MASH TEST 4-12 OF SHALLOW ANCHORAGE SINGLE SLOPE TRAFFIC RAIL (SSTR)

Crash testing performed at:
TTI Proving Ground
1254 Avenue A, Building 7091
Bryan, TX 77807

Test Report 0-6968-R10
Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the Federal Highway Administration and the Texas Department of Transportation

The purpose of the tests reported herein was to assess the performance of the Texas Department of Transportation’s (TxDOT’s) shallow anchorage single slope traffic rail (SSTR) according to the safety-performance evaluation guidelines included in the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware (MASH)*. *MASH* Test 4-12 was performed on the TxDOT shallow anchorage SSTR to determine the structural adequacy of the anchorage.

Two different barrier configurations were evaluated: with and without dowel bars between barrier segments across expansion joints. This report provides details of the TxDOT shallow anchorage SSTR, the crash tests and results, and the performance assessment of the TxDOT shallow anchorage SSTR as a *MASH* Test Level 4 (TL-4) longitudinal barrier.

Both variations of the TxDOT shallow anchorage SSTR (with and without dowel bars between barrier segments across expansion joints) were determined to be *MASH* TL-4 compliant. No delamination or damage to the deck was observed in the test installation after impact.
MASH TEST 4-12 OF SHALLOW ANCHORAGE SINGLE SLOPE TRAFFIC RAIL (SSTR)

by

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and the
Federal Highway Administration

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College Station, Texas 77843-3135
DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permit purposes. The engineer in charge of this project was Roger P. Bligh, P.E. Texas #78550. The United States Government and the State of Texas do not endorse products or manufacturers. Trade of manufacturers’ names appear herein solely because they are considered essential to the object of this report.

TTI PROVING GROUND DISCLAIMER

The results of the crash testing reported herein apply only to the article tested.

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ACKNOWLEDGMENTS

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Figures</td>
<td>xi</td>
</tr>
<tr>
<td>List of Tables</td>
<td>xiii</td>
</tr>
<tr>
<td><strong>Chapter 1. Introduction</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>Chapter 2. System Details</strong></td>
<td>3</td>
</tr>
<tr>
<td>2.1. Test Article and Installation Details</td>
<td>3</td>
</tr>
<tr>
<td>2.2. Design Modifications</td>
<td>3</td>
</tr>
<tr>
<td>2.3. Material Specifications</td>
<td>3</td>
</tr>
<tr>
<td><strong>Chapter 3. Test Requirements and Evaluation Criteria</strong></td>
<td>7</td>
</tr>
<tr>
<td>3.1. Crash Test Performed/Matrix</td>
<td>7</td>
</tr>
<tr>
<td>3.2. Evaluation Criteria</td>
<td>8</td>
</tr>
<tr>
<td><strong>Chapter 4. Test Conditions</strong></td>
<td>11</td>
</tr>
<tr>
<td>4.1. Test Facility</td>
<td>11</td>
</tr>
<tr>
<td>4.2. Vehicle Tow and Guidance System</td>
<td>11</td>
</tr>
<tr>
<td>4.3. Data Acquisition Systems</td>
<td>12</td>
</tr>
<tr>
<td>4.3.1. Vehicle Instrumentation and Data Processing</td>
<td>11</td>
</tr>
<tr>
<td>4.3.2. Anthropomorphic Dummy Instrumentation</td>
<td>12</td>
</tr>
<tr>
<td>4.3.3. Photographic Instrumentation Data Processing</td>
<td>12</td>
</tr>
<tr>
<td><strong>Chapter 5. MASH Test 4-12 (Crash Test No. 469680-02-1)</strong></td>
<td>15</td>
</tr>
<tr>
<td>5.1. Test Designation and Actual Impact Conditions</td>
<td>15</td>
</tr>
<tr>
<td>5.2. Weather Conditions</td>
<td>16</td>
</tr>
<tr>
<td>5.3. Test Vehicle</td>
<td>16</td>
</tr>
<tr>
<td>5.4. Test Description</td>
<td>17</td>
</tr>
<tr>
<td>5.5. Damage to Test Installation</td>
<td>17</td>
</tr>
<tr>
<td>5.6. Damage to Test Vehicle</td>
<td>17</td>
</tr>
<tr>
<td>5.7. Vehicle Instrumentation</td>
<td>17</td>
</tr>
<tr>
<td><strong>Chapter 6. MASH Test 4-12 without Dowel Rods (Crash Test No. 469680-02-2)</strong></td>
<td>21</td>
</tr>
<tr>
<td>6.1. Test Designation and Actual Impact Conditions</td>
<td>21</td>
</tr>
<tr>
<td>6.2. Weather Conditions</td>
<td>21</td>
</tr>
<tr>
<td>6.3. Test Vehicle</td>
<td>22</td>
</tr>
<tr>
<td>6.4. Test Description</td>
<td>22</td>
</tr>
<tr>
<td>6.5. Damage to Test Installation</td>
<td>23</td>
</tr>
<tr>
<td>6.6. Damage to Test Vehicle</td>
<td>23</td>
</tr>
<tr>
<td>6.7. Vehicle Instrumentation</td>
<td>23</td>
</tr>
<tr>
<td><strong>Chapter 7. MASH Test 4-12 without Dowel Bars and with Concrete Apron Extended Downstream of the Barrier (Crash Test No. 469680-02-3)</strong></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>30</td>
</tr>
<tr>
<td>7.3. Test Vehicle</td>
<td>30</td>
</tr>
<tr>
<td>7.4. Test Description</td>
<td>31</td>
</tr>
<tr>
<td>7.5. Damage to Test Installation</td>
<td>31</td>
</tr>
<tr>
<td>7.6. Damage to Test Vehicle</td>
<td>31</td>
</tr>
<tr>
<td>7.7. Vehicle Instrumentation</td>
<td>34</td>
</tr>
</tbody>
</table>
Chapter 8. Summary and Conclusions ................................................................. 37
  8.1. Assessment of Test Results ....................................................................... 37
  8.2. Conclusions ............................................................................................ 37

Chapter 9. Implementation .................................................................................. 41
References ............................................................................................................ 43

Appendix A. Details of Shallow Anchorage SSTR .............................................. 45
Appendix B. Supporting Certification Documents .............................................. 49

Appendix C. MASH Test 4-12 (Crash Test No. 469680-02-1) ............................. 69
  C.1. Vehicle Properties and Information ......................................................... 69
  C.2. Sequential Photographs ........................................................................... 71
  C.3. Vehicle Angular Displacements .............................................................. 74
  C.4. Vehicle Accelerations ............................................................................. 75

Appendix D. MASH Test 4-12 without Dowel Bars (Crash Test No. 469680-02-2) .......... 81
  D.1. Vehicle Properties and Information ......................................................... 81
  D.2. Sequential Photographs ........................................................................... 83
  D.3. Vehicle Angular Displacements .............................................................. 85
  D.4. Vehicle Accelerations ............................................................................. 86

Appendix E. MASH Test 4-12 without Dowel Bars and with Concrete Apron Extended
  Downstream of Barrier (Crash Test No. 469680-02-3) ...................................... 93
  E.1. Vehicle Properties and Information ......................................................... 93
  E.2. Sequential Photographs ........................................................................... 95
  E.3. Vehicle Angular Displacements .............................................................. 98
  E.4. Vehicle Accelerations ............................................................................. 99
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 2.1.</td>
<td>TxDOT Shallow Anchorage SSTR Details .............................................</td>
<td>4</td>
</tr>
<tr>
<td>Figure 2.2.</td>
<td>TxDOT Shallow Anchorage SSTR prior to Testing ....................................</td>
<td>5</td>
</tr>
<tr>
<td>Figure 3.1.</td>
<td>Target CIP for First and Third MASH Test 4-12 on TxDOT Shallow Anchorage SSTR (Test No. 469680-02-1 and 3)</td>
<td>7</td>
</tr>
<tr>
<td>Figure 3.2.</td>
<td>Target CIP for Second MASH Test 4-12 on TxDOT Shallow Anchorage SSTR (Test No. 469680-02-2)</td>
<td>8</td>
</tr>
<tr>
<td>Figure 5.1.</td>
<td>TxDOT Shallow Anchorage SSTR/Test Vehicle Geometrics for Test No. 469680-02-1</td>
<td>15</td>
</tr>
<tr>
<td>Figure 5.2.</td>
<td>Test Vehicle before Test No. 469680-02-1 .........................................</td>
<td>16</td>
</tr>
<tr>
<td>Figure 5.3.</td>
<td>TxDOT Shallow Anchorage SSTR after Test No. 469680-02-1 ........................</td>
<td>18</td>
</tr>
<tr>
<td>Figure 5.4.</td>
<td>Test Vehicle after Test No. 469680-02-1 .........................................</td>
<td>19</td>
</tr>
<tr>
<td>Figure 5.5.</td>
<td>Interior of Test Vehicle after Test No. 469680-02-1 ..........................</td>
<td>19</td>
</tr>
<tr>
<td>Figure 5.6.</td>
<td>Summary of Results for MASH Test 4-12 on TxDOT Shallow Anchorage SSTR ....</td>
<td>20</td>
</tr>
<tr>
<td>Figure 6.1.</td>
<td>TxDOT Shallow Anchorage SSTR without Dowel Bars/Test Vehicle Geometrics for Test No. 469680-02-2</td>
<td>21</td>
</tr>
<tr>
<td>Figure 6.2.</td>
<td>Test Vehicle before Test No. 469680-02-2 .........................................</td>
<td>22</td>
</tr>
<tr>
<td>Figure 6.3.</td>
<td>TxDOT Shallow Anchorage SSTR after Test No. 469680-02-2 ........................</td>
<td>24</td>
</tr>
<tr>
<td>Figure 6.4.</td>
<td>Field Side of SSTR after Test No. 469680-02-2 ..................................</td>
<td>25</td>
</tr>
<tr>
<td>Figure 6.5.</td>
<td>Test Vehicle after Test No. 469680-02-2 .........................................</td>
<td>25</td>
</tr>
<tr>
<td>Figure 6.6.</td>
<td>Test Vehicle (Uprighted) after Test No. 469680-02-2 ..........................</td>
<td>26</td>
</tr>
<tr>
<td>Figure 6.7.</td>
<td>Summary of Results for MASH Test 4-12 on TxDOT Shallow Anchorage SSTR without Dowel Bars</td>
<td>27</td>
</tr>
<tr>
<td>Figure 7.1.</td>
<td>Runout Area Extended for Test No. 469680-02-3 ..................................</td>
<td>29</td>
</tr>
<tr>
<td>Figure 7.2.</td>
<td>TxDOT Shallow Anchorage SSTR without Dowel Bars and with Concrete Apron Extended Downstream of Barrier/Test Vehicle Geometrics for Test No. 469680-02-3</td>
<td>30</td>
</tr>
<tr>
<td>Figure 7.3.</td>
<td>Test Vehicle before Test No. 469680-02-3 .........................................</td>
<td>30</td>
</tr>
<tr>
<td>Figure 7.4.</td>
<td>TxDOT Shallow Anchorage SSTR after Test No. 469680-02-3 ........................</td>
<td>32</td>
</tr>
<tr>
<td>Figure 7.5.</td>
<td>Field Side of SSTR after Test No. 469680-02-3 ..................................</td>
<td>33</td>
</tr>
<tr>
<td>Figure 7.6.</td>
<td>Test Vehicle after Test No. 469680-02-3 .........................................</td>
<td>33</td>
</tr>
<tr>
<td>Figure 7.7.</td>
<td>Test Vehicle (Uprighted) after Test No. 469680-02-3 ..........................</td>
<td>34</td>
</tr>
<tr>
<td>Figure 7.8.</td>
<td>Interior of Test Vehicle after Test No. 469680-02-3 ..........................</td>
<td>34</td>
</tr>
<tr>
<td>Figure 7.9.</td>
<td>Summary of Results for MASH Test 4-12 on TxDOT Shallow Anchorage SSTR without Dowel Bars and with Concrete Apron Extended Downstream of the Barrier</td>
<td>35</td>
</tr>
<tr>
<td>Figure C.1.</td>
<td>Sequential Photographs for Test No. 469680-02-1 (Overhead and Frontal Views)</td>
<td>71</td>
</tr>
<tr>
<td>Figure C.2.</td>
<td>Sequential Photographs for Test No. 469680-02-1 (Rear View) ..................</td>
<td>73</td>
</tr>
<tr>
<td>Figure C.3.</td>
<td>Vehicle Angular Displacements for Test 469680-02-1 ............................</td>
<td>74</td>
</tr>
<tr>
<td>Figure C.4.</td>
<td>Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-1 (Accelerometer Located at Center of Gravity)</td>
<td>75</td>
</tr>
</tbody>
</table>
Figure C.5. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-1 (Accelerometer Located at Center of Gravity). .......................................................... 76
Figure C.6. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-1 (Accelerometer Located at Center of Gravity). .......................................................... 77
Figure C.7. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-1 (Accelerometer Located at Rear of Vehicle). .......................................................... 78
Figure C.8. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-1 (Accelerometer Located at Rear of Vehicle). .......................................................... 79
Figure C.9. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-1 (Accelerometer Located at Rear of Vehicle). .......................................................... 80
Figure D.1. Sequential Photographs for Test No. 469680-02-2 (Overhead and Frontal Views). .......................................................... 83
Figure D.2. Vehicle Angular Displacements for Test No. 469680-02-2 .......................................................... 85
Figure D.3. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-2 (Accelerometer Located at Center of Gravity). .......................................................... 86
Figure D.4. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-2 (Accelerometer Located at Center of Gravity). .......................................................... 87
Figure D.5. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-2 (Accelerometer Located at Center of Gravity). .......................................................... 88
Figure D.6. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-2 (Accelerometer Located at Rear of Vehicle). .......................................................... 89
Figure D.7. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-2 (Accelerometer Located at Rear of Vehicle). .......................................................... 90
Figure D.8. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-2 (Accelerometer Located at Rear of Vehicle). .......................................................... 91
Figure E.1. Sequential Photographs for Test No. 469680-02-3 (Overhead and Frontal Views). .......................................................... 95
Figure E.2. Sequential Photographs for Test No. 469680-02-3 (Rear View). .......................................................... 97
Figure E.3. Vehicle Angular Accelerations for Test No. 479680-02-3 .......................................................... 98
Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-3 (Accelerometer Located at Center of Gravity). .......................................................... 99
Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-3 (Accelerometer Located at Center of Gravity). .......................................................... 100
Figure E.6. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-3 (Accelerometer Located at Center of Gravity). .......................................................... 101
Figure E.7. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-3 (Accelerometer Located at Rear of Vehicle). .......................................................... 102
Figure E.8. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-3 (Accelerometer Located at Rear of Vehicle). .......................................................... 103
Figure E.9. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-3 (Accelerometer Located at Rear of Vehicle). .......................................................... 104
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 3.1.</td>
<td>Test Conditions and Evaluation Criteria Specified for MASH TL-4 Longitudinal Barriers.</td>
<td>7</td>
</tr>
<tr>
<td>Table 3.2.</td>
<td>Evaluation Criteria Required for MASH Test 4-12.</td>
<td>9</td>
</tr>
<tr>
<td>Table 5.1.</td>
<td>Events during Test No. 469680-02-1.</td>
<td>16</td>
</tr>
<tr>
<td>Table 6.1.</td>
<td>Events during Test No. 469680-02-2.</td>
<td>22</td>
</tr>
<tr>
<td>Table 7.1.</td>
<td>Events during Test No. 469680-02-3.</td>
<td>31</td>
</tr>
<tr>
<td>Table 8.1.</td>
<td>Performance Evaluation Summary for MASH Test 4-12 on TxDOT Shallow Anchorage SSTR.</td>
<td>38</td>
</tr>
<tr>
<td>Table 8.2.</td>
<td>Performance Evaluation Summary for MASH Test 4-12 on TxDOT Shallow Anchorage SSTR without Dowel Bars.</td>
<td>39</td>
</tr>
<tr>
<td>Table 8.3.</td>
<td>Performance Evaluation Summary for MASH Test 4-12 on TxDOT Shallow Anchorage SSTR without Dowel Bars and with Concrete Apron Extended Downstream of the Barrier.</td>
<td>40</td>
</tr>
<tr>
<td>Table C.1.</td>
<td>Vehicle Properties for Test No. 469680-02-1.</td>
<td>69</td>
</tr>
<tr>
<td>Table D.1.</td>
<td>Vehicle Properties for Test No. 469680-02-2.</td>
<td>81</td>
</tr>
<tr>
<td>Table E.1.</td>
<td>Vehicle Properties for Test No. 469680-02-3.</td>
<td>93</td>
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**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 | 5(F-32)/9 | Celsius | °C |
| or (F-32)/1.8 |

**FORCE and PRESSURE or STRESS** | | | | |
| lbf  | poundforce   | 4.45        | newtons   | N      |
| lbf/in² | poundforce per square inch | 6.89 | kilopascals | kPa |

**APPROXIMATE CONVERSIONS FROM SI UNITS** | | | | |
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<td><strong>VOLUME</strong></td>
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<tr>
<td>mL</td>
<td>milliliters</td>
<td>0.034</td>
<td>fluid ounces</td>
<td>oz</td>
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<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>
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<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 “t”)</td>
<td>megagrams (or “metric ton”)</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>1.8C+32</td>
<td>Fahrenheit</td>
<td>°F</td>
</tr>
</tbody>
</table>

**FORCE and PRESSURE or STRESS** | | | | |
| N   | newtons      | 0.225       | poundforce | lbf |
| kPa | kilopascals  | 0.145       | poundforce per square inch | lb/in² |

*SI is the symbol for the International System of Units*
CHAPTER 1. INTRODUCTION

The Texas Department of Transportation’s (TxDOT’s) single slope traffic rail (SSTR) has performed acceptably according to the American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH) Test Level 4 (TL-4) longitudinal barriers (1). Different configurations of the SSTR have been tested and shown to satisfy MASH TL-4 criteria (2). However, it is further desired to be able to anchor an SSTR into a 4½-inch-thick cast-in-place deck slab that is constructed over a prestressed box beam, slab beam, or prestressed panel. The main concern with this application is the strength of the anchoring system.

The purpose of the tests reported herein was to assess the performance of the TxDOT shallow anchorage SSTR according to the safety-performance evaluation guidelines included in the AASHTO MASH. MASH Test 4-12 was performed on the TxDOT shallow anchorage SSTR to determine the structural adequacy of the anchorage.

This report provides details of the TxDOT shallow anchorage SSTR, the crash tests and results, and the performance assessment of the TxDOT shallow anchorage SSTR as a MASH TL-4 longitudinal barrier.
CHAPTER 2. SYSTEM DETAILS

2.1. TEST ARTICLE AND INSTALLATION DETAILS

The installation consisted of three sections of 36-inch-tall concrete SSTR. Two of the sections were 25 ft. in length, and the third section, placed on the left end when viewing from the traffic side, was 74 ft. 9¾ inches long. There was a 2-inch joint between each barrier section, which resulted in a total length of 125 ft. 1¾ inches. The SSTR was anchored in place using No. 4 rebar anchors embedded in a cast-in-place concrete slab measuring 4½ inches thick. The rebar anchors rested on the top surface of precast concrete panels that were 8 ft. 4 inches long, 10 ft. wide, and 4 inches thick. The upper concrete slab was then cast in place over the precast concrete panels to simulate field construction.

Figure 2.1 presents overall information on the TxDOT shallow anchorage SSTR, and Figure 2.2 provides photographs of the test installation. Appendix A provides further details on the TxDOT shallow anchorage SSTR. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, and construction was performed by Tucker Construction and supervised by TTI Proving Ground personnel.

2.2. DESIGN MODIFICATIONS

For Test No. 469680-02-2, the dowel bars between barrier segments across the expansion joints were cut through so the barrier segments were not connected. After only minor barrier movement and damage in Test No. 469680-02-1, this was done to see if acceptable impact performance could be achieved without the need for dowel bars across adjacent joints. Prior to the third test (Test No. 469680-02-3), the concrete apron was extended downstream of the barrier to replace the soil beyond the end of the barrier to provide a more uniform and representative runout area.

2.3. MATERIAL SPECIFICATIONS

The specified compressive strength of the concrete used in the panels, deck, and parapet was 5000 psi, 4000 psi, and 3600 psi, respectively. On the day of the first test, June 16, 2020, the average compressive strength of the concrete was as follows:

- Average concrete strength for the panels: 5360 psi at 42 days of age.
- Average concrete strength for the deck: 5121 psi at 33 days of age.
- Average concrete strength for the parapet: 4255 psi at 25 days of age.

Appendix B provides material certification documents for the materials used to install/construct the TxDOT shallow anchorage SSTR.
Figure 2.1. TxDOT Shallow Anchorage SSTR Details.
Figure 2.2. TxDOT Shallow Anchorage SSTR prior to Testing.
CHAPTER 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1. CRASH TEST PERFORMED/MATRIX

Table 3.1 shows the recommended test conditions and evaluation criteria for MASH TL-4 longitudinal barriers.

Table 3.1. Test Conditions and Evaluation Criteria Specified for MASH TL-4 Longitudinal Barriers.

<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>Longitudinal Barrier</td>
<td>4-10</td>
<td>1100C</td>
<td>62 mi/h 25°</td>
<td>A, D, F, H, I</td>
</tr>
<tr>
<td></td>
<td>4-11</td>
<td>2270P</td>
<td>62 mi/h 25°</td>
<td>A, D, F, H, I</td>
</tr>
<tr>
<td></td>
<td>4-12</td>
<td>10000S</td>
<td>56 mi/h 15°</td>
<td>A, D, G</td>
</tr>
</tbody>
</table>

MASH Test 4-12 was performed on the TxDOT shallow anchorage SSTR. Test 4-12 was the critical test for evaluating the strength of the anchorage system. Tests 4-10 and 4-11 were not considered necessary to assess MASH compliance of the anchorage system. Previous tests that have been performed on single slope barriers indicate the profile is MASH compliant for the 1100C passenger car and 2270P pickup truck (3, 4).

The target critical impact point (CIP) for the test was determined using the information provided in MASH Section 2.2.1, Section 2.3.2, and Table 2-8. Figure 3.1 shows the target CIP for MASH Test 4-12 on the TxDOT shallow anchorage SSTR, which is 5 ft. upstream of an expansion joint.

Figure 3.1. Target CIP for First and Third MASH Test 4-12 on TxDOT Shallow Anchorage SSTR (Test No. 469680-02-1 and 3).
In Test No. 469680-02-2, the dowels bars across the expansion joints were cut such that the barrier segments were not connected. For this test, the impact point was shifted to an undamaged barrier section with the CIP as shown in Figure 3.1. In this test, the vehicle rolled onto its roof, causing excessive occupant compartment deformation. The rollover was partially attributed to an uneven runout area (part soil and part concrete) beyond the barrier installation. Therefore, MASH Test 4-12 was repeated on the system without dowel bars (Test No. 469680-02-3) with a more uniform and representative runout area. Since both barrier segments had been previously impacted, the impact point was shifted back to the first barrier segment as shown in Figure 3.1.

The crash test and data analysis procedures were in accordance with guidelines presented in MASH. Chapter 4 presents brief descriptions of these procedures.

### 3.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2 and 5-1 of MASH were used to evaluate the crash tests reported herein. Table 3.1 lists the test conditions and evaluation criteria required for MASH Test 4-12, and Table 3.2 provides detailed information on the evaluation criteria. An evaluation of the crash test results is presented in Chapter 7.
Table 3.2. Evaluation Criteria Required for MASH Test 4-12.

<table>
<thead>
<tr>
<th>Evaluation Factors</th>
<th>Evaluation Criteria</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>
</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><strong>Occupant Risk</strong></td>
<td>G. It is preferable, although not essential, that the vehicle remain upright during and after the collision.</td>
</tr>
</tbody>
</table>
CHAPTER 4. TEST CONDITIONS

4.1. TEST FACILITY

The full-scale crash tests reported herein were 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 tests were 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 TxDOT shallow anchorage SSTR 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.

4.2. VEHICLE TOW AND GUIDANCE SYSTEM

Each test 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.

4.3. DATA ACQUISITION SYSTEMS

4.3.1. Vehicle Instrumentation and Data Processing

Each 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 axes 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).

4.3.2. Anthropomorphic Dummy Instrumentation

*MASH* does not recommend or require use of a dummy in the 10000S vehicle, and no
dummy was placed in the vehicle.

4.3.3. 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 TxDOT shallow anchorage SSTR. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.
CHAPTER 5, MASH TEST 4-12 (CRASH TEST NO. 469680-02-1)

5.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 4-12 involves a 10000S vehicle weighing 22,000 lb ± 660 lb impacting the CIP of the longitudinal barrier at an impact speed of 56 mi/h ± 2.5 mi/h and an angle of 15 degrees ± 1.5 degrees. The CIP for MASH Test 4-12 on the TxDOT shallow anchorage SSTR was 5 ft ± 1 ft upstream of the centerline of the joint between Segments 1 and 2. Figure 3.1 and Figure 5.1 depict the target impact setup.

Figure 5.1. TxDOT Shallow Anchorage SSTR/Test Vehicle Geometrics for Test No. 469680-02-1.

The 10000S vehicle weighed 22,340 lb, and the actual impact speed and angle were 56.9 mi/h and 14.6 degrees. Minimum target impact severity (IS) was 142 kip-ft, and actual IS was 153 kip-ft. The actual impact point was 3.4 ft upstream of the centerline of the joint between Segments 1 and 2, which is 1.6 ft downstream of the target impact point and 0.6 ft outside the recommended MASH tolerance for impact point, and thus is out of specifications for MASH. When speaking about the impact point for large trucks, MASH Section 2.3.2.2 states that “the critical impact point for these vehicles should be chosen to maximize loading on critical barrier elements such as joints and splices.” Section A2.3.2.2 further elaborates that “impact point selection guidelines presented in Section 2.3.2.2 are based on the distance from initial contact to the location of maximum lateral force.” The objective of MASH Test 4-12 on the TxDOT shallow anchorage SSTR was to evaluate the effectiveness of the shallow anchorage system at a critical area near a barrier end/joint. Film analysis of this test showed that both the initial frontal impact and the subsequent rear impact of the truck occurred on the downstream end of the impacted barrier segment in advance of the joint. In fact, the lateral impact forces were applied to the barrier at a point closer to the segment end than initially planned, making it even more critical for evaluation of both the barrier and anchorage system. Thus, the outcome of the test was considered valid despite the actual impact point falling 0.6 ft downstream of the recommended MASH tolerance for CIP.
5.2. WEATHER CONDITIONS

The test was performed on the afternoon of June 16, 2020. Weather conditions at the time of testing were as follows: wind speed: 10 mi/h; wind direction: 203 degrees (vehicle was traveling at a heading of 185 degrees); temperature: 89°F; relative humidity: 48 percent.

5.3. TEST VEHICLE

Figure 5.2 shows the 2011 International 4300 single-unit truck (SUT) used for the crash test. The vehicle’s test inertia weight was 22,340 lb, and its gross static weight was 22,340 lb. The height to the lower edge of the vehicle bumper was 18.5 inches, and height to the upper edge of the bumper was 33.5 inches. The height to the center of gravity of the vehicle’s ballast was 61.75 inches. Table C.1 in Appendix C.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system and was released to be freewheeling and unrestrained just prior to impact.

![Test Vehicle before Test No. 469680-02-1.](image)

5.4. TEST DESCRIPTION

Table 5.1 lists events that occurred during Test No. 469680-02-1. Figures C.1 and C.2 in Appendix C.2 present sequential photographs during the test.

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
<td>Vehicle bumper impacts barrier</td>
</tr>
<tr>
<td>0.006</td>
<td>Right front tire leaves pavement</td>
</tr>
<tr>
<td>0.035</td>
<td>Vehicle begins to redirect</td>
</tr>
<tr>
<td>0.143</td>
<td>Left front tire leaves pavement</td>
</tr>
<tr>
<td>0.207</td>
<td>Left rear tires leave pavement</td>
</tr>
<tr>
<td>0.244</td>
<td>Vehicle travels parallel with barrier</td>
</tr>
<tr>
<td>0.251</td>
<td>Right lower rear corner of box contacts top of barrier</td>
</tr>
<tr>
<td>1.105</td>
<td>Left front tire contacts pavement</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 65.6 ft for heavy vehicles). The test vehicle exited within the exit box criteria defined in \textit{MASH}. Brakes on the vehicle were applied at 2.5 s after impact. After loss of contact with the barrier, the vehicle came to rest 279 ft downstream of the point of impact and 70 ft toward the field side of the barrier.

5.5. \textbf{DAMAGE TO TEST INSTALLATION}

Figure 5.3 shows the damage to the TxDOT shallow anchorage SSTR. Before the test, any cracks in the deck and barrier were noted with a black paint marker. No additional cracks or enlarging of existing cracks were evident after the test. The deck was tested for delamination at the interface between the two concrete slabs, and none were detected. There was gouging and scuffing present on the traffic face of the barrier at the impacted joint. Rebar was exposed on the downstream end of Segment 1 at the joint between Segments 1 and 2. There was also gouging at the top of the field side corner of Segments 1 and 2 from contact with the bottom frame of the box of the truck. Working width\(^*\) was 78.4 inches, and height of working width was 152.2 inches. No dynamic deflection during the test or permanent deformation after the test was observed.

5.6. \textbf{DAMAGE TO TEST VEHICLE}

Figure 5.4 shows the damage sustained by the vehicle. The front bumper, hood, right front tire and rim, right front spring assembly and U-bolts, right fuel tank and side steps, right door, right floor pan, right lower edge of box, right rear outer tire and rim, and right rear U-bolts were damaged. Maximum exterior crush to the vehicle was 18.0 inches in the front plane at the right front corner at bumper height. Maximum occupant compartment deformation was 2.5 inches in the right front floor pan/firewall. Figure 5.5 shows the interior of the vehicle.

5.7. \textbf{VEHICLE INSTRUMENTATION}

Data from the accelerometers were digitized for informational purposes only and are reported in Figure 5.6. Figure C.3 in Appendix C.3 shows the vehicle angular displacements, and Figures C.4 through C.9 in Appendix C.4 show acceleration versus time traces. Figure 5.6 summarizes pertinent information from the test.

\* Per \textit{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 5.3. TxDOT Shallow Anchorage SSTR after Test No. 469680-02-1.
Figure 5.4. Test Vehicle after Test No. 469680-02-1.

Figure 5.5. Interior of Test Vehicle after Test No. 469680-02-1.
0.000 s 0.200 s 0.400 s 0.700 s

General Information
Test Agency: Texas A&M Transportation Institute (TTI)
Test Standard Test No.: MASH Test 4-12
TTI Test No.: 469680-02-1
Test Date: 2020-06-16

Test Article
Type: Longitudinal Barrier—Bridge Rail
Name: TxDOT Shallow Anchorage SSTR
Installation Length: 125 ft 1½ inches
Material or Key Elements: 36-inch-tall single sloped barrier anchored to a 4½-inch-thick concrete slab cast in place on top of precast panels measuring 8 ft 4 inches long x 10 ft wide x 4 inches thick

Soil Type and Condition: Concrete slab, damp

Impact Conditions
Speed: 56.9 mi/h
Angle: 14.6°
Location/Orientation: 3.4 ft upstream of joint 1–2

Impact Severity: 153 kip-ft

Exit Conditions
Speed: Out of view
Trajectory/Heading Angle: Along barrier

Occupant Risk Values
Longitudinal OIV: 6.2 ft/s
Lateral OIV: 13.5 ft/s
Longitudinal Ridedown: 4.3 g
Lateral Ridedown: 6.9 g
THIV: 4.5 m/s
ASI: 0.6
Max. 0.050-s Average
Longitudinal: −2.2 g
Lateral: −4.6 g
Vertical: −3.6 g

Post-Impact Trajectory
Stopping Distance: 279 ft downstream

Vehicle Stability
Maximum Yaw Angle: 15°
Maximum Pitch Angle: 27°
Maximum Roll Angle: 12°
Vehicle Snagging: No
Vehicle Pocketing: No

Test Article Deflections
Dynamic: None measurable
Permanent: None measurable
Working Width: 78.4 inches
Height of Working Width: 152.2 inches

Vehicle Damage
VDS: NA
CDC: 01FREW3
Max. Exterior Deformation: 18.0 inches
OCDI: NA
Max. Occupant Compartment Deformation: 2.5 inches

Note: OIV = Occupant Impact Velocity; THIV = Theoretical Head Impact Velocity; ASI = Acceleration Severity Index; NA = Not Applicable.

Figure 5.6. Summary of Results for MASH Test 4-12 on TxDOT Shallow Anchorage SSTR.
CHAPTER 6. MASH TEST 4-12 WITHOUT DOWEL BARS 
(CRASH TEST NO. 469680-02-2)

6.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

In the original test installation, dowel bars were included between barrier segments across the expansion joints to provide load transfer and continuity between barrier segments and limit barrier movement and possible deck damage. Based on the results of the first test (i.e., no barrier movement and no deck damage or delamination), TxDOT requested an additional MASH Test 4-12 without the dowel bars. If successful, this configuration would reduce construction complexity of the barrier in the field.

For Test No. 469680-02-2, the dowel bars between barrier segments across the expansion joints were cut through such that the barrier segments were not connected. The CIP for MASH Test 4-12 on the TxDOT shallow anchorage SSTR without dowel bars was 5 ft ± 1 ft upstream of the centerline of the joint between Segments 2 and 3. This downstream joint was selected to avoid the need for barrier repair at the previously impacted joint.

Figure 3.2 and Figure 6.1 depict the target impact setup. The remaining target impact conditions for MASH Test 4-12 are stated in Section 5.1.

![Diagram of impact setup](image)

Figure 3.2 and Figure 6.1 depict the target impact setup. The remaining target impact conditions for MASH Test 4-12 are stated in Section 5.1.

The 10000S vehicle weighed 22,190 lb, and the actual impact speed and angle were 56.7 mi/h and 14.2 degrees. The actual impact point was 4.5 ft upstream of the centerline of the joint between Segments 2 and 3. Minimum target IS was 142 kip-ft, and actual IS was 144 kip-ft.
6.2. WEATHER CONDITIONS

The test was performed on the morning of August 10, 2020. Weather conditions at the time of testing were as follows: wind speed: 9 mi/h; wind direction: 190 degrees (vehicle was traveling at a heading of 185 degrees); temperature: 89°F; relative humidity: 58 percent.

6.3. TEST VEHICLE

Figure 6.2 shows the 2011 International 4300 SUT used for the crash test. The vehicle’s test inertia weight was 22,190 lb, and its gross static weight was 22,190 lb. The height to the lower edge of the vehicle bumper was 18.25 inches, and height to the upper edge of the bumper was 33.25 inches. The height to the center of gravity of the vehicle’s ballast was 63.4 inches. Table D.1 in Appendix D.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

![Test Vehicle](image)

Figure 6.2. Test Vehicle before Test No. 469680-02-2.

6.4. TEST DESCRIPTION

Table 6.1 lists events that occurred during Test No. 469680-02-2. Figure D.1 in Appendix D.2 presents sequential photographs during the test.

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0000</td>
<td>Vehicle bumper impacts barrier</td>
</tr>
<tr>
<td>0.0150</td>
<td>Right front tire leaves pavement</td>
</tr>
<tr>
<td>0.0360</td>
<td>Vehicle begins to redirect</td>
</tr>
<tr>
<td>0.1050</td>
<td>Left front tire leaves pavement</td>
</tr>
<tr>
<td>0.2450</td>
<td>Left rear tires leave pavement</td>
</tr>
<tr>
<td>0.2890</td>
<td>Vehicle travels parallel with barrier</td>
</tr>
<tr>
<td>0.8370</td>
<td>Left front tire returns to pavement</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 65.6 ft for heavy vehicles). The test vehicle exited within the exit box criteria defined in MASH. Brakes on the vehicle were not applied. After loss of contact with the barrier, the vehicle rolled 192 degrees and came to rest on its roof 229 ft downstream of the point of impact and 43 ft toward the field side of the barrier.

6.5. DAMAGE TO TEST INSTALLATION

Figure 6.3 and Figure 6.4 show the damage to the TxDOT shallow anchorage SSTR without dowel bars. No cracks were observed in the barrier or deck slab. No delaminations were detected at the interface between the two concrete slabs. Some gouging occurred on the traffic face of the barrier in the impact region, and contact and scuff marks were evident from the point of impact to the end of the barrier. Working width* was 60.6 inches, and height of working width was 150.9 inches. No dynamic deflection during the test nor permanent deformation after the test was observed.

6.6. DAMAGE TO TEST VEHICLE

Figure 6.5 and Figure 6.6 show the damage sustained by the vehicle. After loss of contact with the barrier, the vehicle rolled 192 degrees and came to rest on its roof. Before the vehicle rolled over, the front bumper, hood, front axle, right and left front spring assembly and U-bolts, right front tire and rim, right front door, right fuel tank and side steps, rear of cab, lower edge of the box, and right rear outer rim were damaged. Maximum exterior crush to the vehicle before rollover was 16.0 inches in the side plane at the right front corner at bumper height. Due to rollover, the occupant compartment deformation was unable to be measured.

6.7. VEHICLE INSTRUMENTATION

Data from the accelerometers were digitized for informational purposes only and are reported in Figure 6.2. Figure D.2 in Appendix D.3 shows the vehicle angular displacements, and Figures D.3 through D.8 in Appendix D.4 show acceleration versus time traces. Figure 6.7 summarizes pertinent information from the test.

* 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 6.3. TxDOT Shallow Anchorage SSTR without Dowel Bars after Test No. 469680-02-2.
Figure 6.4. Field Side of SSTR without dowel bars after Test No. 469680-02-2.

Figure 6.5. Test Vehicle after Test No. 469680-02-2.
Figure 6.6. Test Vehicle (Uprighted) after Test No. 469680-02-2.
General Information
Test Agency: Texas A&M Transportation Institute (TTI)
Test Standard Test No: MASH Test 4-12
TTI Test No: 469680-02-2
Test Date: 2020-08-10

Type: Longitudinal Barrier—Bridge Rail
Name: TxDOT Shallow Anchorage SSTR
Installation Length: 125 ft 1½ inches
Material or Key Elements: 36-inch-tall single sloped barrier anchored to a 4½-inch-thick concrete slab cast in place on top of precast panels measuring 8 ft 4 inches long x 10 ft wide x 4 inches thick

Soil Type and Condition: Concrete slab, damp

Test Vehicle
Type/Designation: 10000S
Make and Model: 2011 International 4300 SUT
Curb: 13,020 lb
Test Inertial: 22,190 lb
Dummy: No dummy
Gross Static: 22,190 lb

Impact Conditions
Speed: 56.7 mi/h
Angle: 14.2°
Location/Orientation: 4.5 ft upstream of joint 2–3

Impact Severity
Exit Conditions
Speed: 144 kip-ft
Trajectory/Heading Angle: Out of view

Occupant Risk Values
Longitudinal OIV: 5.6 ft/s
Lateral OIV: 9.8 ft/s
Longitudinal Ridedown: 2.9 g
Lateral Ridedown: 10.5 g
THIV: 3.4 m/s
ASI: 0.5
Max. 0.050-s Average
Longitudinal: -1.6 g
Lateral: 3.9 g
Vertical: 17.3 g

Post-Impact Trajectory
Stopping Distance: 229 ft downstream
43 ft twd field side

Vehicle Stability
Maximum Yaw Angle: 17°
Maximum Pitch Angle: 35°
Maximum Roll Angle: 192°
Vehicle Snagging: No
Vehicle Pocketing: No

Test Article Deflections
Dynamic: None measurable
Permanent: None measurable
Working Width: 60.6 inches
Height of Working Width: 150.9 inches

Vehicle Damage
VDS: NA
CDC: NA
Max. Exterior Deformation: Vehicle rolled 192°
OCDI: NA
Max. Occupant Compartment Deformation: Vehicle rolled 192°

Figure 6.7. Summary of Results for MASH Test 4-12 on TxDOT Shallow Anchorage SSTR without Dowel Bars.
CHAPTER 7. MASH TEST 4-12 WITHOUT DOWEL BARS AND WITH CONCRETE APRON EXTENDED DOWNSTREAM OF THE BARRIER 
(CRASH TEST NO. 469680-02-3)

7.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

In the previous MASH Test 4-12 (469680-02-2), the vehicle rolled onto its roof, causing excessive occupant compartment deformation. Analysis indicated that soil in the runout area immediately downstream of the test installation contributed to the roll of the SUT after it exited the barrier system. The impact side tires and wheels furrowed into the soil, while the tires on the opposite side of the truck were on concrete pavement. MASH Section 3.2 states that “a flat surface, preferably paved, should be used when accelerating the test vehicle to the desired speed and to provide for unrestricted trajectory of the vehicle following impact. The surface should be free of curbs, swales, ditches, or other irregularities that could influence impact or post-impact behavior of the vehicle except when test conditions require such features.”

Consequently, MASH Test 4-12 was repeated with a modification to the runout area. Figure 7.1 shows how the concrete apron was extended downstream of the test installation to replace the existing soil immediately beyond the end of the barrier. The extension of the concrete downstream of the barrier is considered more representative of the field applications for this system on high-speed bridge structures. The CIP for MASH Test 4-12 on the TxDOT shallow anchorage SSTR without dowel bars was 5 ft ± 1 ft upstream of the centerline of the joint between Segments 1 and 2. Damage to the barrier at this location from Test No. 469680-02-1 was repaired using a non-shrink grout. Figure 3.1 and Figure 7.2 depict the target impact setup. The remaining target impact conditions for MASH Test 4-12 are described in Section 5.1.

The 10000S vehicle weighed 22,500 lb, and the actual impact speed and angle were 57.4 mi/h and 14.7 degrees. The actual impact point was 5.0 ft upstream of the centerline of the joint between Segments 1 and 2. Minimum target IS was 142 kip-ft, and actual IS was 160 kip-ft.

![Figure 7.1. Runout Area Extended for Test No. 469680-02-3.](image-url)
7.2. WEATHER CONDITIONS

The test was performed on the afternoon of August 19, 2020. Weather conditions at the time of testing were as follows: wind speed: 8 mi/h; wind direction: 72 degrees (vehicle was traveling at a heading of 185 degrees); temperature: 96°F; relative humidity: 23 percent.

7.3. TEST VEHICLE

Figure 7.3 shows the 2009 International 4300 SUT used for the crash test. The vehicle’s test inertia weight was 22,500 lb, and its gross static weight was 22,500 lb. The height to the lower edge of the vehicle bumper was 18.25 inches, and height to the upper edge of the bumper was 33.25 inches. The height to the center of gravity of the vehicle’s ballast was 61.25 inches. Table E.1 in Appendix E.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.
7.4.  TEST DESCRIPTION

Table 7.1 lists events that occurred during Test No. 469680-02-3. Figures E.1 and E.2 in Appendix E.2 present sequential photographs during the test.

Table 7.1. Events during Test No. 469680-02-3.

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
<td>Vehicle bumper impacts barrier</td>
</tr>
<tr>
<td>0.012</td>
<td>Right front tire leaves pavement</td>
</tr>
<tr>
<td>0.037</td>
<td>Vehicle begins to redirect</td>
</tr>
<tr>
<td>0.185</td>
<td>Left front tire leaves pavement</td>
</tr>
<tr>
<td>0.226</td>
<td>Left rear tires leave pavement</td>
</tr>
<tr>
<td>0.234</td>
<td>Lower right rear corner of box frame contacts barrier</td>
</tr>
<tr>
<td>0.294</td>
<td>Vehicle travels parallel with barrier</td>
</tr>
<tr>
<td>0.650</td>
<td>Left front tire returns to pavement</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 65.6 ft for heavy vehicles). The test vehicle exited within the exit box criteria defined in MASH. Brakes on the vehicle were applied at 2.75 s after impact. After loss of contact with the barrier, the vehicle came to rest 263 ft downstream of the point of impact and 99 ft toward the field side of the barrier.

7.5.  DAMAGE TO TEST INSTALLATION

Figure 7.4 and Figure 7.5 show the damage to the TxDOT shallow anchorage SSTR without dowel bars. No cracks were observed in the barrier or deck slab. No delamination was detected at the interface between the two concrete slabs. There was some gouging on the face of the concrete barrier in the impact region and on Segment 2, with scuffing running along the length of the barrier. A section of rebar was exposed on the traffic side of Segment 1 at the joint between Segments 1 and 2. Working width* was 81.5 inches, and height of working width was 142.5 inches. No dynamic deflection during the test nor permanent deformation after the test was observed.

7.6.  DAMAGE TO TEST VEHICLE

Figure 7.6 and Figure 7.7 show the damage sustained by the vehicle. The front bumper, hood, right floor pan, front axle, U-bolts, spring assembly, right front tire and rim, right fuel tank and side steps, right front corner of the box, and right rear outer tire and rim were damaged due to contact with the barrier. After loss of contact with the barrier, the vehicle rolled onto its left side, which caused damage to the left front door, windshield, left side steps and battery box, and left air tanks. Maximum exterior crush to the vehicle was 16.0 inches in the side plane at the

* 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.
right front corner at bumper height. Maximum occupant compartment deformation was 9.75 inches in the right floor pan area at the seam with the right door. Figure 7.8 shows the interior of the vehicle after the test.

Figure 7.4. TxDOT Shallow Anchorage SSTR without Dowel Bars and with Concrete Apron Extended Downstream of Barrier after Test No. 469680-02-3.
Figure 7.5. Field Side of SSTR without Dowel Bars and with Concrete Apron Extended Downstream of Barrier after Test No. 469680-02-3.

Figure 7.6. Test Vehicle after Test No. 469680-02-3.
7.7. VEHICLE INSTRUMENTATION

Data from the accelerometers were digitized for informational purposes only and are reported in Figure 7.9. Figure E.3 in Appendix E.3 shows the vehicle angular displacements, and Figures E.4 through E.9 in Appendix E.4 show acceleration versus time traces. Figure 7.9 summarizes pertinent information from the test.
Figure 7.9. Summary of Results for MASH Test 4-12 on TxDOT Shallow Anchorage SSTR without Dowel Bars and with Concrete Apron Extended Downstream of the Barrier.
CHAPTER 8. SUMMARY AND CONCLUSIONS

8.1. ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed in accordance with MASH Test 4-12 on the TxDOT shallow anchorage SSTR. During the first test (469680-02-1), the impact point was out of the ± 1 ft specification per MASH, but the outcome of the test was considered valid since the vehicle impacted the barrier at a location more critical for evaluation of both the barrier and anchorage system. Table 8.1 provides an assessment of this test based on the applicable safety evaluation criteria for MASH Test 4-12 for longitudinal barriers.

For both the second and third tests (469680-02-2 and 3), the dowel bars between barrier segments across the expansion joints were cut through such that the barrier segments were not connected. In the second test (469680-02-2), the vehicle rolled over onto its roof. Table 8.2 provides an assessment of the test based on the applicable safety evaluation criteria for MASH Test 4-12 for longitudinal barriers. The third test was a repeat of the second test. It was determined that soil in the runout area at the end of the test installation contributed to the rollover of the truck in the second test. Therefore, prior to the third test (469680-02-3), the concrete apron was extended downstream of the barrier to replace the soil immediately beyond the end of the barrier to provide a runout area that was more uniform and consistent with anticipated field implementation. Table 8.3 provides an assessment of the test based on the applicable safety evaluation criteria for MASH Test 4-12 for longitudinal barriers.

8.2. CONCLUSIONS

Table 8.1 and Table 8.3 show that the TxDOT shallow anchorage SSTR (with and without dowel bars between barrier segments across expansion joints) meets the performance criteria for MASH Test 4-12 for longitudinal barriers.
Table 8.1. Performance Evaluation Summary for MASH Test 4-12 on TxDOT Shallow Anchorage SSTR.

<table>
<thead>
<tr>
<th>MASH Test 4-12 Evaluation Criteria</th>
<th>Test Results</th>
<th>Assessment</th>
</tr>
</thead>
</table>
| **Structural Adequacy**  
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. | The TxDOT shallow anchorage SSTR contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the installation. No measurable dynamic deflection or permanent deformation was observed. | Pass |
| **Occupant Risk**  
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.  

Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.  

G. It is preferable, although not essential, that the vehicle remain upright during and after collision. | No detached elements, fragments, or other debris from the test article were present to penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area.  

Maximum occupant compartment deformation was 2.5 inches in the right front floor pan/firewall area.  

The 10000S vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 12° and 27°. | Pass |
### Table 8.2. Performance Evaluation Summary for MASH Test 4-12 on TxDOT Shallow Anchorage SSTR without Dowel Bars.

<table>
<thead>
<tr>
<th>MASH Test 4-12 Evaluation Criteria</th>
<th>Test Results</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural Adequacy</strong></td>
<td></td>
<td></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 TxDOT shallow anchorage SSTR without dowel bars contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the installation. No measurable dynamic deflection or permanent deformation was observed.</td>
<td>Pass</td>
</tr>
<tr>
<td><strong>Occupant Risk</strong></td>
<td></td>
<td></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 from the test article were present to penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area.</td>
<td>Fail</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 MASH.</td>
<td>Rolled over onto roof.</td>
<td></td>
</tr>
<tr>
<td>G. It is preferable, although not essential, that the vehicle remain upright during and after collision.</td>
<td>The 10000S vehicle rolled 192° and came to rest on its roof. <em>MASH</em> Section A2.2.1 permits only a ¼ roll of the vehicle.</td>
<td>Fail</td>
</tr>
</tbody>
</table>
Table 8.3. Performance Evaluation Summary for MASH Test 4-12 on TxDOT Shallow Anchorage SSTR without Dowel Bars and with Concrete Apron Extended Downstream of the Barrier.

<table>
<thead>
<tr>
<th>MASH Test 4-12 Evaluation Criteria</th>
<th>Test Results</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural Adequacy</strong></td>
<td></td>
<td>Pass</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 TxDOT shallow anchorage SSTR without dowel bars contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the installation. No measurable dynamic deflection or permanent deformation was observed.</td>
<td>Pass</td>
</tr>
<tr>
<td><strong>Occupant Risk</strong></td>
<td></td>
<td>Pass</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 from the test article were present to penetrate or show potential for penetrating the occupant compartment, or 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 MASH.</td>
<td>Maximum occupant compartment deformation was 9.75 inches in the right floor pan at a seam location with the door.</td>
<td>Pass</td>
</tr>
<tr>
<td>G. It is preferable, although not essential, that the vehicle remain upright during and after collision.</td>
<td>The 10000S vehicle rolled counterclockwise and came to rest on its left side.</td>
<td>Pass</td>
</tr>
</tbody>
</table>
CHAPTER 9. IMPLEMENTATION*

The TxDOT shallow anchorage SSTR attached to a 4.5-inch-thick cast-in-place deck performed acceptably for MASH Test 4-12 both with and without No. 8 rebar dowels between adjacent barrier segments across expansion joints. There was no structural damage to the deck, and only minor damage to the SSTR.

MASH Test 4-10 with the 1100C passenger car and Test 4-11 with the 2270P pickup truck were considered unnecessary. When impacted by the SUT, the shallow anchorage SSTR had no dynamic or permanent movement and behaved as a rigid barrier. The SSTR has previously been successfully crash tested with the passenger vehicles, demonstrating the impact performance of the single slope profile (3, 4). Thus, the TxDOT shallow anchorage SSTR attached to a 4.5-inch-thick cast-in-place deck is considered MASH compliant.

The shallow anchorage applications of interest to TxDOT include anchorage over a prestressed concrete panel inset from the deck edge, and on the edge of a deck over a prestressed box or slab beam. The application over a panel would have a minimum cast-in-place deck thickness of 4.5 inches, and the deck over a box or slab beam would have a thickness of at least 5 inches. The shallow anchorage over a panel was considered to be the critical case for evaluation due to the shallower anchor embedment and opportunity for concrete fracture or delamination around or beneath the anchor bars. Based on the successful MASH testing of this application, the less critical application of a shallow anchorage SSTR attached to the edge of a 5-inch-thick deck cast in place over a prestressed box beam or slab beam is also considered MASH compliant and suitable for implementation.

The 25-ft barrier segments evaluated in the tests represent a minimum segment length for field implementation. Implementation can be accomplished through revision of bridge rail standard detail sheets.

* The opinions/interpretations identified/expressed in this chapter are outside the scope of TTI Proving Ground’s A2LA Accreditation.
REFERENCES

3. William F. Williams, Roger P. Bligh, and Wanda L. Menges. MASH Test 3-11 of the TxDOT Single Slope Bridge Rail (Type SSTR) on Pan-Formed Bridge Deck. Report No. 9-1002-3, Texas A&M Transportation Institute, College Station, TX, March 2011.
APPENDIX A. DETAILS OF SHALLOW ANCHORAGE SSTR

Test Installation

Plan View

2" Joints in cast-in-place slab and parapet.

Elevation View

Section A-A

Scale 1 : 20

8'-4" x 10'-0" pre-cast panel
Typ x 15, with 1/8" joints

Existing Concrete

Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground

Project #469880-02-2 Shallow Anchorage SSTR 2020-07-14
Drawn by GES Scale 1:200 Sheet 1 of 4 Test Installation
Panel Details

Elevation View

Section B-B

Rebar, Ø1/2" x 6'-1"

Rebar, Ø1/2" x 9'-8"

Utilize a vibrating screed, touch up with wood floats, and apply broom finish meeting the 6-9 surface profile requirements.

Detail C

Scale 1 : 5

Typ x 4

Nut, 3/4 coupling

Washer, 3/4 F844 Tack weld to Bolt head.

Bolt, 3/4 x 2 1/2" hex

Plan View

Scale 1 : 50

5,000 psi concrete

8'-4"

10'-0"

25"

25"

75"

8'-4"

0"

36"

84"

5,000 psi concrete

Roadside Safety and Physical Security Division - Proving Ground

Project #69680-02-2 Shallow Anchorage SSTR

2020-07-14

Drawn by GES  Scale 1:15  Sheet 2 of 4  Panel Details
**Deck and Parapet**

Pre-cast Panels not shown for clarity

3a. Secure in existing concrete with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions, with 6" embedment. Space @ 18" in 25' sections and @ 36" in long section.

3b. Minimum rebar lap is 19" for #4 bars and welded wire. All rebar is grade 60.

3c. All rebar dimensions are to center of bar unless otherwise indicated by "cfr" (cover).

3d. Cast-in-place Deck is 4,000 psi Concrete. Parapet is 3,600 psi Concrete.

3e. Chamfer top edges of Parapet 1” (3/4” each way).

---

Elevation View

at Joint

Cross-section

3f. Thoroughly wet all precast concrete panels before placing concrete on them. Remove free water from the surface before placing concrete. Provide surfaces that are in a moist, saturated surface-dry condition when placing concrete.
Welded Wire

4a. This excerpt from the TxDOT Type SSTR Drawing (Rstd014) shows the allowable options for the welded wire. The contractor shall supply the fabrication drawing and material specifications for the welded wire used for the installation.
## APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

<table>
<thead>
<tr>
<th>Load No.</th>
<th>Truck No.</th>
<th>Ticket No.</th>
<th>Location (from concrete map)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Tucker</td>
<td>449</td>
<td>First 10 Blocks starting from the south</td>
</tr>
<tr>
<td>T2</td>
<td>Tucker</td>
<td>858</td>
<td>Last 5 blocks in the north</td>
</tr>
</tbody>
</table>

See attached Reports from Terracon
### Tucker Concrete

**Ticket # 858**

**Start Date:** 2020-05-04  **Time:** 10:37:31  
**Stop Date:** 2020-05-04  **Time:** 11:07:14

**Mix Design:** B1500

<table>
<thead>
<tr>
<th>Material</th>
<th>Rate Setting</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>8.45 lbs/4LBS</td>
<td>3251.792</td>
</tr>
<tr>
<td>Sand</td>
<td>4.37 lbs GAT</td>
<td>7030.18L</td>
</tr>
</tbody>
</table>

---

**Raw Cement Counts:** 3943  
**Raw Conveyor Counts:** 134153  
**Conveyor Speed:** 45  
**Total Yards:** 3.3

---

**Stone ADJUSTED:** 5.70 lbs GAT  
**Adjusted:** 9709.104

**Water ADJUSTED:** 21.48 lbs GALLON  
**Adjusted:** 138.19 GALLON

**A DMix #1:** 0.00Z/IN MIN  
**DMix #2:** 0.00Z/IN MIN  
**DMix #3:** 0.00Z/IN MIN

---

**Total Yards:** 10.50

---

**Mix Design:** B1500

---

**Raw Cement Counts:** 8078  
**Raw Conveyor Counts:** 5998

---

**Material**  
**Rate Setting**  
**Total**

<table>
<thead>
<tr>
<th>Material</th>
<th>Rate Setting</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CapType1</td>
<td>487 LBS/PM</td>
<td>6415 LBS</td>
</tr>
<tr>
<td>LRM Sand</td>
<td>5.2 GATE</td>
<td>13851.2 LBS</td>
</tr>
<tr>
<td>RgbLend</td>
<td>5.9 GATE</td>
<td>19129.3 LBS</td>
</tr>
<tr>
<td>WATER</td>
<td>25.5 GPM</td>
<td>0.0 GAL</td>
</tr>
<tr>
<td>SIKA686</td>
<td>1.0 GPM</td>
<td>12.0 GAL</td>
</tr>
</tbody>
</table>

**Max GPM:** 23.4  
**Max GPY:** 22.53

---

**Name:** I.A.  
**Notes:** I.A.

---

TR No. 0-6968-R10  
50  
2020-12-15
CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1711057.0114
Service Date: 05/04/20
Report Date: 05/04/20
Task: PO #4069680-02

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

Project
Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Sample Information
Sample Date: 05/04/20
Sample Time: 1007
Sampled By: Cullen Turney
Weather Conditions: Cloudy, light wind
Accumulative Yards: 10.5
Batch Size (cy): 10.5
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: 3rd Panel
Placement Location: Panels

Material Information
Specified Strength: 5,000 psi @ 28 days
Mix ID: R1500
Supplier: Tucker
Batch Time: 0940
Plant:
Ticket No.: 449

Field Test Data
<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump (in):</td>
<td>4</td>
<td>Not Specified</td>
</tr>
<tr>
<td>Air Content (%):</td>
<td>2.4</td>
<td>Not Specified</td>
</tr>
<tr>
<td>Concrete Temp. (F):</td>
<td>76</td>
<td>40 - 95</td>
</tr>
<tr>
<td>Ambient Temp. (F):</td>
<td>79</td>
<td>40 - 95</td>
</tr>
<tr>
<td>Plastic Unit Wt. (pcf):</td>
<td>146.0</td>
<td>Not Specified</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</td>
<td>A</td>
<td>6.00</td>
<td>28.27</td>
<td>05/05/20</td>
<td>06/15/20</td>
<td>42 F</td>
<td>136,970</td>
<td>4,840</td>
<td>1</td>
<td>SLS</td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>6.00</td>
<td>28.27</td>
<td>05/05/20</td>
<td>06/15/20</td>
<td>42 F</td>
<td>141,110</td>
<td>4,960</td>
<td>2</td>
<td>SLS</td>
</tr>
<tr>
<td>1</td>
<td>C</td>
<td>6.00</td>
<td>28.27</td>
<td>05/05/20</td>
<td>06/15/20</td>
<td>42 F</td>
<td>140,090</td>
<td>5,270</td>
<td>1</td>
<td>SLS</td>
</tr>
<tr>
<td>1</td>
<td>D</td>
<td>6.00</td>
<td>28.27</td>
<td>05/05/20</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
Start/Stop: 0930-1200

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.: Cullen Turney
Reported To:
Contractor:
Report Distribution:
1) Texas Transportation Institute, Gary Gerk
2) Terracon Consultants, Inc., Alex Dangert, P.E.
3) Texas Transportation Institute, Bill Giese

Test Methods: AS1M C 31, ASTM C143, ASTM C231, AS1M C1064

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Page 1 of 2
CONCRETE COMpressive STRENGTH TEST REPORT

Report Number: A1711057.0114
Service Date: 05/04/20
Report Date: 05/04/20
Task: PO #469680-02

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

Project
Riverside Campus
Bryan, TX
Project Number: A1171057

Material Information
Specified Strength: 5,000 psi @ 28 days
Mix ID: B1500
Supplier: Tucker
Batch Time: 1037
Plant:
Ticket No.: 858

Sample Information
Sample Date: 05/04/20
Sample Time: 10:45
Sampled By: Cullen Turney
Weather Conditions: Cloudy, light wind
Accumulative Yards: 16/16
Batch Size (cy): 5.5
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: 12th Panel
Placement Location: Panels

Field Test Data
<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump (in):</td>
<td>4 3/4</td>
<td>Not Specified</td>
</tr>
<tr>
<td>Air Content (%):</td>
<td>2.1</td>
<td>Not Specified</td>
</tr>
<tr>
<td>Concrete Temp. (F):</td>
<td>83</td>
<td>40 - 95</td>
</tr>
<tr>
<td>Ambient Temp. (F):</td>
<td>81</td>
<td>40 - 95</td>
</tr>
<tr>
<td>Plastic Unit Wt. (pcf):</td>
<td>146.8</td>
<td>Not Specified</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>2</td>
<td>A</td>
<td>6.00</td>
<td>28.27</td>
<td>05/05/20</td>
<td>06/15/20</td>
<td>42 F</td>
<td>160,640</td>
<td>5,680</td>
<td>1</td>
<td>SLS</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>6.00</td>
<td>28.27</td>
<td>05/05/20</td>
<td>06/15/20</td>
<td>42 F</td>
<td>161,570</td>
<td>5,710</td>
<td>1</td>
<td>SLS</td>
</tr>
<tr>
<td>2</td>
<td>C</td>
<td>6.00</td>
<td>28.27</td>
<td>05/05/20</td>
<td>06/15/20</td>
<td>42 F</td>
<td>160,280</td>
<td>5,670</td>
<td>2</td>
<td>SLS</td>
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<tr>
<td>2</td>
<td>D</td>
<td>6.00</td>
<td>28.27</td>
<td>05/05/20</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.: Cullen Turney
Start/Stop: 0930-1200
Reported To:

Contractor: Report Distribution:
(1) Texas Transportation Institute, Gary Gerke
(2) Terracon Consultants, Inc., Alex Dangar, P.E.
(3) Texas Transportation Institute, Bill Griffin

Reviewed By: Alexander Dangar
Project Manager

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

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<table>
<thead>
<tr>
<th>Load No.</th>
<th>Truck No.</th>
<th>Ticket No.</th>
<th>Location (from concrete map)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Tucker</td>
<td>1467</td>
<td>30' of northern portion of deck</td>
</tr>
<tr>
<td>T2</td>
<td>Tucker</td>
<td>102</td>
<td>Remaining deck up to 6 feet in the south</td>
</tr>
<tr>
<td>T3</td>
<td>Tucker</td>
<td>481</td>
<td>Remaining 6 foot section of deck in the south</td>
</tr>
</tbody>
</table>

See attached Reports from Terracon
CONCRETE COMpressive STRENGTH TEST REPORT

Report Number: A1717057.0115
Service Date: 05/13/20
Report Date: 05/14/20
Task: PO #849680-02

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

Project
Riverside Campus
Bryan, TX

Material Information
Specified Strength: 3,000 psi @ 28 days
Mix ID: B1400
Supplier: Tucker Concrete
Batch Time: 1100 Plant:
Truck No.: Ticket No.: 1406

Field Test Data
Test Slump (in): 7 1/2
Air Content (%): 1.4
Concrete Temp. (F): 86 40 - 95
Ambient Temp. (F): 75 40 - 95
Plastic Unit Wt. (pcf): Not Specified
Yield (Cu. Yds.):

Sample Information
Sample Date: 05/13/20 Sample Time: 1100
Sampled By: Mohammed Mobeen
Weather Conditions: Partly cloudy, light wind
Accumulative Yards: 7.96/20 Batch Size (cy): 7.96
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: Northside
Placement Location: Colorado deck

Laboratory Test Data

<table>
<thead>
<tr>
<th>Set No.</th>
<th>Specimen ID</th>
<th>Avg Diam.</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</td>
<td>A</td>
<td>6.00</td>
<td>28.27</td>
<td>05/14/20</td>
<td>06/15/20</td>
<td>33 F</td>
<td>149,520</td>
<td>5,290</td>
<td>2</td>
<td>SLS</td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>6.00</td>
<td>28.27</td>
<td>05/14/20</td>
<td>06/15/20</td>
<td>33 F</td>
<td>144,480</td>
<td>5,110</td>
<td>1</td>
<td>SLS</td>
</tr>
<tr>
<td>1</td>
<td>C</td>
<td>6.00</td>
<td>28.27</td>
<td>05/14/20</td>
<td>06/15/20</td>
<td>33 F</td>
<td>146,360</td>
<td>5,180</td>
<td>1</td>
<td>SLS</td>
</tr>
<tr>
<td>1</td>
<td>D</td>
<td>6.00</td>
<td>28.27</td>
<td>05/14/20</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: Not tested for plastic unit weight. 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
Reported To:

Contractor: Report Distribution:
(1) Texas Transportation Institute, Gary Gerke
(2) Terracon Consultants, Inc., Alex Damper, P.E.
(3) Texas Transportation Institute, Bill Gribble

Test Methods: AS1M C 31, ASTM C143, ASTM C231, AS1M C1064

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Page 1 of 3

TR No. 0-6968-R10 55 2020-12-15
CONCRETE COMpressive STRENGTH TEST REPORT

Report Number: A1171057.0115
Service Date: 05/13/20
Report Date: 05/14/20
Task: PO #469680-02

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

Project
Riverside Campus
Bryan, TX

Sample Information
Sample Date: 05/13/20
Sample Time: 1230
Sampled By: Mohammed Moeen
Weather Conditions: Partly cloudy
Accumulative Yards: 10.64
Batch Size (cy): 10.64
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: South side
Placement Location: Colorado deck

Material Information
Specified Strength: 3,000 psi @ 28 days
Mix ID: R4100
Supplier: Tucker Concrete
Batch Time: 1115

Field Test Data

<table>
<thead>
<tr>
<th>Test</th>
<th>Specimen</th>
<th>Result</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump (in)</td>
<td>A</td>
<td>7</td>
<td>Not Specified</td>
</tr>
<tr>
<td>Air Content (%)</td>
<td>D</td>
<td>1.4</td>
<td>Not Specified</td>
</tr>
<tr>
<td>Concrete Temp. (F)</td>
<td>C</td>
<td>86</td>
<td>40 - 95</td>
</tr>
<tr>
<td>Ambient Temp. (F)</td>
<td>B</td>
<td>75</td>
<td>40 - 95</td>
</tr>
<tr>
<td>Plastic Unit Wt. (pcf)</td>
<td>A</td>
<td>Not Specified</td>
<td></td>
</tr>
<tr>
<td>Yield (Cu. Yds):</td>
<td></td>
<td></td>
<td></td>
</tr>
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</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>2</td>
<td>A</td>
<td>6.00</td>
<td>28.27</td>
<td>05/14/20</td>
<td>06/15/20</td>
<td>33 F</td>
<td>148,500</td>
<td>5,250</td>
<td>2</td>
<td>SLS</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>6.00</td>
<td>28.27</td>
<td>05/14/20</td>
<td>06/15/20</td>
<td>33 F</td>
<td>141,290</td>
<td>5,000</td>
<td>2</td>
<td>SLS</td>
</tr>
<tr>
<td>2</td>
<td>C</td>
<td>6.00</td>
<td>28.27</td>
<td>05/14/20</td>
<td>06/15/20</td>
<td>33 F</td>
<td>148,510</td>
<td>5,250</td>
<td>2</td>
<td>SLS</td>
</tr>
<tr>
<td>2</td>
<td>D</td>
<td>6.00</td>
<td>28.27</td>
<td>05/14/20</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: Not tested for plastic unit weight. 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 Moeen
Start/Stop: 0930-1400

Test Methods: AS1M C 31, ASTM C143, ASTM C231, AS1M C1064

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Page 2 of 3

TR No. 0-6968-R10

56
2020-12-15
CONCRETE COMPRRESSIVE STRENGTH TEST REPORT

Report Number: A171057.0115
Service Date: 05/13/20
Report Date: 05/14/20
Task: PO #469680-02

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

Project
Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information
Specified Strength: 3,000 psi @ 28 days

Mix ID: B1400
Supplier: Tucker Concrete
Batch Time: 1217
Plant: Ticket No.: 481

Field Test Data
Test Result Specification
Slump (in): 7 1/2 Not Specified
Air Content (%): 1.5 Not Specified
Concrete Temp. (F): 88 40 - 95
Ambient Temp. (F): 76 40 - 95
Plastic Unit Wt. (pcf): Not Specified
Yield (Cu. Yds.):

Sample Information
Sample Date: 05/13/20
Sample Time: 1300
Sampled By: Mohammed Mobeen
Weather Conditions: Partly cloudy, light wind
Accumulative Yards: 1.51
Batch Size (cy): 1.5
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: South side
Placement Location: Colorado deck

Laboratory Test Data

<table>
<thead>
<tr>
<th>Set</th>
<th>Specimen</th>
<th>Avg Diam.</th>
<th>Area</th>
<th>Date Received</th>
<th>Date Tested</th>
<th>Age at Test (days)</th>
<th>Maximum Load</th>
<th>Compressive Strength (psi)</th>
<th>Fracture Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>A</td>
<td>4.00</td>
<td>12.57</td>
<td>05/14/20</td>
<td>06/15/20</td>
<td>33 F</td>
<td>62,640</td>
<td>4,980</td>
<td>1 SLS</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>4.00</td>
<td>12.57</td>
<td>05/14/20</td>
<td>06/15/20</td>
<td>33 F</td>
<td>57,350</td>
<td>4,560</td>
<td>1 SLS</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>4.00</td>
<td>12.57</td>
<td>05/14/20</td>
<td>06/15/20</td>
<td>33 F</td>
<td>68,780</td>
<td>5,470</td>
<td>1 SLS</td>
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<tr>
<td>3</td>
<td>D</td>
<td>4.00</td>
<td>12.57</td>
<td>05/14/20</td>
<td>06/15/20</td>
<td>33 F</td>
<td>68,780</td>
<td>5,470</td>
<td>1 SLS</td>
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<tr>
<td>3</td>
<td>E</td>
<td>4.00</td>
<td>12.57</td>
<td>05/14/20</td>
<td>Hold</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Initial Cure: Outside Final Cure: Field Cured

Comments: Not tested for plastic unit weight. 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
Start/Stop: 0930-1400

Reviewed By: Alexander G. Bingham
Project Manager

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

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TR No. 0-6968-R10
57
2020-12-15
<table>
<thead>
<tr>
<th>Load No.</th>
<th>Truck No.</th>
<th>Ticket No.</th>
<th>Location (from concrete map)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Tucker</td>
<td>134</td>
<td>North 3/4 of barrier</td>
</tr>
<tr>
<td>T2</td>
<td>Tucker</td>
<td>914</td>
<td>south 1/4 of barrier</td>
</tr>
</tbody>
</table>

Load No. | Break Date | Cylinder Age | Total Load (lbs) | Break (psi) | Average |

See attached Reports from Teracon
<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>RATE SETTING</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEMENT</td>
<td>4.499 24LBS/</td>
<td>1348.384</td>
</tr>
<tr>
<td>SAND</td>
<td>5.248 304 GA</td>
<td>3551.292</td>
</tr>
</tbody>
</table>

MIX DESIGN: B1400

RAW CEMENT COUNTS: 1348.384
RAW SAND COUNTS: 3551.292
CONVEYOR SPEED: 45
TOTAL YARDS 2.75

WATER / CEMENT RATIO: 0.44
REQUEST ASTM INFORMATION

NAME:
NOTES:

ASTM DATA AVAILABLE UPON REQ

NAME:
NOTES:
CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0117
Service Date: 05/21/20
Report Date: 05/21/20
Task: PO #469680-02

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

Project
Riverside Campus
Bryan, TX

Material Information
Specified Strength: 3,000 psi @
Mix ID: R1400
Supplier: Tucker Concrete
Batch No.: 1410

Sample Information
Sample Date: 05/21/20
Sample Time: 1415
Sampled By: Justin Mass
Weather Conditions: Cloudy, light wind
Accumulative Yields: 10/12
Batch Size (cy): 2
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: Southeast end
Placement Location: PO #469680-02

Field Test Data
Test Result Specification
Slump (in): 8 1/2 Not Specified
Air Content (%): 1.9 Not Specified
Concrete Temp. (F): 90 40 - 95
Ambient Temp. (F): 96 40 - 95
Plastic Unit Wt. (pcf): 146.4 Not Specified
Yield (Cu. Yds.):

Laboratory Test Data

<table>
<thead>
<tr>
<th>Set</th>
<th>Specimen</th>
<th>Avg Diam.</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</td>
<td>A</td>
<td>6.00</td>
<td>28.27</td>
<td>05/22/20</td>
<td>06/15/20</td>
<td>25</td>
<td>121,650</td>
<td>4,300</td>
<td>1</td>
<td>SLS</td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>6.00</td>
<td>28.27</td>
<td>05/22/20</td>
<td>06/15/20</td>
<td>25</td>
<td>125,180</td>
<td>4,430</td>
<td>1</td>
<td>SLS</td>
</tr>
<tr>
<td>1</td>
<td>C</td>
<td>6.00</td>
<td>28.27</td>
<td>05/22/20</td>
<td>06/15/20</td>
<td>25</td>
<td>119,800</td>
<td>4,240</td>
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<td>SLS</td>
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<tr>
<td>1</td>
<td>D</td>
<td>6.00</td>
<td>28.27</td>
<td>05/22/20</td>
<td>Hold</td>
<td>25</td>
<td>114,500</td>
<td>4,130</td>
<td>1</td>
<td>SLS</td>
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</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.: Justin Mass
Start/Stop: 1315-1530

Test Methods: AS1M C 31, ASTM C 143, ASTM C 231, AS1M C 1064

Test results and material properties are subject to change based on time and conditions. This report is 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 transmitted 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.

Page 1 of 2
CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0117
Service Date: 05/21/20
Report Date: 05/21/20
Task: PO #469680-02

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

Project
Riverside Campus
Riverside Campus
Bryan, TX

Material Information
Specified Strength: 3,000 psi @
Mix ID: B1400
Supplier: Tucker Concrete
Batch Time: 1443
Plant: Ticket No.: 914

Field Test Data
Slump (in): 7 1/2
Air Content (%): 1.9
Concrete Temp. (F): 90
Ambient Temp. (F): 87
Plastic Unit Wt. (pcf): 147.0
Yield (Cu. Yds.):

Sample Information
Sample Date: 05/21/20
Sample Time: 1445
Sampled By: Justin Maas
Weather Conditions: Cloudy, light wind
Accumulative Yards: 12/12
Batch Size (cy): 10
Placement Method: Direct Discharge
Water Added Before (gal): 0
Water Added After (gal): 0
Sample Location: Southeast end
Placement Location: PO #469680-02

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>
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<tbody>
<tr>
<td>2 A</td>
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<td>06/15/20</td>
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<tr>
<td>2 C</td>
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<td>06/15/20</td>
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<td>05/21/20</td>
<td>Hold</td>
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<td></td>
<td></td>
<td></td>
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</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.: Justin Maas
Reviewed By: Alexander.jpg
Report Distribution:
- Texas Transportation Institute, Gary Gerke
- Terracon Consultants, Inc., Alex Daigle, P.E.
- Texas Transportation Institute, Bill Griffith

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

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively 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.

Page 2 of 2
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
<th>Characteristic</th>
<th>Value</th>
<th>Characteristic</th>
<th>Value</th>
</tr>
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<td>Bend Test Diameter</td>
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<tr>
<td>Mn</td>
<td>0.65%</td>
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<td></td>
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<tr>
<td>P</td>
<td>0.008%</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>S</td>
<td>0.046%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>0.17%</td>
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<td></td>
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</tr>
<tr>
<td>Cu</td>
<td>0.33%</td>
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<tr>
<td>Cr</td>
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<td></td>
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</tr>
<tr>
<td>Ni</td>
<td>0.19%</td>
<td></td>
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<td></td>
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<tr>
<td>Mo</td>
<td>0.074%</td>
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<td></td>
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<tr>
<td>V</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Nb</td>
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<td></td>
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<tr>
<td>Sn</td>
<td>0.020%</td>
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<tr>
<td>Al</td>
<td>0.000%</td>
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<tr>
<td>Yield Strength test1</td>
<td>68.2ksi</td>
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<tr>
<td>Tensile Strength test1</td>
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<tr>
<td>Elongation test1</td>
<td>14%</td>
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<tr>
<td>Elongation Gage Lnth test1</td>
<td>8%</td>
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<tr>
<td>Tensile to Yield ratio test1</td>
<td>1.56</td>
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<td>Bend Test 1 Passed</td>
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<td></td>
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</tr>
</tbody>
</table>

The Following is true of the material represented by this MTR:
- *Material is fully killed
- *100% melted and rolled in the USA
- *EN10204-3.1 complaint
- *Contains no weld repair
- *Contains no Mercury contamination
- *Manufactured in compliance with the latest version of the plant quality manual
- *Meets the "Buy America" requirements of 23 CFR685.410. 49 CFR 661
- *Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov

REMARKS:
### CERTIFIED MILL TEST REPORT

We hereby certify that the test results presented here are accurate and conform to the reported grade specification.

Jim Hall  
Quality Assurance Manager

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.31%</td>
<td>Rebar Deformation Av., Spac</td>
<td>0.330IN</td>
</tr>
<tr>
<td>Mn</td>
<td>0.66%</td>
<td>Rebar Deformation Av. Heigh</td>
<td>0.033IN</td>
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<tr>
<td>P</td>
<td>0.008%</td>
<td>Rebar Deformation Max. Gap</td>
<td>0.130IN</td>
</tr>
<tr>
<td>S</td>
<td>0.062%</td>
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<td></td>
</tr>
<tr>
<td>Si</td>
<td>0.19%</td>
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</tr>
<tr>
<td>Cu</td>
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<td></td>
</tr>
<tr>
<td>Cr</td>
<td>0.10%</td>
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<tr>
<td>Ni</td>
<td>0.12%</td>
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</tr>
<tr>
<td>Mo</td>
<td>0.015%</td>
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<td>V</td>
<td>0.003%</td>
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<td>Sn</td>
<td>0.007%</td>
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<tr>
<td>Yield Strength test 1</td>
<td>93.4kcal</td>
<td>Tensile Strength test 1 (metri)</td>
<td>109.5kcal</td>
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<td>Yield Strength test 1 (metri)</td>
<td>644MPa</td>
<td>Tensile Strength test 1 (metric)</td>
<td>750MPa</td>
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<tr>
<td>Elongation Gage Lgth test 1</td>
<td>8IN</td>
<td>Elongation Gage Lgth 1 (metri)</td>
<td>200mm</td>
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<tr>
<td>Bend Test 1</td>
<td>Passed</td>
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</table>

The Following is true of the material represented by this MTR:

* Material is fully killed
* >150% melted and rolled in the USA
* EN10024: 2005 3.1 compliant
* Contains no weld repair
* Contains no Mercury contamination
* Manufactured in accordance with the latest version of the plant quality manual
* Meets the "Buy America" requirements of 33 CFR635, 410, 49 CFR661
* Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov

**REMARKS:** ALSE MEETS AASHTO M31

Page 1 OF 1 05/01/2020 07:25:21
HEAT NO.: 3094648  
SECTION: REBAR 16MM (#5) 40'0" 420/60  
GRADE: ASTM A615-18e1 Gr 420/60  
ROLL DATE: 02/14/2020  
MELT DATE: 02/04/2020  
Cert. No.: 83003290 / 094648A765

<table>
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<th>Value</th>
<th>Characteristic</th>
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<tr>
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<td>Si</td>
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<tr>
<td>Cr</td>
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<tr>
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<tr>
<td>Mo</td>
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<tr>
<td>Al</td>
<td>0.000%</td>
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<td></td>
</tr>
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</table>

Yield Strength test 1 65.7ksi  
Tensile Strength test 1 104.6ksi  
Elongation test 1 14%  
Elongation Gage Lenth test 1 8IN  
Tensile to Yield ratio test 1.59  
Bend Test 1 Passed

The Following is true of the material represented by this MTR:  
*Material in fully killed  
*100% milled and rolled in the USA  
*EN10204-3.1 complaint  
*Contains no weld repair  
*Contains no Mercury contamination  
*Manufactured in accordance with the latest version of the plant quality manual  
*Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661  
*Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov

REMARKS:

We hereby certify that the test results presented here are accurate and conform to the reported grade specification.
Quality Control Department  
Certificate of Analysis and Test

12262 FM 3083, Conroe, TX. 77301

Customer:  
CMC Construction Serv. / Houston  
2001 Brittmoore Rd. 
Houston, TX 77043

#1  
P.O.: 
Order #:  S-6161

<table>
<thead>
<tr>
<th>QTY</th>
<th>ITEM DESCRIPTION</th>
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<tbody>
<tr>
<td>6</td>
<td>VX6 D10.7XD13.4 68&quot;(+1/-1/2&quot;,+1&quot;) X 24&quot;(6&quot;,18&quot;)</td>
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### Mechanical Properties

<table>
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<tr>
<th>Test Date:</th>
<th>3/25/2020</th>
<th>3/25/2020</th>
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<tbody>
<tr>
<td>Wire Size</td>
<td>D13.4</td>
<td>D10.7</td>
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<tr>
<td>Heat Number</td>
<td>2020598</td>
<td>2020150</td>
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<tr>
<td>Diameter</td>
<td>0.413</td>
<td>0.369</td>
</tr>
<tr>
<td>Avg. Lbs Force</td>
<td>12,300</td>
<td>10,000</td>
</tr>
<tr>
<td>Avg. Tensile (psi)</td>
<td>91,600</td>
<td>93,000</td>
</tr>
<tr>
<td>Avg. Yield (psi)</td>
<td>88,300</td>
<td>91,600</td>
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<tr>
<td>Avg. Weld Shear (psi)</td>
<td>48,400</td>
<td>48,400</td>
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<tr>
<td>Bend Test</td>
<td>PASS</td>
<td>PASS</td>
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<tr>
<td>Reduction of Area %</td>
<td>N/A</td>
<td>N/A</td>
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</table>

The undersigned certifies that the material tested above complies with the ASTM A1064/A1064M-18a. The wire was melted and manufactured in the United States of America and complies with Buy America Requirements.

Signed:  
Jose Torres  
Quality Control Manager  
4/29/2020  
Date
MATERIAL TEST REPORT
Date Printed: 02/26/2020

Bill to:
NATIONAL WIRE CORPORATION
12262 F.M. 3083
alejandra@nationalwirellc.com
CONROE, TX 77301

Ship to:
NATIONAL WIRE CORP.
12262 F.M. 3083
CONROE, TX 77301, TX 77301

Customer No: 0000000006002
PO Number: 1480
Ship Date: 02/26/2020
Order Number: 109159
Load Number: 133572

Item Number Description
D15321012IQM 1012IQ - 15/32 In Rod

<table>
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<tr>
<th>Heat Number</th>
<th>C</th>
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<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Sn</th>
<th>V</th>
<th>Al</th>
<th>N</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020598</td>
<td>0.1200</td>
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<td>0.0100</td>
<td>0.0270</td>
<td>0.1400</td>
<td>0.2000</td>
<td>0.1200</td>
<td>0.1400</td>
<td>0.0300</td>
<td>0.0080</td>
<td>0.0030</td>
<td>0.0000</td>
<td>0.0091</td>
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</table>

MECHANICAL PROPERTIES
Heat Number Yield Tensile Elongation Reduction Bend Test
(Psi) (Psi) (%) (%) Pass/ Fail
2020598 47164 psi / 65513 psi / 23.44 68.79

The melting and rolling processes used to manufacture the above described material took place in the United States of America. The material was produced and tested in accordance with ASTM A-510.
MATERIAL TEST REPORT

Date Printed: 02/17/2020

Bill to:
NATIONAL WIRE CORPORATION
12262 F.M. 3083
alejandra@nationalwirellc.com
CONROE, TX 77301

Ship to:
NATIONAL WIRE CORP.
12262 F.M. 3083
CONROE, TX 77301, TX 7730

Customer No: 00000006002
PO Number: 1478
Ship Date: 02/17/2020
Order Number: 108617
Load Number: 133374

<table>
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<th>Item Number</th>
<th>Description</th>
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<td>27/64 1012 ROD</td>
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### CHEMICAL ANALYSIS

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<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Sn</th>
<th>V</th>
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<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020150</td>
<td>0.1200</td>
<td>0.5000</td>
<td>0.0100</td>
<td>0.0280</td>
<td>0.1700</td>
<td>0.2200</td>
<td>0.0800</td>
<td>0.0800</td>
<td>0.0200</td>
<td>0.0100</td>
<td>0.0010</td>
<td>0.0000</td>
<td>0.0077</td>
<td>0.0002</td>
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### MECHANICAL PROPERTIES

<table>
<thead>
<tr>
<th>Heat Number</th>
<th>Yield (Psi)</th>
<th>Tensile (Psi)</th>
<th>Elongation (%)</th>
<th>Reduction (%)</th>
<th>Bend Test Pass/Fail</th>
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<td>41635</td>
<td>62441</td>
<td>25.00</td>
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The melting and rolling processes used to manufacture the above described material took place in the United States of America. The material was produced and tested in accordance with ASTM A-510.

Quality Assurance:
APPENDIX C. MASH TEST 4-12 (CRASH TEST NO. 469680-02-1)

C.1. VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 469680-02-1.

<table>
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<th>Test No.</th>
<th>VIN No.</th>
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<td>469680-2</td>
<td>1HTMMAAN5BH388517</td>
</tr>
<tr>
<td>Year</td>
<td>2011</td>
<td>Make: INTERNATIONAL</td>
</tr>
<tr>
<td>Odometer</td>
<td>140395</td>
<td>Model: 4300</td>
</tr>
<tr>
<td>Tire Size Front</td>
<td>275/80R22.5</td>
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</tr>
<tr>
<td>Tire Size Rear</td>
<td>275/80R22.5</td>
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</tr>
</tbody>
</table>

Vehicle Geometry: 

- A Front Bumper Width: 92.50
- B Overall Height: 138.00
- C Overall Length: 330.75
- D Rear Overhang: 86.50
- E Wheel Base: 204.75
- F Front Overhang: 39.50
- G C.G. Height: 
- H C.G. Horizontal Dist. w/Ballast: 129.32
- I Front Bumper Bottom: 18.50
- J Front Bumper Top: 33.50
- K Rear Bumper Bottom: 
- L Rear Frame Top: 37.00
- M Front Track Width: 80.00
- N Roof Width: 71.00
- O Hood Height: 59.00
- P Bumper Extension: 
- Q Front Tire Width: 39.00
- R Front Wheel Width: 23.50
- S Bottom Door Height: 37.00
- T Overall Width: 96.00
- U Cab Length: 106.00
- V Trailer/Box Length: 221.50
- W Gap Width: 2.25
- X Overall Front Height: 98.50
- Y Roof-Hood Distance: 30.00
- Z Roof-Box Height Difference: 39.50
- AA Rear Track Width: 73.00
- BB Ballast Center of Mass: 61.75
- CC Cargo Bed Height: 48.75

Allowable Range: C = 394 inches max.; E = 246 inches max.; CC = 49 ±2 inches; BB = 63 ±2 inches above ground.

Wheel Center Height Front 19.00
Wheel Center Height Rear 19.00
Wheel Well Clearance (Front) 9.00
Wheel Well Clearance (Rear) 2.50
Bottom Frame Height (Front) 25.50
Bottom Frame Height (Rear) 27.50
Table C.1. Vehicle Properties for Test No. 469680-02-1 (Continued).

<table>
<thead>
<tr>
<th>Date:</th>
<th>2020-6-16</th>
<th>Test No.:</th>
<th>469680-2</th>
<th>VIN No.: 1HTMMAAN5BH388517</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year:</td>
<td>2011</td>
<td>Make:</td>
<td>INTERNATIONAL</td>
<td>Model: 4300</td>
</tr>
</tbody>
</table>

**WEIGHTS**

<table>
<thead>
<tr>
<th></th>
<th>CURB</th>
<th>TEST INERTIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_{\text{front axle}}$</td>
<td>7040</td>
<td>8230</td>
</tr>
<tr>
<td>$W_{\text{rear axle}}$</td>
<td>6600</td>
<td>14110</td>
</tr>
<tr>
<td>$W_{\text{total}}$</td>
<td>13640</td>
<td>22340</td>
</tr>
</tbody>
</table>

Allowable Range for CURB = 13,200 ± 2200 lb | Allowable Range for TIM = 22,048 ± 660 lb

Ballast: 8700 lb (as-needed)

(See MASH Section 4.2.1.2 for recommended ballasting)

**Mass Distribution**

<table>
<thead>
<tr>
<th></th>
<th>LF: 4170</th>
<th>RF: 4060</th>
<th>LR: 7320</th>
<th>RR: 6790</th>
</tr>
</thead>
</table>

Accelerometer Locations:

- x:
- y:
- z:

- Front: 
- Center: 129.30, 0, 48.25
- Rear: 229.30, 0, 48.25

Describe any damage to the vehicle prior to test: None

**Other notes to include ballast type, dimensions, mass, location, center of mass, and method of attachment:**

Two blocks 30 inches high x 60 inches wide x 30 inches long.

Centered in middle of bed.

61.75 inches from ground to center of block.

Tied down with four 5/16-inch cables.

Performed by: SCD Date: 2020-6-16

Referenced to the front axle.

Above ground.
C.2. SEQUENTIAL PHOTOGRAPHS

Figure C.1. Sequential Photographs for Test No. 469680-02-1 (Overhead and Frontal Views).
Figure C.1. Sequential Photographs for Test No. 469680-02-1 (Overhead and Frontal Views) (Continued).
Figure C.2. Sequential Photographs for Test No. 469680-02-1 (Rear View).
Figure C.3. Vehicle Angular Displacements for Test 469680-02-1.
Figure C.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-1 (Accelerometer Located at Center of Gravity).
Figure C.5. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-1
(Accelerometer Located at Center of Gravity).
Figure C.6. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-1
(Accelerometer Located at Center of Gravity).
Figure C.7. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-1
(Accelerometer Located at Rear of Vehicle).
Figure C.8. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-1 (Accelerometer Located at Rear of Vehicle).
Figure C.9. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-1 (Accelerometer Located at Rear of Vehicle).
APPENDIX D. MASH TEST 4-12 WITHOUT DOWEL BARS  
(CRASH TEST NO. 469680-02-2)

D.1. VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 469680-02-2.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>2020-8-10</td>
</tr>
<tr>
<td>Test No.</td>
<td>469680-02-2</td>
</tr>
<tr>
<td>VIN No.</td>
<td>1HTMMAA6BH318203</td>
</tr>
<tr>
<td>Year</td>
<td>2011</td>
</tr>
<tr>
<td>Make</td>
<td>INTERNATIONAL</td>
</tr>
<tr>
<td>Model</td>
<td>4300</td>
</tr>
<tr>
<td>Odometer</td>
<td>168769</td>
</tr>
<tr>
<td>Tire Size Front</td>
<td>275/80R22.5</td>
</tr>
<tr>
<td>Tire Size Rear</td>
<td>275/80R22.5</td>
</tr>
<tr>
<td>Wheel Base</td>
<td>204.75</td>
</tr>
<tr>
<td>Front Bumper Width</td>
<td>92.50</td>
</tr>
<tr>
<td>Overall Height</td>
<td>135.00</td>
</tr>
<tr>
<td>Overall Length</td>
<td>329.75</td>
</tr>
<tr>
<td>Rear Overhang</td>
<td>85.00</td>
</tr>
<tr>
<td>Roof Width</td>
<td>71.00</td>
</tr>
<tr>
<td>Cab Length</td>
<td>106.00</td>
</tr>
<tr>
<td>Trailer/Box Length</td>
<td>223.00</td>
</tr>
<tr>
<td>Gap Width</td>
<td>2.25</td>
</tr>
<tr>
<td>Overall Front Height</td>
<td>98.50</td>
</tr>
<tr>
<td>Roof-Hood Distance</td>
<td>30.00</td>
</tr>
<tr>
<td>Rear Track Width</td>
<td>73.00</td>
</tr>
<tr>
<td>Ballast Center of Mass</td>
<td>63.37</td>
</tr>
<tr>
<td>Cargo Bed Height</td>
<td>50.80</td>
</tr>
</tbody>
</table>

Vehicle Geometry:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Bumper Width</td>
<td>92.50</td>
</tr>
<tr>
<td>Overall Height</td>
<td>135.00</td>
</tr>
<tr>
<td>Overall Length</td>
<td>329.75</td>
</tr>
<tr>
<td>Rear Overhang</td>
<td>85.00</td>
</tr>
<tr>
<td>Wheel Base</td>
<td>204.75</td>
</tr>
<tr>
<td>C.G. Height</td>
<td>130.10</td>
</tr>
<tr>
<td>C.G. Horizontal Dist. w/Ballast</td>
<td>18.25</td>
</tr>
<tr>
<td>Front Bumper Bottom</td>
<td>33.25</td>
</tr>
<tr>
<td>T Overall Width</td>
<td>97.00</td>
</tr>
</tbody>
</table>

Allowable Range:  
- C = 384 inches max.;  
- E = 240 inches max.;  
- CC = 49 ±2 inches;  
- BB = 63 ±2 inches above ground;

More Information needed on next page
Table D.1. Vehicle Properties for Test No. 469680-02-2 (Continued).

<table>
<thead>
<tr>
<th>Date: 2020-8-10</th>
<th>Test No.: 469680-02-2</th>
<th>VIN No.: 1HTMMAA6BH318203</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year: 2011</td>
<td>Make: INTERNATIONAL</td>
<td>Model: 4300</td>
</tr>
</tbody>
</table>

**WEIGHTS**

<table>
<thead>
<tr>
<th>WEIGHTS (lb or kg)</th>
<th>CURB</th>
<th>TEST INERTIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wfront axle</td>
<td>6960</td>
<td>8090</td>
</tr>
<tr>
<td>Wrear axle</td>
<td>6060</td>
<td>14100</td>
</tr>
<tr>
<td>Wtotal</td>
<td>13020</td>
<td>22190</td>
</tr>
</tbody>
</table>

**Ballast:** 9170 lb or kg (as-needed) (See MASH Section 4.2.1.2 for recommended ballasting)

**Mass Distribution**

| LF: 3950 | RF: 4140 | LR: 7260 | RR: 6840 |

<table>
<thead>
<tr>
<th>Engine Type: DT</th>
<th>Engine Size: 466</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Transmission Type:</th>
<th>Auto</th>
<th>Manual</th>
</tr>
</thead>
<tbody>
<tr>
<td>FWD</td>
<td>RWD</td>
<td>4WD</td>
</tr>
</tbody>
</table>

**Accelerometer Locations**

<table>
<thead>
<tr>
<th>x¹</th>
<th>y</th>
<th>z²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front:</td>
<td>130.1</td>
<td>0</td>
</tr>
<tr>
<td>Center:</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rear:</td>
<td>265</td>
<td>0</td>
</tr>
</tbody>
</table>

Describe any damage to the vehicle prior to test: NONE

**Other notes to include ballast type, dimensions, mass, location, center of mass, and method of attachment:**

- Two Blocks 30 inches high x 60 inches wide x 30 inches long
- Centered in middle of bed
- 63.37 inches from ground to center of block
- Tied down with four 5/16-inch cables per block

**Performed by:** SCD | Date: 2020-8-10

---

¹ Referenced to the front axle
² Above ground
D.2. SEQUENTIAL PHOTOGRAPHS

Figure D.1. Sequential Photographs for Test No. 469680-02-2 (Overhead and Frontal Views).
Figure D.1. Sequential Photographs for Test No. 469680-02-2 (Overhead and Frontal Views) (Continued).
Axes are vehicle-fixed.
Sequence for determining orientation:
1. Yaw.
2. Pitch.
3. Roll.

Figure D.2. Vehicle Angular Displacements for Test No. 469680-02-2.
Figure D.3. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-2
(Accelerometer Located at Center of Gravity).
Figure D.4. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-2
(Accelerometer Located at Center of Gravity).
Figure D.5. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-2
(Accelerometer Located at Center of Gravity).
Figure D.6. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-2
(Accelerometer Located at Rear of Vehicle).
Figure D.7. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-2
(Accelerometer Located at Rear of Vehicle).
Figure D.8. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-2 (Accelerometer Located at Rear of Vehicle).
APPENDIX E. MASH TEST 4-12 WITHOUT DOWEL BARS AND WITH CONCRETE APRON EXTENDED DOWNSTREAM OF BARRIER (CRASH TEST NO. 469680-02-3)

E.1. VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 469680-02-3.

<table>
<thead>
<tr>
<th>Date:</th>
<th>2020-8-19</th>
<th>Test No.:</th>
<th>469680-02-3</th>
<th>VIN No.:</th>
<th>1HTMAAN89H164197</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year:</td>
<td>2009</td>
<td>Make:</td>
<td>INTERNATIONAL</td>
<td>Model:</td>
<td>4300</td>
</tr>
<tr>
<td>Odometer:</td>
<td>235522</td>
<td>Tire Size Front:</td>
<td>275/80R22.5</td>
<td>Tire Size Rear:</td>
<td>275/80R22.5</td>
</tr>
</tbody>
</table>

Vehicle Geometry:

- A Front Bumper Width: 92.50
- B Overall Height: 151.50
- C Overall Length: 329.75
- D Rear Overhang: 65.00
- E Wheel Base: 204.75
- F Front Overhang: 40.00
- G C.G. Height: 130.13
- H C.G. Horizontal Dist. w/Ballast: 18.25
- I Front Bumper Bottom: 33.25

Vehicle Geometry Units: Inches

- K Rear Bumper Bottom: 69.00
- L Rear Frame Top: 38.00
- M Front Track Width: 80.00
- N Roof Width: 71.00
- O Hood Height: 58.50
- P Bumper Extension: 39.00
- Q Front Tire Width: 23.50
- S Bottom Door Height: 37.00
- T Overall Width: 102.00

Allowable Range: C = 364 inches max.; E = 240 inches max.; CC = 48 ± 2 inches; BB = 63 ± 2 inches above ground.

Wheel Center Height Front: 19.00
Wheel Center Height Rear: 19.00
Wheel Well Clearance (Front): 9.00
Wheel Well Clearance (Rear): 4.50
Bottom Frame Height (Front): 25.50
Bottom Frame Height (Rear): 27.50
Table E.1. Vehicle Properties for Test No. 469680-02-3 (Continued).

<table>
<thead>
<tr>
<th>Date:</th>
<th>2020-8-19</th>
<th>Test No.:</th>
<th>469680-02-3</th>
<th>VIN No.:</th>
<th>1HTMMAAN89H164197</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year:</td>
<td>2009</td>
<td>Make:</td>
<td>INTERNATIONAL</td>
<td>Model:</td>
<td>4300</td>
</tr>
</tbody>
</table>

**WEIGHTS**

<table>
<thead>
<tr>
<th>(☐ lb or ☐ kg)</th>
<th>CURB</th>
<th>TEST INERTIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>W&lt;sub&gt;front&lt;/sub&gt;</td>
<td>7040</td>
<td>8200</td>
</tr>
<tr>
<td>W&lt;sub&gt;rear&lt;/sub&gt;</td>
<td>6730</td>
<td>14300</td>
</tr>
<tr>
<td>W&lt;sub&gt;Total&lt;/sub&gt;</td>
<td>13770</td>
<td>22500</td>
</tr>
</tbody>
</table>

Allowable Range for CURB = 13,200 ±2200 lb | Allowable Range for TIM = 22,040 ±560 lb

Ballast: 8730 ☐ lb or ☐ kg

(as-needed)

(See MASH Section 4.2.1.2 for recommended ballasting)

**Mass Distribution**

<table>
<thead>
<tr>
<th>☐ lb or ☐ kg</th>
<th>LF: 4190</th>
<th>RF: 4010</th>
<th>LR: 7160</th>
<th>RR: 7140</th>
</tr>
</thead>
</table>

Engine Type: DT

Engine Size: 466

Transmission Type:

☑ Auto or □ Manual

☐ FWD ☑ RWD ☐ 4WD

Accelerometer Locations (☐ inches or ☐ mm)

<table>
<thead>
<tr>
<th>x&lt;sup&gt;1&lt;/sup&gt;</th>
<th>y</th>
<th>z&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Center:</td>
<td>130.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Rear:</td>
<td>238.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Describe any damage to the vehicle prior to test: None

__________________________________________________________

Other notes to include ballast type, dimensions, mass, location, center of mass, and method of attachment:

Two blocks 30 inches high x 60 inches wide x 30 inches long

Centered in middle of bed

61.25 inches from ground to center of block

Tied down with four 5/16-inch cables per block

__________________________________________________________

Performed by: SCD Date: 2020-8-19

---

<sup>1</sup> Referenced to the front axle

<sup>2</sup> Above ground
E.2. SEQUENTIAL PHOTOGRAPHS

Figure E.1. Sequential Photographs for Test No. 469680-02-3 (Overhead and Frontal Views).
Figure E.1. Sequential Photographs for Test No. 469680-02-3 (Overhead and Frontal Views) (Continued).
Figure E.2. Sequential Photographs for Test No. 469680-02-3 (Rear View).
Axes are vehicle-fixed.
Sequence for determining orientation:
1. Yaw.
2. Pitch.
3. Roll.

Test Number: 469680-02-3
Test Standard Test Number: MASH Test 4-12
Test Article: Shallow Anchorage SSTR
Test Vehicle: 2009 International 4300 SUT
Inertial Mass: 22,500 lb
Gross Mass: 22,500 lb
Impact Speed: 57.4 mi/h
Impact Angle: 14.7°

Figure E.3. Vehicle Angular Accelerations for Test No. 479680-02-3.
Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-3
(Accelerometer Located at Center of Gravity).
Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-3  
(Accelerometer Located at Center of Gravity).

Test Number: 469680-02-3  
Test Standard Test Number: MASH Test 4-12  
Test Article: Shallow Anchorage SSTR  
Test Vehicle: 2009 International 4300 SUT  
Inertial Mass: 22,500 lb  
Gross Mass: 22,500 lb  
Impact Speed: 57.4 mi/h  
Impact Angle: 14.7°
Figure E.6. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-3  
(Accelerometer Located at Center of Gravity).
Figure E.7. Vehicle Longitudinal Accelerometer Trace for Test No. 469680-02-3
(Accelerometer Located at Rear of Vehicle).
Figure E.8. Vehicle Lateral Accelerometer Trace for Test No. 469680-02-3 (Accelerometer Located at Rear of Vehicle).
Figure E.9. Vehicle Vertical Accelerometer Trace for Test No. 469680-02-3
(Accelerometer Located at Rear of Vehicle).