MASH TEST 3-21 EVALUATION OF SHORT W-BEAM TRANSITION

by

Maysam Kiani, Ph.D., P.E.
Assistant Research Engineer

Wanda L. Menges
Research Specialist

William J. L. Schroeder
Engineering Research Associate

Bill L. Griffith
Research Specialist

and

Darrell L. Kuhn, P.E.
Research Specialist

Contract No.: T4541-DO
Test No.: 613121-01-1
Test Date: 2021-04-19

Sponsored by
Roadside Safety Research Program Pooled Fund
Study No. TPF-5(114)
DISCLAIMER

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

The results reported herein apply only to the article tested. The full-scale crash tests were performed according to TTI Proving Ground quality procedures and Manual for Assessing Safety Hardware guidelines and standards.

The Proving Ground Laboratory within TTI’s Roadside Safety and Physical Security Division (“TTI Lab”) strives for accuracy and completeness in its crash test reports. On rare occasions, unintentional or inadvertent clerical errors, technical errors, omissions, oversights, or misunderstandings (collectively referred to as “errors”) may occur and may not be identified for corrective action prior to the final report being published and issued. If, and when, the TTI Lab discovers an error in a published and issued final report, the TTI Lab will promptly disclose such error to the Roadside Pooled Fund Group, WSDOT, and all parties shall endeavor in good faith to resolve this situation. The TTI Lab will be responsible for correcting the error that occurred in the report, which may be in the form of errata, amendment, replacement sections, or up to and including full reissuance of the report. The cost of correcting an error in the report shall be borne by the TTI Lab. Any such errors or inadvertent delays that occur in connection with the performance of the related testing contract will not constitute a breach of the testing contract.

THE TTI LAB WILL NOT BE LIABLE FOR ANY INDIRECT, CONSEQUENTIAL, PUNITIVE, OR OTHER DAMAGES SUFFERED BY THE ROADSIDE POOLED FUND GROUP, WSDOT, OR ANY OTHER PERSON OR ENTITY, WHETHER SUCH LIABILITY IS BASED, OR CLAIMED TO BE BASED, UPON ANY NEGLIGENT ACT, OMISSION, ERROR, CORRECTION OF ERROR, DELAY, OR BREACH OF AN OBLIGATION BY THE TTI LAB.
When roadways intersect with restrictive features such as a bridge rail, it becomes difficult to fit a transition system with proper length. For this project, American Association of State Highway and Transportation (AASHTO) *Manual for Assessing Safety Hardware (MASH)* Test Level 3 (TL-3) W beam transitions with shorter length are desired to be tested. These systems are used when State Departments of Transportation (DOTs) need to implement a shorter transition without compromising the integrity of the guardrail system.

The objective of this study was to model and crash test shorter W-beam transition systems for *MASH* TL-3 compliance. A *MASH* compliant transition with shorter length would provide the members of the Roadside Safety Pooled Fund with a valuable option in restrictive conditions against roadside hazards.

Due to the high occupant ridedown acceleration during the crash test, the short transition did not satisfy the performance criteria for *MASH* Test 3-21 for transitions.
### SI* (MODERN METRIC) CONVERSION FACTORS

**APPROXIMATE CONVERSIONS TO SI UNITS**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>When You Know</th>
<th>Multiply By</th>
<th>To Find</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LENGTH</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in</td>
<td>inches</td>
<td>25.4</td>
<td>millimeters</td>
<td>mm</td>
</tr>
<tr>
<td>ft</td>
<td>feet</td>
<td>0.305</td>
<td>meters</td>
<td>m</td>
</tr>
<tr>
<td>yd</td>
<td>yards</td>
<td>0.914</td>
<td>meters</td>
<td>m</td>
</tr>
<tr>
<td>mi</td>
<td>miles</td>
<td>1.61</td>
<td>kilometers</td>
<td>km</td>
</tr>
<tr>
<td><strong>AREA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in²</td>
<td>square inches</td>
<td>645.2</td>
<td>square millimeters</td>
<td>mm²</td>
</tr>
<tr>
<td>ft²</td>
<td>square feet</td>
<td>0.093</td>
<td>square meters</td>
<td>m²</td>
</tr>
<tr>
<td>yd²</td>
<td>square yards</td>
<td>0.836</td>
<td>square meters</td>
<td>m²</td>
</tr>
<tr>
<td>ac</td>
<td>acres</td>
<td>0.405</td>
<td>hectares</td>
<td>ha</td>
</tr>
<tr>
<td>mi²</td>
<td>square miles</td>
<td>2.59</td>
<td>square kilometers</td>
<td>km²</td>
</tr>
<tr>
<td><strong>VOLUME</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fl oz</td>
<td>fluid ounces</td>
<td>29.57</td>
<td>milliliters</td>
<td>mL</td>
</tr>
<tr>
<td>gal</td>
<td>gallons</td>
<td>3.785</td>
<td>liters</td>
<td>L</td>
</tr>
<tr>
<td>ft³</td>
<td>cubic feet</td>
<td>0.028</td>
<td>cubic meters</td>
<td>m³</td>
</tr>
<tr>
<td>yd³</td>
<td>cubic yards</td>
<td>0.765</td>
<td>cubic meters</td>
<td>m³</td>
</tr>
</tbody>
</table>

NOTE: volumes greater than 1000L shall be shown in m³

| **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  
°C Celsius

°F = (°C × 9/5) + 32
°C = (°F - 32) × 5/9

**FORCE and PRESSURE or STRESS**

lbf  poundforce  
kPa kilopascals

<table>
<thead>
<tr>
<th>Symbol</th>
<th>When You Know</th>
<th>Multiply By</th>
<th>To Find</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LENGTH</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mm</td>
<td>millimeters</td>
<td>0.039</td>
<td>inches</td>
<td>in</td>
</tr>
<tr>
<td>m</td>
<td>meters</td>
<td>3.28</td>
<td>feet</td>
<td>ft</td>
</tr>
<tr>
<td>m</td>
<td>meters</td>
<td>1.09</td>
<td>yards</td>
<td>yd</td>
</tr>
<tr>
<td>km</td>
<td>kilometers</td>
<td>0.621</td>
<td>miles</td>
<td>mi</td>
</tr>
<tr>
<td><strong>AREA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mm²</td>
<td>square millimeters</td>
<td>0.0016</td>
<td>square inches</td>
<td>in²</td>
</tr>
<tr>
<td>m²</td>
<td>square meters</td>
<td>10.764</td>
<td>square feet</td>
<td>ft²</td>
</tr>
<tr>
<td>m²</td>
<td>square meters</td>
<td>1.195</td>
<td>square yards</td>
<td>yd²</td>
</tr>
<tr>
<td>ha</td>
<td>hectares</td>
<td>2.47</td>
<td>acres</td>
<td>ac</td>
</tr>
<tr>
<td>km²</td>
<td>Square kilometers</td>
<td>0.386</td>
<td>square miles</td>
<td>mi²</td>
</tr>
<tr>
<td><strong>VOLUME</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mL</td>
<td>milliliters</td>
<td>0.034</td>
<td>fluid ounces</td>
<td>oz</td>
</tr>
<tr>
<td>L</td>
<td>liters</td>
<td>0.264</td>
<td>gallons</td>
<td>gal</td>
</tr>
<tr>
<td>m³</td>
<td>cubic meters</td>
<td>35.314</td>
<td>cubic feet</td>
<td>ft³</td>
</tr>
<tr>
<td>m³</td>
<td>cubic meters</td>
<td>1.307</td>
<td>cubic yards</td>
<td>yd³</td>
</tr>
<tr>
<td><strong>MASS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g</td>
<td>grams</td>
<td>0.035</td>
<td>ounces</td>
<td>oz</td>
</tr>
<tr>
<td>kg</td>
<td>kilograms</td>
<td>2.202</td>
<td>pounds</td>
<td>lb</td>
</tr>
<tr>
<td>Mg (or &quot;t&quot;)</td>
<td>megagrams (or &quot;metric ton&quot;)</td>
<td>1.103</td>
<td>short tons (2000lb)</td>
<td>T</td>
</tr>
<tr>
<td><strong>TEMPERATURE (exact degrees)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>°C</td>
<td>Celsius</td>
<td>1.8°C+32</td>
<td>Fahrenheit</td>
<td>°F</td>
</tr>
</tbody>
</table>

**FORCE and PRESSURE or STRESS**

N  newtons  
kPa kilopascals

<table>
<thead>
<tr>
<th>Symbol</th>
<th>When You Know</th>
<th>Multiply By</th>
<th>To Find</th>
<th>Symbol</th>
</tr>
</thead>
</table>

*SI is the symbol for the International System of Units*
ACKNOWLEDGMENTS

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

Roadside Safety Research Pooled Fund Committee
Revised January 2021

<table>
<thead>
<tr>
<th>State</th>
<th>Contact Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALABAMA</td>
<td><strong>Stanley (Stan) C. Biddick, P.E.</strong>&lt;br&gt;Assistant State Design Engineer&lt;br&gt;Design Bureau, Final Design Division&lt;br&gt;Alabama Dept. of Transportation&lt;br&gt;1409 Coliseum Boulevard, T-205&lt;br&gt;Montgomery, AL 36110&lt;br&gt;(334) 242-6833&lt;br&gt;<a href="mailto:biddicks@dot.state.al.us">biddicks@dot.state.al.us</a></td>
</tr>
<tr>
<td></td>
<td><strong>Steven E. Walker</strong>&lt;br&gt;Alabama Dept. of Transportation&lt;br&gt;(334) 242-6488&lt;br&gt;<a href="mailto:walkers@dot.state.al.us">walkers@dot.state.al.us</a></td>
</tr>
<tr>
<td>ALASKA</td>
<td><strong>Jeff C. Jeffers, P.E.</strong>&lt;br&gt;Statewide Standard Specifications&lt;br&gt;Alaska Depart. of Transportation &amp; Public Facilities&lt;br&gt;3132 Channel Drive&lt;br&gt;P.O. Box 112500&lt;br&gt;Juneau, AK 99811-2500&lt;br&gt;(907) 465-8962&lt;br&gt;<a href="mailto:Jeff.Jeffers@alaska.gov">Jeff.Jeffers@alaska.gov</a></td>
</tr>
<tr>
<td>COLORADO</td>
<td><strong>Joshua Keith, P.E.</strong>&lt;br&gt;Standards &amp; Specifications Engineer&lt;br&gt;Project Development Branch&lt;br&gt;Colorado Dept. of Transportation&lt;br&gt;4201 E Arkansas Ave, 4th Floor&lt;br&gt;Denver, CO 80222&lt;br&gt;(303) 757-9021&lt;br&gt;<a href="mailto:Josh.Keith@state.co.us">Josh.Keith@state.co.us</a></td>
</tr>
<tr>
<td></td>
<td><strong>Joshua Palmer, P.E.</strong>&lt;br&gt;Guardrail Engineer&lt;br&gt;Colorado Dept. of Transportation&lt;br&gt;2829 W. Howard Pl&lt;br&gt;Denver, CO 80204&lt;br&gt;(303) 757-9229&lt;br&gt;<a href="mailto:Joshua.j.palmer@state.co.us">Joshua.j.palmer@state.co.us</a></td>
</tr>
<tr>
<td></td>
<td><strong>Chih Shawn Yu</strong>&lt;br&gt;(303) 757-9474&lt;br&gt;<a href="mailto:Shawn.yu@state.co.us">Shawn.yu@state.co.us</a></td>
</tr>
<tr>
<td></td>
<td><strong>Andrew Pott, P.E. II</strong>&lt;br&gt;Staff Bridge&lt;br&gt;(303) 512-4020&lt;br&gt;<a href="mailto:Andrew.pott@state.co.us">Andrew.pott@state.co.us</a></td>
</tr>
<tr>
<td>CALIFORNIA</td>
<td><strong>Bob Meline, P.E.</strong>&lt;br&gt;Caltrans&lt;br&gt;Office of Materials and Infrastructure&lt;br&gt;Division of Research and Innovation&lt;br&gt;5900 Folsom Blvd&lt;br&gt;Sacramento, CA 95819&lt;br&gt;(916) 227-7031&lt;br&gt;<a href="mailto:Bob.Meline@dot.ca.gov">Bob.Meline@dot.ca.gov</a></td>
</tr>
<tr>
<td></td>
<td><strong>John Jewell, P.E.</strong>&lt;br&gt;Senior Crash Testing Engineer&lt;br&gt;Office of Safety Innovation &amp; Cooperative Research&lt;br&gt;(916) 227-5824&lt;br&gt;<a href="mailto:John_Jewell@dot.ca.gov">John_Jewell@dot.ca.gov</a></td>
</tr>
<tr>
<td>CONNECTICUT</td>
<td><strong>David Kilpatrick</strong>&lt;br&gt;State of Connecticut Depart. of Transportation&lt;br&gt;2800 Berlin Turnpike&lt;br&gt;Newington, CT 06131-7546&lt;br&gt;(806) 594-3288&lt;br&gt;<a href="mailto:David.Kilpatrick@ct.gov">David.Kilpatrick@ct.gov</a></td>
</tr>
</tbody>
</table>
DELAWARE
Mark Buckalew, P.E.
Safety Program Manager
Delaware Depart. of Transportation
169 Brick Store Landing Road
Smyrna, DE 19977
(302) 659-4073
Mark.Buckalew@state.de.us

FLORIDA
Derwood C. Sheppard, Jr., P.E.
Standard Plans Publication Engineer
Florida Depart. of Transportation
Roadway Design Office
605 Suwannee Street, MS-32
Tallahassee, FL 32399-0450
(850) 414-4334
Derwood.Sheppard@dot.state.fl.us

IDAHO
Kevin Sablan
Design and Traffic Engineer
Idaho Transportation Department
P. O. Box 7129
Boise, ID 83707-1129
(208) 334-8558
Kevin.Sablan@ITD.idaho.gov

Rick Jensen, P.E.
ITD Bridge Design
(208) 334-8589
Rick.jensen@itd.idaho.gov

Shanon M. Murgoitio, P.E.
Engineer Manager 1
ITD Bridge Division
(208) 334-8589
Shanon.murgoitio@ird.idaho.gov

Marc Danley, P.E.
Technical Engineer
(208) 334-8558
Marc.danley@itd.idaho.gov

ILLINOIS
Martha A. Brown, P.E.
Safety Design Bureau Chief
Bureau of Safety Programs and Engineering
Illinois Depart. of Transportation
2300 Dirksen Parkway, Room 005
Springfield, IL 62764
(217) 785-3034
Martha.A.Brown@illinois.gov

Tim Craven
Tim.craven@illinois.gov

Filberto (Fil) Sotelo
Safety Evaluation Engineer
(217) 785-5678
Filberto.Sotelo@illinois.gov

Jon M. McCormick
Safety Policy & Initiatives Engineer
(217) 785-5678
Jon.M.McCormick@illinois.gov

LOUISIANA
Chris Guidry
Bridge Manager
Louisiana Transportation Center
Bridge & Structural Design Section
P.O. Box 94245
Baton Rouge, LA 79084-9245
(225) 379-1933
Chris.Guidry@la.gov

Kurt Brauner, P.E.
Bridge Engineer Manager
Louisiana Transportation Center
1201 Capital Road, Suite 605G
Baton Rouge, LA 70802
(225) 379-1933
Kurt.Brauner@la.gov

Brian Allen, P.E.
Bridge Design Engineer
(225) 379-1840
Brian.allen@la.gov

Steve Mazur
Bridge Design
(225) 379-1094
Steven.Mazur@la.gov
OREGON
Christopher Henson
Senior Roadside Design Engineer
Oregon Depart. of Transportation
Technical Service Branch
4040 Fairview Industrial Drive, SE
Salem, OR 97302-1142
(503) 986-3561
Christopher.S.Henson@odot.state.or.us

PENNSYLVANIA
Guozhou Li
Pennsylvania DOT
GuLi@pa.gov
Hassan Raza
Standards & Criteria Engineer
Pennsylvania Depart. of Transportation
Bureau of Project Delivery
400 North Street, 7th Floor
Harrisburg, PA 17120
(717) 783-5110
HRaza@pa.gov

TENNESSEE
Ali Hangul, P.E., CPESC
Assistant Director
Tennessee Depart. of Transportation
Roadway Design & Office of Aerial Surveys
James K. Polk State Office Bldg.
505 Deaderick Street
Nashville, TN 37243
(615) 741-0840
Ali.Hangul@tn.gov

TEXAS
Chris Lindsey
Transportation Engineer
Design Division
Texas Department of Transportation
125 East 11th Street
Austin, TX 78701-2483
(512) 416-2750
Christopher.Lindsey@txdot.gov
Taya Retterer P.E.
TXDOT Bridge Standards Engineer
(512) 416-2719
Taya.Retterer@txdot.gov

WASHINGTON
John Donahue
Design Policy and Analysis Manager
Washington State Dept. of Transportation
Development Division
P.O. Box 47329
Olympia, WA 98504-7246
(360) 704-6381
donahjo@wsdot.wa.gov
Mustafa Mohamedali
Assistant Research Project Manager
P.O. Box 47372
Olympia, WA 98504-7372
(360) 704-6307
mohamem@wsdot.wa.gov
Anne Freeman
Program Administrator
Research & Library Services
(306) 705-7945
Freeann@wsdot.gov

WEST VIRGINIA
Donna J. Hardy, P.E.
Safety Programs Engineer
West Virginia Depart. of Transportation – Traffic Engineering
Building 5, Room A-550
1900 Kanawha Blvd E.
Charleston, WV 25305-0430
(304) 558-9576
Donna.J.Hardy@wv.gov

UTAH
Shawn Debenham
Traffic and Safety Division
Utah Depart. of Transportation
4501 South 2700 West
PO Box 143200
Salt Lake City UT 84114-3200
(801) 965-4590
sdebenham@utah.gov

Wade Odell
Transportation Engineer
Research & Technology Implementation
200 E. Riverside Drive
Austin, TX 78704
Wade.Odell@txdot.gov
WEST VIRGINIA (continued)
Ted Whitmore
Traffic Services Engineer
(304) 558-9468
Ted.J.Whitmore@wv.gov

Joe Hall, P.E.
Division of Highways & Engineering
Technical Policy QA/QC Engineer
Value Engineering Coordinator
1334 Smith Street
Charleston, WV 25305-0430
(304) 558-9733
Joe.H.Hall@wv.gov

WISCONSIN
Erik Emerson, P.E.
Standards Development Engineer – Roadside Design
Wisconsin Department of Transportation
Bureau of Project Development
4802 Sheboygan Avenue, Room 651
P. O. Box 7916
Madison, WI 53707-7916
(608) 266-2842
Erik.Emerson@wi.gov

CANADA – ONTARIO
Kenneth Shannon, P. Eng.
Senior Engineer, Highway Design (A)
Ontario Ministry of Transportation
301 St. Paul Street
St. Catharines, ON L2R 7R4
CANADA
(904) 704-3106
Kenneth.Shannon@ontario.ca

FEDERAL HIGHWAY ADMINISTRATION (FHWA)
WebSite: safety.fhwa.dot.gov

Richard B. (Dick) Albin, P.E.
Safety Engineer
FHWA Resource Center Safety & Design Technical Services Team
711 S. Capital
Olympia, WA 98501
(303) 550-8804
Dick.Albin@dot.gov

Eduardo Arispe
Research Highway Safety Specialist
U.S. Department of Transportation
Federal Highway Administration
Turner-Fairbank Highway Research Center
Mail Code: HRDS-10
6300 Georgetown Pike
McLean, VA 22101
(202) 493-3291
Eduardo.arispe@dot.gov

Greg Schertz, P.E.
FHWA – Federal Lands Highway Division
Safety Discipline Champion
12300 West Dakota Ave. Ste. 210
Lakewood, CO 80228
(720)-963-3764
Greg.Schertz@dot.gov

Christine Black
Highway Safety Engineer
Central Federal Lands Highway Division
12300 West Dakota Ave.
Lakewood, CO 80228
(720) 963-3662
Christine.black@dot.gov

TEXAS A&M TRANSPORTATION INSTITUTE (TTI)
WebSite: tti.tamu.edu
www.roadsidepooledfund.org

D. Lance Bullard, Jr., P.E.
Senior Research Engineer
Texas A&M Transportation Institute
3135 TAMU
College Station, TX 77843-3135
(979) 317-2855
L-Bullard@tti.tamu.edu

Roger P. Bligh, Ph.D., P.E.
Senior Research Engineer
(979) 317-2703
R-Bligh@tti.tamu.edu

Chiara Silvestri Dobrovolny, Ph.D.
Research Scientist
(979) 317-2687
C-Silvestri@tti.tamu.edu
REPORT AUTHORIZATION

REPORT REVIEWED BY:

Glenn Schroeder, Research Specialist
Drafting & Reporting

Ken Reeves, Research Specialist
Electronics Instrumentation

Gary Gerke, Research Specialist
Construction

Richard Badillo, Research Specialist
Photographic Instrumentation

Scott Dobrovolny, Research Specialist
Mechanical Instrumentation

Wanda L. Menges, Research Specialist
Research Evaluation and Reporting

Bill L. Griffith, Research Specialist
Deputy Quality Manager

Darrell L. Kuhn, P.E., Research Specialist
Quality Manager

Matthew N. Robinson, Research Specialist
Test Facility Manager & Technical Manager

Maysam Kiani
Assistant Research Engineer
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disclaimer</td>
</tr>
<tr>
<td>Report Authorization</td>
</tr>
<tr>
<td>List of Figures</td>
</tr>
<tr>
<td>List of Tables</td>
</tr>
</tbody>
</table>

## Chapter 1. Introduction

1. Background
2. Work Plan
  1.1. Task 1: Engineering Analysis and Review
  1.2. Task 2: Simulation
  1.3. Task 3: MASH Test 3-21 Crash Testing of the Transition with Shorter Length
  1.4. Task 4: Evaluation and Reporting

## Chapter 2. Literature Review

2.1. Introduction
2.2. Development of MGS Approach Guardrail Transition using Standardized Steel Posts
2.3. MASH Test 3-21 on TL-3 Thrie Beam Transition without Curb
2.4. Dynamic Evaluation of MGS Stiffness Transition with Curb
2.5. MASH TL-3 Evaluation of Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure
2.6. MASH TL-3 Evaluation of 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition
2.7. Summary and Conclusions from Literature Search

## Chapter 3. Simulation

3.1. Introduction
3.2. System Design
3.3. Detailed Modeling
3.4. Simulation
  3.4.1. MASH Test 3-21: Pickup Truck Impacting the Shorter Transition
  3.4.2. MASH Test 3-20: Small Car Impacting Shorter Transition
3.5. Summary and Conclusions

## Chapter 4. System Details

4.1. Test Article and Installation Details
4.2. Design Modifications during Tests
4.3. Material Specifications
4.4. Soil Conditions

## Chapter 5. Test Requirements and Evaluation Criteria

5.1. Crash Test Performed/Matrix
5.2. Evaluation Criteria

## Chapter 6. Test Conditions

6.1. Test Facility
6.2. Vehicle Tow and Guidance System
TABLE OF CONTENTS (CONTINUED)

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3. Data Acquisition Systems</td>
<td>25</td>
</tr>
<tr>
<td>6.3.1. Vehicle Instrumentation and Data Processing</td>
<td>25</td>
</tr>
<tr>
<td>6.3.2. Anthropomorphic Dummy Instrumentation</td>
<td>26</td>
</tr>
<tr>
<td>6.3.3. Photographic Instrumentation Data Processing</td>
<td>26</td>
</tr>
<tr>
<td>7. MASH Test 3-21 (Crash Test No. 613121-01-1)</td>
<td>29</td>
</tr>
<tr>
<td>7.1. Test Designation and Actual Impact Conditions</td>
<td>29</td>
</tr>
<tr>
<td>7.2. Weather Conditions</td>
<td>29</td>
</tr>
<tr>
<td>7.3. Test Vehicle</td>
<td>29</td>
</tr>
<tr>
<td>7.4. Test Description</td>
<td>30</td>
</tr>
<tr>
<td>7.5. Damage to Test Installation</td>
<td>30</td>
</tr>
<tr>
<td>7.6. Damage to Test Vehicle</td>
<td>32</td>
</tr>
<tr>
<td>7.7. Occupant Risk Factors</td>
<td>33</td>
</tr>
<tr>
<td>8. Conclusions</td>
<td>37</td>
</tr>
<tr>
<td>8.1. Assessment of Test Results</td>
<td>37</td>
</tr>
<tr>
<td>8.2. Conclusions</td>
<td>37</td>
</tr>
<tr>
<td>8.3. Recommendations</td>
<td>37</td>
</tr>
<tr>
<td>References</td>
<td>39</td>
</tr>
<tr>
<td>Appendix A. Details of Short Transition</td>
<td>41</td>
</tr>
<tr>
<td>Appendix B. Supporting Certification Documents</td>
<td>59</td>
</tr>
<tr>
<td>Appendix C. Soil Properties</td>
<td>71</td>
</tr>
<tr>
<td>Appendix D. MASH Test 3-21 (Crash Test No. 613121-01-1)</td>
<td>73</td>
</tr>
<tr>
<td>D.1. Vehicle Properties and Information</td>
<td>73</td>
</tr>
<tr>
<td>D.2. Sequential Photographs</td>
<td>77</td>
</tr>
<tr>
<td>D.3. Vehicle Angular Displacements</td>
<td>81</td>
</tr>
<tr>
<td>D.4. Vehicle Accelerations</td>
<td>82</td>
</tr>
</tbody>
</table>
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Thrie Beam Guardrail Bridge Transition and Connection [WVDOT Standard Drawing, 2016]</td>
<td>1</td>
</tr>
<tr>
<td>2.1</td>
<td>MwRSF Simplified Steel Post Stiffness Transition System</td>
<td>3</td>
</tr>
<tr>
<td>2.2</td>
<td>Simplified Thrie Beam transition without Curb and Rubrail</td>
<td>4</td>
</tr>
<tr>
<td>2.3</td>
<td>MGS to Thrie Beam Stiffness Transition Details with Curb</td>
<td>5</td>
</tr>
<tr>
<td>2.4</td>
<td>Installation Details for Transition on Wingwall.</td>
<td>6</td>
</tr>
<tr>
<td>2.5</td>
<td>Details of 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition</td>
<td>7</td>
</tr>
<tr>
<td>3.1</td>
<td>Plan View and Elevation of Installation.</td>
<td>9</td>
</tr>
<tr>
<td>3.2</td>
<td>Preliminary Transition Details</td>
<td>10</td>
</tr>
<tr>
<td>3.3</td>
<td>Moment Slab and Parapet Details</td>
<td>10</td>
</tr>
<tr>
<td>3.4</td>
<td>Rebar Details.</td>
<td>11</td>
</tr>
<tr>
<td>3.5</td>
<td>Front View of System.</td>
<td>12</td>
</tr>
<tr>
<td>3.6</td>
<td>Rear View of System.</td>
<td>12</td>
</tr>
<tr>
<td>3.7</td>
<td>MASH Test Vehicles: (a) 1100C and (b) 2270P.</td>
<td>13</td>
</tr>
<tr>
<td>3.8</td>
<td>MASH 2270P Vehicle/Installation Setup – Isometric View</td>
<td>14</td>
</tr>
<tr>
<td>3.9</td>
<td>MASH 2270P Vehicle/Installation Setup – Front View</td>
<td>15</td>
</tr>
<tr>
<td>3.10</td>
<td>MASH 2270P Vehicle/Installation Setup – Top View</td>
<td>15</td>
</tr>
<tr>
<td>3.11</td>
<td>Target CIP for MASH Test 3-21.</td>
<td>16</td>
</tr>
<tr>
<td>3.12</td>
<td>Sequential Images of MASH Test 3-21 for Shorter Terminal</td>
<td>16</td>
</tr>
<tr>
<td>3.13</td>
<td>MASH 1100C Vehicle/Installation Setup – Isometric View</td>
<td>17</td>
</tr>
<tr>
<td>3.14</td>
<td>MASH 1100C Vehicle/Installation Setup – Tire Snagging to Parapet.</td>
<td>17</td>
</tr>
<tr>
<td>3.15</td>
<td>MASH 1100C Vehicle/Installation Setup – Effect of Added Deflector Plate in Reducing Tire Snagging</td>
<td>18</td>
</tr>
<tr>
<td>4.1</td>
<td>Details of Transition.</td>
<td>20</td>
</tr>
<tr>
<td>4.2</td>
<td>Transition prior to Testing.</td>
<td>21</td>
</tr>
<tr>
<td>5.1</td>
<td>Target CIP for MASH Test 3-21 on Transition</td>
<td>23</td>
</tr>
<tr>
<td>7.1</td>
<td>Transition/Test Vehicle Geometrics for Test No. 613121-01-1.</td>
<td>29</td>
</tr>
<tr>
<td>7.2</td>
<td>Test Vehicle before Test No. 613121-01-1</td>
<td>30</td>
</tr>
<tr>
<td>7.3</td>
<td>Transition after Test No. 613121-01-1</td>
<td>31</td>
</tr>
<tr>
<td>7.4</td>
<td>Field Side of Transition after Test No. 613121-01-1</td>
<td>32</td>
</tr>
<tr>
<td>7.5</td>
<td>Test Vehicle after Test No. 613121-01-1</td>
<td>33</td>
</tr>
<tr>
<td>7.6</td>
<td>Interior of Test Vehicle after Test No. 613121-01-1</td>
<td>33</td>
</tr>
<tr>
<td>7.7</td>
<td>Summary of Results for MASH Test 4-21 on Short Transition</td>
<td>35</td>
</tr>
<tr>
<td>D.1</td>
<td>Sequential Photographs for Test No. 613121-01-1 (Overhead and Frontal Views).</td>
<td>77</td>
</tr>
<tr>
<td>D.2</td>
<td>Sequential Photographs for Test No. 613121-01-1 (Rear View).</td>
<td>79</td>
</tr>
<tr>
<td>D.3</td>
<td>Vehicle Angular Displacements for Test No. 613121-01-1</td>
<td>81</td>
</tr>
<tr>
<td>D.4</td>
<td>Vehicle Longitudinal Accelerometer Trace for Test No. 613121-01-1 (Accelerometer Located at Center of Gravity)</td>
<td>82</td>
</tr>
<tr>
<td>D.5</td>
<td>Vehicle Lateral Accelerometer Trace for Test No. 613121-01-1 (Accelerometer Located at Center of Gravity)</td>
<td>83</td>
</tr>
<tr>
<td>D.6</td>
<td>Vehicle Vertical Accelerometer Trace for Test No. 613121-01-1 (Accelerometer Located at Center of Gravity)</td>
<td>84</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 3.1. Test Conditions and Evaluation Criteria for Transitions According to MASH TL-3 ................................................................. 13
Table 3.2. Evaluation Criteria for Transitions According to MASH TL-3 ........................................................................................................ 14
Table 5.1. Test Conditions and Evaluation Criteria Specified for MASH TL-3 Transitions .............................................................................. 23
Table 5.2. Evaluation Criteria Required for MASH TL-3 Transitions ........................................................................................................... 24
Table 7.1. Events during Test No. 613121-01-1 ............................................................................................................................................ 30
Table 7.2. Post Movement after Test No. 613121-01-1 ................................................................................................................................. 32
Table 7.3. Occupant Risk Factors for Test No. 613121-01-1 .......................................................................................................................... 34
Table 8.1. Performance Evaluation Summary for MASH Test 3-21 on Short Transition .................................................................................. 38
Table C.1. Summary of Strong Soil Test Results for Establishing Installation Procedure .................................................................................... 71
Table C.2. Test Day Static Soil Strength Documentation for Test No. 613121-01-1 .................................................................................. 72
Table D.1. Vehicle Properties for Test No. 613121-01-1 ................................................................................................................................. 73
Table D.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 613121-01-1 ............................................................................... 74
Table D.3. Exterior Crush Measurements for Test No. 613121-01-1 ............................................................................................................. 75
Table D.4. Occupant Compartment Measurements for Test No. 613121-01-1 ............................................................................................ 76
CHAPTER 1. INTRODUCTION

1.1. BACKGROUND

When roadways intersect with restrictive features such as a bridge rail, it becomes difficult to fit a transition system with proper length. For this project, American Association of State Highway and Transportation (AASHTO) Manual for Assessing Safety Hardware (MASH) Test Level 3 (TL-3) W beam transitions with shorter length are desired to be tested. These systems are used when State Departments of Transportation (DOTs) need to implement a shorter transition without compromising the integrity of the guardrail system.

The objective of this study was to model and crash test shorter W-beam transition systems for MASH TL-3 compliance. A MASH compliant transition with shorter length would provide the members of the Roadside Safety Pooled Fund with a valuable option in restrictive conditions against roadside hazards.

Figure 1.1 shows a similar transition design that was used for the installation constructed during this project. The objective was to reduce the 25-ft transition length. For this purpose, the TTI research team first performed an engineering review of available transition systems and their design variables to shortlist a set of candidates for modeling and evaluation. The researchers conducted a series of simulations of the candidate set. The final design was then crash tested for MASH TL-3 compliance.

Figure 1.1. Thrie Beam Guardrail Bridge Transition and Connection [WVDOT Standard Drawing, 2016].
1.2. WORK PLAN

The work plan for the project consisted of four tasks. Details of the tasks are described below:

1.2.1. Task 1: Engineering Analysis and Review

The TTI research team performed a thorough engineering review of the available transition systems and their design variables to prepare a set of simulation design concepts. The proposed design concept list was simulated under Task 2.

1.2.2. Task 2: Simulation

The TTI research team modeled the concept transition systems and conducted extensive simulations to evaluate the impact performance of the systems to finalize an optimized shorter transition for full-scale crash testing under Task 3.

1.2.3. Task 3: MASH Test 3-21 Crash Testing of the Transition with Shorter Length

The TTI research team completed full-scale MASH Test 3-21 on a transition with shorter length. The MASH 2270P (5000-lb) pickup truck impacts the transition at a speed of 62 mph and an angle of 25 degrees. This test evaluates the performance of a shorter transition system upon impact with the 2270P pickup truck.

1.2.4. Task 4: Evaluation and Reporting

The TTI research team prepared this research report fully documenting the simulation and evaluation of the crash test completed in this project. The report includes detailed engineering drawings of the transition system.
CHAPTER 2. LITERATURE REVIEW*

2.1. INTRODUCTION

A literature review was performed and completed for this project. The engineering review of the available transition systems satisfies the requirement of Task 1.

2.2. DEVELOPMENT OF MGS APPROACH GUARDRAIL TRANSITION USING STANDARDIZED STEEL POSTS

The researchers at Midwest Roadside Safety Facility (MwRSF) developed a simplified version of the original Midwest Guardrail System (MGS) stiffness transition by utilizing two common sizes of steel posts, and it was full-scale crash tested according to MASH TL-3 criteria (2). The design of the stiffness transition for this project included a standard MGS, a previously accepted thrie beam approach guardrail transition (AGT) system, and an asymmetrical W-beam to thrie beam transition element.

A new, simplified steel-post stiffness transition between the MGS and a thrie beam AGT previously accepted by FHWA was developed and tested for this project. This system consists of standard steel posts and an asymmetric W-to-thrie transition element. A very stiff thrie beam guardrail transition was used during the full-scale crash test. This system satisfied all MASH TL-3 criteria. Figure 2.1 illustrates the details of the recommended transition design for the MGS system to thrie beam. The design is similar to the standard approach transition that West Virginia Department of Transportation is using.

Figure 2.1. MwRSF Simplified Steel Post Stiffness Transition System.

2.3. MASH TEST 3-21 ON TL-3 THRIE BEAM TRANSITION WITHOUT CURB

TTI researchers evaluated the performance of a simplified approach transition design without a curb or a rubrail (Figure 2.2) (3). The test was performed in accordance with the MASH criteria under the impact conditions for Test Designation 3-21.

* The opinions/interpretations identified/expressed in this section of the report are outside the scope of TTI Proving Ground’s A2LA Accreditation.
Figure 2.2. Simplified Thrie Beam transition without Curb and Rubrail.

The single slope bridge rail was constructed according to the Texas Department of Transportation (TxDOT) standards with a height of 36 inches. The guardrail was constructed using 19 posts. Posts 1 and 2 were installed as part of the standard 31-inch ET-2000 Terminal. Posts 3 through 11 were installed as part of a standard 12-gauge W-Beam Guardrail (RWM04a). Each post in this section is a 72-inch long W6×8.5 SLP (PEW01) attached to the 12-gauge rail element using an 8-inch wood blockout. The posts were placed at the mid-span of each rail. Between posts 11 and 13, a 10-gauge thrie beam to W-beam asymmetric transition piece is utilized and is supported by a 72-inch long W6×8.5 SLP. A nested 12-gauge thrie beam (RTM02a) rail is used between post 13 and the end of the single slope barrier. In this section, 84-inch long W6×8.5 posts with 6×8×18-inch wood blockouts are used. A 10-gauge thrie beam end shoe (RTE01b) is used to attach the nested thrie beam to the ¼-inch thick adapter plate.

The TxDOT TL-3 transition did not perform acceptably for MASH Test 3-21 due to a pickup truck rollover. Signs of wheel snagging at the blunt end of the single slope concrete barrier could have contributed to destabilizing the vehicle.

Three design modifications to improve the system performance were proposed:
1. A short curb may be placed at the end of the parapet under the rail to help prevent the wheel snagging.
2. The steel blockout at the end of the parapet could be increased in depth to offset the rail to decrease the amount of snagging.
3. The posts in the nested section of the guardrail could be strengthened by using a larger size post and increasing the embedment depth.
2.4. DYNAMIC EVALUATION OF MGS STIFFNESS TRANSITION WITH CURB

MwRSF Research Project Number TPF-5(193)

MwRSF researchers developed a stiffness transition with a 4-inch tall concrete curb to connect MGS to a previously developed thrie beam approach guardrail system (4). The test installation is shown in Figure 2.3.

![Figure 2.3. MGS to Thrie Beam Stiffness Transition Details with Curb.](image)

Three crash tests were conducted: Test Nos. MWTC-1, MWTC-2, and MWTC-3. Test Nos. MWTC-1 and MWTC-2 were performed according to test designation MASH Test No. 3-20 with an 1100C small car. Test No. MWTC-3 was performed according to test designation MASH Test No. 3-21 with a 2270P pickup truck. In the first crash test (Test No. MWTC-1), the MGS Stiffness Transition with Curb did not perform acceptably. The front of the 1100C vehicle penetrated under the W-beam rail while the wheel overrode the curb. The combination of these events resulted in the W-beam rail to rupture at the splice adjacent to the rail elements, which eventually caused the W-beam rail to rupture.

After the failed crash test, the design was modified to incorporate an additional 12 gauge W-beam segment such that 12.5 ft of nested guardrail preceded the asymmetric W-beam to thrie beam transition element. After this modification was incorporated in the stiffness transition system, Test Nos. MWTC-2 and MWTC-3 were performed with an 1100C small car and 2270P pickup truck, respectively. The modification resulted in a successful completion of the MASH TL-3 testing matrix. Therefore, this system was found to satisfy current safety standards.

2.5. MASH TL-3 EVALUATION OF GUARDRAIL TO RIGID BARRIER TRANSITION ATTACHED TO BRIDGE OR CULVERT STRUCTURE

TTI Test Report No. FHWA/TX-19/0-6954-R1

TTI researchers evaluated a guardrail to rigid barrier transition attached to a bridge or culvert structure using computer simulations and full-scale crash testing (5).
The Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure installation consisted of a 16-ft long reinforced concrete parapet and moment slab, a 27 ft-6¼ inch long W-beam to thrie-beam to parapet transition section that was anchored to the parapet, 50 ft of W-beam guardrail, and a TxDOT Downstream Anchor Terminal (DAT). The posts in the thrie-beam portion of the installation were anchored to a reinforced concrete wingwall that was embedded in the soil with the top at grade, and the rest of the posts were embedded directly into the soil. The top edge of the thrie-beam and W-beam rails were at 31 inches above grade. The wingwall was 13 ft long, 12 inches thick, and 5 ft deep. A C6×8.2 rub rail was positioned below the thrie-beam section of the transition. Figure 2.4 shows the transition installation on a wingwall.

![Figure 2.4. Installation Details for Transition on Wingwall.](image)

The target critical impact points (CIPs) were determined using computer simulation. Three crash tests were conducted. Two on the upstream of the transition and one on the downstream. The target CIPs for MASH Test 3-20 (Test No. 469549-01-1) and MASH Test 3-21 (Test No. 469549-01-2) were the centerline of post 13 and 14, respectively. The target CIP for MASH Test 3-21 (Test No. 469549-01-4) was 5 inches downstream of the centerline of post 19 at the connection with the rail.

The Guardrail to Rigid Barrier Transition Attached to Bridge or Culvert Structure performed acceptably for MASH TL-3 criteria.

### 2.6. MASH TL-3 EVALUATION OF 2019 MASH 2-TUBE BRIDGE RAIL THRIE BEAM TRANSITION

TTI Test Report No. 608331-4-6

TTI researchers assessed the performance of the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition according to the safety-performance evaluation guidelines included in AASHTO MASH (6).
The target critical impact point (CIP) for each test was determined in accordance with the guidance provided in MASH. For MASH Test 3-20, the target CIP was 5.1 ft upstream of the end of the concrete parapet. The target CIP for MASH Test 3-21 on the thrie beam to bridge rail transition was 7.0 ft upstream of the concrete parapet. The target CIP for MASH Test 3-21 on the W-beam to thrie beam transition was 7.3 ft upstream of the centerline of post 7. TTI researchers determined that MASH Test 3-20 on the W-beam to thrie beam transition was not necessary and was therefore not performed.

The 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition performed acceptably for a MASH TL-3 transition.

2.7. SUMMARY AND CONCLUSIONS FROM LITERATURE SEARCH

Based on the engineering review of previous studies, the following conclusions can be drawn:

1. In the case of not using a curb or rubrail, the blunt end of the concrete parapet needs to be protected to reduce the possibility of wheel snagging.
2. The thrie beam upstream of the parapet needs to be nested.
3. Crash testing should be performed on the nested thrie beam or the W-to-thrie transition section.
CHAPTER 3. SIMULATION*

1.1. INTRODUCTION

Finite element modeling simulations were conducted on the transition design as part of Task 2. The computer simulations were performed using LS-DYNA.

3.2. SYSTEM DESIGN

The 99 ft-5¼ inch installation consists of four sections: A 16-ft vertical wall parapet, a 24 ft-4-¾ inch transition section, a 50 ft length of need, and a 9 ft-½ inch TxDOT DAT. All the posts are 72-inch long W6×8.5 with 6×8×14-inch wood blockouts throughout the test installation. A 6 ft-¼ inch long nested Thrie beam is connecting the W-to-thrie segment to the concrete parapet via a 10 gauge thrie beam end shoe. Figure 3.1 through Figure 3.4 show details of the transition design used in the preliminary simulation effort.

Figure 3.1. Plan View and Elevation of Installation.

* The opinions/interpretations identified/expressed in this section of the report are outside the scope of TTI Proving Ground’s A2LA Accreditation.
Figure 3.2. Preliminary Transition Details.

Figure 3.3. Moment Slab and Parapet Details.
3.3. DETAILED MODELING

An explicit finite element model of the transition system was created using detailed geometrical and material properties. Figure 3.5 and Figure 3.6 show the front and rear views of the system modeled, including the moment slab, parapet, transition posts, nested thrie section, and approaching W-beam guardrail. The rear view shows the utilization of 14-inch blockouts all through the system. The moment slab was modeled as rigid and did not consider any material failure from the impact loads. The shorter transition system comprised of a nested 6 ft-3 inch 12 gauge thrie-beam followed by an asymmetric W-to-thrie transition segment. Figure 3.7 shows views of the MASH 1100C and 2270P vehicle models used in the computer simulations.
Figure 3.5. Front View of System.

Figure 3.6. Rear View of System.
Figure 3.7. MASH Test Vehicles: (a) 1100C and (b) 2270P.

3.4. SIMULATION

All impact simulations were performed under *MASH* TL-3 impact conditions. The research team performed an extensive parametric analysis to investigate the system and impacting vehicles performance at various impact points. The objective was to identify the critical impact point for the full-scale crash testing. Table 3.1 and Table 3.2 show the test conditions and evaluation criteria for transitions, respectively. The simulation procedure and the results are presented below.

<table>
<thead>
<tr>
<th>Test Article</th>
<th>Test Designation</th>
<th>Test Vehicle</th>
<th>Impact Conditions</th>
<th>Evaluation Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transition</td>
<td>3-20</td>
<td>1100C</td>
<td>62 mi/h</td>
<td>A, D, F, H, I</td>
</tr>
<tr>
<td></td>
<td>3-21</td>
<td>2270P</td>
<td>62 mi/h</td>
<td>A, D, F, H, I</td>
</tr>
</tbody>
</table>
Table 3.2. Evaluation Criteria for Transitions According to MASH TL-3.

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

3.4.1. MASH Test 3-21: Pickup Truck Impacting the Shorter Transition

Figure 3.8 through Figure 3.10 show the images of the vehicle setup for this impact simulation. The vehicle used in this simulation is a 2270P vehicle weighing 5000 lb and impacting the barrier at a speed of 62 mph and an angle of 25 degrees.

![Figure 3.8. MASH 2270P Vehicle/Installation Setup – Isometric View.](image)
According to the literature review section, in transitions without curb or rubrail, the main reason for failing full-scale crash test was vehicle rollover. Thus, the researchers investigated various design modifications to improve the system performance and reduce vehicular instability. The parametric analysis indicated that the maximum roll angle occurs when the target critical impact point (CIP) is the centerline of post 17 (Figure 3.11). The sequential images of the simulation are presented in Figure 3.12.
Figure 3.11. Target CIP for MASH Test 3-21.

Figure 3.12. Sequential Images of MASH Test 3-21 for Shorter Terminal.
3.4.2. *MASH* Test 3-20: Small Car Impacting Shorter Transition

Figure 3.13 shows the vehicle setup for small car impact simulation. The vehicle used in this simulation is a 1100C vehicle impacting the barrier at a speed of 62 mph and an angle of 25 degrees. As depicted in Figure 3.14, the impact side tire experienced severe snagging to the parapet toe that may cause higher occupant risk factors in a full-scale crash test. To reduce the possibility of tire snagging, a deflector plate was placed between the parapet toe and the field side flange of Post 20 (the second post from the parapet) (Figure 3.15).

![Figure 3.13. *MASH* 1100C Vehicle/Installation Setup – Isometric View.](image)

![Figure 3.14. *MASH* 1100C Vehicle/Installation Setup – Tire Snagging to Parapet.](image)
3.5. SUMMARY AND CONCLUSIONS

Based on the simulation effort, the recommended system for evaluation needs to have the following specifications:

- Shorter blockouts (14-inch W-beam blockouts) behind the thrie beam to allow the bottom of the thrie beam to bend inward upon the impact to dissipate the energy and consequently reduce the bottom of the vehicle bouncing back. This design would reduce the possibility of excessive roll angle observed in previous transitions of similar structure (transitions without any curb and/or rubrail) that caused vehicular instability, and rollover in some cases.
- A deflector plate or a similar method for a smooth redirection of the small car tire from the concrete parapet’s blunt end.

*MASH* recommends conducting Test 3-20 “if there is a reasonable uncertainty regarding the impact performance of the system for impact with small car.” By utilizing the deflector plate that controls the tire snagging at the concrete parapet toe, the immediate area upstream of the concrete parapet appeared favorable for *MASH* Test 3-20, so this test did not need to be performed.

Figure 3.15. *MASH* 1100C Vehicle/Installation Setup – Effect of Added Deflector Plate in Reducing Tire Snagging.
CHAPTER 4. SYSTEM DETAILS

4.1 TEST ARTICLE AND INSTALLATION DETAILS

The test installation was 99 ft-9¼ inches long and consisted of an upstream Texas Department of Transportation Downstream Anchor Terminal (DAT) guardrail terminal, a length of W-beam guardrail transitioning to thrie-beam guardrail, and a downstream reinforced concrete parapet. The top edge of the guardrail measured 31 inches above grade and was supported by steel posts with timber blockouts. Beginning at the end of the DAT, posts 2 through 11 supporting the W-beam were spaced at 75 inches for 50 ft, followed by posts 11 through 14 spaced at 37½ inches for 9 ft-4½ inches. At this point, the W-beam asymmetrically transitioned to a thrie-beam over 75 inches, followed by two nested 75-inch-long sections of thrie-beam guardrail. Posts 14 through 21 were spaced at 18¾ inches in the transition and thrie-beam sections, spanning 10 ft-11¼ inches. The rail was not attached to posts 15, 17, 19, and 21 in the transition and thrie-beam sections. Guardrail splices were located mid-span between the posts except for the splices located at posts 14 and 18. The developed system was desired to be readily installation existing vertical concrete end posts.

The nested thrie-beam rails were attached to a thrie-beam end shoe, which was secured to a 16-ft long 32-inch-tall steel reinforced concrete parapet that had a vertical traffic side face. A deflector plate was attached to the traffic side face of the parapet below the thrie-beam. It angled toward the field side of the installation, passed on the traffic side of post 21 (the post nearest the parapet), and was secured to post 20 on its field side. This plate was 8 inches wide, ¼-inch thick, and approximately 36 inches long, with two bends.

Figure 4.1 presents the overall information on the short transition, and Figure 4.2 provides photographs of the installation. Appendix A provides further details on the short transition. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, and rail construction was performed by DMA Construction Inc. supervised by TTI Proving Ground personnel. Concrete construction was performed by TTI Proving Ground personnel.

4.2 DESIGN MODIFICATIONS DURING TESTS

No modification was made to the installation during the testing phase.

4.3 MATERIAL SPECIFICATIONS

The specified compressive strength of the TxDOT Class C concrete used in the parapet was 3600 psi. On April 8, 2021, the average compressive strength of the concrete was 5900 psi.

Appendix B provides material certification documents for the materials used to install/construct the transition.
Figure 4.1. Details of Transition.

1b. Recessed Guardrail Nuts on all 5/8" Bolts. All Steel components, including hardware, are galvanized, and all Bolts are ASTM A307 unless otherwise indicated.
1c. W-beam Guardrail is typical at posts 3 - 10. Blockout and Guardrail Bolt is typical at posts 3 - 12. Post is typical at 3 - 19 and 21.
1d. Use 2" Guardrail Bolts at rail joints with 3 thicknesses, and 1-1/4" Guardrail Bolts at rail joints with 2 thicknesses.
Figure 4.2. Transition prior to Testing.
4.4 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 transition for full-scale crash testing, two 6-ft long W6×16 posts were installed in the immediate vicinity of the transition using the same fill materials and installation procedures used in the test installation and the standard dynamic test. Table C.1 in Appendix C 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 C, Table C.1, the minimum post loads required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, are 3940 lbf, 5500 lbf, and 6540 lbf (90 percent of static load for the initial standard installation). On the day of the test, April 19, 2021, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 7020 lbf, 7777 lbf, and 8383 lbf. Table C.2 in Appendix C shows the strength of the backfill material in which the transition was installed met minimum MASH requirements for soil strength.
CHAPTER 5. TEST REQUIREMENTS AND EVALUATION CRITERIA

5.1 CRASH TEST PERFORMED/MATRIX

Table 5.1 shows the test conditions and evaluation criteria for MASH TL-3 for transitions. The target critical impact points (CIPs) for each test were determined using the information provided in MASH Section 2.2.2. Figure 5.1 shows the target CIP for MASH Test 3-21 on the transition.

Table 5.1. Test Conditions and Evaluation Criteria Specified for MASH TL-3 Transitions.

<table>
<thead>
<tr>
<th>Test Article</th>
<th>Test Designation</th>
<th>Test Vehicle</th>
<th>Impact Conditions</th>
<th>Evaluation Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transition</td>
<td>3-20</td>
<td>1100C</td>
<td>62 mi/h, 25°</td>
<td>A, D, F, H, I</td>
</tr>
<tr>
<td></td>
<td>3-21</td>
<td>2270P</td>
<td>62 mi/h, 25°</td>
<td>A, D, F, H, I</td>
</tr>
</tbody>
</table>

Figure 5.1. Target CIP for MASH Test 3-21 on Transition.

Based on the transition design evaluation by computer simulation, MASH Test 3-20 did not present reasonable uncertainty of success, so this test was not performed (considered optional for MASH).

The crash tests and data analysis procedures were in accordance with guidelines presented in MASH. Chapter 6 presents brief descriptions of these procedures.

5.2 EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-3 and 5-1 of MASH were used to evaluate the crash test reported herein. Table 5.1 lists the test conditions and evaluation criteria required for MASH TL-3, and Table 5.2 provides detailed information on the evaluation criteria. An evaluation of the crash test results is presented in Chapter 8.
**Table 5.2. Evaluation Criteria Required for MASH TL-3 Transitions.**

<table>
<thead>
<tr>
<th>Evaluation Factors</th>
<th>Evaluation Criteria</th>
<th>3-20 and 3-21</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural Adequacy</strong></td>
<td>A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I. The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</td>
<td></td>
</tr>
</tbody>
</table>

| **Occupant Risk** | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
CHAPTER 6. TEST CONDITIONS

6.1 TEST FACILITY

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

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

6.2 VEHICLE TOW AND GUIDANCE SYSTEM

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

6.3 DATA ACQUISITION SYSTEMS

6.3.1 Vehicle Instrumentation and Data Processing

The test vehicle was instrumented with a self-contained onboard data acquisition system. The signal conditioning and acquisition system is a 16-channel Tiny Data Acquisition System (TDAS) Pro produced by Diversified Technical Systems Inc. The accelerometers, which measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra-small, solid-state units designed for crash test service. The TDAS Pro hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 16 channels is capable of providing precision amplification, scaling, and filtering based on
transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 samples per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit in case the primary battery cable is severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

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

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

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

6.3.2. Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the front seat on the impact side of the 2270P vehicle. The dummy was not instrumented.

6.3.3. Photographic Instrumentation Data Processing

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

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

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the transition. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.
7. **MASH TEST 3-21 (CRASH TEST NO. 613121-01-1)**

7.1. **TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS**

*MASH* Test 3-21 involves a 2270P vehicle weighing 5000 lb ± 110 lb impacting the CIP of the longitudinal barrier at an impact speed of 62 mi/h ± 2.5 mi/h and an angle of 25 degrees ± 1.5 degrees. The CIP for *MASH* Test 3-21 on the short transition was at the centerline of post 17 ±1 ft. Figure 5.1 and Figure 7.1 depict the target impact setup.

![Figure 7.1. Transition/Test Vehicle Geometrics for Test No. 613121-01-1.](image)

The 2270P vehicle weighed 5061 lb, and the actual impact speed and angle were 62.6 mi/h and 25.4 degrees. The actual impact point was the centerline of post 17. Minimum target impact severity (IS) was 106 kip-ft, and actual IS was 122 kip-ft.

7.2. **WEATHER CONDITIONS**

The test was performed on the morning/afternoon of April 19, 2021. Weather conditions at the time of testing were as follows: wind speed: 2 mi/h; wind direction: 296 degrees (vehicle was traveling at a heading of 195 degrees); temperature: 64°F; relative humidity: 59 percent.

7.3. **TEST VEHICLE**

Figure 7.2 shows the 2016 RAM 1500 pickup truck used for the crash test. The vehicle’s test inertia weight was 5061 lb, and its gross static weight was 5226 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle’s center of gravity was 28.25 inches. Tables D.1 and D.2 in Appendix D.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.
7.4. TEST DESCRIPTION

Table 7.1 lists events that occurred during Test No. 613121-01-1. Figures D.1 and D.2 in Appendix D.2 present sequential photographs during the test.

Table 7.1. Events during Test No. 613121-01-1.

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0000</td>
<td>Vehicle impacts the transition</td>
</tr>
<tr>
<td>0.0380</td>
<td>Vehicle begins to redirect</td>
</tr>
<tr>
<td>0.1090</td>
<td>Left front tire lifts off of the pavement</td>
</tr>
<tr>
<td>0.1100</td>
<td>Left rear tire lifts off of the pavement</td>
</tr>
<tr>
<td>0.2080</td>
<td>Vehicle traveling parallel with transition</td>
</tr>
<tr>
<td>0.2213</td>
<td>Left rear bumper contacts the installation</td>
</tr>
<tr>
<td>0.3850</td>
<td>Vehicle loses contact with transition while traveling at 46.9 mi/h, at a trajectory of 9.7 degrees, and a heading of 12.9 degrees</td>
</tr>
</tbody>
</table>

For longitudinal barriers, it is desirable for the vehicle to redirect and exit the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in MASH. Brakes on the vehicle were applied after the vehicle exited the test site. The vehicle came to rest 165 ft downstream of the point of impact and 68 ft toward traffic lanes.

7.5. DAMAGE TO TEST INSTALLATION

Figure 7.3 and Figure 7.4 show the damage to the transition. The existing cracks were marked in black, and the post-impact cracks were marked in red. The rail was scuffed and deformed at impact. The soil was disturbed at posts 14 and 15, and there was slight spalling on the upstream end of the concrete barrier. Table 7.2 provides additional measurements and
damage details. Working width* was 27.6 inches, and height of working width was 29.7 inches. Maximum dynamic deflection during the test was 10.4 inches, and maximum permanent deformation was 7.8 inches.

Figure 7.3. Transition after Test No. 613121-01-1.

* Per MASH, “The working width is the maximum dynamic lateral position of any major part of the system or vehicle. These measurements are all relative to the pre-impact traffic face of the test article.” In other words, working width is the total barrier width plus the maximum dynamic intrusion of any portion of the barrier or test vehicle past the field side edge of the barrier.
Figure 7.4. Field Side of Transition after Test No. 613121-01-1.

Table 7.2. Post Movement after Test No. 613121-01-1.

<table>
<thead>
<tr>
<th>Post #</th>
<th>Lean from Vertical</th>
<th>Traffic Side Gap in Soil (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>2°</td>
<td>(\frac{5}{8})</td>
</tr>
<tr>
<td>17</td>
<td>4°</td>
<td>(1\frac{3}{8})</td>
</tr>
<tr>
<td>18</td>
<td>8°</td>
<td>(2\frac{1}{4})</td>
</tr>
<tr>
<td>19</td>
<td>10°</td>
<td>(2\frac{3}{4})</td>
</tr>
<tr>
<td>20</td>
<td>9°</td>
<td>4</td>
</tr>
<tr>
<td>21</td>
<td>6°</td>
<td>-</td>
</tr>
</tbody>
</table>

7.6. DAMAGE TO TEST VEHICLE

Figure 7.5 shows the damage sustained by the vehicle. The front bumper, hood, grill, radiator and support, right front fender, right frame rail, right upper and lower control arms, right front tire and rim, right front corner of the floor pan, right front door, right front and rear doors, right lower cab corner, right exterior bed, right rear rim, and rear bumper were damaged. The windshield sustained stress cracks radiating upward and inward from the right lower corner. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 16.0 inches in the front and side planes at the right front corner at bumper height. Maximum occupant compartment deformation was 7.75 inches in the right front firewall/toe pan area. Figure 7.6 shows the interior
of the vehicle. Tables D.3 and D.4 in Appendix D.1 provide exterior crush and occupant compartment measurements.

![Figure 7.5. Test Vehicle after Test No. 613121-01-1.](image)

![Figure 7.6. Interior of Test Vehicle after Test No. 613121-01-1.](image)

### 7.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 7.3. Figure D.3 in Appendix D.3 shows the vehicle angular displacements, and Figures D.4 through D.6 in Appendix D.4 show acceleration versus time traces. Figure 7.7 summarizes pertinent information from the test.
Table 7.3. Occupant Risk Factors for Test No. 613121-01-1.

<table>
<thead>
<tr>
<th>Occupant Risk Factor</th>
<th>Value</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Occupant Impact Velocity (OIV)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal</td>
<td>22.3 ft/s</td>
<td>at 0.1053 s on right side of interior</td>
</tr>
<tr>
<td>Lateral</td>
<td>27.3 ft/s</td>
<td></td>
</tr>
<tr>
<td><strong>Occupant Ridedown Accelerations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal</td>
<td>24.3 g</td>
<td>0.1054 - 0.1154 s</td>
</tr>
<tr>
<td>Lateral</td>
<td>10.3 g</td>
<td>0.1053 - 0.1153 s</td>
</tr>
<tr>
<td><strong>Theoretical Head Impact Velocity (THIV)</strong></td>
<td>10.3 m/s</td>
<td>at 0.1029 s on right side of interior</td>
</tr>
<tr>
<td><strong>Acceleration Severity Index (ASI)</strong></td>
<td>1.7</td>
<td>0.0931 - 0.1431 s</td>
</tr>
<tr>
<td><strong>Maximum 50-ms Moving Average</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal</td>
<td>−13.6 g</td>
<td>0.0657 - 0.1157 s</td>
</tr>
<tr>
<td>Lateral</td>
<td>−12.6 g</td>
<td>0.0534 - 0.1034 s</td>
</tr>
<tr>
<td>Vertical</td>
<td>3.7 g</td>
<td>0.112 - 0.1612 s</td>
</tr>
<tr>
<td><strong>Maximum Yaw, Pitch, and Roll Angles</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roll</td>
<td>22°</td>
<td>0.5159 s</td>
</tr>
<tr>
<td>Pitch</td>
<td>18°</td>
<td>0.7082 s</td>
</tr>
<tr>
<td>Yaw</td>
<td>61°</td>
<td>2.0000 s</td>
</tr>
</tbody>
</table>
Figure 7.7. Summary of Results for MASH Test 4-21 on Short Transition.
8 CONCLUSIONS

8.1. ASSESSMENT OF TEST RESULTS

The crash test reported herein was performed in accordance with MASH Test 3-21 on the transition. Table 8.1 provides an assessment of the test based on the applicable safety evaluation criteria for MASH Test 3-21 for transitions.

8.2. CONCLUSIONS

Due to the high occupant ridedown acceleration during the crash test, the short transition did not satisfy the performance criteria for MASH Test 3-21 for transitions.

8.3. RECOMMENDATIONS*

The researchers believe that excessive deflection at the immediate upstream regions caused a higher interaction of the vehicle with the parapet blunt end which resulted in a higher ridedown acceleration than the MASH maximum limit. The deflector plate helped to reduce tire snagging and possible instability of the vehicle that was observed in previous similar systems. However, the deflector plate was not adequate in controlling the vehicle-parapet interaction. The following are possible design changes that could improve the performance of the system.

First, using two W6×15 posts at the upstream of the parapet would reduce the excessive dynamic deflection which should mitigate the pickup interaction with the parapet. This would be a viable option when the parapet/bridge rail already existed, and the purpose is to retrofit the system.

Second, using a concrete parapet with larger tapering reduces the interaction of the rail with the parapet's blunt end. This would be a good option if it is a new installation and the parapet can be designed and constructed this way.

Further development, analysis, and full-scale crash testing would be required to evaluate any of these proposed modifications.

* The opinions/interpretations identified/expressed in this section of the report are outside the scope of TTI Proving Ground’s A2LA Accreditation.
Table 8.1. Performance Evaluation Summary for *MASH* Test 3-21 on Short Transition.

<table>
<thead>
<tr>
<th>Test Agency: Texas A&amp;M Transportation Institute</th>
<th>Test No.: 613121-01-1</th>
<th>Test Date: 2021-04-19</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MASH Test 3-21 Evaluation Criteria</strong></td>
<td><strong>Test Results</strong></td>
<td><strong>Assessment</strong></td>
</tr>
<tr>
<td><strong>Structural Adequacy</strong></td>
<td><strong>Test Results</strong></td>
<td><strong>Assessment</strong></td>
</tr>
<tr>
<td>A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td>
<td>The transition contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 10.4 inches.</td>
<td>Pass</td>
</tr>
<tr>
<td><strong>Occupant Risk</strong></td>
<td><strong>Test Results</strong></td>
<td><strong>Assessment</strong></td>
</tr>
<tr>
<td>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.</td>
<td>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.</td>
<td>Pass</td>
</tr>
<tr>
<td>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of <em>MASH</em>.</td>
<td>Maximum occupant compartment deformation was 7.75 inches in the right front firewall/toe pan area</td>
<td></td>
</tr>
<tr>
<td>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td>
<td>The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 22° and 18°.</td>
<td>Pass</td>
</tr>
<tr>
<td>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.</td>
<td>Longitudinal OIV was 22.3 ft/s, and lateral OIV was 27.3 ft/s.</td>
<td>Pass</td>
</tr>
<tr>
<td>I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</td>
<td>Maximum longitudinal occupant ridedown acceleration was 24.3 g, and maximum lateral occupant ridedown acceleration was 10.3 g.</td>
<td>Fail</td>
</tr>
</tbody>
</table>
REFERENCES


Test Installation

16'-0" Parapet
24'-4-3/4" Transition
50'-0" Length of Need
99'-9-1/4" DAT

Plan View

Existing Concrete Apron

2" Guardrail Bolt x 8
8 spaces at 75"
50'-0"

Elevation View

4-space W-beam Guardrail
Timber Blockout, for W-section Post

10" Guardrail Bolt
72" Wide-Flange Guardrail Post

Ground Line

Section A-A
Scale 1 : 20
See 1c

Detail B
Scale 1 : 20
1-1/4" Guardrail Bolt x 8 at W-beam joints
See 1d

1b. Recessed Guardrail Nuts on all 5/8" Bolts. All Steel components, including hardware, are galvanized, and all Bolts are ASTM A307 unless otherwise indicated.
1c. W-beam Guardrail is typical at posts 3 - 10. Blockout and Guardrail Bolt is typical at posts 3 - 12. Post is typical at 3 - 19 and 21.
1d. Use 2" Guardrail Bolts at rail joints with 3 thicknesses, and 1-1/4" Guardrail Bolts at rail joints with 2 thicknesses.

Roadside Safety and
Physical Security Division -
Proving Ground

Project #613121 TL-3 Transition
2021-04-01

Drawn by GES Scale 1:140 Sheet 1 of 6 Test Installation
2a. Recessed Guardrail Nuts on all 5/8" Bolts. All Steel components, including hardware, are galvanized, and all Bolts are ASTM A307 unless otherwise indicated.

2b. Rail does not attach at Posts 15, 17, 19, and 21.
5a. Secure in existing concrete apron with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions, with 6" embedment at 18" spacing.
5b. All rebar dimensions are to center unless otherwise indicated by "cvr" (cover).
5c. 1" chamfer (3/4" each way) exposed edges of parapet as shown.
**DAT System**

**Isometric View**

<table>
<thead>
<tr>
<th>#</th>
<th>Part Name</th>
<th>Qty.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Foundation Tube</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Terminal Timber Post</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>BCT Bearing Plate</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>DAT Strut</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>BCT Post Sleeve</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Shelf Angle Bracket</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>DAT Terminal Rail</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>W-beam End Section</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Anchor Cable Assembly</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Guardrail Anchor Bracket</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>Bolt, 5/8 x 2&quot; hex</td>
<td>8</td>
</tr>
<tr>
<td>12</td>
<td>Bolt, 5/8 x 8&quot; hex</td>
<td>4</td>
</tr>
<tr>
<td>13</td>
<td>Bolt, 5/8 x 10&quot; hex</td>
<td>2</td>
</tr>
<tr>
<td>14</td>
<td>Washer, 5/8 F844</td>
<td>16</td>
</tr>
<tr>
<td>15</td>
<td>10&quot; Guardrail Bolt</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>1-1/4&quot; Guardrail Bolt</td>
<td>4</td>
</tr>
<tr>
<td>17</td>
<td>Recessed Guardrail Nut</td>
<td>20</td>
</tr>
</tbody>
</table>

1a. All bolts are ASTM A307.

1b. Hardware secures Shelf Angle Bracket to Post. Rail is supported by Shelf Angle Bracket and does not attach directly to Post.
DAT Parts sheet 1

DAT Strut
C 3 x 5

BCT Post Sleeve
2" schedule 40 Pipe - Scale 1:10

BCT Bearing Plate
5/8" Plate - Scale 1:10

Terminal Timber Post
5-1/4" x 7-1/4"

Guardrail Anchor Bracket
Scale 1:5

Foundation Tube
HSS 8" x 6" x 1/8"

Slot, 3/4" x 1"

1-1/2"

3/16" Plate

3 sides

1/4"

3/4" Holes

16"

14"

10"

6"

2-3/4"

5-1/2"

6"

1-3/8"

1-3/8"
DAT Parts sheet 2

Anchor Cable Assembly

Nut, 1" A563 heavy hex
Washer, 1" F844
Standard Swedge Fitting and Stud
3/4" 6x19 Cable
1" - 8 threads
78"

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

W-beam End Section
12 gauge steel - Scale 1:20
Timber Blockout for W-section Post

Elevation View

\[ \text{1a. Timber blockouts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.} \]
1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all sizes.
1a. Material is ASTM A 563 Grade A.
Rectangular Guardrail Washer

0.20" thick
Section View

1a. Manufacture per AASHTO M180 specifications.

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

10 gauge

Elevation View

Section A-A
See Thrie-beam Drawing

Section B-B
See W-beam Drawing

3/4" x 2-1/2" Slot
Typ x 5

29/32" x 1-1/8" Slot
Typ x 20

Roadside Safety and
Physical Security Division -
Proving Ground

36-9/16" x 1-1/8" Slot
Typ x 20

Texas A&M
Transportation
Institute

Thrie- to W-beam Transition
2019-08-22

Drawn by GES
Scale 1:10
Sheet 1 of 1
Thrie-beam End Shoe
10 gauge (0.1345" before galvanizing)

- 3/4" x 2-1/2" Slots
- Slot, 15/16" x 3" Typ x 12
- See Thrie-beam drawing for cross-section.

Elevation View

Isometric View
4-space Thriebeam

8-space Thriebeam
Dimensions not shown here same as 4-space Thriebeam

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

Section A-A
Scale 1 : 5
Typical all Thriebeams

Detail B
Scale 1 : 10
Typical all Thriebeams, both ends

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

This Memorandum is an acknowledgment that a Bill of Lading has been issued and is not the original Bill of Lading, nor a copy or duplicate, covering the property herein described, and is intended solely for filing and record.

RECEIVED, subject to the classifications and tariffs in effect on the date of issue of the Bill of Lading or the date of delivery of the property, whichever is later.

Shippers No. 16-83397
S/O No. 1385825

Consignment:
SSEAL MATERIALS
TTL
1090 STATE HWY 47
BLDG 2090
17702
Ship:
4/19/2021
Arrive:
4/18/2021
5:05 PM

Collect On Delivery: $ and remit to:
C.O.D. charge to be paid by Consignee

Charges assessed.

SPECIAL INSTRUCTIONS:

SHIPPER LOAD - CONSIGNEE UNLOAD

16-83397
Total Weight 2

If the shipment moves between two ports by a carrier by water, the law requires that the bill of lading shall state whether it is "shipper's or consignee's weight." NOTE: Where the rate is based on value, shippers are required to state specifically in writing the agreed or declared value of the property.

Shippers are advised to carefully examine the packing and safety precautions.

16-83397

TR No. 613121-01-1  59  2021-12-02
This Memorandum

RECEIVED, subject to the classifications and tariffs in effect on the date of receipt by the carrier of the property described in the Original Bill of Lading.

Date: 10/21

Shipper: Trinity Highway Products, LLC

Terms: F.O.B. delivery, all materials subject to Trinity Highway Products, LLC Standard Return Policy No. QMS-LG-002

Open delivery, all materials subject to Trinity Highway Products, LLC Standard Return Policy No. QMS-LG-002

Signature: Dary Gibeck

 trä 2021-12-02

TR No. 613121-01-1

Shippers No.: 16-83307

S/O No.: 16-83307

Consignment to: 

SAMPLES, TESTING MATERIALS

BLDG 7090

1050 STATE HWY 87

STATE: TX

ZIP: 77451

Ship: 41092021

Arrive: 41092021 5:30:00PM

Shipper's No.: 16-83307

S/O No.: 16-83307

Per: Trinity Highway Products, LLC

C.O.D. charge to be paid by: Consignee

Collect On Delivery:

$ and remit to:

Street: 

City: 

State: 

Vehicle or Car Initial: No.

Charges assessed:

SPECIAL INSTRUCTIONS

SHIPPER LOAD - CONSIGNEE UNLOAD

"If this product moves between two ports on a carrier by vessel, the last port of delivery is to be the port of delivery of the property. The carrier is hereby authorized to deliver the property at the port of delivery."

NOTE: Where the one is dependent on value, ships are required to include specifically in writing the agreed or declared value of the property.

Consignee: 16-83307

Total Weight: 80

TR 613121-01-1

This Bill of Lading is to be signed by the shipper and agent of the carrier issuing same.

CONSIGNEE/CUSTOMER COPY

TR 613121-01-1

60

2021-12-02
# Certified Analysis

| Qty | Part # | Description | Spec | CL | TV | Heat Code/Heat | Yield | TS | Elg | C | Mn | P | S | Si | Cu | Ch | Cr | Vn | ACW |
|-----|--------|-------------|------|----|----|----------------|-------|----|-----|----|----|----|---|----|----|----|----|----|     |
| 1   | 205G   | T12/8/37/4-12/25 | R1C  | 2  | L32018 | 64,980 | 82,800 | 27.4 | 0.190 | 0.720 | 0.013 | 0.002 | 0.020 | 0.150 | 0.000 | 0.070 | 0.001 | 4   |
|     | M-180  | A 2 | 225409 | 64,910 | 82,350 | 23.3 | 0.280 | 0.740 | 0.012 | 0.008 | 0.030 | 0.020 | 0.140 | 0.000 | 0.070 | 0.002 | 4   |
|     | M-180  | A 2 | 225410 | 64,110 | 79,440 | 27.4 | 0.180 | 0.720 | 0.009 | 0.004 | 0.010 | 0.110 | 0.000 | 0.070 | 0.002 | 4   |
|     | M-180  | A 2 | 225511 | 61,440 | 81,340 | 20.7 | 0.180 | 0.720 | 0.011 | 0.004 | 0.010 | 0.110 | 0.000 | 0.080 | 0.001 | 4   |
|     | M-180  | A 2 | 225512 | 61,510 | 80,400 | 26.7 | 0.019 | 0.720 | 0.010 | 0.003 | 0.020 | 0.100 | 0.000 | 0.070 | 0.002 | 4   |
|     | M-180  | A 2 | F10621 | 64,100 | 86,100 | 23.0 | 0.210 | 0.760 | 0.008 | 0.001 | 0.030 | 0.080 | 0.002 | 0.040 | 0.003 | 4   |

Upon delivery, all materials subject to Trinity Highway Products LLC Storage Stain Policy QMS-LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410. ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.

ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)

ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B, P, OR S, ARE UNCOATED BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-444 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2179, UNLESS OTHERWISE STATED.

3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA  ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB
Trinity Highway Products LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Pnh: (817) 665-1499
Customer: SAMPLES, TESTING MATERIALS
15601 Dallas Pkwy
Suite 525
ADDISON, TX 75001

Order Number: 1335835
Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 
BOL Number: 83397 
Document #: 1 
Ship Date: 
Shipped To: TX 
Use State: TX 

As of: 4/9/21

State of Texas, County of Tarrant. Sworn and subscribed before me this 9th day of April, 2021.

Notary Public:
Commission Expires: / 

Melissa Gutierrez
Notary Public, State of Texas
Comm. Expires 01-14-2023
Notary ID: 1300376334

Certified By:
Trinity Highway Products LLC

Quality Assurance
<table>
<thead>
<tr>
<th>Qty</th>
<th>Part #</th>
<th>Description</th>
<th>Spec</th>
<th>CL</th>
<th>TV</th>
<th>Heat Code/Heat</th>
<th>Yield</th>
<th>TS</th>
<th>Elg</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Cr</th>
<th>Vas</th>
<th>ACW</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>11G</td>
<td>15/16G/31.38</td>
<td>M-180</td>
<td>A</td>
<td>2</td>
<td>210688</td>
<td>65,500</td>
<td>88,400</td>
<td>20.0</td>
<td>0.240</td>
<td>1.600</td>
<td>0.010</td>
<td>0.001</td>
<td>0.020</td>
<td>0.110</td>
<td>0.003</td>
<td>0.600</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>M-180</td>
<td>A</td>
<td>2</td>
<td>2207234</td>
<td>65,700</td>
<td>87,700</td>
<td>21.0</td>
<td>0.240</td>
<td>1.300</td>
<td>0.011</td>
<td>0.001</td>
<td>0.020</td>
<td>0.110</td>
<td>0.001</td>
<td>0.050</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>M-180</td>
<td>A</td>
<td>2</td>
<td>2207255</td>
<td>60,100</td>
<td>84,200</td>
<td>27.0</td>
<td>0.230</td>
<td>0.990</td>
<td>0.011</td>
<td>0.001</td>
<td>0.020</td>
<td>0.110</td>
<td>0.002</td>
<td>0.060</td>
<td>0.004</td>
</tr>
<tr>
<td>1</td>
<td>305G</td>
<td>T10/30/31-1/2</td>
<td>J80C</td>
<td>2</td>
<td>1.5</td>
<td>210688</td>
<td>62,118</td>
<td>79,700</td>
<td>25.3</td>
<td>0.190</td>
<td>0.730</td>
<td>0.012</td>
<td>0.003</td>
<td>0.010</td>
<td>0.100</td>
<td>0.000</td>
<td>0.060</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>M-180</td>
<td>A</td>
<td>2</td>
<td>257709</td>
<td>60,995</td>
<td>76,200</td>
<td>24.6</td>
<td>0.190</td>
<td>0.720</td>
<td>0.011</td>
<td>0.003</td>
<td>0.020</td>
<td>0.080</td>
<td>0.000</td>
<td>0.060</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>M-180</td>
<td>B</td>
<td>2</td>
<td>253966</td>
<td>60,100</td>
<td>79,300</td>
<td>27.0</td>
<td>0.190</td>
<td>0.710</td>
<td>0.011</td>
<td>0.003</td>
<td>0.020</td>
<td>0.120</td>
<td>0.000</td>
<td>0.060</td>
<td>0.004</td>
</tr>
<tr>
<td>19</td>
<td>533G</td>
<td>60 POST/5 STUD</td>
<td>A-36</td>
<td>1.5</td>
<td>2</td>
<td>1801947</td>
<td>50,000</td>
<td>68,200</td>
<td>25.6</td>
<td>0.070</td>
<td>0.830</td>
<td>0.007</td>
<td>0.028</td>
<td>0.250</td>
<td>0.090</td>
<td>0.014</td>
<td>0.040</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A-36</td>
<td></td>
<td></td>
<td>58046122</td>
<td>59,584</td>
<td>70,959</td>
<td>24.4</td>
<td>0.070</td>
<td>0.900</td>
<td>0.015</td>
<td>0.038</td>
<td>0.200</td>
<td>0.330</td>
<td>0.020</td>
<td>0.210</td>
<td>0.001</td>
</tr>
<tr>
<td>1</td>
<td>533G</td>
<td>A-36</td>
<td>2817878</td>
<td></td>
<td></td>
<td></td>
<td>59,800</td>
<td>71,100</td>
<td>25.0</td>
<td>0.070</td>
<td>0.860</td>
<td>0.007</td>
<td>0.030</td>
<td>0.160</td>
<td>0.260</td>
<td>0.014</td>
<td>0.050</td>
<td>0.004</td>
</tr>
<tr>
<td>1</td>
<td>850G</td>
<td>12/120R ROLLED</td>
<td>M-180</td>
<td>A</td>
<td>2</td>
<td>235602</td>
<td>63,956</td>
<td>80,908</td>
<td>21.9</td>
<td>0.190</td>
<td>0.730</td>
<td>0.009</td>
<td>0.004</td>
<td>0.010</td>
<td>0.110</td>
<td>0.000</td>
<td>0.050</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>M-180</td>
<td>A</td>
<td>2</td>
<td>31347970</td>
<td>48,400</td>
<td>62,300</td>
<td>35.0</td>
<td>0.060</td>
<td>0.450</td>
<td>0.015</td>
<td>0.001</td>
<td>0.030</td>
<td>0.090</td>
<td>0.000</td>
<td>0.070</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>850G</td>
<td></td>
<td></td>
<td></td>
<td>63,096</td>
<td>80,986</td>
<td>21.9</td>
<td>0.190</td>
<td>0.730</td>
<td>0.009</td>
<td>0.004</td>
<td>0.010</td>
<td>0.110</td>
<td>0.000</td>
<td>0.050</td>
<td>0.002</td>
</tr>
<tr>
<td>1</td>
<td>975G</td>
<td>T10/END SHOE</td>
<td>A-1011</td>
<td></td>
<td></td>
<td>95839</td>
<td>50,900</td>
<td>628,000</td>
<td>35.4</td>
<td>0.060</td>
<td>0.490</td>
<td>0.010</td>
<td>0.001</td>
<td>0.030</td>
<td>0.110</td>
<td>0.000</td>
<td>0.070</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>WIRE</td>
<td></td>
<td></td>
<td>8194928</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3009G</td>
<td>CHS 3/4X6-0/0.51</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>105</td>
<td>3349G</td>
<td>5/8 GR HEX NUT</td>
<td>FAST</td>
<td></td>
<td></td>
<td>21-54-005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 of 5
## Certified Analysis

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

**Customer:** SAMPLES, TESTING MATERIALS  
15601 Dallas Pkwy  
Suite 525  
ADDISON, TX 75001  

**Order Number:** 1335835  
Prod Ln Grp: 3-Guardrail (Dom)  

**BOL Number:** 83079  
Ship Date:  

---

<table>
<thead>
<tr>
<th>Qty</th>
<th>Part #</th>
<th>Description</th>
<th>Spec</th>
<th>CL</th>
<th>TV</th>
<th>Heat Code/Heat</th>
<th>Yield</th>
<th>TS</th>
<th>Elg</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Cr</th>
<th>Vn</th>
<th>ACW</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>3350G</td>
<td>5/8&quot;X1.25&quot; GR BOLT</td>
<td>A307-3350</td>
<td>922351-13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>3400G</td>
<td>5/8&quot;X2&quot; GR BOLT</td>
<td>A307-3400</td>
<td>934110-9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>3590G</td>
<td>5/8&quot;X10&quot; GR BOLT A307</td>
<td>A307-3500</td>
<td>931506-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>3726G</td>
<td>7/8&quot; ROUND WASHER F436</td>
<td>F436-3726</td>
<td>P39340 R73428-02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>3736G</td>
<td>7/8&quot; HEX HEX NUT A194 2H</td>
<td>FAST</td>
<td>P39175 R73430-01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>4076G</td>
<td>WD BLK RTD 6X3X14</td>
<td>WOOD</td>
<td>6122</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4850G</td>
<td>3/8&quot;X1/4&quot; HEX BOLT A325</td>
<td>FAST</td>
<td>40113666</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 2   | 19481G | CIX58X6-8" RUBRAIL | A-36 | 307310 | 55,400 | 77,200 | 32.0 | 0.170 | 0.560 | 0.013 | 0.039 | 0.210 | 0.330 | 0.002 | 0.050 | 0.017 | 4  
| 19481G | A-36 | 3086787 | 56,100 | 76,000 | 29.0 | 0.150 | 0.630 | 0.013 | 0.035 | 0.210 | 0.320 | 0.000 | 0.130 | 0.000 | 4  
| 1   | 20207G | 12/94 5/8-HOLE ANCHER | A-36 | 2 | F0121 |  
| M-100 A 2 | 2160683 | 65,400 | 86,900 | 21.0 | 0.230 | 0.990 | 0.011 | 0.008 | 0.030 | 0.160 | 0.010 | 0.060 | 0.004 | 4  
| M-180 A 2 | 2160703 | 61,900 | 85,900 | 24.0 | 0.220 | 0.880 | 0.010 | 0.007 | 0.030 | 0.160 | 0.010 | 0.050 | 0.004 | 4  
| M-180 A 2 | 2260703 | 63,500 | 85,600 | 22.0 | 0.210 | 0.780 | 0.009 | 0.001 | 0.030 | 0.090 | 0.010 | 0.040 | 0.004 | 4  
| M-100 | 2207254 | 63,700 | 87,700 | 21.0 | 0.240 | 1.030 | 0.011 | 0.001 | 0.020 | 0.110 | 0.010 | 0.050 | 0.004 | 4  
| M-180 | 2207255 | 60,100 | 84,200 | 27.0 | 0.230 | 0.990 | 0.011 | 0.001 | 0.020 | 0.110 | 0.002 | 0.060 | 0.004 | 4  
| M-180 A 2 | 22072619 | 63,800 | 85,300 | 19.0 | 0.210 | 0.790 | 0.009 | 0.001 | 0.030 | 0.080 | 0.010 | 0.030 | 0.004 | 4  
| 1   | 32211G | T10 TR/AN/1B/WR/Aiosity R | M-100 B 2 | 42014850 | 50,000 | 70,000 | 28.0 | 0.040 | 0.770 | 0.014 | 0.001 | 0.040 | 0.120 | 0.047 | 0.070 | 0.003 | 4  
| 1   | 36420A | DAT-31-TX-4HD-W-CAN | A-36 | 4110300 | 47,000 | 66,600 | 34.0 | 0.180 | 0.400 | 0.015 | 0.002 | 0.010 | 0.040 | 0.011 | 0.060 | 1.000 | 4  

---
## Certified Analysis

Trinity Highway Products LLC  
2548 N.E. 28th St.  
Ft Worth (TPA), TX 76111  
Phone (817) 665-1499

Customer: SAMPLES, TESTING MATERIALS  
15601 Dallas Pkwy  
Suite 525  
ADDISON, TX 75001

Project: WEST VIRGINIA DOT 613121

| Qty | Part # | Description | Spec | CL | TY | Heat Code/Heat | Yield | TS | Elg | C | Mn | P | S | Si | Cu | Ch | Cr | Vn | ACW |
|-----|--------|-------------|------|----|----|---------------|-------|----|-----|---|----|---|---|----|----|----|----|----|----|----|
| 36120A | 16552240 | WIRE | 61,500 | 65,000 | 29.8 | 0.110 | 0.350 | 0.014 | 0.004 | 0.010 | 0.150 | 0.001 | 0.080 | 0.001 | 4 |
| 36120A | X66030 | A-500 | 64249 | 4 |
| 36120A | F844-3300 | FAST | 21-54-006 | 4 |
| 36120A | A107-3340 | 022031-13 | 4 |
| 36120A | A107-3483 | 848773-8 | 4 |
| 36120A | A107-3500 | 931596-4 | 4 |
| 36120A | 025689 | HW | 45,000 | 68,000 | 31.0 | 0.180 | 0.780 | 0.015 | 0.011 | 0.009 | 0.020 | 0.000 | 0.640 | 0.000 | 4 |
| 36120A | F844-3300 | A-36 | 99592D | 4 |
| 36120A | A563-3910 | 939341 | 4 |
| 36120A | A107-4470 | 89306-7 | 4 |
| 36120A | A107-4500 | 940249-4 | 4 |
Trinity Highway Products LLC  
2548 N.E. 28th St.  
Ft Worth (HP), TX 76111  
Phone: (817) 665-1499

Customer: SAMPLES, TESTING MATERIALS  
15601 Dallas Pkwy  
Suite 525  
ADDISON, TX 75001

Order Number: 1335835  
Prod Ln Grp: 3-Guardrail (Dom)

As of: 3/19/21

<table>
<thead>
<tr>
<th>Qty</th>
<th>Part #</th>
<th>Description</th>
<th>Spec</th>
<th>CL</th>
<th>TV</th>
<th>Heat Code/Heat</th>
<th>Yield</th>
<th>TS</th>
<th>Elg</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Cr</th>
<th>Vn</th>
<th>ACW</th>
</tr>
</thead>
<tbody>
<tr>
<td>36120A</td>
<td>A-36</td>
<td>1100008623</td>
<td>58,600</td>
<td>60,100</td>
<td>21.0</td>
<td>0.130</td>
<td>0.022</td>
<td>0.020</td>
<td>0.212</td>
<td>0.310</td>
<td>0.000</td>
<td>0.190</td>
<td>0.202</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36120A</td>
<td>A-36</td>
<td>1053561</td>
<td>60,000</td>
<td>71,100</td>
<td>23.0</td>
<td>0.160</td>
<td>0.750</td>
<td>0.018</td>
<td>0.024</td>
<td>0.180</td>
<td>0.336</td>
<td>0.003</td>
<td>0.260</td>
<td>0.203</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1308960</td>
<td>6' TUBE SL/123X3X6</td>
<td>A-500</td>
<td>PL70724</td>
<td>56,815</td>
<td>76,042</td>
<td>31.0</td>
<td>0.190</td>
<td>0.370</td>
<td>0.007</td>
<td>0.001</td>
<td>0.027</td>
<td>0.120</td>
<td>0.006</td>
<td>0.050</td>
<td>0.004</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6260798</td>
<td>W3 3'10 POST</td>
<td>WOOD</td>
<td>3660</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy QMS-LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.

ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.

ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)

ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329, UNLESS OTHERWISE STATED.

3/4" X 19 ZINC COATED SWAGED ENDS AISI C-1035 STEEL ANNEALED STUD 1" DIA  ASTM 449 AASHTO M36, TYPE II BREAKING STRENGTH – 46000 LB
# QF 7.3-01 Concrete Sampling

## Quality Form

<table>
<thead>
<tr>
<th>Project No.</th>
<th>Casting Date</th>
<th>Mix Design (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>613121-01-1</td>
<td>2/23/2021</td>
<td>3600</td>
</tr>
</tbody>
</table>

### Load No. | Truck No. | Ticket No. | Location (from concrete map) |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>9020</td>
<td>6589653</td>
<td>100% of repaired end of barrier</td>
</tr>
</tbody>
</table>

### Load No. | Break Date | Cylinder Age | Total Load (lbs) | Break (psi) | Average |
|------------|------------|--------------|------------------|-------------|---------|
**CUSTOMER'S COPY**

**Truck Ticket**

**Martin Marietta**
1503 LBJ Freeway
Suite 400
Dallas, TX 75234

---

**Load Time**

<table>
<thead>
<tr>
<th>To Job</th>
<th>Arrive Job Site</th>
<th>Begin Pour</th>
<th>Finish Pour</th>
<th>Leave Job Site</th>
<th>Arrive Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:34</td>
<td>10:11</td>
<td>10:52</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Water Added on Job at Customer's Request**

- **GAL.**

- **Allowable Water (withheld from batch)**

- **Test Cylinder Taken**

- **No**

- **Cylinder Taken**

- **Before**

- **After Water**

**Additional Water Added to this Concrete Will Reduce Its Strength.** Any water added in excess of specified slump is at customer's risk.

**Customer Signature**

- V

**Delivery of these materials is subject to the terms and conditions on the reverse side hereof as accepted signature above.**

---

**Customer Name and Delivery Address**

- Texas A & M University
- TTI-Riverside Campus

**Load Quantity**

<table>
<thead>
<tr>
<th>Product Code</th>
<th>Description</th>
<th>Unit Price</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>R9240528</td>
<td>COM, RG 2, 4000, RE</td>
<td>3.00</td>
<td>3.00</td>
</tr>
</tbody>
</table>

---

**Special Delivery Instructions**

- 2013 RT ON LEONARD RT ON HWY-47-LFT INTO RIVERSIDE CAMPUS WILL MEET AT GATE

**Danger! May Cause Alkali Burns**

See Warnings on Reverse Side.

---

**For Office Use Only**

**Form: TR No. 613121-01-1**

---

**Truck Ticket**

**Driver:** 726159

**User:** 6589653

**Disp Ticket Num:** 900372

**Ticket ID:** 900372

**Time Date:** 9:42 2/23/21

**Load Size:** 3.00 CYDS

**Mix Code:** R9240528

**Returned Qty:**

<table>
<thead>
<tr>
<th>Material</th>
<th>Design Qty</th>
<th>Required</th>
<th>Batched</th>
<th>X Var</th>
<th>% Variance</th>
<th>Actual Wat</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/16</td>
<td>1036 lb</td>
<td>796 lb</td>
<td>944 lb</td>
<td>-8.652%</td>
<td>1.28 m</td>
<td>9.6 gl</td>
</tr>
<tr>
<td>3/16</td>
<td>320 lb</td>
<td>336 lb</td>
<td>313 lb</td>
<td>-4.33%</td>
<td>1.00 m</td>
<td>2 gl</td>
</tr>
<tr>
<td>3/8</td>
<td>387 lb</td>
<td>392 lb</td>
<td>362 lb</td>
<td>-1.5%</td>
<td>1.00 m</td>
<td>2 gl</td>
</tr>
<tr>
<td>2/3</td>
<td>1312 lb</td>
<td>1427 lb</td>
<td>1346 lb</td>
<td>9.56%</td>
<td>1.00 m</td>
<td>2 gl</td>
</tr>
<tr>
<td>HEU</td>
<td>422 lb</td>
<td>413 lb</td>
<td>389 lb</td>
<td>-4.00%</td>
<td>1.00 m</td>
<td>2 gl</td>
</tr>
<tr>
<td>P1650C</td>
<td>100 lb</td>
<td>168 lb</td>
<td>125 lb</td>
<td>-27%</td>
<td>1.00 m</td>
<td>23 gl</td>
</tr>
<tr>
<td>L22</td>
<td>208 lb</td>
<td>662 lb</td>
<td>634 lb</td>
<td>-4.37%</td>
<td>1.00 m</td>
<td>2 gl</td>
</tr>
<tr>
<td>21610</td>
<td>17 oz</td>
<td>32 oz</td>
<td>52 oz</td>
<td>2 oz</td>
<td>0.031%</td>
<td>52 gl</td>
</tr>
</tbody>
</table>

**Actual:** 1

**Load Total:** 11533 lb Design 0.463 Water/Conc 0.463 T Design 39.9 gl Actual 82.3 gl To Add: 7.6 gl

**Slump:** 5.00 in # Water in Truck: 6.0 gl Adjust Water: 0.0 gl / Load Trim Water: -1.3 gl/CYD

---

**Date:** 6/12/2011

---

**TR No. 613121-01-1**

**68**

**2021-12-02**
CONCRETE COMPRRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0167
Service Date: 02/23/21
Report Date: 04/09/21
Task: PO# 613121-01

Client
Texas Transportation Institute
Attn: Gary Cerke
TII Business Office
3135 TAMU
College Station, TX 77843-3135

Project
Riverside Campus
Riverside Campus
Bryan, TX

Material Information
Specified Strength: 4,000 psi @ 28 days
Mix ID: R940528
Supplier: Martin Marietta
Batch Time: 0942
Plant: 617
Truck No.: 9020
Ticket No.: 6589653

Sample Information
Sample Date: 02/23/21
Sample Time: 1150
Sampled By: Mohammed Mobeen
Weather Conditions: Clear, Light Wind
Accumulative Yards: 3
Batch Size (cy): 3
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: PO #613121-01
Placement Location: PO #613121-01

Field Test Data
<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump (in):</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Air Content (%):</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>Concrete Temp. (F):</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>Ambient Temp. (F):</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>Plastic Unit Wt. (pcf):</td>
<td>146.8</td>
<td></td>
</tr>
<tr>
<td>Yield (Cu. Yds.):</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Laboratory Test Data

<table>
<thead>
<tr>
<th>Set No.</th>
<th>Specimen ID</th>
<th>Avg Diam. (in)</th>
<th>Area (sq in)</th>
<th>Date Received</th>
<th>Date Tested</th>
<th>Age at Test (days)</th>
<th>Maximum Load (lbs)</th>
<th>Compressive Strength (psi)</th>
<th>Fracture Type</th>
<th>Tested By</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 A</td>
<td>6.0</td>
<td>28.37</td>
<td></td>
<td>04/08/21</td>
<td>44 F</td>
<td>162,590</td>
<td>5,730</td>
<td>1</td>
<td>SLS</td>
<td></td>
</tr>
<tr>
<td>1 B</td>
<td>6.0</td>
<td>28.37</td>
<td></td>
<td>04/08/21</td>
<td>44 F</td>
<td>172,550</td>
<td>6,070</td>
<td>1</td>
<td>SLS</td>
<td></td>
</tr>
<tr>
<td>1 C</td>
<td>6.0</td>
<td>28.37</td>
<td></td>
<td>04/08/21</td>
<td>44 F</td>
<td>167,390</td>
<td>5,900</td>
<td>1</td>
<td>SLS</td>
<td></td>
</tr>
<tr>
<td>1 D</td>
<td>6.0</td>
<td>28.37</td>
<td></td>
<td></td>
<td>Hold</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Initial Cure: Outside
Final Cure: Field Cured

Comments: F = Field Cured

Samples Made By: Terracon
Services: Obtain samples of fresh concrete at the placement locations (ASTM C 172), perform required field tests and cast, cure, and test compressive strength samples (ASTM C 31, C 39, C 1231).

Terracon Rep.: Mohammed Mobeen
Reviewed By: [Signature]

Test Methods: ASTM C 31, ASTM C143, ASTM C231, ASTM C1064

The tests were performed in general accordance with applicable ASTM, AASHO, or DOT test methods. This report is exclusive for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results contained herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

C69011, 11-16-21, Rev 4
Page 1 of 1

TR No. 613121-01-1

69

2021-12-02
Table C.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.

<table>
<thead>
<tr>
<th>Date</th>
<th>2008-11-05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Facility and Site Location</td>
<td>TTI Proving Ground, 3100 SH 47, Bryan, TX 77807</td>
</tr>
<tr>
<td>In Situ Soil Description (ASTM D2487)</td>
<td>Sandy gravel with silty fines</td>
</tr>
<tr>
<td>Fill Material Description (ASTM D2487) and sieve analysis</td>
<td>AASHTO M147 Grade B Soil-Aggregate (see sieve analysis above)</td>
</tr>
<tr>
<td>Description of Fill Placement Procedure</td>
<td>6-inch lifts tamped with a pneumatic compactor</td>
</tr>
<tr>
<td>Bogie Weight</td>
<td>5009 lb</td>
</tr>
<tr>
<td>Impact Velocity</td>
<td>20.5 mph</td>
</tr>
</tbody>
</table>

Dynamic Test Installation Details

Static Load Test Installation Details

Comparison of Load vs. Displacement at 23-inch height

Dynamic Test Setup

Post-Test Photo

Static Load Test
Table C.2. Test Day Static Soil Strength Documentation for Test No. 613121-01-1.

<table>
<thead>
<tr>
<th>Date</th>
<th>Load vs. Displacement from Static Load Test</th>
<th>Minimum Static Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>2021-04-19</td>
<td>7,020</td>
<td>7,777</td>
</tr>
<tr>
<td></td>
<td>3,940</td>
<td>5,500</td>
</tr>
<tr>
<td></td>
<td>6,540</td>
<td>8,383</td>
</tr>
</tbody>
</table>

**Comparison of Static Load Test Results and Required Minimum:**
Load versus Displacement at 25 inch Height

**Date:** 2021-04-19 – Test No. 613121-01-1
**Test Facility and Site Location:** TTI Proving Ground – 3100 SH 47, Bryan, Tx
**In Situ Soil Description (ASTM D2487):** Sandy gravel with silty fines
**Fill Material Description (ASTM D2487) and sieve analysis:** AASHTO M147 Grade B Soil-Aggregate
**Description of Fill Placement Procedure:** 6-inch lifts tamped with a pneumatic compactor
## APPENDIX D. MASH TEST 3-21 (CRASH TEST NO. 613121-01-1)

### D.1. VEHICLE PROPERTIES AND INFORMATION

**Table D.1. Vehicle Properties for Test No. 613121-01-1.**

<table>
<thead>
<tr>
<th>Date: 2021-4-19</th>
<th>Test No.: 613121-01-1</th>
<th>VIN No.: 1C6RR6GT0GS367972</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Year: 2016</th>
<th>Make: RAM</th>
<th>Model: 1500</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Tire Size: 265/70 R 17</th>
<th>Tire Inflation Pressure: 35 psi</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Tread Type: Highway</th>
<th>Odometer: 124409</th>
</tr>
</thead>
</table>

Note any damage to the vehicle prior to test: None

• Denotes accelerometer location.

**NOTES:** None

**Engine Type:** V-8  
**Engine CID:** 5.7 L  
**Transmission Type:**  
- [ ] Auto or [ ] Manual  
- [ ] FWD  
- [x] RWD  
- [ ] 4WD

**Optional Equipment:** None

**Dummy Data:**  
- **Type:** 50th Percentile Male  
- **Mass:** 165 lb  
- **Seat Position:** IMPACT SIDE

**Geometry:** inches

<table>
<thead>
<tr>
<th>A</th>
<th>78.50</th>
<th>F</th>
<th>40.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>74.00</td>
<td>G</td>
<td>28.25</td>
</tr>
<tr>
<td>C</td>
<td>227.50</td>
<td>H</td>
<td>59.93</td>
</tr>
<tr>
<td>D</td>
<td>44.00</td>
<td>I</td>
<td>11.75</td>
</tr>
<tr>
<td>E</td>
<td>140.50</td>
<td>J</td>
<td>27.00</td>
</tr>
</tbody>
</table>

**Wheel Center:**  
- Height Front: 14.75 inches  
- Height Rear: 14.75 inches

**Wheel Well Clearances:**  
- Clearance (Front): 6.00 inches  
- Clearance (Rear): 9.25 inches

**Bottom Frame Heights:**  
- Height - Front: 12.50 inches  
- Height - Rear: 22.50 inches

**GVWR Ratings:**  
- Mass: lb  
  - Curb: 2965  
  - Test Inertial: 2902  
  - Gross Static: 2987

**Back:**  
- 3900 lb  
- M rear: 2120 lb  
- 2159 lb

**Total:**  
- 6700 lb  
- M total: 5085 lb  
- 5061 lb

**Mass Distribution:** lb  
- LF: 1447 lb  
- RF: 1455 lb  
- LR: 1125 lb  
- RR: 1034 lb

(Allowable Range for TIM and SSMM = 5000 lb ± 110 lb)
Table D.2. Measurements of Vehicle Vertical Center of Gravity for Test No. 613121-01-1.

<table>
<thead>
<tr>
<th>Date</th>
<th>2021-4-19</th>
<th>Test No.</th>
<th>613121-01-1</th>
<th>VIN:</th>
<th>1C6RR6GT0GS367972</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>2016</td>
<td>Make:</td>
<td>RAM</td>
<td>Model:</td>
<td>1500</td>
</tr>
<tr>
<td>Body Style</td>
<td>Quad Cab</td>
<td>Mileage:</td>
<td>124409</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine</td>
<td>5.7 L V-8</td>
<td>Transmission</td>
<td>Automatic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Level</td>
<td>Empty</td>
<td>Ballast:</td>
<td>60</td>
<td></td>
<td>(440 lb max)</td>
</tr>
<tr>
<td>Tire Pressure</td>
<td>Front: 35 psi</td>
<td>Rear: 35 psi</td>
<td>Size: 265/70 R17</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Measured Vehicle Weights:** (lb)

<table>
<thead>
<tr>
<th>LF:</th>
<th>1447</th>
<th>RF:</th>
<th>1455</th>
<th>Front Axle:</th>
<th>2902</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR:</td>
<td>1125</td>
<td>RR:</td>
<td>1034</td>
<td>Rear Axle:</td>
<td>2159</td>
</tr>
<tr>
<td>Left:</td>
<td>2572</td>
<td>Right:</td>
<td>2489</td>
<td>Total:</td>
<td>5061</td>
</tr>
</tbody>
</table>

5000 ±110 lb allowed

Wheel Base: 140.50 inches
Track: F: 68.50 inches, R: 68.00 inches
148 ±12 inches allowed
Track = (F+R)/2 = 67 ±1.5 inches allowed

**Center of Gravity, SAE J874 Suspension Method**

<table>
<thead>
<tr>
<th>X:</th>
<th>59.94 inches</th>
<th>Rear of Front Axle</th>
<th>(63 ±4 inches allowed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y:</td>
<td>-0.56 inches</td>
<td>Left - Right + of Vehicle Centerline</td>
<td></td>
</tr>
<tr>
<td>Z:</td>
<td>28.25 inches</td>
<td>Above Ground</td>
<td>(minimum 28.0 inches allowed)</td>
</tr>
</tbody>
</table>

Hood Height: 46.00 inches
Front Bumper Height: 27.00 inches
43 ±4 inches allowed

Front Overhang: 40.00 inches
Rear Bumper Height: 30.00 inches
39 ±3 inches allowed

Overall Length: 227.50 inches
237 ±13 inches allowed
### Table D.3. Exterior Crush Measurements for Test No. 613121-01-1.

<table>
<thead>
<tr>
<th>Date:</th>
<th>2021-4-19</th>
<th>Test No.:</th>
<th>613121-01-1</th>
<th>VIN No.:</th>
<th>1C6RR6GT0GS367972</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year:</td>
<td>2016</td>
<td>Make:</td>
<td>RAM</td>
<td>Model:</td>
<td>1500</td>
</tr>
</tbody>
</table>

#### VEHICLE CRUSH MEASUREMENT SHEET\(^1\)

<table>
<thead>
<tr>
<th>End Damage</th>
<th>Side Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undeformed end width</td>
<td>Bowing: B1 X1</td>
</tr>
<tr>
<td>Corner shift: A1</td>
<td>B2 X2</td>
</tr>
<tr>
<td>A2</td>
<td></td>
</tr>
<tr>
<td>End shift at frame (CDC)</td>
<td>Bowing constant</td>
</tr>
</tbody>
</table>
| (check one) | \[
\frac{X_1+X_2}{2} = \_\_\_\_\_\_
\] |
| < 4 inches | |
| ≥ 4 inches | |

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

<table>
<thead>
<tr>
<th>Specific Impact Number</th>
<th>Plane* of C-Measurements</th>
<th>Direct Damage Width*** (CDC)</th>
<th>Max*** Crush</th>
<th>Field L**</th>
<th>(C_1)</th>
<th>(C_2)</th>
<th>(C_3)</th>
<th>(C_4)</th>
<th>(C_5)</th>
<th>(C_6)</th>
<th>±D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Front plane at bumper (mp</td>
<td>18</td>
<td>16</td>
<td>48</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>Side plane above bumper</td>
<td>18</td>
<td>16</td>
<td>72</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>84</td>
</tr>
</tbody>
</table>

- Measurements recorded
  - [ ] inches
  - [x] mm

\(^1\)Table taken from National Accident Sampling System (NASS).

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

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

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

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

Note: Use as many lines/columns as necessary to describe each damage profile.
Table D.4. Occupant Compartment Measurements for Test No. 613121-01-1.

<table>
<thead>
<tr>
<th>Date: 2021-4-19</th>
<th>Test No.: 613121-01-1</th>
<th>VIN No.: 1C6RR6GT0GS367972</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year: 2016</td>
<td>Make: RAM</td>
<td>Model: 1500</td>
</tr>
</tbody>
</table>

**OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT**

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
<th>Differ.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>65.00</td>
<td>65.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A2</td>
<td>63.00</td>
<td>63.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A3</td>
<td>65.50</td>
<td>65.50</td>
<td>0.00</td>
</tr>
<tr>
<td>B1</td>
<td>45.00</td>
<td>45.00</td>
<td>0.00</td>
</tr>
<tr>
<td>B2</td>
<td>38.00</td>
<td>38.00</td>
<td>0.00</td>
</tr>
<tr>
<td>B3</td>
<td>45.00</td>
<td>40.00</td>
<td>-5.00</td>
</tr>
<tr>
<td>B4</td>
<td>39.50</td>
<td>39.50</td>
<td>0.00</td>
</tr>
<tr>
<td>B5</td>
<td>43.00</td>
<td>43.00</td>
<td>0.00</td>
</tr>
<tr>
<td>B6</td>
<td>39.50</td>
<td>39.50</td>
<td>0.00</td>
</tr>
<tr>
<td>C1</td>
<td>26.00</td>
<td>26.00</td>
<td>0.00</td>
</tr>
<tr>
<td>C2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>C3</td>
<td>26.00</td>
<td>18.25</td>
<td>-7.75</td>
</tr>
<tr>
<td>D1</td>
<td>11.00</td>
<td>11.00</td>
<td>0.00</td>
</tr>
<tr>
<td>D2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>D3</td>
<td>11.50</td>
<td>6.00</td>
<td>-5.50</td>
</tr>
<tr>
<td>E1</td>
<td>58.50</td>
<td>53.50</td>
<td>-5.00</td>
</tr>
<tr>
<td>E2</td>
<td>63.50</td>
<td>66.50</td>
<td>3.00</td>
</tr>
<tr>
<td>E3</td>
<td>63.50</td>
<td>63.50</td>
<td>0.00</td>
</tr>
<tr>
<td>E4</td>
<td>63.50</td>
<td>63.50</td>
<td>0.00</td>
</tr>
<tr>
<td>F</td>
<td>59.00</td>
<td>59.00</td>
<td>0.00</td>
</tr>
<tr>
<td>G</td>
<td>59.00</td>
<td>59.00</td>
<td>0.00</td>
</tr>
<tr>
<td>H</td>
<td>37.50</td>
<td>37.50</td>
<td>0.00</td>
</tr>
<tr>
<td>I</td>
<td>37.50</td>
<td>36.50</td>
<td>-1.00</td>
</tr>
<tr>
<td>J*</td>
<td>25.00</td>
<td>19.00</td>
<td>-6.00</td>
</tr>
</tbody>
</table>

*Lateral area across the cab from driver’s side kickpanel to passenger’s side kickpanel.*
D.2. SEQUENTIAL PHOTOGRAPHS

Figure D.1. Sequential Photographs for Test No. 613121-01-1 (Overhead and Frontal Views).
Figure D.1. Sequential Photographs for Test No. 613121-01-1 (Overhead and Frontal Views) (Continued).
Figure D.2. Sequential Photographs for Test No. 613121-01-1 (Rear View).
Axes are vehicle-fixed.
Sequence for determining orientation:
1. Yaw.
2. Pitch.
3. Roll.

Figure D.3. Vehicle Angular Displacements for Test No. 613121-01-1.

Test Number: 613121-01-1
Test Standard Test Number: MASH Test 3-21
Test Article: Short Transition
Test Vehicle: 2016 RAM 1500 Pickup
Inertial Mass: 5061 lb
Gross Mass: 5226 lb
Impact Speed: 62.6 mi/h
Impact Angle: 25.4 degrees
Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 613121-01-1
(Accelerometer Located at Center of Gravity).
Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 613121-01-1 (Accelerometer Located at Center of Gravity).
Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 613121-01-1
(Accelerometer Located at Center of Gravity)