lb
 Gross Static..... 2605 lb

Impact Conditions

Speed..... 63.0 mi/h
 Angle..... 0°
 Location/Orientation Center of mailbox post aligned 14 inches off center of vehicle on driver's side
 Impact Severity..... 324 kip*ft

Exit Conditions

Speed..... 61.3 mi/h
 Exit Trajectory/Heading 0°

Occupant Risk Values

Longitudinal OIV..... 3.0 ft/s
 Lateral OIV..... 2.6 ft/s
 Longitudinal Ridedown 0.2 g
 Lateral Ridedown..... 0.4 g
 THIV..... 1.3 m/s
 PHD..... 0.4 g
 ASI..... 0.2
 Max. 0.050-s Average
 Longitudinal..... -1.9g
 Lateral..... 0.5 g
 Vertical..... 0.7 g

Post-Impact Trajectory

Stopping Distance..... 265 ft

Vehicle Stability

Maximum Yaw Angle..... 3°
 Maximum Pitch Angle.... 1°
 Maximum Roll Angle..... 3°
 Vehicle Snagging..... No
 Vehicle Pocketing..... n/a

Test Article Deflections

Dynamic..... n/a
 Permanent..... n/a
 Working Width..... n/a
 Working Width Height.... n/a

Vehicle Damage

VDS..... n/a
 CDC..... n/a
 Max. Exterior Deformation None measurable
 OCDI..... n/a
 Max. Occupant Compartment Deformation..... None measurable

Figure 11.17. Summary of Results for MASH Test 3-61 on the Extra-Large Mailbox on Thin-Wall Galvanized Tube with Type 2 Foundation.

Table 11.6. Performance Evaluation Summary for MASH Test 3-61 on the Centennial Model Mailbox on Type 2 Foundation.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-10-2

Test Date: 2019-06-25

MASH Test 3-61 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
<i>B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</i>	The Centennial model mailbox on a Type 2 foundation yielded to the 1100C vehicle.	Pass
<u>Occupant Risk</u>		
<i>D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i>	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</i>	No occupant compartment deformation or intrusion occurred.	
<i>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 3° and 1°, respectively.	Pass
<i>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.</i>	Longitudinal OIV was 3.0 ft/s, and lateral OIV was 2.6 ft/s.	Pass
<i>I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>	Maximum longitudinal occupant ridedown acceleration was 0.2 g, and maximum lateral occupant ridedown acceleration was 0.4 g.	Pass
<u>Vehicle Trajectory</u>		
<i>N. Vehicle trajectory behind the test article is acceptable.</i>	The 1100C vehicle came to rest 265 ft behind the installation.	Pass

11.4 LOCKABLE MAILBOX ON THIN-WALL GALVANIZED TUBE WITH TYPE 2 FOUNDATION

11.4.1 System Details

This system consisted of a lockable mailbox attached to a galvanized thin-wall steel tube support secured inside a 12-gauge galvanized anchor socket embedded in a concrete footing. The bottom (floor) of the mailbox was mounted 42 inches above grade. Details of this system are described in Maintenance Division standard MB-15(1).

The Oasis Jr. Elite lockable mailbox (Model #620010B-10) had approximate dimensions of 15 inches tall by 12 inches wide by 18.1 inches deep and weighed 23 lb. Attachment of the mailbox to the post was accomplished using a mailbox bracket with an integral collar (DHT #161443). The bracket was secured to the bottom of the mailbox using four $\frac{3}{8}$ -inch-diameter by $\frac{1}{4}$ -inch-long SAE Grade 5 hex bolts, two 2-inch by $5\frac{1}{2}$ -inch by $\frac{1}{8}$ -inch ASTM A36 plate washers, and associated hardware. The collar on the mailbox bracket was positioned over and secured to the top of the support post using a $\frac{5}{16}$ -inch-diameter by 3-inch-long SAE Grade 5 hex bolt with associated hardware.

The support post was a $2\frac{3}{8}$ -inch-outside-diameter by 0.095-inch-thick galvanized thin-wall steel tube (DHT #143426). The support post was inserted approximately 8 inches into a $2\frac{3}{8}$ -inch-outside-diameter by 0.125-inch-thick galvanized thin-wall steel tube socket (DHT #143434) and secured with a curved steel wedge plate (DHT #143433) on the impact side. The socket was embedded 27 inches deep and installed flush with the top of a TxDOT Type 2 non-reinforced concrete footer that measured approximately 12 inches in diameter by 30 inches deep.

Figure 11.18 presents overall information on the lockable mailbox on thin-wall galvanized tube with Type 2 foundation, and Figure 11.19 provides photographs of the test installation. Further details are provided in Appendix J.3.1.

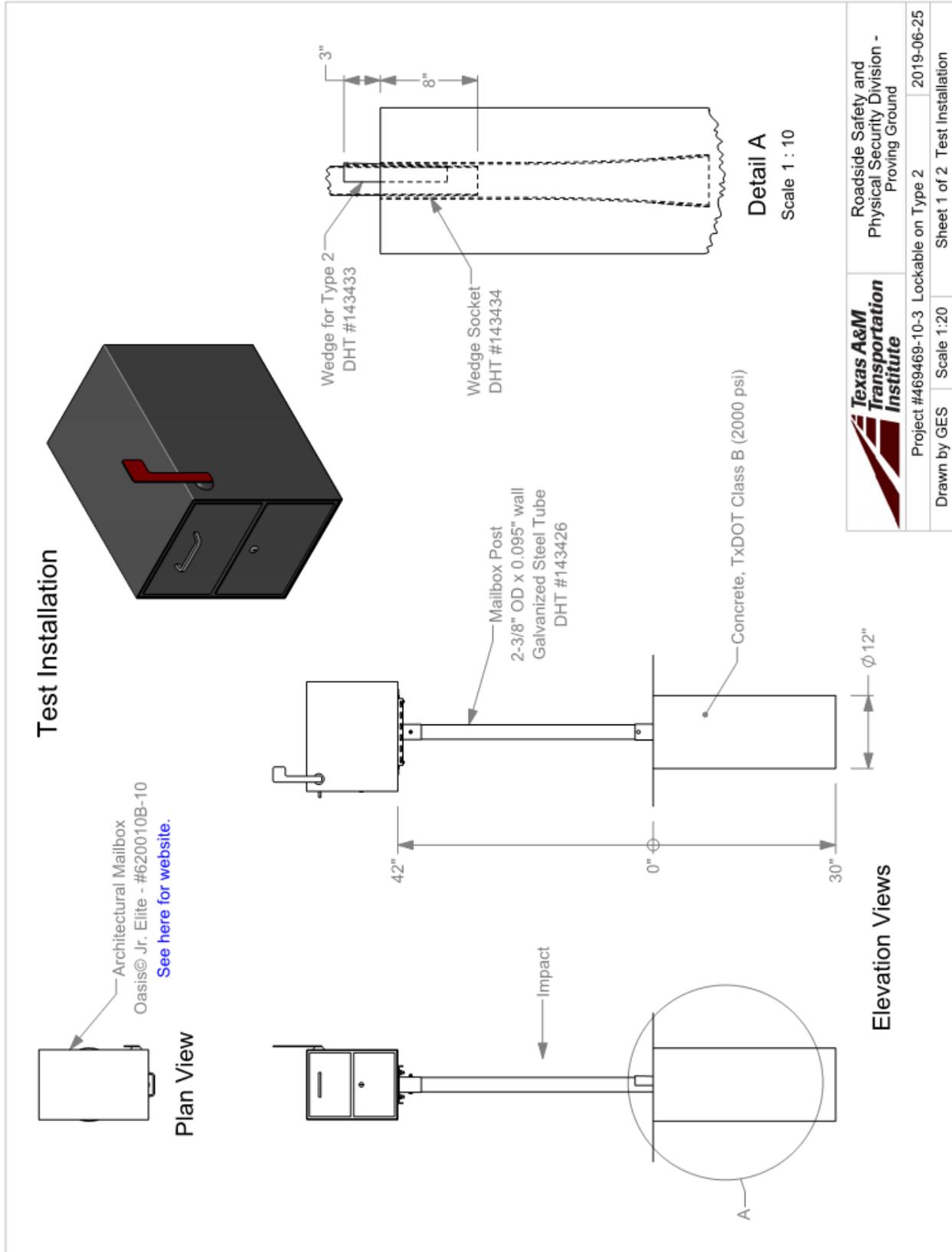


Figure 11.18. Overall Details of the Lockable Mailbox on Steel Tube Post.

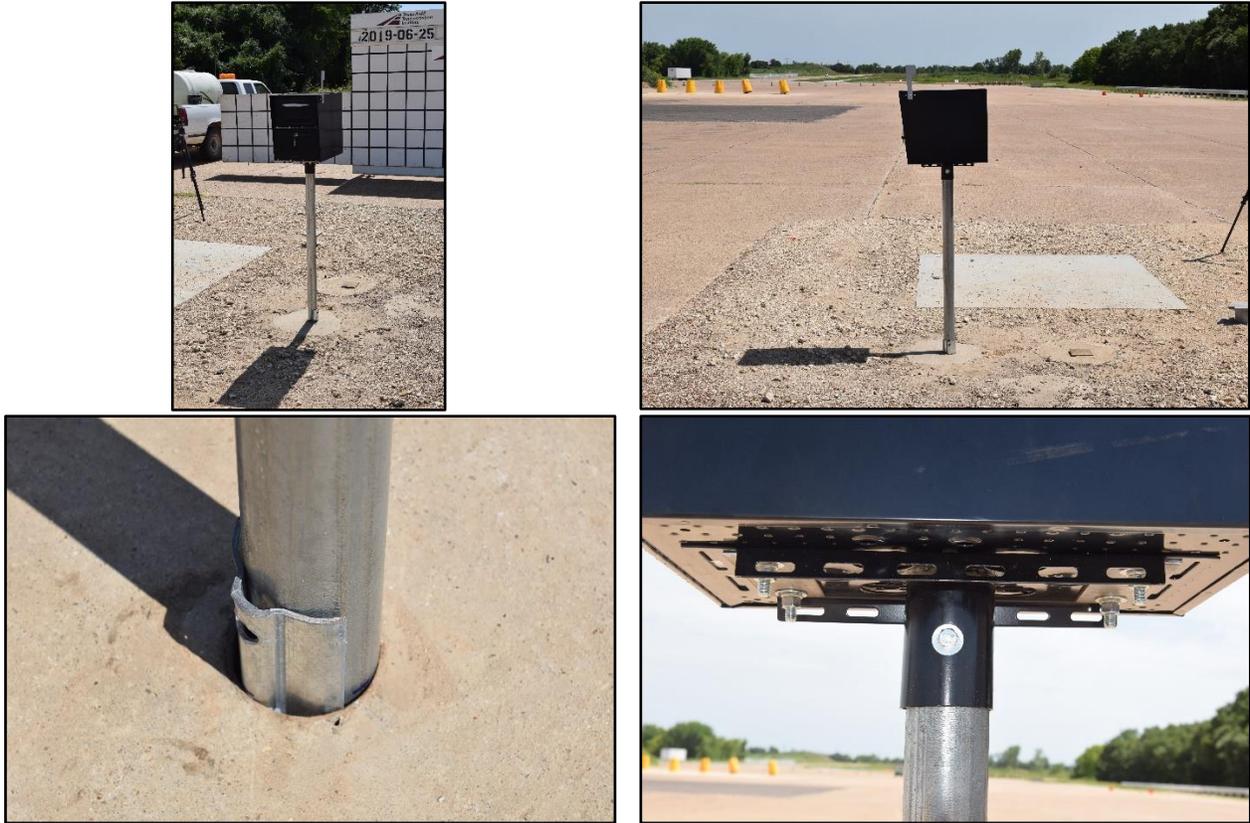


Figure 11.19. Lockable Mailbox on Steel Tube Post prior to Testing.

11.4.2 MASH Test 3-61 (Crash Test No. 469469-10-3)

11.4.2.1 Test Designation and Actual Impact Conditions

MASH Test 3-61 involves a 1100C vehicle weighing 2420 lb \pm 55 lb impacting the lockable mailbox on thin-wall galvanized tube with Type 2 Foundation at an impact speed of 62 mi/h \pm 2.5 mi/h and an angle of 0° \pm 1.5°. The target impact point was the centerline of the mailbox support aligned 14 inches toward the driver's side from the centerline of the vehicle.

The 2011 Kia Rio used in the test weighed 2440 lb, and the actual impact speed and angle were 62.6 mi/h and 0°, respectively. The actual impact point on the vehicle was 14 inches toward the driver's side from the centerline of the vehicle. Minimum target impact severity was 288 kip-ft, and actual IS was 320 kip-ft.

11.4.2.2 Weather Conditions

The test was performed on the afternoon of June 25, 2019. Weather conditions at the time of testing were as follows: wind speed: 10 mi/h; wind direction: 158° with respect to the vehicle (vehicle was traveling at a magnetic heading of 180°); temperature: 88°F; relative humidity: 66 percent.

11.4.2.3 Test Vehicle

The 2011 Kia Rio,¹⁴ shown in Figure 11.20 and Figure 11.21, was used for the crash test. The vehicle's test inertia weight was 2440 lb, and its gross static weight was 2605 lb. The height to the lower edge of the vehicle bumper was 7.8 inches, and height to the upper edge of the bumper was 21.5 inches. Table J.9 in Appendix J.3.2 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 11.20. Lockable Mailbox on Thin-Wall Galvanized Tube with Type 2 Foundation/Test Vehicle Geometrics for Test No. 469469-10-3.



Figure 11.21. Test Vehicle before Test No. 469469-10-3.

11.4.2.4 Test Description

Table 11.7 lists events that occurred during Test No. 469469-10-3. Figure J.1.1 in Appendix J.3.3 presents sequential photographs during the test.

¹⁴ The 2011 model vehicle used is older than the 6-year age noted in *MASH* and was selected based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2011 model vehicle met the *MASH* requirements.

Table 11.7. Events during Test No. 469469-10-3.

Time	Events
0.000	Vehicle contacts mailbox support
0.011	Mailbox support begins to pull out of base
0.024	Mailbox support is fully released from base socket
0.025	Mailbox on support impacts hood of vehicle
0.104	Mailbox on support rebounds off hood

The brakes were applied 1.5 seconds after impact, and the vehicle came to rest 296 ft downstream of and in line of the point of impact.

11.4.2.5 Damage to Test Installation

Figure 11.22 shows the damage to the lockable mailbox on thin-wall galvanized tube with Type 2 foundation. The mailbox-post assembly remained intact. The mailbox, bracket, and support post were deformed. The lockable mailbox on thin-wall galvanized tube with Type 2 foundation assembly came to rest 311 ft downstream of its original location.

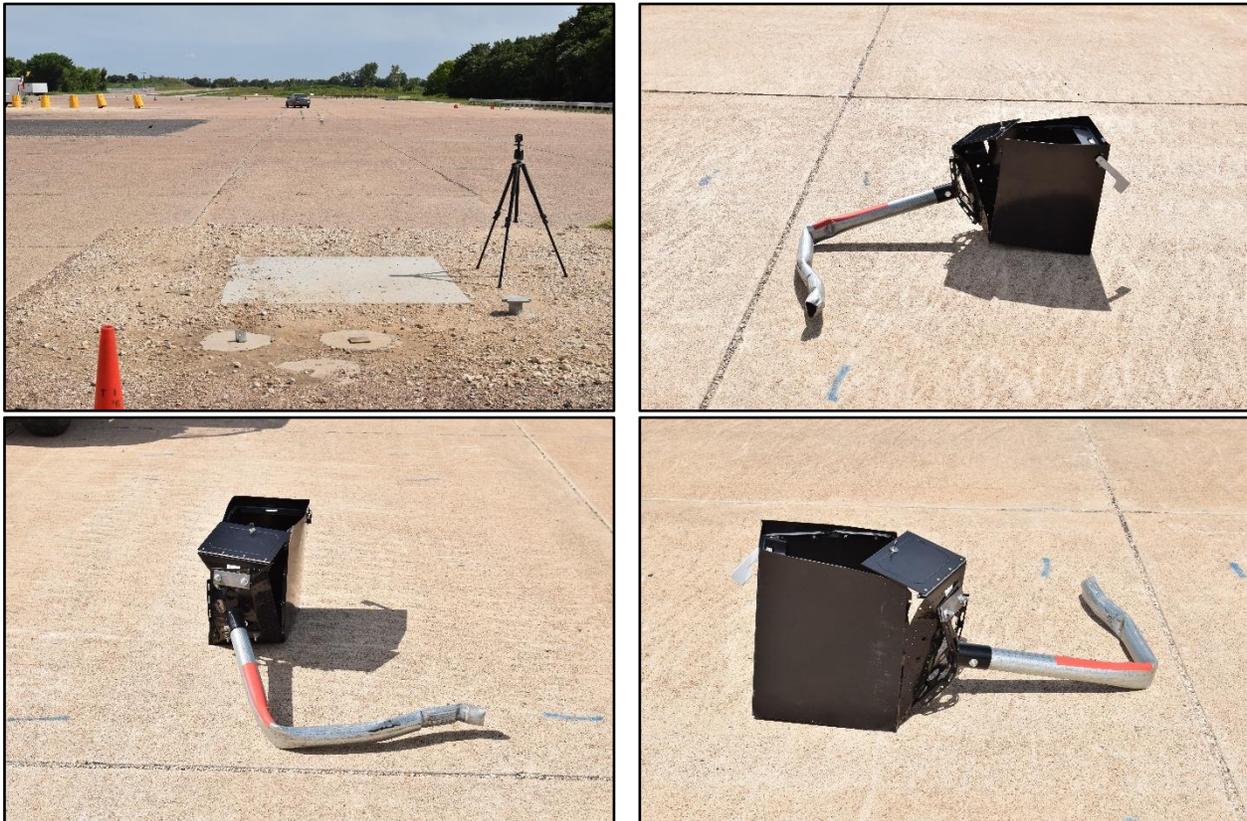


Figure 11.22. Lockable Mailbox on Thin-Wall Galvanized Tube with Type 2 Foundation after Test No. 469469-10-3.

11.4.2.6 Damage to Test Vehicle

Figure 11.23 and Figure 11.24 show the damage sustained by the vehicle. The front bumper sustained a 3-inch-deep dent, 14 inches from the centerline of the vehicle. The left side hood of the vehicle had a 26-inch by 33-inch by 1.5-inch-deep dent with a ¼-inch by ½-inch cut. The lower left area of the windshield was cracked over an area approximately 8 inches by 8 inches. There was no measurable exterior crush or interior deformation to the vehicle. Table J.10 and Table J.11 in Appendix J.3.2 provide further details.



Figure 11.23. Test Vehicle after Test No. 469469-10-3.

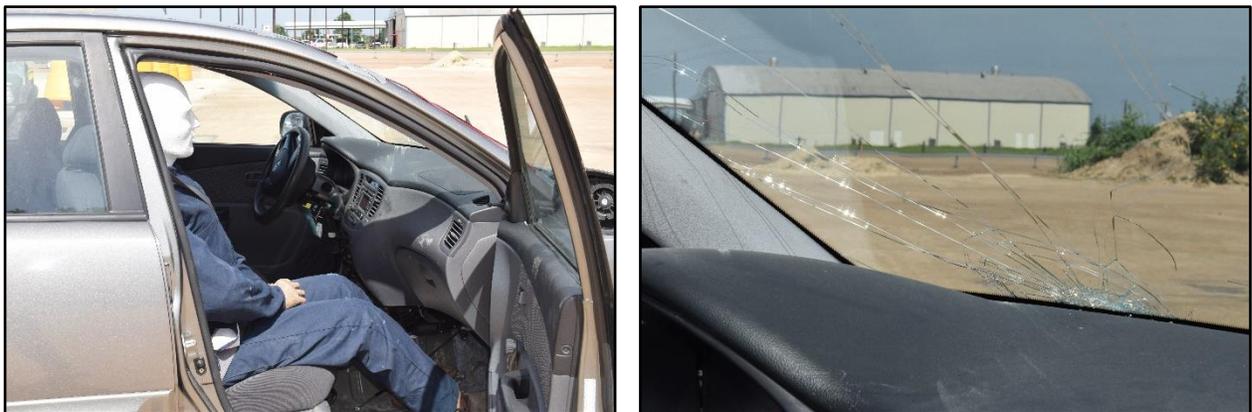


Figure 11.24. Interior of Test Vehicle for Test No. 469469-10-3.

11.4.2.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 11.8. Figure 11.25 summarizes these data and other pertinent information from the test. Figure J.12 in Appendix J.3.4 shows the vehicle angular displacements, and Figure J.13 through Figure J.15 in Appendix J.3.5 show acceleration versus time traces.

Table 11.8. Occupant Risk Factors for Test No. 469469-10-3.

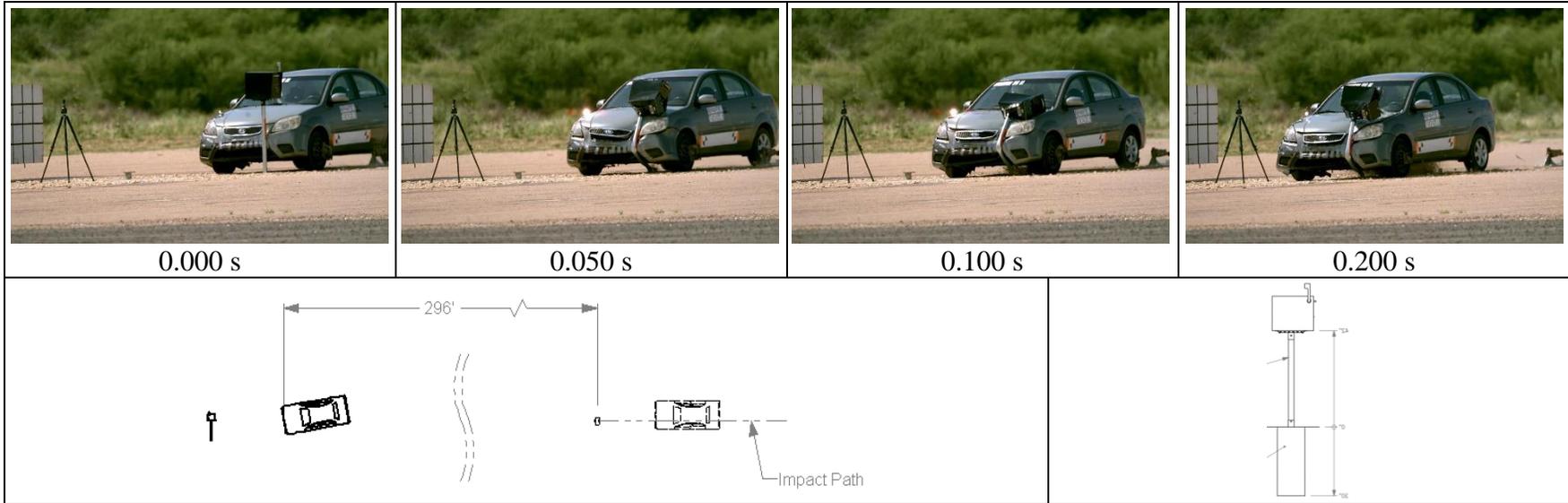
Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV) Longitudinal Lateral	ft/s	at 0.7785 seconds on front of interior
	2.6	
	2.3	
Occupant Ridedown Accelerations (g's) Longitudinal Lateral		
	0.2	(0.9327–0.9427 seconds)
	0.5	(0.7785–0.7885 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.7808 seconds on front of interior
	1.0	
Post Head Deceleration (PHD) (g's)	0.5	(0.7808–0.7908 seconds)
Acceleration Severity Index (ASI)	0.15	(0.0124–0.0624 seconds)
Maximum 50-ms Moving Average (g's) Longitudinal Lateral Vertical		
	-1.6	(0.0018–0.0518 seconds)
	0.4	(0.0198–0.0698 seconds)
	0.6	(0.0302–0.0802 seconds)
Maximum Roll, Pitch, and Yaw Angles Roll Pitch Yaw	Degrees	
	3	(0.6426 seconds)
	1	(0.1101 seconds)
	3	(0.7270 seconds)

11.4.2.8 Assessment of Results

An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-61 is provided in Table 11.9.

11.4.3 Conclusions

The lockable mailbox mounted on a 2³/₈-inch OD by 0.095-inch wall galvanized steel tube post performed acceptably for *MASH* Test 3-61.



General Information

Test Agency Texas A&M Transportation Institute (TTI)
 Test Standard Test No. *MASH* Test 3-61
 TTI Test No. 469469-10-3
 Test Date 2019-06-25

Test Article

Type..... Mailbox support
 Name Lockable mailbox on thin-wall tube with Type 2 foundation
 Installation Length..... n/a
 Material or Key Elements Lockable mailbox attached to 2 $\frac{3}{8}$ -inch OD steel tube inserted into a steel anchor tube embedded in concrete footing and secured by a curved steel wedge

Soil Type and Condition

AASHTO M147-65(2004) Grade B crushed limestone road base

Test Vehicle

Type/Designation 1100C
 Make and Model 2011 Kia Rio
 Curb..... 2455 lb
 Test Inertial 2440 lb
 Dummy 165 lb
 Gross Static 2605 lb

Impact Conditions

Speed 62.6 mi/h
 Angle 0°
 Location/Orientation 14 inches off center of vehicle on driver's side with center of mailbox
 Impact Severity..... 320 kip*ft

Exit Conditions

Speed 60.7 mi/h
 Exit Trajectory/Heading 0°

Occupant Risk Values

Longitudinal OIV..... 2.6 ft/s
 Lateral OIV..... 2.3 ft/s
 Longitudinal Ridedown 0.2 g
 Lateral Ridedown 0.5 g
 THIV 3.7 km.h
 PHD 0.5 g
 ASI 0.15
 Max. 0.050-s Average
 Longitudinal..... -1.6g
 Lateral..... 0.4 g
 Vertical..... 0.6 g

Post-Impact Trajectory

Stopping Distance 296 ft

Vehicle Stability

Maximum Yaw Angle..... 3°
 Maximum Pitch Angle.... 1°
 Maximum Roll Angle 3°
 Vehicle Snagging No
 Vehicle Pocketing..... n/a

Test Article Deflections

Dynamic..... n/a
 Permanent n/a
 Working Width..... n/a
 Working Width Height... n/a

Vehicle Damage

VDS n/a
 CDC n/a
 Max. Exterior Deformation None measurable
 OCDI..... n/a
 Max. Occupant Compartment Deformation None measurable

Figure 11.25. Summary of Results for *MASH* Test 3-61 on the Lockable Mailbox on Thin-Wall Galvanized Tube with Type 2 Foundation.

Table 11.9. Performance Evaluation Summary for MASH Test 3-61 on the Lockable Mailbox on Type 2 Foundation.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-10-3

Test Date: 2019-06.25

MASH Test 3-61 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
<i>B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</i>	The lockable mailbox on a Type 2 foundation yielded to the 1100C vehicle.	Pass
<u>Occupant Risk</u>		
<i>D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i>	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</i>	No occupant compartment deformation or intrusion occurred.	
<i>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 3° and 1°, respectively.	Pass
<i>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.</i>	Longitudinal OIV was 2.6 ft/s, and lateral OIV was 2.3 ft/s.	Pass
<i>I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>	Maximum longitudinal occupant ridedown acceleration was 0.2 g, and maximum lateral occupant ridedown acceleration was 0.5 g.	Pass
<u>Vehicle Trajectory</u>		
<i>N. Vehicle trajectory behind the test article is acceptable.</i>	The 1100C vehicle came to rest 296 ft behind the installation.	Pass

CHAPTER 12: TXDOT ROUND WOOD POST GUARDRAIL IN CONCRETE MOW STRIP

12.1 BACKGROUND

TxDOT frequently installs guardrail in a concrete mow strip. Pavement mow strips are used to combat vegetation growth around guardrail posts to avoid the use of herbicides, decrease maintenance costs, and reduce the safety risk to workers associated with hand mowing around guardrail. A sacrificial grout layer is used in a leave-out section formed in the mow strip around the guardrail posts. During an impact, the grout is crushed, and the post is able to rotate in the leave-out section and dissipate the energy of the impacting vehicle. After an impact, the damaged posts and grout can be replaced within the leave-out region without demolishing and reconstructing the surrounding mow strip.

The TxDOT round wood post guardrail system in soil with 36-inch post embedment performed acceptably in *MASH* Test 3-11 (11). Additional constraint on the round wood posts beyond the standard soil embedment can change the dynamic response of the guardrail system. *MASH* Test 3-11 is considered the critical test for evaluation of the round wood post guardrail system in a concrete mow strip. This test places more demand on the mow-strip-confined posts and, therefore, is more likely to result in fracture of the round wood posts and pocketing or rupture of the W-beam guardrail.

MASH Test 3-10 was not considered necessary on the round wood post guardrail in a concrete mow strip. *MASH* Test 3-10 was successfully performed on a guardrail in a concrete mow strip with both W6×8.5 steel posts and 6-inch by 8-inch rectangular wood posts (12). The geometries of the steel and rectangular wood posts are considered more critical in terms of the vehicle snagging and deceleration compared to the round wood post.

12.2 SYSTEM DETAILS

12.2.1 Test Article and Installation Details

The round wood post guardrail in a concrete mow strip test installation consisted of 162 ft 6 inches of 12-gauge W-beam guardrail attached to nominal 7¼-inch-diameter wood posts embedded 36 inches. A TxDOT downstream anchor terminal was installed on each end of the test installation for a total length of 181 ft 3 inches. The top of the W-beam rail was mounted 31 inches above grade, the posts were spaced 75 inches center to center, and the guardrail splices were located mid-span between every other post. The W-beam rail was offset from the posts using routed wood offset blocks.

A 4-inch-thick by 42-inch-wide by 100-ft-long concrete mow strip was placed in the central section of the test installation. The posts in this region were placed in 19-inch-square voids or leave-outs cast into the concrete mow strip. These posts were installed in 18-inch-diameter drilled holes and backfilled with compacted soil up to the bottom of the mow strip. The remaining 4-inch-deep voids corresponding to the thickness of the mow strip were filled with a low-strength grout after the posts were installed.

Figure 12.1 presents overall information on the round wood post guardrail in a concrete mow strip, and Figure 12.2 provides photographs of the installation. Appendix K.1 provides further details of the round wood post guardrail in a concrete mow strip.

12.2.2 Material Specifications

The specified concrete strength for the mow strip was 2000 psi. Concrete strength was taken on October 9, 2017, and at 17 days of age was 3040 psi.

The low-strength grout mix used in the leave-outs was comprised of 1 part Type 1A cement, 14 parts sand, and 5 parts water, by volume. Grout compressive strength was taken on November 27, 2018, and at 20 days of age was 100 psi.

Appendix K.2 provides material certification documents for the materials used to install/construct the round wood post guardrail in a concrete mow strip.

12.2.3 Soil Conditions

The test installation was installed in standard soil meeting Grading B of AASHTO standard specification M147-65(2004), “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 guardrail system for full-scale crash testing, two 6-ft-long W6×16 posts were installed in the immediate vicinity of the guardrail system using the same fill materials and installation procedures used in the test installation and the standard dynamic test. Table K.1 in Appendix K.2 presents minimum soil strength properties established through the dynamic testing performed in accordance with *MASH* Appendix B.

As determined by the tests summarized in Appendix K.2, Table K.2, the minimum post loads required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, are 3940 lb, 5500 lb, and 6540 lb, respectively (90 percent of static load for the initial standard installation).

On the day of the first test, December 4, 2018, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 7525 lbf, 7878 lbf, and 7727 lbf, respectively. Tables K.2 in Appendix K.2 shows that the strength of the backfill material in which the guardrail system was installed met the minimum *MASH* requirements.

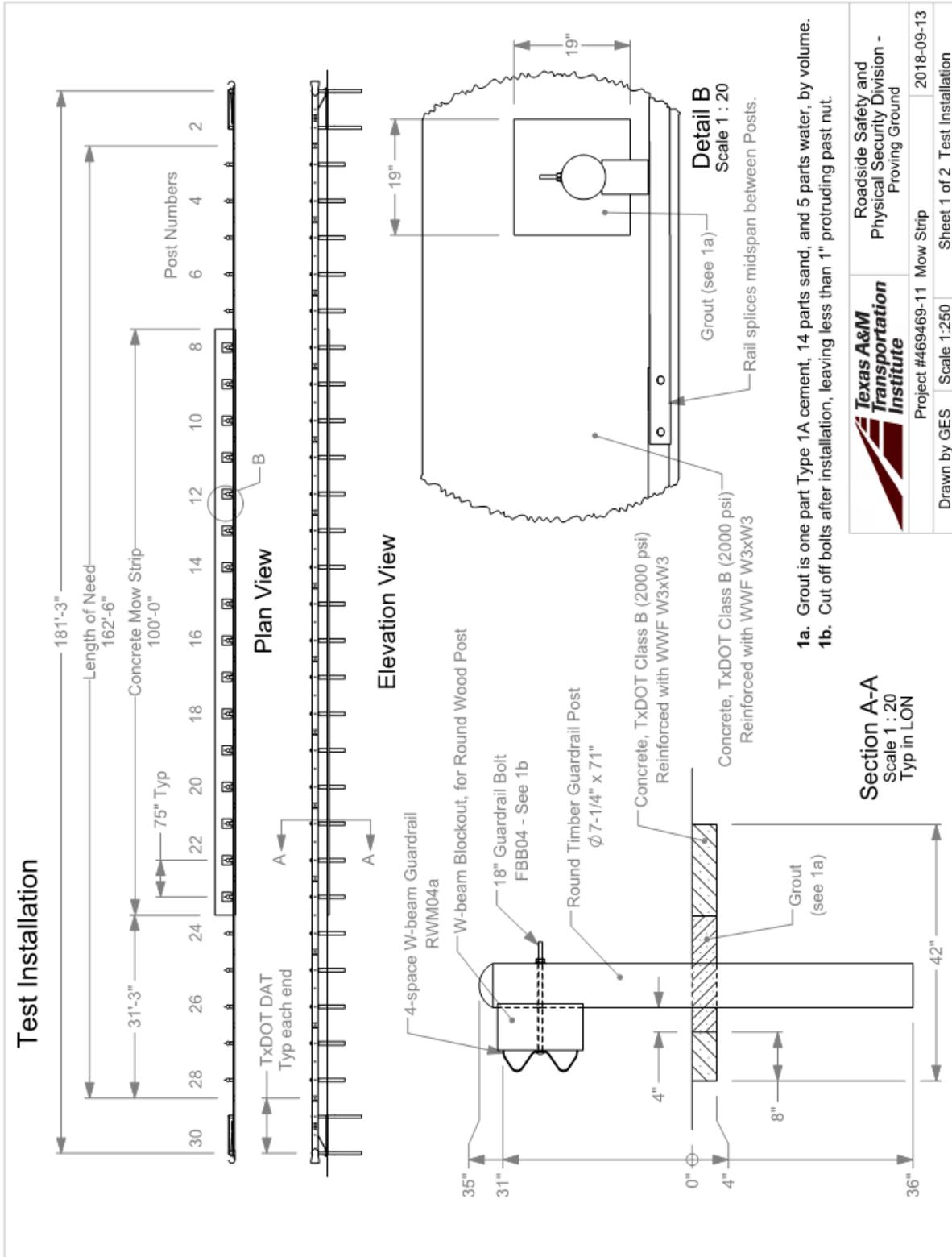


Figure 12.1. Overall Details of the Round Wood Post Guardrail in Concrete Mow Strip.



Figure 12.2. Round Wood Post Guardrail in a Concrete Mow Strip prior to Testing.

12.3 MASH TEST 3-11 (TEST NO. 469469-11)

12.3.1 Test Designation and Actual Impact Conditions

MASH Test 3-11 involves a 2270P vehicle weighing 5000 lb \pm 110 lb impacting the CIP of the round wood post guardrail in a concrete mow strip at an impact speed of 62 mi/h \pm 2.5 mi/h and an angle of 25° \pm 1.5°. The CIP for *MASH* Test 3-11 on the round wood post guardrail in a concrete mow strip was 11.8 ft upstream of post 15.

The 2012 RAM 1500 used in the test weighed 5020 lb, and the actual impact speed and angle were 63.3 mi/h and 25.3°, respectively. The actual impact point was 12.1 ft upstream of the center of post 15. Minimum target impact severity was 106 kip-ft, and actual IS was 122.8 kip-ft.

12.3.2 Weather Conditions

The test was performed on the morning of December 4, 2018. Weather conditions at the time of testing were as follows: wind speed: 4 mi/h; wind direction: 48° with respect to the vehicle (vehicle was traveling in a southerly direction); temperature: 49°F; relative humidity: 63 percent.

12.3.3 Test Vehicle

The 2012 RAM 1500, shown in Figure 12.3 and Figure 12.4, was used for the crash test. The vehicle's test inertia weight was 5020 lb, and its gross static weight was 5020 lb. The height to the lower edge of the vehicle bumper was 11.8 inches, and height to the upper edge of the bumper was 27 inches. The height to the vehicle's center of gravity was 28 inches. Table K.3 and Table K.4 in Appendix K.3.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 12.3. Round Wood Post Guardrail in Concrete Mow Strip/Test Vehicle Geometrics for Test No. 469469-11.



Figure 12.4. Test Vehicle before Test No. 469469-11.

12.3.4 Test Description

Table 12.1 lists events that occurred during Test No. 469469-11. Figure K.1 and Figure K.2 in Appendix K.3.2 present sequential photographs during the test.

Table 12.1. Events during Test No. 469469-11.

Time	Events
0.000	Vehicle contacts barrier
0.049	Vehicle begins to redirect
0.071	Guardrail begins to tear
0.076	Guardrail is fully torn. Vehicle continues to pass through rail.

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from impact for cars and pickups). The 2270P vehicle went through the guardrail and came to rest 210 ft downstream of the impact and 80 ft on the field side of the guardrail.

12.3.5 Damage to Test Installation

Figure 12.5 shows the damage to the round wood post guardrail in a concrete mow strip. The rail released from posts 14 to 20 and ruptured at post 14. Post 13 was leaning 1.5° toward the field side, and posts 14, 15, and 16 broke off at grade. The vehicle passed through the barrier to the field side.



Figure 12.5. Round Wood Post Guardrail in a Concrete Mow Strip after Test No. 469469-11.

12.3.6 Damage to Test Vehicle

Figure 12.6 and Figure 12.7 show the vehicle after the test. The front bumper, hood, grill, radiator and support, right and left front fender, right front and rear door, right and left head lights, right rear fender, and right rear tire and rim were damaged. Maximum exterior crush to the vehicle was 17.0 inches at the front bumper. There was no measurable occupant compartment deformation. Table K.5 and Table K.6 in Appendix K.3.1 provide exterior crush and occupant compartment measurements.



Figure 12.6. Test Vehicle after Test No. 469469-11.



Figure 12.7. Interior of Test Vehicle for Test No. 469469-11.

12.3.7 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk, and results are shown in Table 12.2. Figure 12.8 summarizes these data and other pertinent information from the test. Figure K.3 in Appendix K.3.3 shows the vehicle angular displacements, and Figure K.4 through Figure K.6 in Appendix K.3.4 show acceleration versus time traces.

Table 12.2. Occupant Risk Factors for Test No. 469469-11.

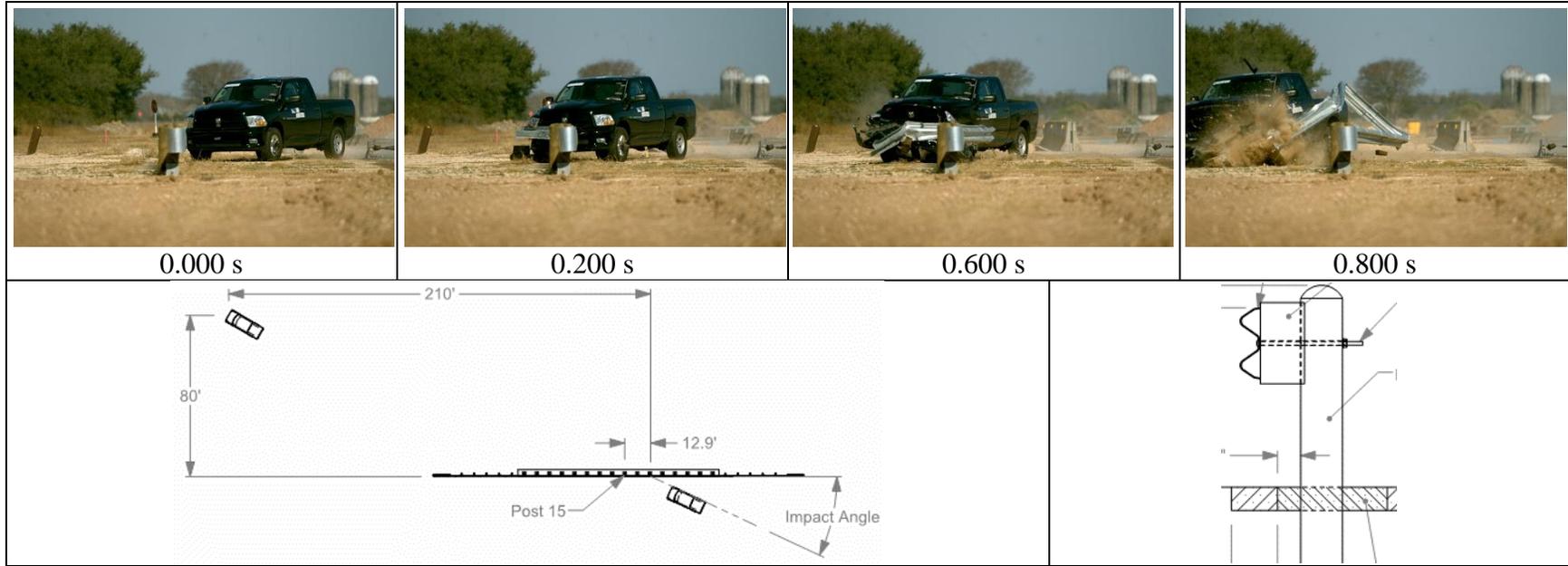
Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV) Longitudinal Lateral	ft/s	at 0.2232 seconds on right side of interior
	14.1	
	4.9	
Occupant Ridedown Accelerations (g's) Longitudinal Lateral		
	3.2	(0.2378–0.2478 seconds)
	2.3	(0.2975–0.3075 seconds)
Theoretical Head Impact Velocity (THIV)	m/s	at 0.2048 seconds on right side of interior
	4.1	
Post Head Deceleration (PHD) (g's)	3.5	(0.2115–0.2215 seconds)
Acceleration Severity Index (ASI)	0.42	(0.0531–0.1031 seconds)
Maximum 50-ms Moving Average (g's) Longitudinal Lateral Vertical		
	-3.6	(0.0866–0.1366 seconds)
	-3.3	(0.0376–0.0876 seconds)
	-1.5	(0.0685–0.1185 seconds)
Maximum Roll, Pitch, and Yaw Angles Roll Pitch Yaw	Degrees	
	5	(0.2335 seconds)
	2	(0.6598 seconds)
	5	(0.2139 seconds)

12.3.8 Assessment of Results

An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-11 is provided in Table 12.3.

12.4 CONCLUSIONS

The round wood post guardrail in a concrete mow strip did not meet *MASH* criteria. The 2270P vehicle penetrated through the guardrail and was not contained or redirected by the round wood post guardrail in a concrete mow strip.



General Information

Test Agency..... Texas A&M Transportation Institute (TTI)
 Test Standard Test No. MASH Test 3-11
 TTI Test No. 469469-11
 Test Date 2018-12-04

Test Article

Type..... Guardrail
 Name..... W-beam guardrail with round wood posts in mow strip
 Installation Length..... 181 ft 3 inches w/ 100-ft concrete mow strip incl.
 Material or Key Elements 7¼-inch-diameter round wood posts, W-beam guardrail, concrete mow strip, grout-filled leave-outs

Soil Type and Condition

4-inch-thick concrete mow strip with grout-filled leave-outs

Test Vehicle

Type/Designation 2270P
 Make and Model 2012 RAM 1500
 Curb..... 5020 lb
 Test Inertial 5020 lb
 Dummy No dummy
 Gross Static 5020 lb

Impact Conditions

Speed 63.3 mi/h
 Angle 25.3°
 Location/Orientation 12.1 ft upstream of center of post 15
 Impact Severity 122.8 kip*ft

Exit Conditions

Speed n/a
 Exit Trajectory/Heading n/a

Occupant Risk Values

Longitudinal OIV..... 14.1 ft/s
 Lateral OIV..... 4.9 ft/s
 Longitudinal Ridedown 3.2 g
 Lateral Ridedown 2.3 g
 THIV 4.1 m/s
 PHD 3.5 g
 ASI..... 0.42
 Max. 0.050-s Average
 Longitudinal..... -3.6 g
 Lateral..... -3.3 g
 Vertical..... -1.5 g

Post-Impact Trajectory

Stopping Distance 210 ft downstrm
 80 ft twd field

Vehicle Stability

Maximum Yaw Angle..... 5°
 Maximum Pitch Angle.... 2°
 Maximum Roll Angle 5°
 Vehicle Snagging No
 Vehicle Pocketing..... Yes

Test Article Deflections

Dynamic..... Guardrail ruptured and vehicle penetrated to field side
 Permanent
 Working Width.....
 Working Width Height....

Vehicle Damage

VDS 01FD4
 CDC 01FLEL2
 Max. Exterior Deformation 17.0 inches
 OCDI..... RF0000000
 Max. Occupant Compartment Deformation No measurable deformation

Figure 12.8. Summary of Results for MASH Test 3-11 on the Round Wood Post Guardrail in Concrete Mow Strip.

Table 12.3. Performance Evaluation Summary for MASH Test 3-11 on the Round Wood Post Guardrail in Concrete Mow Strip.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-11

Test Date: 2018-12-04

MASH Test 3-11 Evaluation Criteria	Test Results	Assessment
<p><u>Structural Adequacy</u></p> <p>A. <i>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underide, or override the installation although controlled lateral deflection of the test article is acceptable</i></p>	The round wood post guardrail in a concrete mow strip failed to contain or redirect the 2270P vehicle.	Fail
<p><u>Occupant Risk</u></p> <p>D. <i>Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i></p> <p><i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</i></p>	<p>No detached elements, fragments, or other debris from the test article were present to penetrate or show potential for penetrating the occupant compartment or to present hazard to others in the area.</p> <p>There was no measurable deformation of the occupant compartment.</p>	Pass
<p>F. <i>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i></p>	The 2270P vehicle remained upright during and after the collision event. Maximum roll was 5°, and maximum pitch was 2°.	Pass
<p>H. <i>Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.</i></p>	Longitudinal OIV was 14.1 ft/s, and lateral OIV was 4.9 ft/s.	Pass
<p>I. <i>Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.</i></p>	Maximum longitudinal 10-ms occupant ridedown acceleration was 3.2 g, and maximum lateral 10-ms occupant ridedown acceleration was 2.3 g.	Pass
<p><u>Vehicle Trajectory</u></p> <p>For redirective devices, it is preferable that the vehicle be smoothly redirected and leave the barrier within the “exit box” criteria (not less than 32.8 ft for the 1100C and 2270P vehicles), and should be documented.</p>	The 2270P vehicle was not contained.	Documentation only

CHAPTER 13: TXDOT TYPE III BARRICADE

13.1 BACKGROUND

Acceptable design configurations for Type III barricades are provided on barricade and construction sheet BC(5)-14 and Section D “Type III Barricades” of the Compliant Work Zone Traffic Control Device List. Numerous material options and combinations are permitted. Evaluation under this project focused on systems with a support structure fabricated using PSST.

Type III barricades with PSST frames can be used with three different rail types: wood, hollow-profile plastic lumber (HPPL), and plastic I-beam rails. The wood and HPPL rails are directly bolted to the barricade uprights, while the plastic I-beam rails clip into brackets attached to the uprights. Because the I-beam rails are releasable, their evaluation requires separate testing. Of the two direct-bolted rail types, wood was considered more critical than HPPL. This is because the wood rails are heavier and can fracture into multiple pieces that can subsequently impact the windshield of the vehicle. Thus, if the Type III barricade with wood rails meets *MASH* requirements, a similar design with HPPL rails would also be considered *MASH* compliant.

The PSST frame consists of uprights and skids. The uprights insert into PSST sleeves that can be connected to the skids by welding or bolted steel hardware. Welded connections were considered the more critical of the two connection types because the small welds have an opportunity to fracture and release the barricade uprights, which could then potentially interact with the vehicle windshield. Therefore, if the Type III barricade with welded connections meets *MASH* requirements, a similar design with bolted hardware connections would also be considered *MASH* compliant.

A lower cross member between the two uprights is an optional feature for the Type III barricades that can be used when needed to provide additional structural support to the barricade frame. This cross member is typically only needed when the plastic I-beam rails are used because these clip-on rails do not provide the same structural rigidity of the direct-bolted rails. Additionally, the barricade system with direct-bolted rails would be considered more critical without the lower cross member because the cross member provides additional strength and rigidity that would make separation of the barricade components less likely during an impact. Consequently, the Type III barricade system evaluated under *MASH* did not include a lower cross member. However, if this system satisfies *MASH* criteria, a similar design with a bolted cross member would also be considered *MASH* compliant.

Finally, TxDOT standards permit Type III barricades to vary in length from 4 ft to 8 ft. A 4-ft length was considered most critical. This length permits both uprights to be impacted simultaneously, thus increasing the probability of the uprights releasing from their skids. In a longer configuration, if only one upright is impacted, the barricade may simply rotate out of the path of the vehicle. Therefore, if a 4-ft-long Type III barricade system satisfies *MASH* criteria, longer variations would also be considered *MASH* compliant.

The *MASH* test matrix for work zone traffic control devices consists of three tests: 3-70, 3-71, and 3-72. Test 3-70 is considered optional for free-standing devices weighing less than 220 lb because “velocity changes during low-speed impacts will be within acceptable limits...” Tests 3-71 and 3-72 evaluate the behavior of the device during high-speed impacts with the

1100C passenger car and 2270P pickup, respectively. *MASH* Section 2.2.4.2 states that “lightweight free-standing features cannot cause sufficient velocity change to result in failure of the test under occupant risk criteria. Therefore, Tests 71 and 72 can be conducted without the instrumentation necessary for determining occupant risk whenever the test article has a total weight of 220 lb (100 kg) or less.” Consequently, the vehicles used for the tests on the Type III barricade reported herein were uninstrumented.

MASH Section 3.4.2.3 recognizes that a work-zone traffic control device such as a barricade may be placed in “out-of-service” orientations. A common practice with barricades is to turn the barricade rails parallel to and out of view of traffic until they are put back in use or picked up from the job site. *MASH* states that “If there is a reasonable expectation that a device will be commonly found adjacent to traffic in an ‘out-of-service’ orientation and this orientation poses a greater risk to the motorist than in the normal position, it should be tested in the alternate position. If it cannot be determined which position is more critical, tests in both the normal and ‘out-of-service’ orientations should be conducted.” Both normal (perpendicular) and parallel orientations were evaluated for the Type III barricade.

13.2 SYSTEM DETAILS

13.2.1 Test Article and Installation Details

The Type III barricade consisted of three 1-inch by 8-inch (nominal) pine boards mounted to two vertical sections of 1½-inch PSST. The top edges of the boards were positioned 20, 40, and 60 inches above grade. The PSST uprights were laterally spaced 36 inches apart. The uprights were inserted into 4-inch-long vertical sleeves fabricated from 1¾-inch PSST. The sleeves were welded to 60-inch-long horizontal skids that were also fabricated from 1¾-inch PSST. The wood rails were attached to the uprights, and the uprights were secured inside the sleeves using ¾-inch-diameter bolts and associated hardware. The total weight of the Type III barricade assembly was 57 lb. A 40-pound sand bag was placed on each end of both horizontal skids, and the assembly rested on concrete pavement with no anchoring.

Figure 13.1 presents overall information on the Type III barricade, and Figure 13.2 provides photographs of the installation. Appendix L.1 provides further details of the Type III barricade.

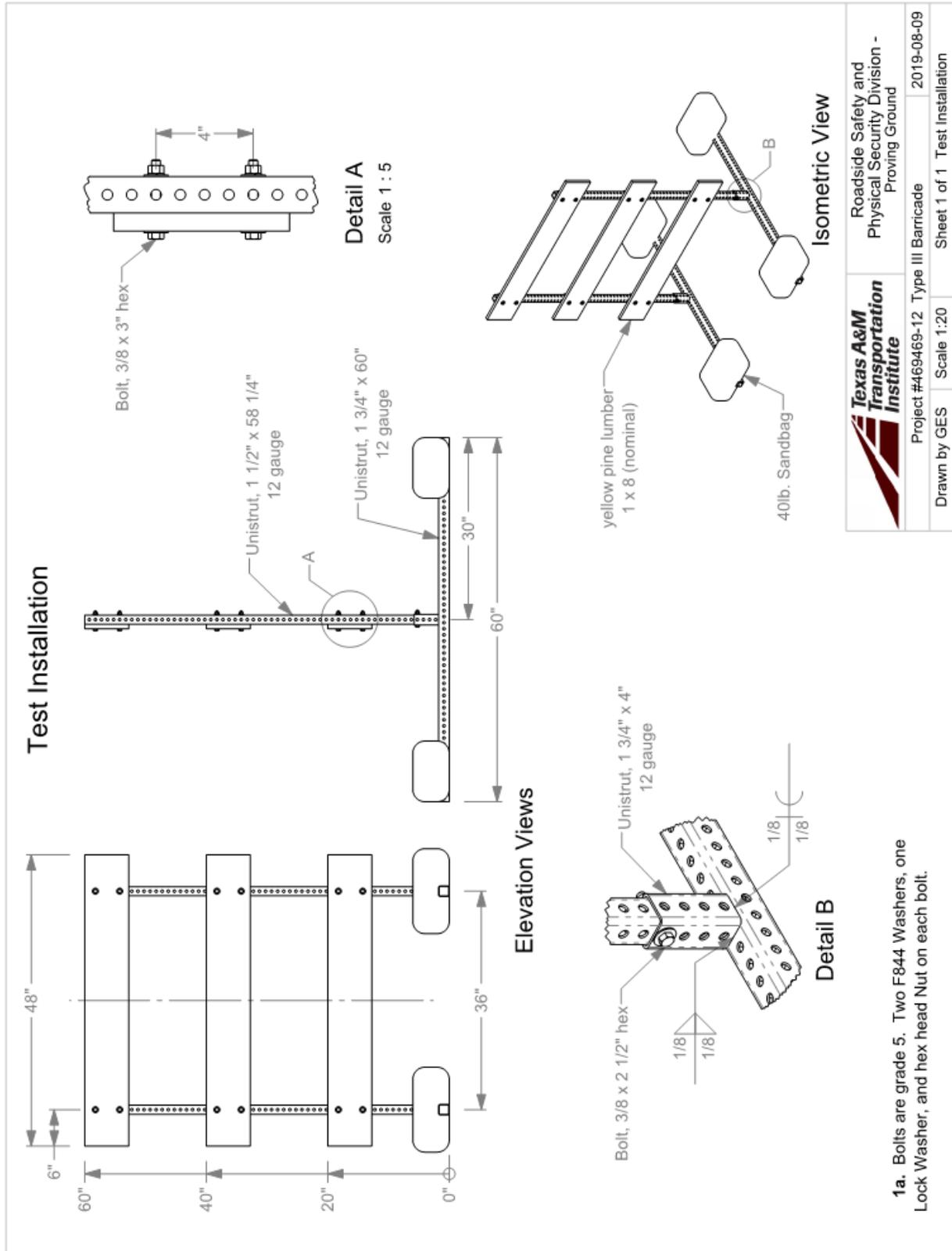


Figure 13.1. Overall Details of the Type III Barricade.

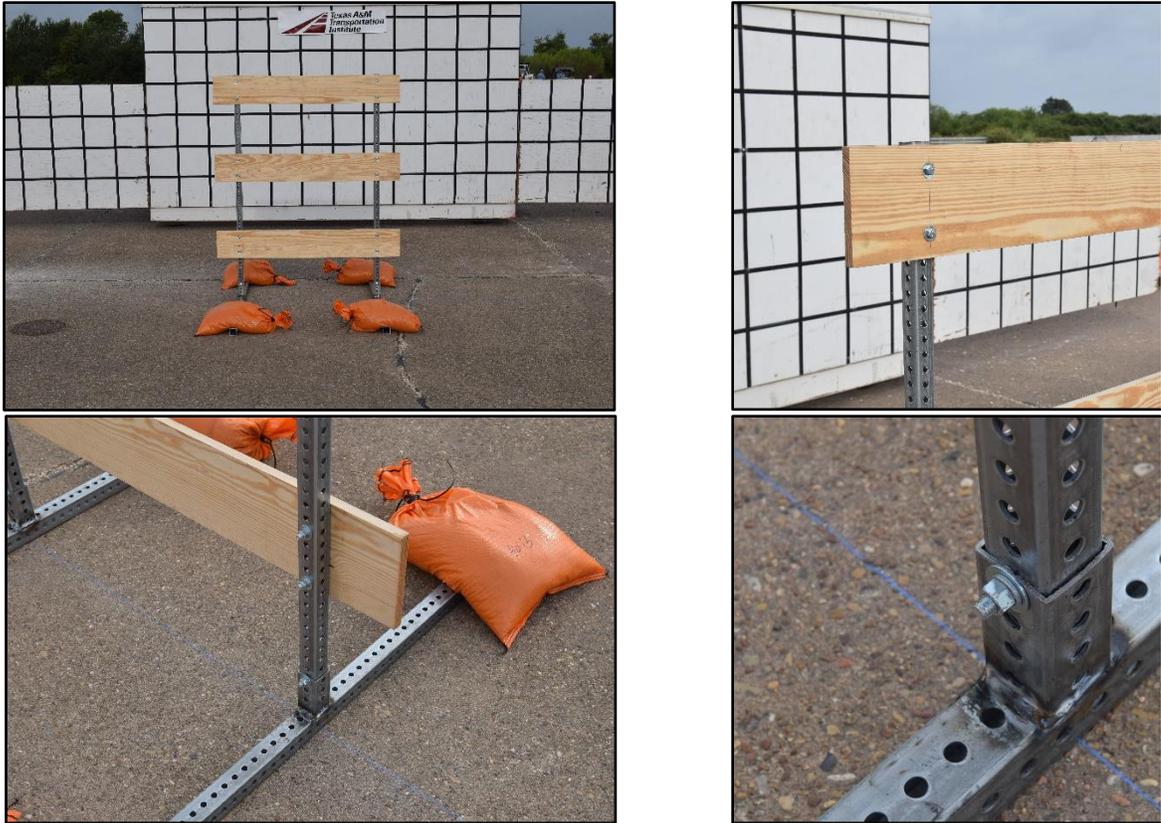


Figure 13.2. Type III Barricade prior to Test

13.3 MASH TEST 3-71 AT 90° (TEST NO. 469469-12-01)

13.3.1 Test Designation and Actual Impact Conditions

MASH Test 3-71 involves a 1100C vehicle weighing 2420 lb \pm 55 lb impacting the Type III barricade at an impact speed of 62 mi/h \pm 2.5 mi/h and an angle of 90° \pm 1.5°. The selected impact point was the centerline of the Type III barricade aligned 14 inches off of the centerline of the vehicle toward the driver's side.

The 2009 Kia Rio used in the test weighed 2416 lb, and the actual impact speed and angle were 62.2 mi/h and 90°, respectively. Minimum target impact severity was 288 kip-ft, and actual IS was 312 kip-ft.

13.3.2 Weather Conditions

The test was performed on the morning of August 27, 2019. Weather conditions at the time of testing were as follows: wind speed: 4 mi/h; wind direction: 191° with respect to the vehicle (vehicle was traveling at a magnetic heading of 0°); temperature: 86°F; relative humidity: 82 percent.

13.3.3 Test Vehicle

The 2009 Kia Rio,¹⁵ shown in Figure 13.3 and Figure 13.4, was used for the crash test. The vehicle's test inertia weight was 2416 lb, and its gross static weight was 2581 lb. The height to the lower edge of the vehicle bumper was 7.75 inches, and the height to the upper edge of the bumper was 21.5 inches. Table L.1 in Appendix L.2.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 13.3. Type III Barricade/Test Vehicle Geometrics for Test No. 469469-12-01.



Figure 13.4. Test Vehicle before Test No. 469469-12-01.

¹⁵ The 2009 model vehicle used is older than the 6-year age noted in *MASH* and was selected based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2009 model vehicle met the *MASH* requirements.

13.3.4 Test Description

Table 13.1 lists events that occurred during Test No. 469469-12-01. Figure L.1 in Appendix L.2.2 presents sequential photographs during the test.

Table 13.1. Events during Test No. 469469-12-01.

Time	Events
0.000	Vehicle contacts barricade
0.004	Barricade uprights begin to bend
0.012	Downstream barricade skid lifts off pavement
0.051	Downstream upright fractures at location of bottom rail
0.078	Downstream skid makes contact with pavement

The 1100C vehicle came to rest 397 ft downstream and 6 ft left of the original impact point.

13.3.5 Damage to Test Installation

Figure 13.5 shows the damage to the Type III barricade. Components of the barricade fractured into multiple pieces that were scattered 165 ft downstream, 13 ft to the right and 43 ft to the left of the original position. The largest section of debris consisting of two wood rails and the fractured uprights came to rest 142 ft downstream and 43 ft to the left of the original impact location.

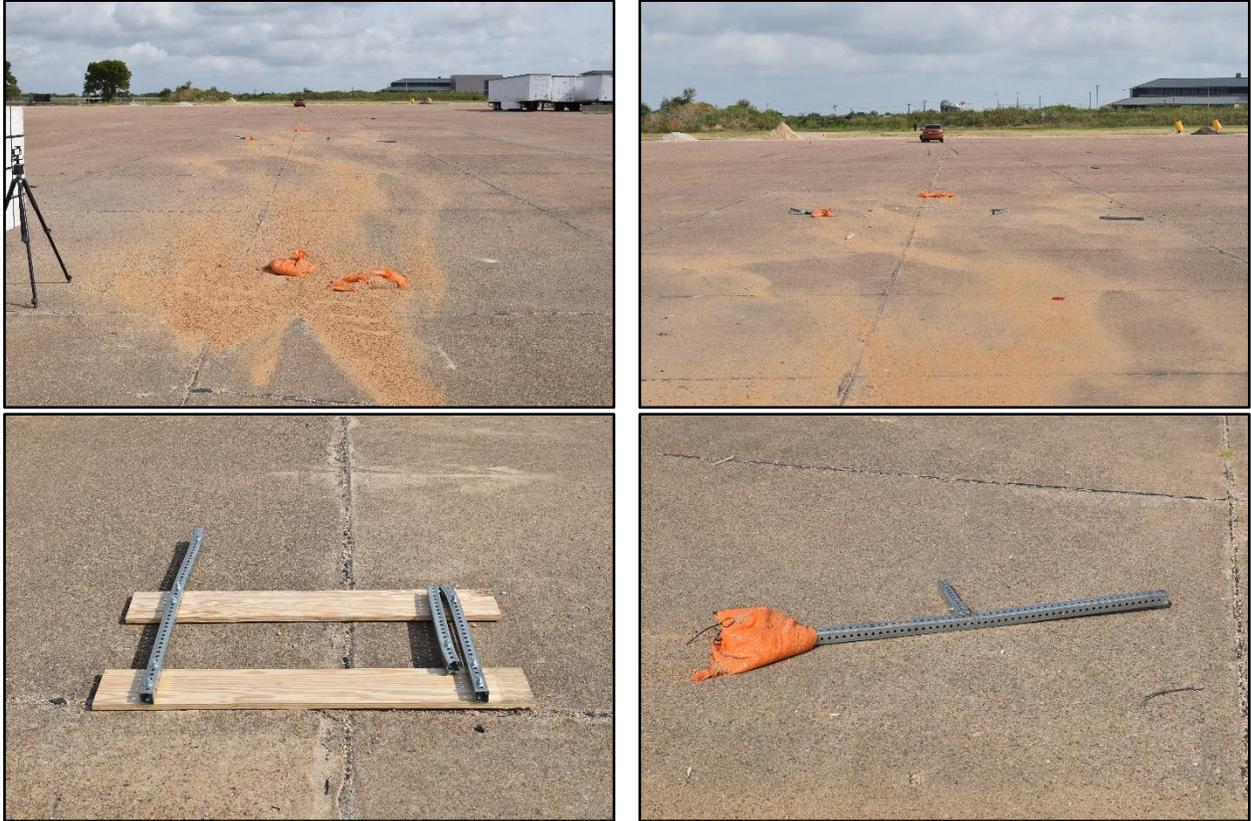


Figure 13.5. Type III Barricade after Test No. 469469-12-01.

13.3.6 Damage to Test Vehicle

Figure 13.6 and Figure 13.7 show the damage sustained by the vehicle. There was a 4-inch by 8-inch by 1.75-inch-deep dent in the front bumper and hood edge, and a 24-inch by 24-inch by 2.5-inch-deep dent in the top left side of the hood. There was no measurable occupant compartment deformation. Table L.2 and Table L.3 in Appendix L.2.1 provide exterior crush and occupant compartment measurements.



Figure 13.6. Test Vehicle after Test No. 469469-12-01.



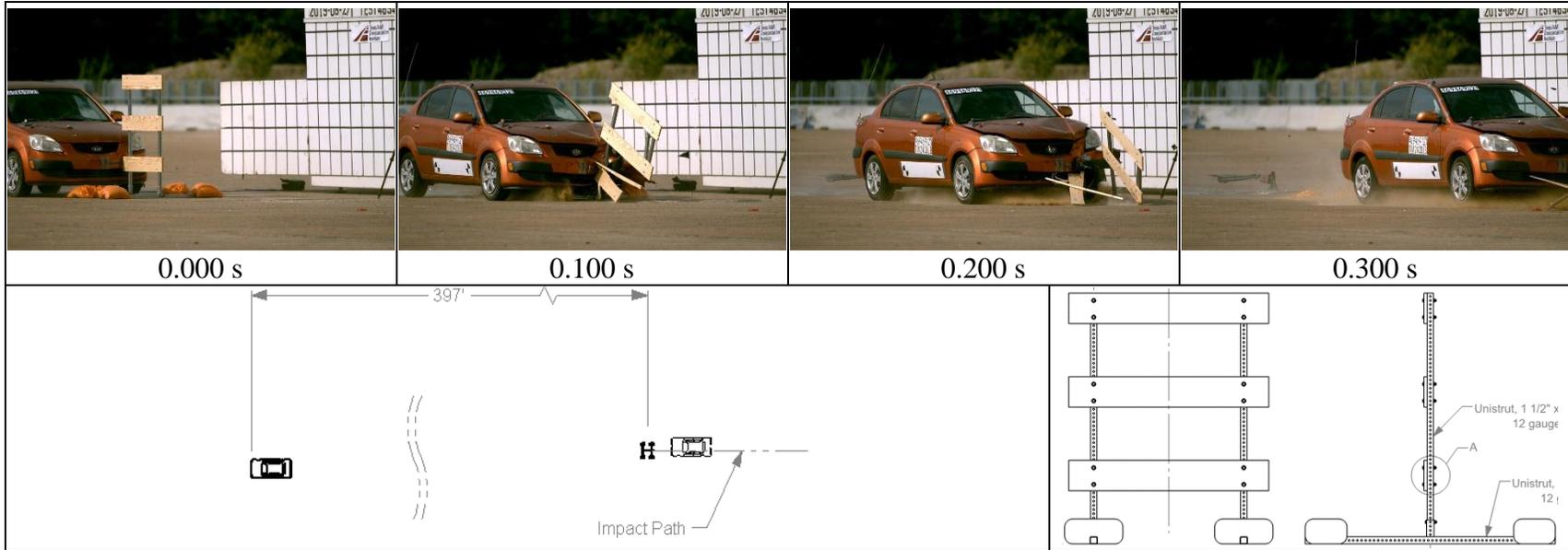
Figure 13.7. Interior of Test Vehicle after Test No. 469469-12-01.

13.3.7 Occupant Risk Factors

According to *MASH*, when the weight of the traffic control device is less than 220 lb, the test may be performed without vehicle instrumentation. The Type III barricade system weighed 57 lb. Therefore, the vehicle was not instrumented, and occupant risk factors were not obtained for this test.

13.3.8 Assessment of Results

The summary of test results can be found in Figure 13.8 and an assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-71 at 90° is provided in Table 13.2.



<p>General Information</p> <p>Test Agency..... Texas A&M Transportation Institute (TTI)</p> <p>Test Standard Test No. <i>MASH</i> Test 3-71</p> <p>TTI Test No..... 469469-12-01</p> <p>Test Date..... 2019-08-27</p> <p>Test Article</p> <p>Type..... Work zone traffic control device</p> <p>Name..... TxDOT Type III barricade</p> <p>Installation Length..... n/a</p> <p>Material or Key Elements Wood boards and perforated square steel tube frame</p> <p>Placed on dry concrete</p> <p>Soil Type and Condition</p> <p>Test Vehicle</p> <p>Type/Designation..... 1100C</p> <p>Make and Model..... 2009 Kia Rio</p> <p>Curb..... 2527 lb</p> <p>Test Inertial..... 2416 lb</p> <p>Dummy..... 165 lb dummy on passenger side</p> <p>Gross Static..... 2581 lb</p>	<p>Impact Conditions</p> <p>Speed..... 62.2 mi/h</p> <p>Angle..... 90°</p> <p>Location/Orientation Center of barricade 14 inches off center of the vehicle toward the driver's side.</p> <p>Impact Severity..... 312 kip*ft</p> <p>Exit Conditions</p> <p>Speed..... n/a</p> <p>Exit Trajectory/Heading n/a</p> <p>Occupant Risk Values</p> <p>Longitudinal OIV..... n/a</p> <p>Lateral OIV..... n/a</p> <p>Longitudinal Ridedown n/a</p> <p>Lateral Ridedown..... n/a</p> <p>THIV..... n/a</p> <p>ASI..... n/a</p> <p>Max. 0.050-s Average</p> <p>Longitudinal..... n/a</p> <p>Lateral..... n/a</p> <p>Vertical..... n/a</p>	<p>Post-Impact Trajectory</p> <p>Stopping Distance..... 397 ft downstrm; 6 ft left</p> <p>Vehicle Stability</p> <p>Maximum Yaw Angle..... n/a</p> <p>Maximum Pitch Angle.... n/a</p> <p>Maximum Roll Angle..... n/a</p> <p>Vehicle Snagging..... n/a</p> <p>Vehicle Pocketing..... n/a</p> <p>Test Article Deflections</p> <p>Dynamic..... n/a</p> <p>Permanent..... n/a</p> <p>Working Width..... n/a</p> <p>Working Width Height.... n/a</p> <p>Vehicle Damage</p> <p>VDS..... 12FL1</p> <p>CDC..... 12FLEN1</p> <p>Max. Exterior Deformation 0 inches</p> <p>OCDI..... LF000000</p> <p>Max. Occupant Compartment Deformation..... 0 inches</p>
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Figure 13.8. Summary of Results for *MASH* Test 3-71 on the Type III Barricade.

Table 13.2. Performance Evaluation Summary for MASH Test 3-71 on the Type III Barricade.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-12-01

Test Date: 2019-08-27

MASH Test 3-60 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
<i>B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</i>	The Type III barricade support yielded to the 1100C vehicle as designed.	Pass
<u>Occupant Risk</u>		
<i>D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i>	After impact, the barricade fragments did not penetrate or show any potential for penetration into the occupant compartment.	Pass
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</i>	There was no occupant compartment deformation	Pass
<i>E. Detached elements, fragments, or other debris from the test article, of vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.</i>	The detached elements did not obstruct the driver's vision or cause loss of control of the vehicle.	Pass
<i>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The vehicle remained upright and stable during and after the impact	Pass
<i>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.</i>	According to MASH, when the weight of the traffic control device is less than 220 lb, the test may be performed without vehicle instrumentation.	n/a
<i>I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>	The Type III barricade system weighed 57 lb. Therefore, the vehicle was not instrumented, and occupant risk factors were not obtained for this test.	n/a
<u>Post-Impact Vehicular Response</u>		
<i>N. Vehicle trajectory behind the test article is acceptable.</i>	The 1100C vehicle came to rest 397 ft behind and 6 ft left of the original position of the installation.	Pass

13.4 MASH TEST 3-72 AT 90° (TEST NO. 469469-12-02)

13.4.1 Test Designation and Actual Impact Conditions

MASH Test 3-72 involves a 2270P vehicle weighing 5000 lb \pm 110 lb impacting the Type III barricade at an impact speed of 62 mi/h \pm 2.5 mi/h and an angle of 90° \pm 1.5°. The selected impact point was the centerline of the Type III barricade post aligned 12 inches off the centerline of the vehicle toward the driver's side.

The 2013 RAM 1500 used in the test weighed 5044 lb, and the actual impact speed and angle were 63.5 mi/h and 90°, respectively. Minimum target impact severity was 594 kip-ft, and actual IS was 680 kip-ft.

13.4.2 Weather Conditions

The test was performed in the afternoon of August 27, 2019. Weather conditions at the time of testing were as follows: wind speed: 3 mi/h; wind direction: 327° with respect to the vehicle (vehicle was traveling at a magnetic heading of 0°); temperature: 93°F; relative humidity: 59 percent.

13.4.3 Test Vehicle

The 2013 RAM 1500, shown in Figure 13.9 and Figure 13.10, was used for the crash test. The vehicle's test inertia weight was 5044 lb, and its gross static weight was 5044 lb. The height to the lower edge of the vehicle bumper was 11.8 inches, and height to the upper edge of the bumper was 27 inches. The height to the vehicle's center of gravity was 28.4 inches. Table L.4 and Table L.5 in Appendix L.3.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 13.9. Type III Barricade/Test Vehicle Geometries for Test No. 469469-12-02.



Figure 13.10. Test Vehicle before Test No. 469469-12-02.

13.4.4 Test Description

Table 13.3 lists events that occurred during Test No. 469469-12-02. Figure L.2 in Appendix L.3.2 present sequential photographs during the test.

Table 13.3. Events during Test No. 469469-12-02.

Time	Events
0.000	Vehicle contacts barricade
0.009	Barricade uprights begin to bend from impact
0.016	Corner of top wood rail begins to impact the hood of the vehicle
0.018	Downstream barricade skid begins to lift off the pavement

The 2270P vehicle came to rest 330 ft downstream and 12 ft to the left of the original impact point.

13.4.5 Damage to Test Installation

Figure 13.11 shows the damage to the Type III barricade. The barricade separated into two pieces. One of the uprights fractured approximately 15 inches above grade. The lower portion of this upright and the attached skid came to rest 218 ft downstream and 40 ft to the left of the impact point. The remaining portion of the fracture upright, the other upright and skid, and the three rails remained together and came to rest 105 ft downstream of the impact point.

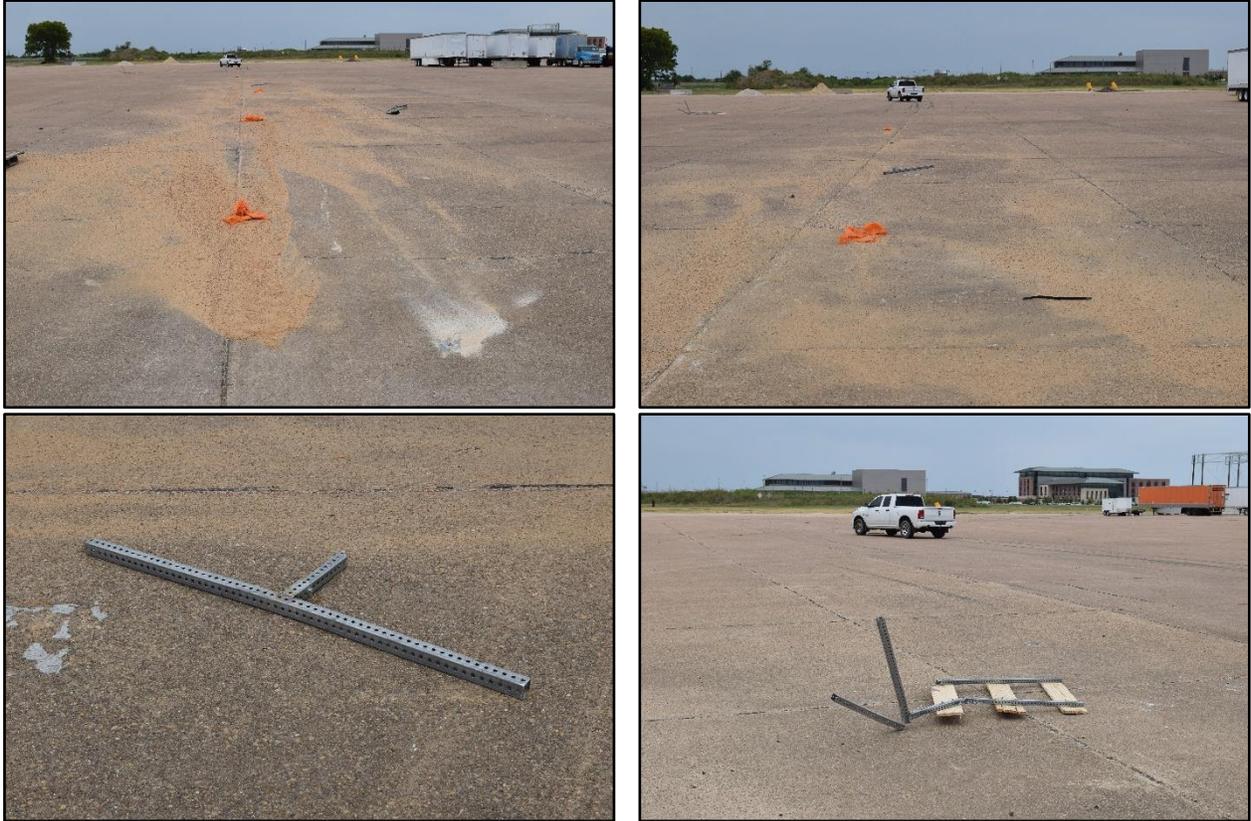


Figure 13.11. Type III Barricade after Test No. 469469-12-02.

13.4.6 Damage to Test Vehicle

Figure 13.12 and Figure 13.13 show the damage sustained by the vehicle. There was an 8-inch by 8-inch dent in the hood, including a 1-inch hole located 1 ft to the left of the centerline of the hood at the front. The front bumper and grill also sustained damage. There was no measurable occupant compartment deformation. Table L.6 and Table L.7 in Appendix L.3.1 provide exterior crush and occupant compartment measurements.



Figure 13.12. Test Vehicle after Test No. 469469-12-02.



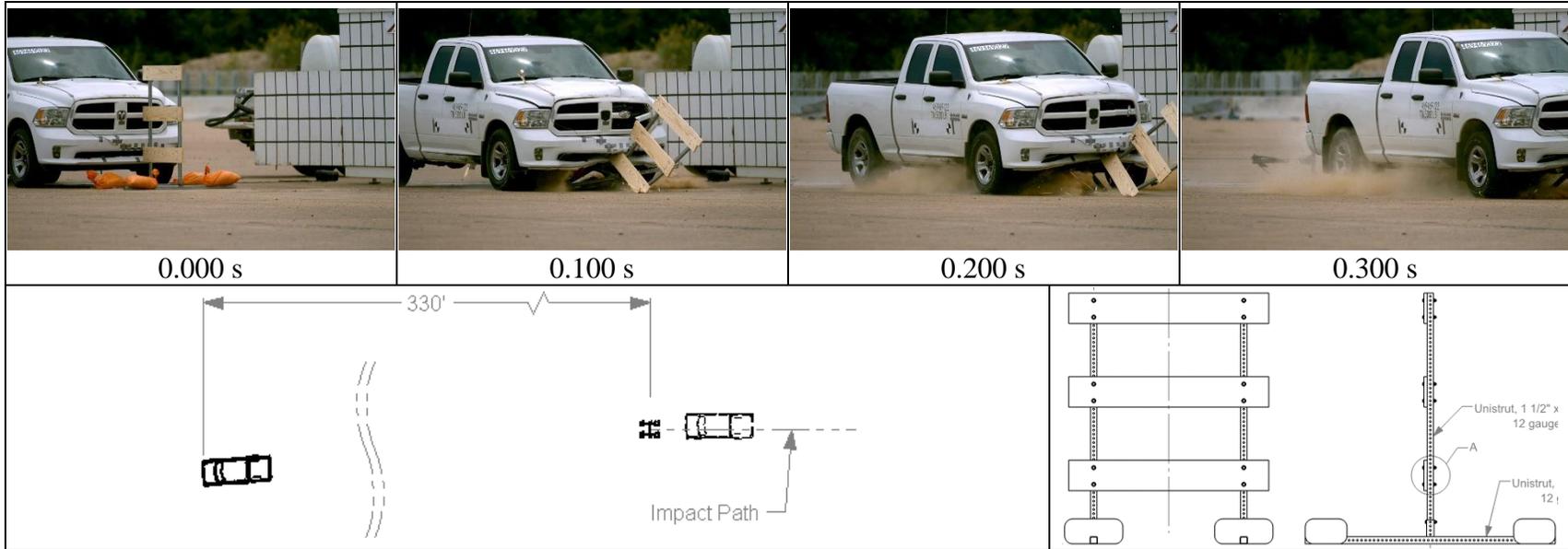
Figure 13.13. Interior of Test Vehicle after Test No. 469469-12-02.

13.4.7 Occupant Risk Factors

According to *MASH*, when the weight of the traffic control device is less than 220 lb, the test may be performed without vehicle instrumentation. The Type III barricade system weighed 57 lb. Therefore, the vehicle was not instrumented, and occupant risk factors were not obtained for this test.

13.4.8 Assessment of Results

The summary of test results can be found in Figure 13.14 and an assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-72 at 90° is provided in Table 13.4.



<p>General Information Test Agency..... Texas A&M Transportation Institute (TTI) Test Standard Test No. <i>MASH</i> Test 3-72 TTI Test No..... 469469-12-02 Test Date..... 2019-08-27</p> <p>Test Article Type..... Work zone traffic control device Name..... TxDOT Type III barricade Installation Length..... n/a Material or Key Elements Wood boards and perforated square steel tube frame</p> <p>Soil Type and Condition Placed on dry concrete</p> <p>Test Vehicle Type/Designation..... 2270P Make and Model..... 2013 RAM 1500 Curb..... 5022 lb Test Inertial..... 5044 lb Dummy..... No dummy Gross Static..... 5044 lb</p>	<p>Impact Conditions Speed..... 63.5 mi/h Angle..... 90° Location/Orientation Center of barricade 14 inches off center of the vehicle toward the driver's side 680 kip*ft</p> <p>Impact Severity..... Exit Conditions Speed..... 60.3 mi/h Exit Trajectory/Heading n/a</p> <p>Occupant Risk Values Longitudinal OIV..... n/a Lateral OIV..... n/a Longitudinal Ridedown n/a Lateral Ridedown..... n/a THIV..... n/a ASI..... n/a Max. 0.050-s Average Longitudinal..... n/a Lateral..... n/a Vertical..... n/a</p>	<p>Post-Impact Trajectory Stopping Distance..... 330 ft downstrm; 12 ft left</p> <p>Vehicle Stability Maximum Yaw Angle.... n/a Maximum Pitch Angle.... n/a Maximum Roll Angle..... n/a Vehicle Snagging..... n/a Vehicle Pocketing..... n/a</p> <p>Test Article Deflections Dynamic..... n/a Permanent..... n/a Working Width..... n/a Working Width Height.... n/a</p> <p>Vehicle Damage VDS..... 12FL1 CDC..... 12FLEN1 Max. Exterior Deformation 0 inches OCDI..... LF000000 Max. Occupant Compartment Deformation..... 0 inches</p>
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Figure 13.14. Summary of Results for *MASH* Test 3-72 on the Type III Barricade.

Table 13.4. Performance Evaluation Summary for MASH Test 3-72 on the Type III Barricade.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-12-02

Test Date: 2019-08-27

MASH Test 3-60 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
<i>B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</i>	The Type III barricade support yielded to the 2270P vehicle as designed.	Pass
<u>Occupant Risk</u>		
<i>D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i>	After impact, the barricade fragments did not penetrate or show any potential for penetration into the occupant compartment.	Pass
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</i>	There was no occupant compartment deformation	Pass
<i>E. Detached elements, fragments, or other debris from the test article, of vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.</i>	The detached elements did not obstruct the driver's vision or cause loss of control of the vehicle.	Pass
<i>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The vehicle remained upright and stable during and after the impact	Pass
<i>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.</i>	According to MASH, when the weight of the traffic control device is less than 220 lb, the test may be performed without vehicle instrumentation.	n/a
<i>I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>	The Type III barricade system weighed 57 lb. Therefore, the vehicle was not instrumented, and occupant risk factors were not obtained for this test.	n/a
<u>Post-Impact Vehicular Response</u>		
<i>N. Vehicle trajectory behind the test article is acceptable.</i>	The 2270P vehicle came to rest 330 ft behind and 12 ft left of the original position of the installation.	Pass

13.5 MASH TEST 3-72 AT 0° (TEST NO. 469469-12-03)

13.5.1 Test Designation and Actual Impact Conditions

MASH Test 3-72 involves a 2270P vehicle weighing 5000 lb \pm 110 lb impacting the Type III barricade at an impact speed of 62 mi/h \pm 2.5 mi/h and an angle of 0° \pm 1.5°. The selected point of impact was the centerline of the Type III barricade aligned with the centerline of the vehicle.

The 2013 RAM 1500 used in the test weighed 5044 lb, and the actual impact speed and angle were 61.3 mi/h and 0°, respectively. Minimum target impact severity was 594 kip-ft, and actual IS was 634 kip-ft.

13.5.2 Weather Conditions

The test was performed at noon on August 29, 2019. Weather conditions at the time of testing were as follows: wind speed: 3 mi/h; wind direction: 102° with respect to the vehicle (vehicle was traveling at a magnetic heading of 0°); temperature: 90°F; relative humidity: 67 percent.

13.5.3 Test Vehicle

The 2013 RAM 1500, shown in Figure 13.15 and Figure 13.16, was used for the crash test. The vehicle's test inertia weight was 5044 lb, and its gross static weight was 5044 lb. The height to the lower edge of the vehicle bumper was 11.8 inches, and the height to the upper edge of the bumper was 27 inches. The height to the vehicle's center of gravity was 28.4 inches. Table L.8 and Table L.9 in Appendix L.4.1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 13.15. Type III Barricade/Test Vehicle Geometrics for Test No. 469469-12-03.



Figure 13.16. Test Vehicle before Test No. 469469-12-03.

13.5.4 Test Description

Table 13.5 lists events that occurred during Test No. 469469-12-03. Figure L.3 in Appendix L.4.2 presents sequential photographs during the test.

Table 13.5. Events during Test No. 469469-12-03.

Time	Events
0.000	Vehicle contacts barricade
0.003	Barricade uprights begin to bend
0.008	Barricade begins to slide
0.012	Top rail of barricade contacts hood of vehicle
0.052	Barricade has slid through sand bags and continues to be pushed forward by vehicle

The 2270P came to rest 430 ft downstream and 14 ft to the left of the original impact point.

13.5.5 Damage to Test Installation

Figure 13.17 shows the damage to the Type III barricade. The barricade remained mostly intact and came to rest 462 ft downstream and 14 ft to the left of the impact location. The welds were cracked at the base, and the supports were bent at 18 inches up from the base.

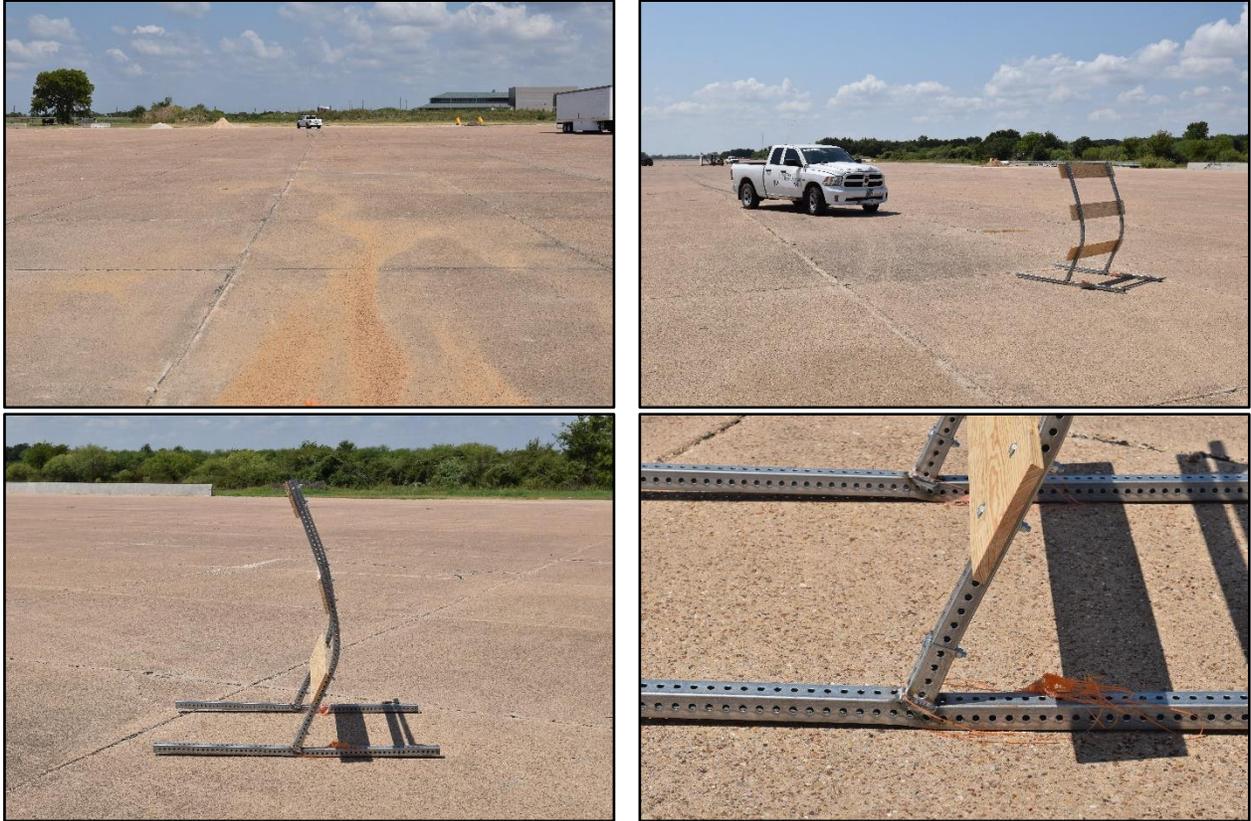


Figure 13.17. Type III Barricade after Test No. 469469-12-03.

13.5.6 Damage to Test Vehicle

Figure 13.18 and Figure 13.19 show the damage sustained by the vehicle. There were scuffs marks on the bumper and grill. There was neither measurable exterior crush on the vehicle nor occupant compartment deformation. Table L.10 and Table L.11 in Appendix L.4.1 provide exterior crush and occupant compartment measurements.



Figure 13.18. Test Vehicle after Test No. 469469-12-03.



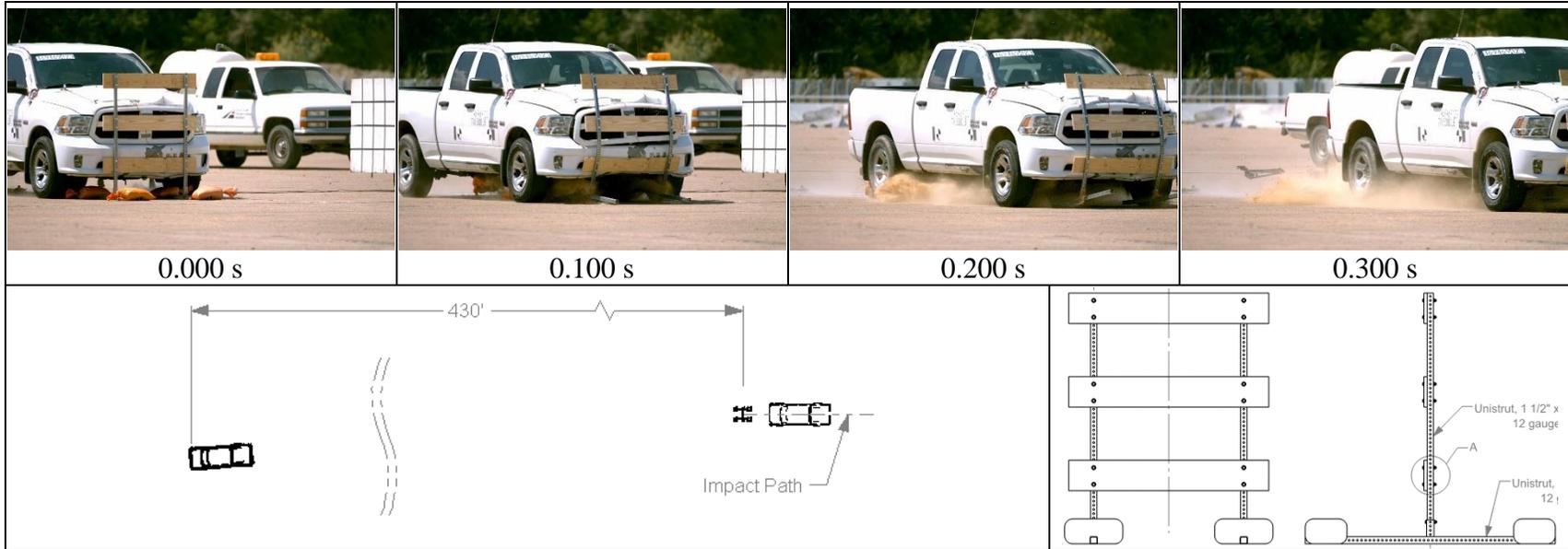
Figure 13.19. Interior of Test Vehicle after Test No. 469469-12-03.

13.5.7 Occupant Risk Factors

According to *MASH*, when the weight of the traffic control device is less than 220 lb, the test may be performed without vehicle instrumentation. The Type III barricade system weighed 57 lb. Therefore, the vehicle was not instrumented, and occupant risk factors were not obtained for this test.

13.5.8 Assessment of Results

The summary of test results can be found in Figure 13.20 and an assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-72 at 0° is provided in Table 13.6.



General Information		Impact Conditions		Post-Impact Trajectory	
Test Agency	Texas A&M Transportation Institute (TTI)	Speed	61.3 mi/h	Stopping Distance	430 ft downstrm; 14 ft left
Test Standard Test No.	MASH Test 3-72	Angle	0°	Vehicle Stability	
TTI Test No.	469469-12-03	Location/Orientation	Center of barricade	Maximum Yaw Angle....	n/a
Test Date	2019-08-29		14 inches off center of the vehicle toward the driver's side	Maximum Pitch Angle....	n/a
Test Article			634 kip*ft	Maximum Roll Angle	n/a
Type	Work zone traffic control device	Impact Severity		Vehicle Snagging	n/a
Name	TxDOT Type III barricade	Exit Conditions		Vehicle Pocketing.....	n/a
Installation Length....	n/a	Speed	n/a	Test Article Deflections	
Material or Key Elements	Wood boards and perforated square steel tube frame	Exit Trajectory/Heading	n/a	Dynamic	n/a
Soil Type and Condition		Occupant Risk Values		Permanent	n/a
Test Vehicle	Placed on dry concrete	Longitudinal OIV.....	n/a	Working Width.....	n/a
Type/Designation	2270P	Lateral OIV	n/a	Working Width Height....	n/a
Make and Model	2013 RAM 1500	Longitudinal Ridedown	n/a	Vehicle Damage	
Curb	50224 lb	Lateral Ridedown	n/a	VDS	12FL1
Test Inertial	5044 lb	THIV	n/a	CDC	12FLEN1
Dummy	No dummy	ASI	n/a	Max. Exterior Deformation	0 inches
Gross Static	5044 lb	Max. 0.050-s Average		OCDI.....	LF000000
		Longitudinal.....	n/a	Max. Occupant Compartment	
		Lateral.....	n/a	Deformation	0 inches
		Vertical.....	n/a		

Figure 13.20. Summary of Results for MASH Test 3-72 on the Type III Barricade.

Table 13.6. Performance Evaluation Summary for MASH Test 3-72 on the Type III Barricade.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-12-03

Test Date: 2019-08-29

MASH Test 3-60 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u> B. <i>The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</i>	The Type III barricade yielded to the 2270P vehicle as designed.	Pass
<u>Occupant Risk</u> D. <i>Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i>	After impact, the barricade fragments did not penetrate or show any potential for penetration into the occupant compartment.	Pass
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</i>	There was no occupant compartment deformation.	Pass
E. <i>Detached elements, fragments, or other debris from the test article, of vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.</i>	The detached elements did not obstruct the driver's vision or cause loss of control of the vehicle.	Pass
F. <i>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The vehicle remained upright and stable during and after the impact	Pass
H. <i>Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.</i>	According to MASH, when the weight of the traffic control device is less than 220 lb, the test may be performed without vehicle instrumentation.	n/a
I. <i>The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>	The Type III barricade system weighed 57 lb. Therefore, the vehicle was not instrumented, and occupant risk factors were not obtained for this test.	n/a
<u>Post-Impact Vehicular Response</u> N. <i>Vehicle trajectory behind the test article is acceptable.</i>	The 2270P vehicle came to rest 430 ft behind and 14 ft left of the original position of the installation.	Pass

13.6 MASH TEST 3-71 AT 0° (TEST NO. 469469-12-04)

13.6.1 Test Designation and Actual Impact Conditions

MASH Test 3-71 involves a 1100C vehicle weighing 2420 lb ±55 lb impacting the Type III barricade at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 0° ±1.5°. The selected impact point was the centerline of the Type III barricade aligned with the centerline of the vehicle.

The 2007 Kia Rio used in the test weighed 2450 lb, and the actual impact speed and angle were 64.5 mi/h and 0°, respectively. Minimum target impact severity was 288 kip-ft, and actual IS was 341 kip-ft.

13.6.2 Weather Conditions

The test was performed late morning on August 27, 2019. Weather conditions at the time of testing were as follows: wind speed: 3 mi/h; wind direction: 182° with respect to the vehicle (vehicle was traveling at a magnetic heading of 0°); temperature: 90°F; relative humidity: 69 percent.

13.6.3 Test Vehicle

The 2007 Kia Rio,¹⁶ shown in Figure 13.21 and Figure 13.22, was used for the crash test. The vehicle's test inertia weight was 2450 lb, and its gross static weight was 2615 lb. The height to the lower edge of the vehicle bumper was 7.75 inches, and the height to the upper edge of the bumper was 21.5 inches. Table L.12 in Appendix L.5.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

¹⁶ The 2007 model vehicle used is older than the 6-year age noted in *MASH* and was selected based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2007 model vehicle met the *MASH* requirements.



Figure 13.21. Type III Barricade/Test Vehicle Geometrics for Test No. 469469-12-04.



Figure 13.22. Test Vehicle before Test No. 469469-12-04.

13.6.4 Test Description

Table 13.7 lists events that occurred during Test No. 469469-12-04. Figure L.4 in Appendix L.5.2 presents sequential photographs during the test.

Table 13.7. Events during Test No. 469469-12-04.

Time	Events
0.000	Vehicle lower bumper contacts sand bags on barricade
0.018	Vehicle bumper contacts lower rail on barricade
0.028	Bottom rail begins to split along its length
0.029	Barricade begins to move downstream
0.036	Middle board impacts hood of vehicle
0.061	Top board impacts hood of vehicle

The 1100C vehicle came to rest 367 ft downstream and in line of the original impact point.

13.6.5 Damage to Test Installation

Figure 13.23 shows the damage to the Type III barricade. The assembly separated into multiple pieces and came to rest in an area 105 to 262 ft downstream of the impact location and 24 ft right to 15 ft left of the impact path.

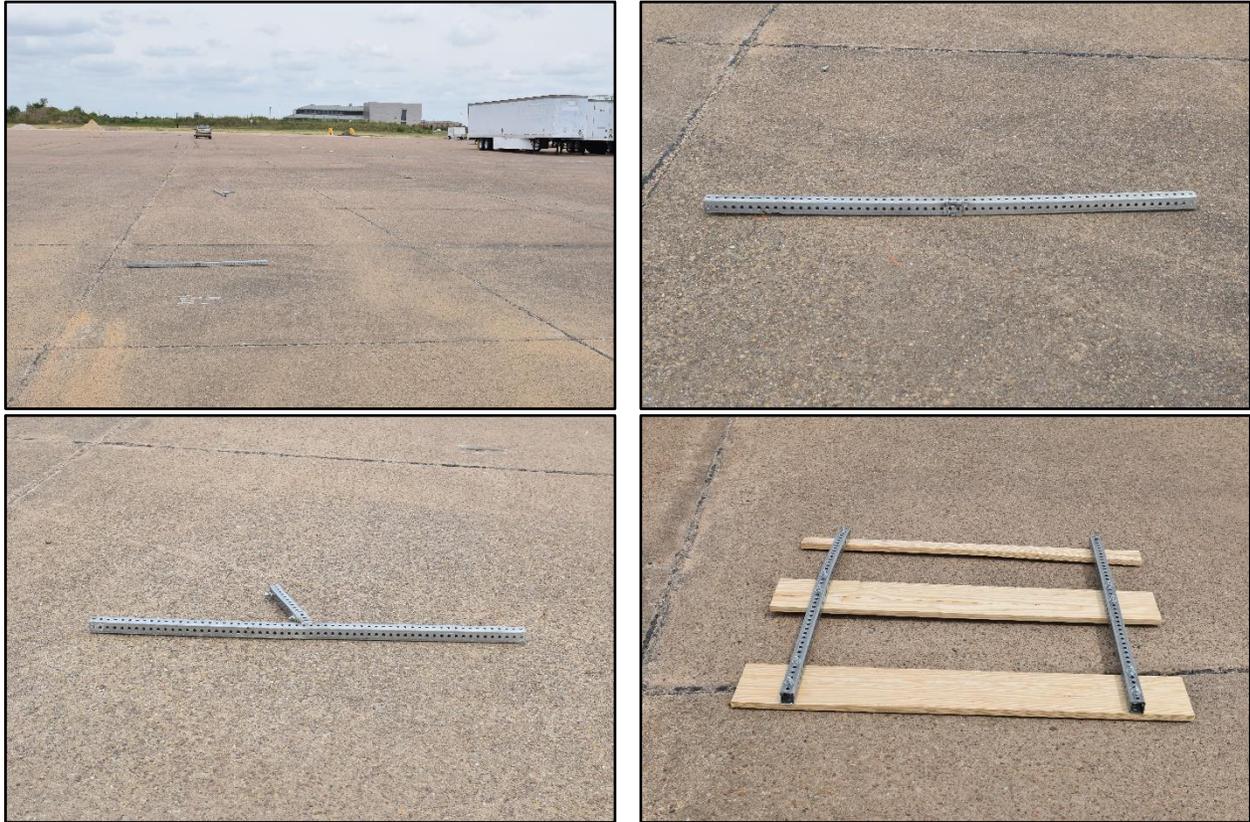


Figure 13.23. Type III Barricade after Test No. 469469-12-04.

13.6.6 Damage to Test Vehicle

Figure 13.24 and Figure 13.25 show the damage sustained by the vehicle. There was a 42-inch by 8-inch by 1.25-inch-deep dent along the front of the hood, and additional damage was sustained by the right head light. There was no measurable occupant compartment deformation. Table L.13 and Table L.14 in Appendix L.5.1 provide exterior crush and occupant compartment measurements.



Figure 13.24. Test Vehicle after Test No. 469469-12-04.



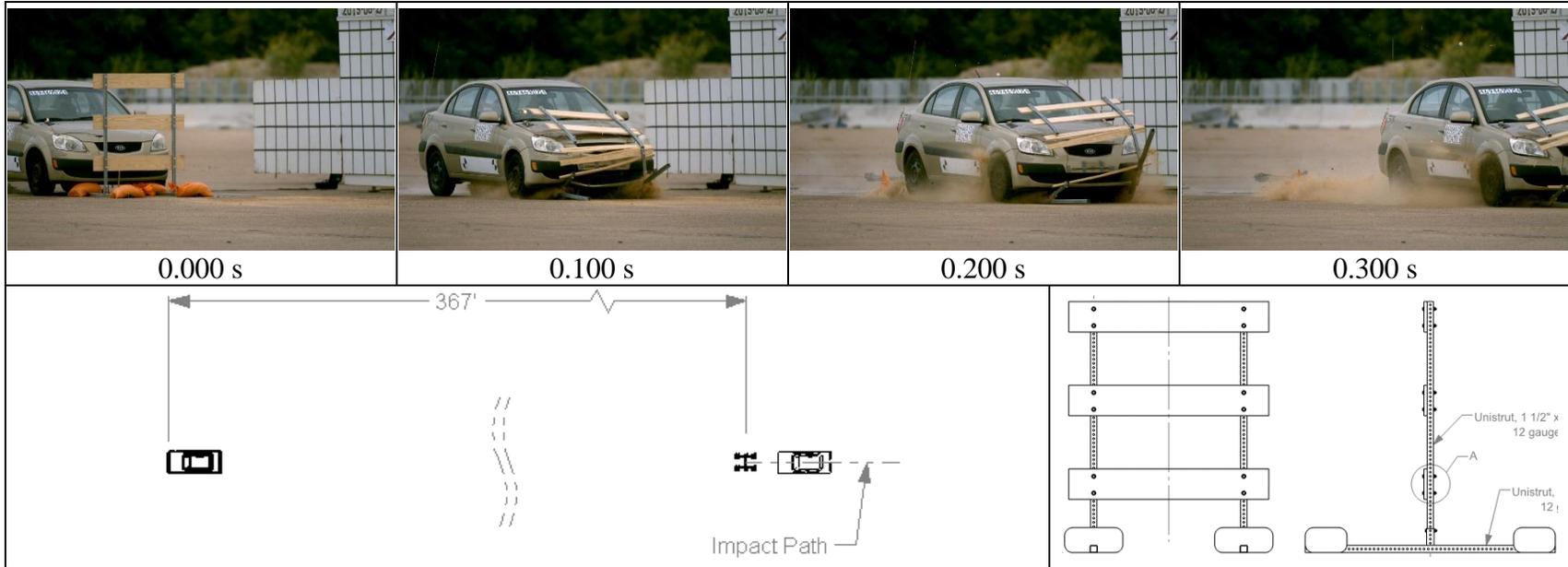
Figure 13.25. Interior of Test Vehicle after Test No. 469469-12-04.

13.6.7 Occupant Risk Factors

According to *MASH*, when the weight of the traffic control device is less than 220 lb, the test may be performed without vehicle instrumentation. The Type III barricade system weighed 57 lb. Therefore, the vehicle was not instrumented, and occupant risk factors were not obtained for this test.

13.6.8 Assessment of Results

The summary of test results can be found in Figure 13.26 and an assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-71 at 0° is provided in Table 13.8.



General Information		Impact Conditions		Post-Impact Trajectory	
Test Agency	Texas A&M Transportation Institute (TTI)	Speed	64.5 mi/h	Stopping Distance	367 ft downstrm
Test Standard Test No.	MASH Test 3-71	Angle	0°	Vehicle Stability	
TTI Test No.	469469-12-04	Location/Orientation	Center of barricade	Maximum Yaw Angle.....	n/a
Test Date	2019-08-27		14 inches off center of the vehicle toward the driver's side	Maximum Pitch Angle....	n/a
Test Article				Maximum Roll Angle	n/a
Type.....	Work zone traffic control device	Impact Severity	341 kip*ft	Vehicle Snagging	n/a
Name	TxDOT Type III barricade	Exit Conditions		Vehicle Pocketing.....	n/a
Installation Length.....	n/a	Speed	61.7 mi/h	Test Article Deflections	
Material or Key Elements	Wood boards and perforated square steel tube frame	Exit Trajectory/Heading	n/a	Dynamic.....	n/a
	Placed on dry concrete	Occupant Risk Values		Permanent	n/a
Soil Type and Condition		Longitudinal OIV.....	n/a	Working Width.....	n/a
Test Vehicle		Lateral OIV.....	n/a	Working Width Height....	n/a
Type/Designation	1100C	Longitudinal Ridedown	n/a	Vehicle Damage	
Make and Model	2007 Kia Rio	Lateral Ridedown	n/a	VDS	12FL1
Curb.....	2453 lb	THIV	n/a	CDC	12FLEN1
Test Inertial.....	2450 lb	ASI.....	n/a	Max. Exterior Deformation	0 inches
Dummy	165 lb dummy on passenger side	Max. 0.050-s Average		OCDI.....	LF000000
Gross Static	2615 lb	Longitudinal.....	n/a	Max. Occupant Compartment	
		Lateral.....	n/a	Deformation	0 inches
		Vertical.....	n/a		

Figure 13.26. Summary of Results for MASH Test 3-71 on the Type III Barricade.

Table 13.8. Performance Evaluation Summary for MASH Test 3-71 on the Type III Barricade.

Test Agency: Texas A&M Transportation Institute

Test No.: 469469-12-04

Test Date: 2019-08-27

MASH Test 3-60 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
<i>B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</i>	The Type III barricade yielded to the 1100C vehicle as designed.	Pass
<u>Occupant Risk</u>		
<i>D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</i>	After impact, the barricade fragments did not penetrate or show any potential for penetration into the occupant compartment.	Pass
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</i>	There was no occupant compartment deformation	Pass
<i>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The vehicle remained upright and stable during and after the impact	Pass
<i>E. Detached elements, fragments, or other debris from the test article, of vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.</i>	The detached elements did not obstruct the driver's vision or cause loss of control of the vehicle.	Pass
<i>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.</i>	According to MASH, when the weight of the traffic control device is less than 220 lb, the test may be performed without vehicle instrumentation.	n/a
<i>I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>	The Type III barricade system weighed 57 lb. Therefore, the vehicle was not instrumented, and occupant risk factors were not obtained for this test.	n/a
<u>Post-Impact Vehicular Response</u>		
<i>N. Vehicle trajectory behind the test article is acceptable.</i>	The 1100C vehicle came to rest 367 ft behind and in line of the original position of the installation.	Pass

13.7 CONCLUSIONS

The Type III barricade performed acceptably in all tests (Table 13.9). Although some of the barricades separated into multiple pieces, these pieces did not penetrate or show any potential for penetrating the occupant compartment. The vehicle remained upright and stable during and after the impact for each test. The Type III barricade performed as designed in all tests and is considered *MASH* compliant.

Table 13.9. Assessment Summary for *MASH* TL-3 Tests on TxDOT Type III Barricade.

Evaluation Factors	Evaluation Criteria	Test No. 469469-12-1	Test No. 469469-12-2	Test No. 469469-12-3	Test No. 469469-12-4
Structural Adequacy	B	S	S	S	S
Occupant Risk	D	S	S	S	S
	E	S	S	S	S
	F	S	S	S	S
	H	S	S	S	S
	I	S	S	S	S
	N	S	S	S	S
	Test No.	<i>MASH</i> Test 3-71	<i>MASH</i> Test 3-72	<i>MASH</i> Test 3-72	<i>MASH</i> Test 3-71
	Pass/Fail	Pass	Pass	Pass	Pass

S = Satisfactory
U = Unsatisfactory

CHAPTER 14: SUMMARY AND CONCLUSIONS

A *MASH* implementation agreement was jointly developed and adopted by FHWA and AASHTO. The agreement establishes various implementation dates for different categories of roadside safety features. In response to the implementation requirements, the TxDOT Bridge, Design, Maintenance, and Traffic Safety Divisions reviewed their standards for roadside safety devices and identified those devices that require testing and evaluation to assess *MASH* compliance. These systems are being crash-tested in accordance with *MASH* criteria in three phases over a 3-year period.

This report documents the Phase III testing and evaluation effort. Test results and assessment of *MASH* compliance for each device are summarized as follows.

14.1 C1W BRIDGE RAIL

The TxDOT C1W bridge rail contained and redirected the 1000S vehicle. The vehicle did not penetrate, underide, or override the installation. Maximum dynamic deflection during the test was 0.9 ft, and maximum permanent deformation was 0.3 ft. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 5.5 inches in the front left corner of the floor pan. The 1000S vehicle remained upright during and after the collision event. Maximum roll and pitch was 23° and 7°, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The C1W bridge rail performed acceptably for according to *MASH* TL-4 evaluation criteria.

14.2 MODIFIED C66 BRIDGE RAIL

The TxDOT Modified C66 bridge rail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underide, or override the installation. Maximum dynamic deflection during the test was 1.1 inches at the steel rail element, and there was no measurable permanent deformation. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 2.0 inches in the driver side floor pan and kick panel areas. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 12° and 7°, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The 2270P vehicle exited within the exit box criteria.

The TxDOT Modified C66 bridge rail contained and redirected the 1100C vehicle. The vehicle did not penetrate, underide, or override the installation. There was no measurable dynamic or permanent deformation. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. Maximum occupant compartment deformation was 2 inches between the floor and roof. The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 18° and 14°, respectively. Occupant risk factors were within the acceptable limits specified in *MASH*. The 1100C vehicle exited within the exit box criteria.

The TxDOT Modified C66 bridge rail performed acceptably according to *MASH* TL-3 evaluation criteria.

14.3 LOW-PROFILE BARRIER

The TxDOT low-profile barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underide, or override the installation. Maximum dynamic deflection during the test was 8.6 inches, and maximum permanent deformation was 8.5 inches. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. There was no observed occupant compartment deformation. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 22° and 10°, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The 2270P vehicle exited within the exit box criteria.

The TxDOT low-profile barrier contained and redirected the 1100C vehicle. The vehicle did not penetrate, underide, or override the installation. Maximum dynamic deflection during the test was 4.9 inches, and maximum permanent deformation was 4.3 inches. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. There was no observed occupant compartment deformation. The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 6° and 3°, respectively. Occupant risk factors were within the allowable limits specified in *MASH*. The 1100C vehicle exited within the exit box criteria.

The TxDOT low-profile barrier performed acceptably according to *MASH* TL-3 evaluation criteria.

14.4 LOW-PROFILE-TO-F-SHAPE TRANSITION

In Test 2-20, the TxDOT low-profile-to-F-shape transition contained and redirected the 1100C vehicle. The vehicle did not penetrate, underide, or override the installation. Maximum dynamic deflection during the test was 8 inches, and permanent deformation was 8 inches. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. There was no observed occupant compartment deformation. The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 17° and 8°, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The 1100C vehicle exited within the exit box criteria.

In Test 2-21, the TxDOT low-profile-to-F-shape transition contained and redirected the 2270P vehicle. The vehicle did not penetrate, underide, or override the installation. Maximum dynamic deflection during the test was 14.5 inches, and permanent deformation was 14 inches. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. There was no observed occupant compartment deformation. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 7° and 7°, respectively. Occupant

risk factors were within the preferred limits specified in *MASH*. The 2270P vehicle exited within the exit box criteria.

The TxDOT low-profile-to-F-shape transition performed acceptably according to *MASH* TL-2 evaluation criteria.

14.5 THRIE-BEAM TRANSITION

The TxDOT thrie-beam transition without end shoe block contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 4.0 inches, and permanent deformation was ½ inch. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. The maximum occupant compartment deformation was 4 inches. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 24° and 7°, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The 2270P vehicle exited within the exit box criteria.

The TxDOT thrie-beam transition without end shoe block performed acceptably according to *MASH* Test 3-21 evaluation criteria.

14.6 SINGLE WOOD POST SKID-MOUNTED SIGN SUPPORT SYSTEM

Upon impact, the wood support post fractured near bumper height. The upper portion of the fractured support with attached aluminum sign panel rotated toward the vehicle, and the corner of the sign panel contacted the windshield and caused a 4-inch-long tear in the laminate. Consequently, the single wood post skid-mounted sign support system failed to comply with *MASH* Test 3-72 criteria.

The TxDOT single wood post skid-mounted sign support system did not perform acceptably according to *MASH* Test 3-72 evaluation criteria.

14.7 PERFORATED SQUARE STEEL TUBE SIGN SUPPORT

The sign support fractured near the ground line as designed. After the support post fractured, the sign panel and support rotated toward the vehicle and impacted the windshield and roof. The sign penetrated through the roof into the occupant compartment, and the roof sustained 11¼ inches of deformation into the occupant compartment. Consequently, the PSST sign support in reinforced anchor stub system did not satisfy *MASH* criteria for breakaway support structures.

The TxDOT PSST sign support did not perform acceptably according to *MASH* Test 3-61 evaluation criteria

14.8 BURN BAN SIGN ON SLIP BASE SUPPORT

The burn ban sign on slip base support did not comply with *MASH* criteria. After release from the slip base, the sign support system rotated over the impacting vehicle, and the top of the sign panel and support contacted and penetrated the rear window.

14.9 BURN BAN SIGN ON WEDGE AND SOCKET SUPPORT

Upon impact with the burn ban sign on wedge and socket support, the support post initially began to pull out of its socket but subsequently fractured about 24 inches above grade. After fracture of the support post, the upper portion wrapped around the front of the vehicle and the upper sign panel and support contacted and penetrated the windshield. Consequently, the burn ban sign on wedge and socket support did not meet *MASH* criteria.

14.10 MAILBOXES

14.10.1 Single Temporary Mailbox on Plastic Drum (Type 6 Foundation)

The mailbox on Type 6 foundation on a plastic drum performed acceptably in *MASH* Test 3-61 and is considered *MASH* compliant. The mailbox deformed but remained connected to the barrel. No part of the test article penetrated or showed any potential for penetrating the occupant compartment. The vehicle remained upright and stable during and after the impact.

14.10.2 Centennial Model Mailbox on Type 2 Foundation

The Centennial model mailbox on Type 2 foundation performed acceptably in *MASH* Test 3-61 and is considered *MASH* compliant. The mailbox deformed and disconnected from the post. The post remained attached to its anchor. No part of the test article penetrated or showed any potential for penetrating the occupant compartment. The vehicle remained upright and stable during and after the impact.

14.10.3 Lockable Mailbox on Thin-Wall Galvanized Tube with Type 2 Foundation

The lockable mailbox on thin-wall galvanized tube with Type 2 foundation performed acceptably in *MASH* Test 3-61 and is considered *MASH* compliant. The mailbox deformed but remained connected to the post, which disengaged from its ground support. No part of the test article penetrated or showed any potential for penetrating the occupant compartment. The vehicle remained upright and stable during and after the impact.

14.11 ROUND WOOD POST GUARDRAIL IN CONCRETE MOW STRIP

The round wood post guardrail in a concrete mow strip did not meet *MASH* criteria. The 2270P vehicle penetrated through the guardrail and was not contained or redirected by the round wood post guardrail in a concrete mow strip.

14.12 TYPE III BARRICADE

The Type III barricade performed acceptably in all tests. Although some of the barricades separated into multiple pieces, these pieces did not penetrate or show any potential for penetrating the occupant compartment. The vehicle remained upright and stable during and after the impact for each test. The Type III barricade performed as designed in all tests and is considered *MASH* compliant.

CHAPTER 15: IMPLEMENTATION

A total of 22 full-scale crash tests were performed under Phase III of this project to evaluate 14 different roadside safety devices or configurations. These tests represent the critical tests considered necessary to demonstrate *MASH* compliance of each device. The systems that met *MASH* requirements for these critical test conditions are considered *MASH* compliant and suitable for continued implementation beyond the *MASH* implementation deadline.

TxDOT standards include multiple configurations or variations for many of these devices to accommodate different design considerations. In such instances, the critical or worst-case configuration was selected and tested. If the critical configuration met *MASH* requirements, other less critical configurations of the device are also considered *MASH* compliant. The implementation recommendations for each system tested and evaluated in accordance with *MASH* are described in the sections as follows.

15.1 C1W BRIDGE RAIL

The C1W bridge rail is a 42-inch-tall combination rail that consists of four rectangular tubular steel rail elements attached to fabricated steel posts mounted on a 9-inch-tall concrete curb. The bridge rail is designed to accommodate both vehicle and pedestrian traffic. When tested in accordance with *MASH* Test 4-12 with a 24,200-lb single-unit truck, the C1W bridge rail met all required *MASH* criteria. Based on previous testing of the T1W to *MASH* TL-3 (I), test designations 4-10 and 4-11 were deemed unnecessary. Compared to the T1W, the C1W provides additional rail contact surface area and reduced clear opening between rail elements, both of which reduce potential for vehicle snagging.

Consequently, the C1W bridge rail is considered *MASH* TL-4 compliant. Continued implementation of this bridge rail system can be achieved by the Bridge Division through its respective standard sheets.

15.2 MODIFIED C66 BRIDGE RAIL

The C66 bridge rail is a concrete beam-and-post system mounted on a 9-inch curb. The C66 rail is a combination version of the T66 rail that is designed to accommodate both vehicle and pedestrian traffic. The additional features incorporated into the C66 rail include a 10-inch-tall steel rail element attached to the top of the system and a steel pipe positioned between posts in the clear opening between the bottom of the concrete beam and top of the curb.

The test installation was constructed in a manner to evaluate *MASH* compliance of both the T66 and C66 bridge rail systems. The C66 steel rail element was incorporated into the test installation to evaluate any potential occupant or vehicle interaction. Since the lower pipe section could potentially reduce the severity of wheel snagging on the concrete posts, the lower pipe was removed from the test installation.

The full *MASH* test matrix was successfully performed on the Modified C66 bridge rail system. The full-scale crash tests included *MASH* test designations 3-10 (small passenger car) and 3-11 (pickup truck). Therefore, both the T66 and the C66 bridge rail systems are considered *MASH* TL-3 compliant. Continued implementation of these bridge rail systems can be achieved by the Bridge Division through their respective standard sheets.

15.3 LOW-PROFILE BARRIER

The low-profile barrier is a 20-inch-tall, free-standing concrete barrier designed to improve sight distance for turning maneuvers within low-speed work zone areas. The low-profile barrier test installation followed a draft specification (Draft LPCB-19) that included some changes from the previous standard. Key among them was the use of two separate washer plates for the two connection bolts rather than a single plate, and polyvinyl chloride (PVC) pipe rather than steel pipe for the connection bolts at each end of the barrier segments.

The full *MASH* TL-2 test matrix was successfully performed on the low-profile barrier. The full-scale crash tests included *MASH* test designations 2-10 with the small passenger car and 2-11 with the pickup truck. Therefore, the low-profile barrier is considered *MASH* TL-2 compliant. Continued implementation of this bridge rail system can be achieved by the Design Division through revision of their respective standard sheets as necessary to reflect the details presented in Appendix C.1.

15.4 LOW-PROFILE-TO-F-SHAPE TRANSITION

This transition barrier segment is used to connect a 20-inch-tall low-profile concrete barrier to a 32-inch-tall F-shape portable concrete barrier. The low-profile barrier is a TL-2 system intended for use on lower-speed roadways, whereas the F-shape barrier is a TL-3 system suitable for use on high-speed roadways. The low-profile-to-F-shape transition section incorporated some changes from the previous standard. The tested transition section incorporated PVC pipe at each, rather than steel pipe for the connection bolts, and the X-bolt connection details on the F-shape end of the transition section were significantly simplified. Additionally, the steel reinforcement was simplified and reduced throughout.

Based on a review of previous analysis and testing of the low-profile-to-F-shape transition (3), it was determined that two tests should be performed to verify the impact performance of the low-profile-to-F-shape transition under *MASH* criteria. *MASH* Test 2-20 with the small passenger car was successfully performed with the vehicle traveling from the F-shape barrier toward the low-profile barrier, and *MASH* Test 2-21 with the pickup truck was successfully performed with the vehicle traveling from the low-profile barrier toward the F-shape barrier. These were the critical directions for these tests based on previous simulation and crash testing of the system. Test 2-20 from the low-profile barrier end and Test 2-21 from the F-shape barrier end were not considered necessary because previous simulations showed them to be less critical (more stable) than the tests that were performed.

Therefore, the low-profile-to-F-shape transition is considered *MASH* TL-2 compliant. Continued implementation of the transition can be achieved by the Design Division through revision of the respective standard sheets as necessary to reflect the details presented in Appendix D.1

15.5 THRIE-BEAM TRANSITION

The TxDOT thrie-beam transition is used to connect an approach guardrail to a bridge rail system. Variations of this transition section have been previously tested to *MASH* at both the upstream and downstream ends (4, 5). When the transition system was tested at the downstream

end near its connection to a safety-shaped concrete parapet, a tapered steel block was positioned under the end shoe to keep the thrie-beam rail in a vertical plane. The TxDOT variation of this transition twists the nested thrie beam and end shoe into the sloped barrier face in lieu of using the tapered steel blockout. It was decided to test the downstream transition without the tapered end shoe block to determine if this configuration is *MASH* compliant.

The critical test for evaluating the need for the tapered end shoe block is *MASH* test designation 3-21 with the 2270P pickup truck. The stability of the pickup truck is most likely to be affected by the sloping thrie-beam rail adjacent to the bridge rail parapet. This test was successfully performed and met all associated *MASH* evaluation criteria. Therefore, the thrie-beam transition without tapered steel block is considered *MASH* compliant. Continued implementation of this transition system can be achieved by the Design Division through their respective standard sheets.

The standard detail sheet for the TxDOT thrie-beam transition permits use of three different post types: W6×8.5 steel posts, 7-inch (178-mm) diameter round wood posts, and 6-inch by 8-inch (152-mm by 203-mm) rectangular wood posts. Researchers consider the W6×8.5 steel post to be the most critical condition in regard to post snagging; therefore, the steel post option was used in the full-scale crash test. Based on the successful impact performance with the steel posts, the transition is also considered *MASH* compliant with the less critical round and rectangular posts types.

TxDOT bridge rail standards include two systems that have sloped faces that attach to the TL-3 thrie-beam transition. These are a 32-inch F-shape parapet (Type T551) and a 36-inch SSTR. The greater slope of the SSTR made it the more critical profile for evaluating the thrie-beam transition without end shoe block. Based on the successful impact performance with the transition attached to the SSTR, the transition is also considered *MASH* compliant when attached to the less-critical T551 F-shape bridge rail.

15.6 SINGLE WOOD POST SKID-MOUNTED SIGN SUPPORT SYSTEM

The single wood post skid-mounted temporary sign support system uses a 4-inch by 4-inch post and is designed for use with a maximum 12-sq-ft sign panel. Details can be found on TxDOT Barricade and Construction sheet BC(5)-14. The *MASH* test matrix for work zone traffic control devices includes a high-speed test with a passenger car (Test 3-71) and pickup truck (Test 3-72) at both 0° and 90° impact orientations.

During Test 3-72 with the single wood post skid-mounted sign support system oriented at 90°, the edge of the aluminum sign panel contacted and penetrated the top of the windshield, resulting in a 4-inch-long tear in the laminate. Thus, the single wood post skid-mounted temporary sign support system did not perform acceptably for *MASH* Test 3-72, and the system is not *MASH* compliant. Further research is required to develop a modified system that will comply with *MASH* requirements.

15.7 PERFORATED SQUARE STEEL TUBE SIGN SUPPORT

TxDOT uses PSST supports for ground-mounted temporary signs. Barricade and construction sheet BC(5)-14 and Section J “Signs and Sign Supports” of the Compliant Work Zone Traffic Control Device List provide three foundation options:

- Option 1 is direct embedment of the sign support.
- Option 2 involves insertion of the sign post into a larger size PSST anchor stub.
- Option 3 incorporates an 18-inch PSST reinforcing sleeve over the PSST anchor stub.

Evaluation efforts under this project focused on the options with anchor stubs because they are much more common in the field.

The TxDOT standards permit the use of both 14-gauge and 12-gauge PSST supports of different sizes to accommodate different sign sizes. A single 2-inch by 14-gauge PSST support in an anchor stub was successfully tested in accordance with *MASH* criteria. Therefore, efforts under this project focused on evaluation of 12-gauge PSST supports. Both foundation Option 2 (PSST support in anchor stub) and Option 3 (PSST support in reinforced anchor stub) were evaluated for a 2-inch, 12-gauge PSST support.

MASH recognizes that sign support systems that are used near an intersection can be struck from virtually any direction. Consequently, *MASH* Section 2.2.4.1 recommends that testing of these systems be conducted at both 90° from the normal direction and at any orientation between 0° and 25° that is deemed to represent the highest risk for the system to fail any of the recommended evaluation criteria. Since these temporary sign supports are used at or near intersections, the recommended test matrix for evaluating the ground-mounted PSST sign support system includes *MASH* Test 3-61 with the 1100C passenger car and Test 3-62 with the 2270P pickup truck at both 0° and 90°.

When Option 2 was evaluated in *MASH* Test 3-61 with the sign in a 90° orientation, the anchor stub fractured, and the sign panel and support rotated toward the vehicle and impacted the windshield and roof. The sign penetrated into the occupant compartment through the windshield and roof. Consequently, the PSST sign support in anchor stub system did not satisfy *MASH* criteria for breakaway support structures.

After the unsuccessful test of the PSST sign support in anchor stub system, it was decided to evaluate the impact performance of a 2-inch by 12-gauge PSST support post in a reinforced anchor stub. The reinforcing sleeve provides additional stiffening of the support post at the ground line, which should help facilitate fracture of the support post during an impact. Quicker fracture of the support post offered the possibility of changing the trajectory of the released sign support system.

When Option 3 was evaluated in *MASH* Test 3-61 with the sign in a 90° orientation, the sign support fractured near the ground line as designed. After the support post fractured, the sign panel and support rotated toward the vehicle and impacted the windshield and roof. The sign penetrated through the roof into the occupant compartment. Consequently, the PSST sign support in reinforced anchor stub system did not satisfy *MASH* criteria for breakaway support structures. Further research is required to develop a modification to this system that will comply with *MASH* requirements.

15.8 BURN BAN SIGN ON SLIP BASE SUPPORT

TxDOT permits counties to post advisory signs on the roadside to alert motorists when a burn ban is in effect. The current practice is to append the burn ban notification signs to existing sign support structures. Since burn ban signs are deployed on support structures along the roadside and not at or near intersections, only evaluation at 0° was considered necessary.

Previous research concluded that the minimum sign area that should be used on a slip base support to meet *MASH* requirements for 0° impacts is 14 sq ft (8). Therefore, it was recommended to append the burn ban sign to a slip base sign support system that has a primary sign panel area of at least 14 sq ft.

Two different sizes of burn ban signs are used. The smaller 24-inch by 24-inch sign is intended to simply communicate that a burn ban is in effect. The larger 30-inch by 36-inch sign additionally indicates the name of the county when needed. The larger sign is the more critical of the two sizes. If testing of the 30-inch by 36-inch burn ban sign is satisfactory, the smaller 24-inch by 24-inch burn ban sign would also be considered *MASH* compliant.

The burn ban sign on slip base support structure did not comply with *MASH* criteria. During *MASH* Test 3-61, the released sign support system rotated over the impacting vehicle, and the top of the sign panel and support contacted and penetrated the rear window. Further research is required to develop a modification to this system that will comply with *MASH* requirements.

15.9 BURN BAN SIGN ON WEDGE AND SOCKET SUPPORT

TxDOT desired to expand the implementation of burn ban signs to include thin-wall steel tubing supports secured in a wedge and socket foundation. Due to the capacity of the thin-wall steel tube support, the smaller 24-inch by 24-inch burn ban sign was evaluated.

During *MASH* Test 3-61, the thin-wall steel support post initially began to pull out of its socket, but it subsequently fractured about 24 inches above grade. After fracture of the support post, the upper portion wrapped around the front of the vehicle and the upper sign panel and support contacted and penetrated the windshield. Consequently, the burn ban sign on wedge and socket support did not meet *MASH* criteria. Further research is required to develop a modification to this system that will comply with *MASH* requirements.

15.10 MAILBOXES

The small passenger car is considered the critical design vehicle for evaluation of mailbox support systems based on the mounting height regulated for mailboxes by the United States Postal Service. At the required mounting height, any interaction between the mailbox and the windshield of the pickup truck design vehicle is improbable. The taller hood height and longer wrap-around distance (i.e., the distance from the ground, around the front end, and across the hood to the base of the windshield) of the 2270P pickup truck significantly decreases the probability of windshield impact and occupant compartment intrusion. Therefore, Test 3-62 with the pickup truck was considered unnecessary for the *MASH* evaluation of the TxDOT mailbox systems.

The *MASH* test matrix for breakaway supports includes two tests with the 1100C small passenger car: a low-speed test at 19 mi/h (Test 3-60) and a high-speed test at 62 mi/h (Test 3-61). In the low-speed small car test, *MASH* testing has shown that the mailbox support assembly will be pushed forward by the impacting vehicle (10). Under the lower impact severity, it is unlikely that the mailbox will separate from the support or that the support assembly will interact with the vehicle windshield.

The most critical test for evaluation of mailbox systems is *MASH* test designation 3-61. This test evaluates both the structural adequacy of the mailbox connection hardware and the interaction of the mailbox support assembly with the vehicle windshield. If the mailbox remains attached during this high-speed test, it is not expected to detach in the low-speed test.

Three different mailbox support systems were selected for *MASH* testing and evaluation during Phase III of the project. Separate tests were successfully performed for each system. These include a single temporary mailbox on a plastic drum (Type 6 foundation), a single extra-large mailbox on thin-wall galvanized steel tube with Type 2 foundation, and a lockable mailbox on thin-wall galvanized steel tube support with a Type 2 foundation.

Each of these systems are considered *MASH* compliant and suitable for implementation. Systems that were tested with a single mailbox should be implemented with a single mailbox only. Smaller mailboxes with similar attachment hardware are less critical and are considered *MASH* compliant. Implementation of these mailbox systems can be achieved by the Maintenance Division through updating of mailbox standard MB-15(1) (as necessary) to reflect the tested details presented in Chapter 11.

15.11 ROUND WOOD POST GUARDRAIL IN CONCRETE MOW STRIP

TxDOT frequently installs guardrail in a concrete mow strip. Pavement mow strips are used to combat vegetation growth around guardrail posts to avoid the use of herbicides, decrease maintenance costs, and reduce the safety risk to workers associated with hand mowing around guardrail. A sacrificial grout layer is used in a leave-out section formed in the mow strip around the guardrail posts. During an impact, the grout is crushed, and the post is able to rotate in the leave-out section.

MASH Test 3-11 is considered the critical test for evaluation of the round wood post guardrail system in a concrete mow strip. This test places more demand on the mow-strip-confined posts. *MASH* Test 3-10 was not considered necessary on the round wood post guardrail in a concrete mow strip because *MASH* Test 3-10 was successfully performed on guardrail in a concrete mow strip with W6×8.5 steel posts and 6-inch by 8-inch rectangular wood posts (12). The geometries of the steel and rectangular wood posts are considered more critical in terms of the vehicle snagging and deceleration compared to the round wood post.

The test installation for the round wood post guardrail system in a concrete mow strip used nominal 7-inch-diameter posts with a 36-inch post embedment. During *MASH* Test 3-11, the 2270P pickup truck penetrated through the guardrail and was not contained or redirected by the round wood post guardrail in a concrete mow strip. Thus, this configuration of round wood post guardrail in a concrete mow strip does not meet *MASH* criteria. Further research is required to develop a modification to this system that will comply with *MASH* requirements. An options

for future consideration is increasing the size (diameter) of the post to delay/prevent post fracture and permit more energy of the vehicle to be dissipated through post deflection.

15.12 TYPE III BARRICADE

Acceptable design configurations for Type III barricades are provided on barricade and construction sheet BC(5)-14 and Section D “Type III Barricades” of the Compliant Work Zone Traffic Control Device List. Numerous material options and combinations are permitted. Evaluation under this project focused on systems with a support structure fabricated using PSST.

Type III barricades with PSST frames can be used with three different rail types: wood, HPPL, and plastic I-beam rails. The wood and HPPL rails are directly bolted to the barricade uprights, while the plastic I-beam rails clip into brackets attached to the uprights. Because the I-beam rails are releasable, their evaluation will require separate testing. Of the two direct-bolted rail types, wood was considered more critical than HPPL. This is because the wood rails are heavier and can fracture into multiple pieces that can subsequently impact the windshield of the vehicle.

The *MASH* test matrix for work zone traffic control devices consists of three tests: 3-70, 3-71, and 3-72. Test 3-70 is considered optional for free-standing devices weighing less than 220 lb because “velocity changes during low-speed impacts will be within acceptable limits...” *MASH* Tests 3-71 and 3-72 were successfully performed with the barricade in both normal (perpendicular) and parallel orientations. Thus, the Type III barricade with PSST supports and wood rails meets *MASH* requirements. Additionally, the similar Type III barricade with PSST supports and less critical HPPL rails is also considered *MASH* compliant.

The PSST barricade frame consists of uprights and skids. The uprights insert into PSST sleeves that can be connected to the skids by welding or bolted steel hardware. Welded connections were considered the more critical of the two connection types because the small welds have an opportunity to fracture and release the barricade uprights, which could then potentially interact with the vehicle windshield. Therefore, given the successful *MASH* evaluation of the Type III barricade with welded connections, the similar design with bolted hardware connections is also considered *MASH* compliant.

A lower cross member between the two uprights is an optional feature for the Type III barricades that can be used when needed to provide additional structural support to the barricade frame. This cross member is typically only needed when the plastic I-beam rails are used because these clip-on rails do not provide the same structural rigidity of the direct-bolted rails. Additionally, the barricade system with direct-bolted rails would be considered more critical without the lower cross member because the cross member provides additional strength and rigidity that would make separation of the barricade components less likely during an impact. Consequently, the Type III barricade system evaluated under this project did not include a lower cross member. Given the successful *MASH* evaluation of the Type III barricade without the lower cross member, the similar design with bolted cross member is also considered *MASH* compliant.

Finally, TxDOT standards permit Type III barricades to vary in length from 4 ft to 8 ft. A 4-ft length was considered most critical. This length permits both uprights to be impacted simultaneously, thus increasing the probability of the uprights releasing from their skids. In a

longer configuration, if only one upright is impacted, the barricade may simply rotate out of the path of the vehicle. Therefore, given the successful evaluation of the 4-ft-long Type III barricade system, longer variations are also considered *MASH* compliant.

CHAPTER 16: REFERENCES

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