Performance Limits for 6-In. High Curbs Placed in Advance of the MGS Using Mash Vehicles Part:II Full-Scale Crash Testing

Karla A. Lechtenberg  
*University of Nebraska - Lincoln*, kpolivka2@unl.edu

Ronald K. Faller  
*University of Nebraska - Lincoln*, rfaller1@unl.edu

Dean L. Sicking  
*University of Nebraska - Lincoln*, dsicking1@unl.edu

Robert W. Bielenberg M.S.C.E., E.I.T.  
*University of Nebraska - Lincoln*, rbielenberg2@unl.edu

Jeffery C. Thiele

*See next page for additional authors*

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PERFORMANCE LIMITS FOR 6-IN. (152-MM) HIGH CURBS PLACED IN ADVANCE OF THE MGS USING MASH VEHICLES
PART II: FULL-SCALE CRASH TESTING

Submitted by

Jeffrey C. Thiele, B.S.C.E., E.I.T.
Graduate Research Assistant

John D. Reid, Ph.D.
Professor

Dean L. Sicking, Ph.D., P.E.
Professor and MwRSF Director

Karla A. Lechtenberg, M.S.M.E., E.I.T.
Research Associate Engineer

Ronald K. Faller, Ph.D., P.E.
Research Assistant Professor

Robert W. Bielenberg, M.S.M.E., E.I.T.
Research Associate Engineer

MIDWEST ROADSIDE SAFETY FACILITY
University of Nebraska-Lincoln
527 Nebraska Hall
Lincoln, Nebraska 68588-0529
(402) 472-0965

MIDWEST STATES’ REGIONAL POOLED FUND PROGRAM
Nebraska Department of Roads
1500 Nebraska Highway 2
Lincoln, Nebraska 68502

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TESTING CERT # 2937.01
A full-scale crash test using Manual for Assessing Safety Hardware (MASH) Test Level 3 (TL-3) criteria was performed on the Midwest Guardrail System (MGS) offset 8 ft (2.44 m) behind a 6-in. (152-mm) high AASHTO Type B curb with a top mounting height of 31 in. (787 mm) relative to the ground [37 in. (940 mm) relative to the roadway]. In the test, the vehicle was contained by the guardrail, but became unstable and rolled over. Analysis of the test revealed that the right-front tire snagged on a post and detached. The right-rear tire of the pickup traversed over the detached tire, causing the rear of the vehicle to pitch upward. The vehicle subsequently became unstable and rolled over. Thus, the MGS offset 8 ft (2.44 m) behind a 6-in. (152-mm) high curb with a top mounting height of 31 in. (787 mm) was deemed to be unacceptable according to TL-3 of MASH.
DISCLAIMER STATEMENT

This report was funded in part through grant[s] from the Federal Highway Administration [and Federal Transit Administration] and U.S. Department of Transportation. The contents of this report reflect the views and opinions 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 views or policies of the state highway departments participating in the Midwest States’ Regional Pooled Fund Program nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, regulation, product endorsement, or an endorsement of manufacturers.

UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in standard full-scale crash testing and non-standard testing of roadside features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration.
ACKNOWLEDGEMENTS

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**Midwest Roadside Safety Facility**

J.C. Holloway, M.S.C.E., E.I.T., Test Site Manager  
S.K. Rosenbaugh, M.S.C.E., E.I.T., Research Associate Engineer  
C.L. Meyer, B.S.M.E., E.I.T., Research Associate Engineer  
A.T. Russell, B.S.B.A., Shop Manager  
K.L. Krenk, B.S.M.A, Maintenance Mechanic  
A.T. McMaster, Laboratory Mechanic  
Undergraduate and Graduate Research Assistants

**Illinois Department of Transportation**

David Piper, P.E., Highway Policy Engineer

**Iowa Department of Transportation**

David Little, P.E., Assistant District Engineer  
Deanna Maifield, P.E., Methods Engineer  
Chris Poole, P.E., Litigation/Roadside Safety Engineer
Kansas Department of Transportation
Ron Seitz, P.E., Bureau Chief
Rod Lacy, P.E., Metro Engineer
Scott King, P.E., Road Design Leader

Minnesota Department of Transportation
Michael Elle, P.E., Design Standard Engineer

Missouri Department of Transportation
Joseph Jones, P.E., Technical Support Engineer

Nebraska Department of Roads
Amy Starr, P.E., Research Engineer
Phil TenHulzen, P.E., Design Standards Engineer
Jodi Gibson, Research Coordinator

Ohio Department of Transportation
Dean Focke, P.E., Road Safety Engineer (Retired)
Michael Bline, P.E., Standards and Geometrics Engineer

South Dakota Department of Transportation
David Huft, Research Engineer
Bernie Clocksin, Lead Project Engineer

Wisconsin Department of Transportation
John Bridwell, P.E., Standards Development Engineer
Eric Emerson, P.E., Standards Development Engineer

Wyoming Department of Transportation
William Wilson, P.E., Standards Engineer

Federal Highway Administration
John Perry, P.E., Nebraska Division Office
Danny Briggs, Nebraska Division Office
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1 INTRODUCTION

1.1 Problem Statement

Highway design policy typically discourages the use of 6 to 8-in. (152 to 203-mm) vertical curbs on high-speed roadways because of their potential to cause drivers to lose control in a crash (1). Curbs can also affect the interaction of errant vehicles with roadside barriers by causing vaulting or underride of the barrier. However, the use of curbs is often required because of restricted right-of-way, drainage considerations, access control, and other curb functions. Often, there is a desire to offset the guardrail from the curb to reduce the propensity for snow plows to gouge and/or damage the W-beam rail sections or to allow for placement of sidewalks or other roadside features.

When curbs are required, the offset of the barrier from the curb has been shown to be critical in the performance of the system through modeling and crash testing. Previous work with steel-post, nested W-beam guardrail has shown that a 4-in. (102-mm) high sloped curb with the toe of the curb placed at the front face of the guardrail is capable of meeting National Cooperative Highway Research Program (NCHRP) Report No. 350 safety requirements (2-4). Further research with standard wood-post W-beam guardrail has shown that a 4-in. (102-mm) high sloped curb with its toe set out 1 in. (25 mm) from the front face of the guardrail is also capable of meeting TL-3 requirements (5).

Investigation of curb-barrier combinations was reported in NCHRP Report 537, Recommended Guidelines for Curbs and Curb-Barrier Combinations (6). This study developed guidelines for the use of curbs and curb-barrier combinations on roadways with operating speeds greater than 37.3 mph (60 km/h). The study recommended that guardrail be installed flush with the face of the sloped curb or offset more than 8.2 ft (2.5 m) behind the curb for operating speeds
in excess of 37.3 mph (60 km/h). In addition, the study recommended that guardrail should not be offset behind sloped curbs for speeds of 62.1 mph (100 km/h) or more.

The recent development and testing of the Midwest Guardrail System (MGS) has demonstrated that this system can be used with a 6-in. (152-mm) tall, American Association of State Highway Transportation Officials (AASHTO) Type B curb positioned 6 in. (152 mm) in front of the face of the guardrail element (7-8). Although this guardrail-to-curb configuration provides increased hydraulic flow for roadway runoff as well as reduced guardrail maintenance arising from snow plowing operations, state departments of transportation (DOTs) often desire to locate roadside curbs farther away from the front face of the guardrail. Thus, a research effort was begun with the goal of determining placement guidelines for the MGS in relation to curbs.

1.2 Background

In 2008, testing was performed with the small car and pickup truck vehicles specified in the Manual for Assessing Safety Hardware (MASH) (9). The tests involved the vehicles impacting a 6-in. (152-mm) high AASTHO Type B curb under Test Level 3 (TL-3) conditions (62 mph or 100 km/h, 25 degrees) to determine vehicle behavior following impact (10-11). The vehicles’ pitch angles and bumper trajectories were the data of interest.

With this, the critical override/underride offset for placing the MGS behind the curb was determined by comparing the critical bumper impact point trajectories against the MGS top/bottom corrugation heights. Results of this analysis created offset guidelines for placement of the MGS with a 6-in. (152-mm) high curb (10-11).

To further investigate the critical offset distance for MGS placement behind an AASHTO Type B curb, finite element analysis was performed. The MGS offset from a 6-in. (152-mm) high AASTHO Type B curb at various distances was impacted with the 2000P test vehicle.
Based on previous vehicle-curb simulation results and to ensure reliability of the model, the offset distance was only investigated for the range of 0.0 ft (0.0 m) to 7.35 ft (2.25 m) behind the curb. Results of the simulation indicated that the current pickup model (2000P) was fairly accurate in predicting the vehicle trajectory within 7.35 ft (2.24 m) behind the curb. Details of this research effort are documented in report references 10 and 11.

1.3 Objective

The objective of this research project was to conduct a full-scale crash test on the MGS offset 8 ft (2.44 m) behind a 6-in. (152-mm) tall AASHTO Type B curb and to evaluate the barrier’s performance according to the TL-3 safety performance criteria set forth in MASH.

1.4 Scope

The research objective was achieved through the completion of several tasks. First, a full-scale vehicle crash test was performed on the MGS system offset 8 ft (2.44 m) behind a 6-in. (152-mm) high AASTHO Type B curb. The MGS was raised 6 in. (152 mm) resulting in a top mounting height of 31 in. (787 mm) relative to the ground. The crash test utilized a pickup truck, weighing approximately 5,004 lb (2,270 kg). Target impact conditions for the test were an impact speed of 62 mph (100 km/h) and an impact angle of 25 degrees. Next, the test results were analyzed, evaluated, and documented. Finally, conclusions and recommendations were made that pertain to the safety performance of the MGS and curb system relative to the test performed.
2 DESIGN DETAILS

The test installation consisted of 175 ft (53.3 m) of MGS guardrail supported by steel posts and positioned 8 ft (2.44 m) behind a 6-in. (152-mm) tall AASHTO Type B curb. Anchorage systems similar to those used on tangent guardrail terminals were utilized on both the upstream and downstream ends of the guardrail system. Design details are shown in Figures 1 through 10. Photographs of the test installation are shown in Figures 11 through 15. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The MGS was constructed with twenty-nine guardrail posts. Post nos. 3 through 27 were galvanized ASTM A36 steel W6x8.5 (W152x12.6) sections measuring 72 in. (1,829 mm) long. Post nos. 1, 2, 28, and 29 were timber posts measuring 5 ½ in. wide x 7 ½ in. deep x 46 in. long (140 mm x 190 mm x 1,168 mm) and were placed in 72-in. (1,829-mm) long steel foundation tubes, as shown in Figures 3 and 6. The timber posts and foundation tubes were part of anchor systems designed to replicate the capacity of a tangent guardrail terminal.

Post nos. 1 through 29 were spaced 75 in. (1,905 mm) on center with a soil embedment depth of 40 in. (1,016 mm), as shown in Figures 1 and 2. The posts were placed in a compacted, coarse, crushed limestone material that met Grading B of AASHTO M147-65 (1990) as described in MASH. For post nos. 3 through 27, 6-in. wide x 12-in. deep x 14 ¾-in. long (152-mm x 305-mm x 362-mm) wood spacer blockouts were used to block the rail away from the front face of the steel posts, as shown in Figures 2 and 5.

Standard 12-gauge (2.67-mm thick) W-beam rails with additional post bolt slots at half post spacing intervals were placed between post nos. 1 and 29, as shown in Figures 1, 3, and 9. The W-beam’s top rail height was 31 in. (787 mm) above the ground surface with a 24 ⅛-in.
(632-mm) center mounting height, or 37 in. (940 mm) above the roadway surface. Rail splices were located at the center of the guardrail span locations, as shown in Figures 1 and 3. All lap splice connections between the rail sections were configured to reduce vehicle snag at the splice during the crash test.

A 6-in. (152-mm) tall AASHTO Type B curb was placed in front of the MGS. The concrete curb constructed in front of the MGS system was 73 ft-6 in. (22.4 m) long, beginning at the midspan between post nos. 8 and 9 to post no. 20, as shown in Figure 1. The toe of the curb was offset 8 ft (2.44 m) in front of the front face of the guardrail. The concrete consisted of a concrete mix with a minimum compressive strength of 4,000 psi (27.6 MPa). All steel reinforcement was specified as ASTM A615 Grade 40 or Grade 60 rebar. Reinforcement consisted of No. 4 longitudinal and vertical bars, as shown in Figure 2.
Figure 1. Test Installation Layout, Test No. MGSC-5
Figure 2. Post and Curb Details, Test No. MGSC-5

Use any number of pieces to fit the length, with a minimum 6" [152] lap.

Note: (1) Curb Offset has a tolerance of 1 3/4" [44] located between the tangent edge of curb and front face of the guardrail.
Figure 3. End Rail and Splice Details, Test No. MGSC-5
Figure 4. Anchor Details, Test No. MGSC-5
Figure 5. Post and Blockout Details, Test No. MGSC-5
Figure 6. BCT Timber Post and Foundation Tube Details, Test No. MGSC-5
Figure 7. BCT Anchor Cable Details, Test No. MGSC-5
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Figure 9. Rail Section Details, Test No. MGSC-5
<table>
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<th>Item No.</th>
<th>QTY.</th>
<th>Description</th>
<th>Material Spec.</th>
<th>Hardware Guide</th>
</tr>
</thead>
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<tr>
<td>a1</td>
<td>25</td>
<td>W6x8.5 [W152x12.6] 72&quot; [1829] long</td>
<td>A36 Steel</td>
<td>PD810a-b</td>
</tr>
<tr>
<td>a2</td>
<td>25</td>
<td>6x12x14 1/4&quot; [152x305x362] Blockout</td>
<td>SYP Grade No.1 or better</td>
<td>-</td>
</tr>
<tr>
<td>a3</td>
<td>12</td>
<td>12&quot;-6&quot; [3810] W-Beam MG5 Section</td>
<td>12 gauge [2.7] AASHTO M180</td>
<td>RWMO4a</td>
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<tr>
<td>a4</td>
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<td>12&quot;-6&quot; [3810] W-Beam MG5 End Section</td>
<td>12 gauge AASHTO M180</td>
<td>RWMO4a</td>
</tr>
<tr>
<td>a5</td>
<td>1</td>
<td>6&quot;-3&quot; [1905] W-Beam MG5 Section</td>
<td>12 gauge [2.7] AASHTO M180</td>
<td>RWMO1a</td>
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<td>a6</td>
<td>4</td>
<td>5/8&quot; [16] Dia. x 10&quot; [254] long Guardrail Bolt</td>
<td>A307</td>
<td>FBB03</td>
</tr>
<tr>
<td>a7</td>
<td>25</td>
<td>5/8&quot; [16] Dia. x 14&quot; [356] long Guardrail Bolt</td>
<td>A307</td>
<td>FBB06</td>
</tr>
<tr>
<td>a8</td>
<td>4</td>
<td>5/8&quot; [16] Dia. x 10&quot; [254] long Hex Head Bolt</td>
<td>A307</td>
<td>FBB16a</td>
</tr>
<tr>
<td>a9</td>
<td>16</td>
<td>5/8&quot; [16] Dia. x 1 1/2&quot; [38] long Hex Head Bolt</td>
<td>A307</td>
<td>FBB16a</td>
</tr>
<tr>
<td>a10</td>
<td>1 12</td>
<td>5/8&quot; [16] Dia. x 1 1/2&quot; [38] Guardrail Bolt</td>
<td>A307</td>
<td>FBB01</td>
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<td>a11</td>
<td>1 61</td>
<td>5/8&quot; [16] Dia. Hex Nut</td>
<td>A5630H</td>
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<td>a12</td>
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<td>5/8&quot; [16] Dia. Flat Washer</td>
<td>F436 Gr. 1</td>
<td>FWC16b</td>
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<tr>
<td>a13</td>
<td>25</td>
<td>160 Double Head Nail</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>b1</td>
<td>4</td>
<td>72&quot; [1829] Foundation Tube</td>
<td>A500 Gr. B</td>
<td>PTE05</td>
</tr>
<tr>
<td>b2</td>
<td>4</td>
<td>BCT Timber Post</td>
<td>SYP Grade No.1 or better (No knots, 18&quot; [457] above or below ground tension face)</td>
<td>PDF01</td>
</tr>
<tr>
<td>b3</td>
<td>4</td>
<td>7/8&quot; [22] Dia. x 7 1/2&quot; [191] long Hex Head Bolt</td>
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<td>FBB22a</td>
</tr>
<tr>
<td>b4</td>
<td>4</td>
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<td>FBB22a</td>
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<tr>
<td>b5</td>
<td>8</td>
<td>7/8&quot; [22] Dia. Flat Washer</td>
<td>F436 Gr. 1</td>
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<tr>
<td>b6</td>
<td>2</td>
<td>3/8&quot; [60] 0.0 x 6&quot; [152] long BCT Post Sleeve</td>
<td>ASTM A53 Grade B Schedule 40</td>
<td>FMM02</td>
</tr>
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<td>b7</td>
<td>2</td>
<td>Strut and Yoke Assembly</td>
<td>A36 Steel</td>
<td>FPF01</td>
</tr>
<tr>
<td>b8</td>
<td>2</td>
<td>Anchor Bracket</td>
<td>A36</td>
<td>FPA01</td>
</tr>
<tr>
<td>b9</td>
<td>2</td>
<td>BCT Cable Anchor Assembly</td>
<td>φ3/4&quot; [19] 6x19 WRG1 IWS Galvanized Wire Rope</td>
<td>FCA01–02</td>
</tr>
<tr>
<td>b10</td>
<td>2</td>
<td>8&quot;x8&quot;x5/8&quot; [203x203x16] Anchor Bearing Plate</td>
<td>A36 Steel</td>
<td>FBP01</td>
</tr>
<tr>
<td>b11</td>
<td>4</td>
<td>1&quot; [25] Dia. Hex Nut</td>
<td>A5630H</td>
<td>FNX24a</td>
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<tr>
<td>b12</td>
<td>4</td>
<td>1&quot; [25] Dia. Flat Washer</td>
<td>F436 Gr. 1</td>
<td>FWC24a</td>
</tr>
<tr>
<td>c1</td>
<td>1</td>
<td>Curb</td>
<td>Concrete (a/g mix) – Min. 4000 psi [27.6 MPa] Comp. Strength</td>
<td>-</td>
</tr>
<tr>
<td>c2</td>
<td>49</td>
<td>#4 Rebar 12&quot; [305] Long</td>
<td>ASTM A615 Grade 40 or Grade 60</td>
<td>-</td>
</tr>
<tr>
<td>c3</td>
<td>1</td>
<td>#4 Rebar 75&quot; [22.3 m] Long</td>
<td>ASTM A615 Grade 40 or Grade 60</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 10. Bill of Materials, Test No. MGSC-5
Figure 11. Test Installation Photographs, Test No. MGSC-5
Figure 12. Test Installation Photographs, Test No. MGSC-5
Figure 13. Test Installation Photographs, Test No. MGSC-5
Figure 14. Test Installation Photographs, Test No. MGSC-5
Figure 15. Test Installation Photographs, Test No. MGSC-5
3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Longitudinal barriers, such as W-beam guardrail systems with curbs, must satisfy impact safety standards provided in MASH (9) in order to be accepted by the Federal Highway Administration (FHWA) for use on National Highway System (NHS) new construction projects or as a replacement for existing designs not meeting current safety standards. According to TL-3 of MASH, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests. The two full-scale crash tests are as follows:

1. Test Designation 3-10 consisting of a 2,425-lb (1,100-kg) passenger car impacting the system at a nominal speed and angle of 62 mph (100 km/h) and 25 degrees, respectively.

2. Test Designation 3-11 consisting of a 5,004-lb (2,270-kg) pickup truck impacting the system at a nominal speed and angle of 62 mph (100 km/h) and 25 degrees, respectively.

The test conditions of TL-3 longitudinal barriers are summarized in Table 1.

Table 1. MASH TL-3 Crash Test Conditions

<table>
<thead>
<tr>
<th>Test Article</th>
<th>Test Designation</th>
<th>Test Vehicle</th>
<th>Speed</th>
<th>Angle (deg.)</th>
<th>Evaluation Criteria 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal Barrier</td>
<td>3-10</td>
<td>1100C</td>
<td>62</td>
<td>100</td>
<td>A,D,F,H,I</td>
</tr>
<tr>
<td></td>
<td>3-11</td>
<td>2270P</td>
<td>62</td>
<td>100</td>
<td>A,D,F,H,I</td>
</tr>
</tbody>
</table>

1 Evaluation criteria explained in Table 2.
3.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the barrier to contain and redirect impacting vehicles. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Vehicle trajectory after collision is a measure of the potential for the post-impact trajectory of the vehicle to become involved in secondary collisions with other vehicles or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 2 and defined in greater detail in MASH. The full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in MASH.

3.3 Soil Strength Requirements

In order to limit the variation of soil strength among testing agencies, foundation soil must satisfy the recommended performance characteristics set forth in Chapter 3 and Appendix B of MASH. Testing facilities must first subject their soil to a dynamic post test to demonstrate a minimum dynamic load of 7.5 kips (33.4 kN) at deflections between 5 and 20 in. (127 and 508 mm). If satisfactory results are observed, a static test is conducted using an identical test installation. The results of this static test become the baseline requirement for soil strength in future full-scale testing. On the full-scale test day, an additional post installed near the impact point is statically tested in the same manner as the baseline test. If the static test results show a resistance equal to 90 percent or greater of the baseline test at deflections of 5, 10, and 15 in. (127, 254, and 381 mm), the soil has adequate strength and the full-scale test can be conducted.
The static test results for the full-scale test along with the baseline static test are shown in Appendix B.

Table 2. MASH Evaluation Criteria for Longitudinal Barriers

<table>
<thead>
<tr>
<th>A. Structural Adequacy</th>
<th>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.</th>
</tr>
</thead>
<tbody>
<tr>
<td>D. Occupant Risk</td>
<td>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 5.3 and Appendix E of MASH.</td>
</tr>
<tr>
<td>F. Occupant Risk</td>
<td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td>
</tr>
<tr>
<td>H. Occupant Risk</td>
<td>Occupant Impact Velocities (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td>
</tr>
<tr>
<td></td>
<td>Occupant Impact Velocity Limits, ft/s (m/s)</td>
</tr>
<tr>
<td></td>
<td>Component</td>
</tr>
<tr>
<td></td>
<td>Longitudinal and Lateral</td>
</tr>
<tr>
<td>I. Occupant Risk</td>
<td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td>
</tr>
<tr>
<td></td>
<td>Occupant Ridedown Acceleration Limits (g’s)</td>
</tr>
<tr>
<td></td>
<td>Component</td>
</tr>
<tr>
<td></td>
<td>Longitudinal and Lateral</td>
</tr>
</tbody>
</table>
4 TEST CONDITIONS

4.1 Test Facility

The testing facility is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 5 miles (8.0 km) northwest of the University of Nebraska-Lincoln.

4.2 Vehicle Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the barrier system. A digital speedometer on the tow vehicle increased the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch (12) was used to steer the test vehicle. A guide-flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lbf (15.6 kN) and supported both laterally and vertically every 100 ft (30.48 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide-flag struck and knocked each stanchion to the ground. For test no. MGSC-5, the vehicle guidance system was 1,101 ft (336 m) long.

4.3 Test Vehicles

For test no. MGSC-5, a 2003 Dodge Ram 1500 Quad Cab pickup truck was used as the test vehicle. The test inertial and gross static weights were 5,028 lb (2,281 kg) and 5,198 lb (2,358 kg), respectively. The test vehicle is shown in Figure 16, and vehicle dimensions are shown in Figure 17.
Figure 16. Test Vehicle, Test No. MGSC-5
**Figure 17. Vehicle Dimensions, Test No. MGSC-5**

- **Date:** 4/8/2009
- **Test Number:** MGSC-5
- **Model:** Ram 1500 Q.C.
- **Make:** Dodge
- **Vehicle I.D.#:** 1D7HA18N8KJ5262581
- **Tire Size:** 265/70 R17
- **Year:** 2003
- **Odometer:** 139905
- **Tire Inflation Pressure:** 32 p.s.i.

### Vehicle Geometry -- in. (mm)

<table>
<thead>
<tr>
<th></th>
<th>a 78.5 (1994)</th>
<th>b 75.25 (1911)</th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>229.5 (5829)</td>
<td>d 45.25 (1149)</td>
</tr>
<tr>
<td>e</td>
<td>140.25 (3562)</td>
<td>f 44 (1118)</td>
</tr>
<tr>
<td>g</td>
<td>28.13 (714)</td>
<td>h 62.33 (1583)</td>
</tr>
<tr>
<td>i</td>
<td>15.5 (394)</td>
<td>j 27.5 (699)</td>
</tr>
<tr>
<td>k</td>
<td>21.5 (546)</td>
<td>l 28.5 (724)</td>
</tr>
<tr>
<td>m</td>
<td>68 (1727)</td>
<td>n 67.75 (1721)</td>
</tr>
<tr>
<td>o</td>
<td>46 (1168)</td>
<td>p 3.5 (89)</td>
</tr>
<tr>
<td>q</td>
<td>31.5 (800)</td>
<td>r 18.5 (470)</td>
</tr>
<tr>
<td>s</td>
<td>15.5 (394)</td>
<td>t 77.5 (1969)</td>
</tr>
</tbody>
</table>

- **Wheel Center Height Front:** 15.25 (387)
- **Wheel Center Height Rear:** 15.375 (391)
- **Wheel Well Clearance (F):** 36 (914)
- **Wheel Well Clearance (R):** 38 (965)
- **Frame Height (F):** 18 (457)
- **Frame Height (R):** 25 (635)

- **Engine Type:** 8 CYL. GAS
- **Engine Size:** 4.7

- **Transmission Type:** Automatic

### Mass Distribution

<table>
<thead>
<tr>
<th>Gross Static</th>
<th>LF 1449</th>
<th>RF 1436</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR 1117</td>
<td>RR 1196</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weights lbs (kg)</th>
<th>Curb</th>
<th>Test Inertial</th>
<th>Gross Static</th>
</tr>
</thead>
<tbody>
<tr>
<td>W-front</td>
<td>2854 (1295)</td>
<td>2769 (1256)</td>
<td>2885 (1309)</td>
</tr>
<tr>
<td>W-rear</td>
<td>2297 (1042)</td>
<td>2259 (1025)</td>
<td>2313 (1049)</td>
</tr>
<tr>
<td>W-total</td>
<td>5151 (2336)</td>
<td>5028 (2281)</td>
<td>5198 (2358)</td>
</tr>
</tbody>
</table>

### GVWR Ratings

- **Front:** 3650
- **Rear:** 3900
- **Total:** 6650

### Dummy Data

- **Type:** Hybrid II
- **Mass:** 170 lbs
- **Seat Position:** Passenger, Full Rearward

**Note any damage prior to test:** Repaired SR-8 test vehicle, some cosmetic damage
The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method (13) was used to determine the vertical component of the c.g. for the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition, as is shown in Figures 17 and 18. Data used to calculate the location of the c.g. is shown in Appendix C.

Square, black and white, checkered targets were placed on the vehicle to aid in the analysis of the high-speed videos, as shown in Figure 18. Round, checkered targets were placed on the center of gravity on the left-side door, the right-side door, and the roof of the vehicle. The remaining targets were located for references so that they could be viewed from the high-speed cameras for video analysis.

The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicle would track properly along the guide cable. A 5B flash bulb was mounted near the center of the vehicle’s dash to pinpoint the time of impact with the barrier system on the high-speed videos. The flash bulb was fired by a pressure tape switch mounted at the impact corner of the bumper. A remote controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.

4.4 Simulated Occupant

A Hybrid II 50th Percentile Adult Male Test Dummy, equipped with clothing and footwear, was placed in the right-front seat of the test vehicle with the seat belt fastened. The dummy, which had a final weight of 170 lb (77 kg), was represented by model no. 572 and
TEST #: MGSC-5
TARGET GEOMETRY-- in. (mm)

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>73.625 (1870)</td>
<td>E</td>
</tr>
<tr>
<td>B</td>
<td>107 (2718)</td>
<td>F</td>
</tr>
<tr>
<td>C</td>
<td>48 (1219)</td>
<td>G</td>
</tr>
<tr>
<td>D</td>
<td>64 (1626)</td>
<td>H</td>
</tr>
</tbody>
</table>

Figure 18. Target Geometry, Test No. MGSC-5
serial no. 451 and was manufactured by Android Systems of Carson, California. As recommended by MASH, the dummy was not included in calculating the c.g. location.

4.5 Data Acquisition Systems

4.5.1 Accelerometers

Three environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. All of the accelerometers were mounted near the center of gravity of the test vehicles.

One triaxial piezoresistive accelerometer system, Model EDR-4 6DOF-500/1200, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan and included three differential channels as well as three single-ended channels. The EDR-4 was configured with 24 MB of RAM memory, a range of ±500 g’s, a sample rate of 10,000 Hz and a 1,677 Hz anti-aliasing filter. “EDR4Com” and “DynaMax Suite” computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The second accelerometer system was a two-Arm piezoresistive accelerometer system developed by Endevco of San Juan Capistrano, California. Three accelerometers were used to measure each of the longitudinal, lateral, and vertical accelerations independently at a sample rate of 10,000 Hz. Data was collected using a Sensor Input Module (SIM), Model TDAS3-SIM-16M, which was developed by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The SIM was configured with 16 MB SRAM memory and 8 sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal backup battery. Both the SIM and module rack were
crashworthy. The “DTS TDAS Control” computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The third system, Model EDR-3, was a triaxial piezoresistive accelerometer, also developed by Instrumented Sensor Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 kB of RAM memory, a range of ±200 g’s, a sample rate of 3,200 Hz, and a 1,120 Hz lowpass filter. “DynaMax 1 (DM-1)” and “DADiSP” computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.5.2 Rate Transducers

An Analog Systems 3-axis rate transducer with a range of 1,200 degrees/sec in each of the three directions (roll, pitch, and yaw) was used to measure the rates of motion of the test vehicle. The rate transducer was mounted inside the body of the EDR-4 6DOF-500/1200 and recorded data at 10,000 Hz to a second data acquisition board inside the EDR-4 6DOF-500/1200 housing. The raw data measurements were then downloaded, converted to the appropriate Euler angles for analysis, and plotted. “EDR4Com” and “DynaMax Suite” computer software programs and a customized Microsoft Excel spreadsheet were used to analyze and plot the rate transducer data.

An additional angle rate sensor, the ARS-1500, with a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) was used to measure the rates of rotation of the test vehicle. The angular rate sensor was mounted on an aluminum block inside the test vehicle near the center of gravity and recorded data at 10,000 Hz to the SIM. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The “DTS TDAS Control” computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.
4.5.3 Pressure Tape Switches

For test no. MGSC-5, five pressure-activated tape switches spaced at 6.56 ft (2 m) intervals were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the right-front tire of the test vehicle passed over it. Test vehicle speeds were determined from electronic timing mark data recorded using TestPoint and LabVIEW computer software programs. Strobe lights and high-speed video analysis are used only as a backup in the event that vehicle speed cannot be determined from the electronic data.

4.5.4 Digital Photography

Two high-speed AOS VITcam digital video cameras, three high-speed AOS X-PRI digital video cameras, four JVC digital video cameras, and two Canon digital video cameras were utilized to film test no. MGSC-5. Camera details, camera operating speeds, lens information, and a schematic of the camera locations are shown in Figure 19. The high-speed videos were analyzed using ImageExpress MotionPlus software. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos.
<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>Operating Speed (frames/sec)</th>
<th>Lens</th>
<th>Lens Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>AOS Vitcam CTM</td>
<td>500</td>
<td>Fixed 12.5 mm</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>AOS Vitcam CTM</td>
<td>500</td>
<td>Sigma 24 - 135 mm</td>
<td>50 mm</td>
</tr>
<tr>
<td>5</td>
<td>AOS X-PRI</td>
<td>500</td>
<td>Sigma 70 - 200 mm</td>
<td>100 mm</td>
</tr>
<tr>
<td>6</td>
<td>AOS X-PRI</td>
<td>500</td>
<td>Sigma 24 - 70 mm</td>
<td>24 mm</td>
</tr>
<tr>
<td>7</td>
<td>AOS X-PRI</td>
<td>500</td>
<td>Sigma Fixed 50 mm</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>Operating Speed (frames/sec)</th>
<th>Lens</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>JVC - GZ-MC500 (Everio)</td>
<td>29.97</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>JVC - GZ-MG27u (Everio)</td>
<td>29.97</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>JVC - GZ-MG27u (Everio)</td>
<td>29.97</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>JVC - GZ-MG27u (Everio)</td>
<td>29.97</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Canon-ZR90</td>
<td>29.97</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Canon-ZR10</td>
<td>29.97</td>
<td></td>
</tr>
</tbody>
</table>

Figure 19. Camera Locations, Test No. MGSC-5
5 FULL-SCALE CRASH TEST NO. MGSC-5

5.1 Static Soil Test

Before full-scale test no. MGSC-5 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static test results, as shown in Appendix B, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and the barrier system was approved for full-scale testing.

5.2 Test No. MGSC-5

The 5,198-lb (2,358-kg) pickup truck, with a dummy placed in the right-front seat, impacted the curb at a speed of 61.9 mph (99.5 km/h) and at an angle of 25.7 degrees. After mounting the curb, the vehicle impacted the guardrail at an angle of 24.4 degrees. A summary of the test results and sequential photographs are shown in Figure 20. Additional sequential photographs are shown in Figures 21 and 22. Documentary photographs of the crash test are shown in Figures 23 and 24.

5.3 Weather Conditions

Test no. MGSC-5 was performed April 8, 2009, at approximately 1:30 p.m. The weather conditions were reported as shown in Table 3.

Table 3. Weather Conditions, Test No. MGSC-5

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>65°F</td>
</tr>
<tr>
<td>Humidity</td>
<td>22%</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>11 mph</td>
</tr>
<tr>
<td>Wind Direction</td>
<td>0° deg from True North</td>
</tr>
<tr>
<td>Sky Conditions</td>
<td>Sunny</td>
</tr>
<tr>
<td>Visibility</td>
<td>10 Statute Miles</td>
</tr>
<tr>
<td>Pavement Surface</td>
<td>Dry</td>
</tr>
<tr>
<td>Previous 3-Day Precipitation</td>
<td>0.03 in.</td>
</tr>
<tr>
<td>Previous 7-Day Precipitation</td>
<td>0.03 in.</td>
</tr>
</tbody>
</table>
5.4 Test Description

Initial vehicle impact with the guardrail was to occur between post nos. 12 and 13, or 14 ft-11 in. (4.55 m) upstream of the splice between post nos. 14 and 15, as shown in Figure 25. The actual point of impact was 14 ft-7 ½ in. (4.46 m) upstream of the splice between post nos. 14 and 15. A sequential description of the impact events is contained in Table 4. The final position of the vehicle was determined to be 130 ft-8 ½ in. (39.84 m) downstream from impact and 22 ft-10 in. (6.96 m) laterally away from the traffic-side face of the barrier, as shown in Figures 20 and 26.

Table 4. Sequential Description of Impact Events

<table>
<thead>
<tr>
<th>TIME (sec)</th>
<th>EVENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.192</td>
<td>The right-front tire contacted face of mountable curb.</td>
</tr>
<tr>
<td>-0.156</td>
<td>The vehicle rolled toward the left.</td>
</tr>
<tr>
<td>-0.060</td>
<td>The right-rear tire contacted face of the mountable curb.</td>
</tr>
<tr>
<td>-0.048</td>
<td>The left-front tire contacted face of the mountable curb.</td>
</tr>
<tr>
<td>-0.016</td>
<td>The right-front tire became airborne.</td>
</tr>
<tr>
<td>-0.012</td>
<td>The vehicle rolled toward the right.</td>
</tr>
<tr>
<td>0.000</td>
<td>The right-front bumper corner contacted the rail.</td>
</tr>
<tr>
<td>0.002</td>
<td>The guardrail deformed at impact location.</td>
</tr>
<tr>
<td>0.004</td>
<td>Post nos. 12 and 13 deflected laterally backward.</td>
</tr>
<tr>
<td>0.008</td>
<td>Posts upstream of impact twisted such that their front flanges turned downstream as the rail was tensioned.</td>
</tr>
<tr>
<td>0.04</td>
<td>Post no. 13 twisted such that its front flange turned upstream.</td>
</tr>
<tr>
<td>0.042</td>
<td>Post nos. 11 and 14 deflected laterally backward.</td>
</tr>
<tr>
<td>0.046</td>
<td>The front end of the vehicle yawed away from the barrier.</td>
</tr>
<tr>
<td>0.062</td>
<td>The rail disengaged from post no. 13, and the right-front tire stopped rotating.</td>
</tr>
<tr>
<td>0.074</td>
<td>Post no. 15 deflected laterally backward and twisted such that its front flange turned upstream.</td>
</tr>
<tr>
<td>0.096</td>
<td>A buckle point formed in the rail at post no. 15, downstream of vehicle.</td>
</tr>
</tbody>
</table>
0.106 The left-rear tire contacted the front face of the mountable curb, and the rail disengaged from post no. 14.

0.124 The left-front tire became airborne.

0.128 Post no. 16 deflected laterally backward.

0.150 The vehicle rolled toward the right.

0.156 The left-rear tire became airborne.

0.160 A buckle point formed in the rail at post no. 12, upstream of vehicle.

0.170 The right-front tire contacted post no. 14 and disengaged from vehicle.

0.208 Post no. 17 deflected laterally backward.

0.216 The front of vehicle pitched upward.

0.220 The rail disengaged from post no. 15.

0.244 The right-rear bumper corner contacted the rail upstream of post no. 13.

0.258 The right side of vehicle contacted the rail along its entire length.

0.284 The rail disengaged from post no. 16, which twisted such that its front flange turned downstream.

0.296 The vehicle became parallel to the barrier with a resultant velocity of 52.5 mph (84.5 km/h).

0.304 Post no. 18 deflected laterally backward.

0.324 The right-rear bumper corner contacted the rail, and the right-front tire contacted the wood blockout at post no. 16.

0.370 The rear end of the vehicle pitched upward.

0.382 The right-rear tire climbed up the face of the rail.

0.384 The front end of the vehicle continued to yaw away from the barrier.

0.450 The right-rear tire lost contact with the top of the rail at post no. 15, and the vehicle exited the system while completely airborne and continuing to roll.

0.508 The rail disengaged from post no. 17.

0.534 The vehicle reached its critical roll angle and rolled over the barrier.

0.556 The right-rear tire contacted the wood blockout at post no. 16, causing the blockout to fracture.

0.634 The vehicle continued to roll.

0.720 The right-front quarter panel contacted the top of the rail between post nos. 20 and 21.

0.982 The right-front bumper corner contacted the ground in front of post no. 23.

1.012 The vehicle rolled approximately 90 degrees.

1.440 The top-right of the truck bed contacted the top of the rail at post no. 26.

1.528 The vehicle rolled approximately 180 degrees.

1.840 The vehicle rolled approximately 270 degrees.
2.130 The vehicle rolled approximately 360 degrees.

2.334 The vehicle rolled approximately 450 degrees.

2.652 The vehicle rolled approximately 540 degrees.

5.5 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 27 through 38. Barrier damage consisted of deformed guardrail posts, disengaged wooden blockouts, contact marks on several sections of guardrail and the curb, and deformed W-beam rail. Five areas of contact between the vehicle and guardrail occurred, with the most substantial damage occurring at the original impact point. Three regions of light scuff marks occurred downstream of the original impact as the vehicle rolled. The final contact area occurred when the vehicle landed upside-down on the guardrail. The length of the original vehicle contact along the system was approximately 30 ft-3 in. (9.22 m), which spanned from 12 in. (305 mm) downstream of post no. 12 through the centerline of post no. 17.

Deformation and flattening of the W-beam guardrail occurred between post nos. 12 and 17, the primary vehicle contact region. Contact marks were visible on the guardrail beginning 12 in. (305 mm) downstream from post nos. 12 and ending at post no. 17. Additional contact marks were found on the top of the rail and included a 37-in. (940-mm) long mark beginning 25 ¾ in. (654 mm) downstream of post no. 20, a 77-in. (1,956-mm) long mark beginning 6 ½ in. (165 mm) downstream of post no. 21, an 18-in. (457-mm) long mark beginning 3 in. (76 mm) upstream of post no. 23, and a 96-in. (2,438-mm) long mark beginning 20 in. (508 mm) downstream of post no. 25.
Slight buckling occurred in the guardrail at post no. 11, with significant buckling at post nos. 12, 16, and 17. The bottom portion of the W-beam was bent upward between post no. 15 and the centerline of the splice between post nos. 16 and 17. The top of the W-beam deformed downward at post nos. 26 and 27 and the splice between post nos. 27 and 28. The W-beam guardrail was detached from post nos. 13 through 17, 26, and 27 as the bolt head was pulled through the rail. Local yielding occurred around the post bolt slots at post nos. 12 through 17, 26, and 27. A rail gap of \( \frac{3}{8} \) in. (9.5 mm) occurred at the splice between post nos. 12 and 13.

Post nos. 11 through 18 and 26 through 27 sustained varying degrees of bending, rotation, and twisting. Post nos. 13 and 15 twisted and rotated backward and downstream. Post no. 14 also twisted, rotated backward, and deflected downstream to the ground. Post no. 16 rotated backward and downstream, but did not twist. Post nos. 26 and 27 bent downstream, with post no. 26 bending to a greater extent than post no. 27. Post nos. 26 and 27 also sustained deformations at their tops. A soil gap of \( \frac{3}{8} \) in. (10 mm) was present at the front face of post no. 11. Soil gaps of 1 \( \frac{1}{4} \) in. (32 mm) and 1 \( \frac{3}{4} \) in. (44 mm) were present at the front and back faces of post no. 12, respectively. Soil gaps of 8 in. (203 mm), 5 in. (127 mm), 4 \( \frac{1}{4} \) in. (108 mm), and 3 \( \frac{1}{4} \) in. (83 mm) were present at the front faces of post nos. 13, 14, 16, and 17, respectively. A minimal soil gap was present at the front face of post no. 18, and a \( \frac{1}{2} \)-in. (13-mm) soil gap was present at its back face. A 6-in. (152-mm) soil gap was present on the upstream side of post no. 26. The upstream anchorage system moved slightly longitudinally, but the downstream anchorage system did not. All four wood BCT posts in both anchorage systems remained undamaged.

The blockout at post no. 13 sustained minor damage near its bottom edge due to contact with the rail. The 4-in. (102-mm) deep blockout at post no. 14 fractured and detached, while the
8-in. (203-mm) deep blockout remained attached after sustaining damage from rail contact. The blockouts at post no. 15 twisted away from the post, bending the bolt, and the 4-in. (102-mm) deep blockout sustained a small fracture at its back face. The 4-in. (102-mm) deep blockout at post no. 16 also fractured and detached, while the 8-in. (203-mm) deep blockout remained attached by the deformed guardrail bolt. The 8-in. (203-mm) deep blockout at post no. 17 twisted, but remained attached to the post. All other blockouts remained attached to the posts and undamaged.

The permanent set of the barrier system is shown in Figure 27. The maximum permanent set rail and post deflections were 24 in. (610 mm) at post no. 15 and 28 in. (711 mm) at post no. 14, respectively, as measured in the field. The maximum lateral dynamic rail and post deflections were 50.5 in. (1,283 mm) at post no. 14 and 28.5 in. (724 mm) at post no. 13, respectively, as determined from high-speed digital video analysis. The working width was not determined due to vehicle rollover.

5.6 Vehicle Damage

The damage to the vehicle was extensive, as shown in Figures 39 through 43. Occupant compartment deformations were judged to be significant to cause serious injury to vehicle occupants. Deformations to the vehicle floorboard were relatively minor, with maximum longitudinal, lateral, and vertical deflections of ¼ in. (6 mm) located throughout the right-side floorboard, ½ in. (13 mm) located along the right side of the right-side floorboard, and 2 in. (51 mm) located near the center of the vehicle’s floorboard, respectively. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.
Exterior damage was located on all portions of the vehicle. Both right-side wheel assemblies were detached from the vehicle. The right-front wheel spindle and assembly detached from the suspension control arms. The rear axle fractured at the right-rear wheel. The right-front quarter panel and bumper were deformed inward toward the engine compartment. Scrapes and gouges were found along the right-side doors and right-rear quarter panel. The right-side headlight and both rear tail lights fractured. The left side of the truck box was significantly deformed and bent away from the cab. Minor deformations occurred along the left-side doors, left-front quarter panel, and rear bumper. Both the left- and right-side mirrors disengaged from the truck. The hood and grill were slightly deformed and displaced. The roof was crushed inward, especially on the left side. The windshield was severely shattered and partially displaced. The right-front door, rear, and both left-side door window glass was fractured and removed from the vehicle. The right-rear door window glass remained undamaged.

5.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 5. It is noted that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV and PHD values are also shown in Table 5. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 20. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.
Table 5. Summary of OIV, ORA, THIV, and PHD Values, Test No. MGSC-5

<table>
<thead>
<tr>
<th></th>
<th>Transducer</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EDR-4</td>
<td>DTS</td>
<td>EDR-3</td>
<td></td>
</tr>
<tr>
<td><strong>OIV ft/s (m/s)</strong></td>
<td>Longitudinal</td>
<td>-14.89</td>
<td>(-4.54)</td>
<td>-16.77</td>
</tr>
<tr>
<td></td>
<td>Lateral</td>
<td>-12.35</td>
<td>(-3.76)</td>
<td>-12.54</td>
</tr>
<tr>
<td><strong>ORA g's</strong></td>
<td>Longitudinal</td>
<td>-13.49</td>
<td>-14.38</td>
<td>-14.12</td>
</tr>
<tr>
<td></td>
<td>Lateral</td>
<td>-15.13</td>
<td>-16.33</td>
<td>-6.74</td>
</tr>
<tr>
<td><strong>THIV ft/s (m/s)</strong></td>
<td></td>
<td>18.21</td>
<td>(5.55)</td>
<td>20.06</td>
</tr>
<tr>
<td><strong>PHD g's</strong></td>
<td></td>
<td>14.37</td>
<td></td>
<td>15.40</td>
</tr>
</tbody>
</table>

### 5.8 Discussion

The analysis of the test results for test no. MGSC-5 showed that the MGS guardrail and curb configuration did not adequately contain nor redirect the 2270P vehicle, since the vehicle did not remain upright after collision with the barrier. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into the occupant compartment that could have caused serious injury did occur with the deformation of the vehicle’s roof. Vehicle roll, pitch, and yaw angular displacements were noted, as shown in Appendix E, and were deemed unacceptable because they adversely influenced occupant risk safety criteria. Therefore, test no. MGSC-5 conducted on the MGS offset 8 ft (2.438 m) behind a 6-in. (152-mm) high curb was determined to be unacceptable according to test designation no. 3-11 of the TL-3 safety performance criteria found in MASH.
Following the unacceptable test results, the causes of vehicle rollover were determined from a series of events. As the vehicle impacted the guardrail, redirection was initiated; however, due to the upward lift of the truck following curb contact, the right-front wheel contacted the guardrail. As the system rotated, post no. 15 applied an upward force on the vehicle’s front end, causing the front of the vehicle to pitch upward and the front bumper to rise above the guardrail. At this same time, the right-front wheel snagged on post no. 15, causing the pickup to roll toward the system. Subsequently, the right-front wheel detached from the vehicle due to the snag and was pulled underneath the pickup truck. As the vehicle continued along its path, the right-rear wheel then contacted the disengaged right-front wheel and overrode it. This caused the rear end of the vehicle to pitch upward, and shortly thereafter the vehicle became airborne. The pickup, which previously began to roll due to wheel snag, lost contact with the guardrail and continued to roll while airborne. This in turn caused the vehicle to roll over completely.
- Test Agency ................................................................. MwRSF
- Test Number ............................................................ MGSC-5
- Date .............................................................................. April 8, 2009
- MASH Test Designation .............................................. 3-11
- Test Article ....................................................................... MGS offset 6 ft behind 6-in. high curb
- Total Length (Curb) ...................................................... 175 ft (53.3 m)
- Key Component – Midwest Guardrail System
  Length ........................................................................... 175 ft (53.3 m)
  Post Spacing .......................................................... 75 in. (1,905 mm)
- Key Component – AASHTO Type B Curb
  Length .......................................................................... 73 ft-6 in. (22.4 m)
  Height .............................................................................. 6 in. (152 mm)
- Soil Type ........................................................................... Grade B, AASHTO M147-65 (1990)
- Vehicle Model .......................................................... 2003 Dodge Ram 1500 Quad Cab Pickup Truck
- Vehicle Damage ........................................................ Extensive
- Test Inertial ..................................................................... 5,028 lb (2,281 kg)
- Gross Static .................................................................... 5,198 lb (2,358 kg)
- Speed ................................................................................ 61.9 mph (99.5 km/h)
- Angle (Guardrail) ...................................................... 25.7 degrees
- Angle (Curb) ............................................................. 24.4 degrees
- Location ........................................................................ 14 ft 7 ½ in. (4.6 m) US of splice between posts 14 and 15
- Exit Conditions
  Speed .............................................................................. N/A
  Angle .............................................................................. N/A
  Exit Box ......................................................................... N/A
- Vehicle Stability ........................................................ Unsatisfactory, rollover
- Vehicle Stopping Distance .................................. 130 ft-8 ½ in. (39.8 m) downstream
- THIV (EDR-4 – not required) .......................... 18.21 ft/s (5.55 m/s)
- THIV (DTS – not required) .................................. 20.06 ft/s (6.11 m/s)
- PHD (DTS – not required) .................................. 15.40 g’s

- Occupant Ridedown Acceleration (DTS)
  Longitudinal .................................................. -16.77 ft/s (-5.11 m/s) < 40 ft/s (12.2 m/s)
  Lateral .................................................. -12.54 ft/s (-3.82 m/s) < 40 ft/s (12.2 m/s)
- Occupant Impact Velocity (DTS)
  Longitudinal .................................................. -14.89 ft/s (-4.54 m/s) < 40 ft/s (12.2 m/s)
  Lateral .................................................. -12.35 ft/s (-3.76 m/s) < 40 ft/s (12.2 m/s)
- Occupant Ridedown Acceleration (EDR-4)
  Longitudinal .................................................. -13.49 g’s < 20.49 g’s
  Lateral .................................................. -15.13 g’s < 20.49 g’s
- Occupant Impact Velocity (EDR-4)
  Longitudinal .................................................. -16.67 ft/s (-5.11 m/s) < 40 ft/s (12.2 m/s)
  Lateral .................................................. -12.54 ft/s (-3.82 m/s) < 40 ft/s (12.2 m/s)
- Occupant Ridedown Acceleration (EDR-3)
  Longitudinal .................................................. -14.12 g’s < 20.49 g’s
  Lateral .................................................. -6.74 g’s < 20.49 g’s
- Occupant Impact Velocity (EDR-3)
  Longitudinal .................................................. -16.29 ft/s (-4.97 m/s) < 40 ft/s (12.2 m/s)
  Lateral .................................................. -12.86 ft/s (-3.92 m/s) < 40 ft/s (12.2 m/s)
- Vehicle Damage ........................................................ Extensive
- Vehicle Stopping Distance .................................. 22 ft-10 in. (7.0 m) traffic-side face
- THIV (DTS – not required) .................................. 18.21 ft/s (5.55 m/s)
- PHD (DTS – not required) .................................. 14.37 g’s
- Angular Displacements (EDR-4)
  Roll .......................................................... 792 degrees
  Pitch .......................................................... 25 degrees
  Yaw ............................................................ -138 degrees

Figure 20. Summary of Test Results and Sequential Photographs, Test No. MGSC-5
Figure 21. Additional Sequential Photographs, Test No. MGSC-5
Figure 22. Additional Sequential Photographs, Test No. MGSC-5
Figure 23. Documentary Photographs, Test No. MGSC-5
Figure 25. Impact Location, Test No. MGSC-5
Figure 26. Vehicle Final Position and Trajectory Marks, Test No. MGSC-5
Figure 27. System Damage, Test No. MGSC-5
Figure 28. Curb Damage, Test No. MGSC-5
Figure 29. Rail Damage, Post Nos. 12 and 13, Test No. MGSC-5
Figure 30. Rail Damage, Post Nos. 14 and 15, Test No. MGSC-5
Figure 31. Rail Damage, Post Nos. 16 and 17, Test No. MGSC-5
Figure 33. Post Nos. 11 and 12 Damage, Test No. MGSC-5
Figure 34. Post Nos. 13 and 14 Damage, Test No. MGSC-5
Figure 35. Post Nos. 15 and 16 Damage, Test No. MGSC-5
Figure 36. Post Nos. 17 and 18 Damage, Test No. MGSC-5
Figure 37. Post Nos. 26 and 27 Damage, Test No. MGSC-5
Figure 38. Upstream Anchorage Damage, Test No. MGSC-5
Figure 39. Vehicle Damage, Test No. MGSC-5
Figure 40. Vehicle Damage, Test No. MGSC-5
6 SUMMARY AND CONCLUSIONS

The MGS installed 8 ft (2.44 m) behind a 6-in. (152-mm) tall AASHTO Type B curb was constructed and full-scale crash tested. One full-scale vehicle crash test was performed according to test designation 3-11 as defined in MASH. The test consisted of a 5,198-lb (2,358-kg) pickup truck impacting the curb at a speed of 61.9 mph (99.5 km/h) and at an angle of 25.7 degrees. After mounting the curb, the vehicle impacted the guardrail at an angle of 24.4 degrees. The impact point for this test was 14 ft 7 ½ in. (4.6 m) upstream of the splice between posts 14 and 15. The vehicle began to redirect, but became unstable during the event and rolled multiple times. This rollover is believed to have been caused by the upward lift of the pickup truck following impact with the curb, snag and disengagement of the right-front tire, and subsequent override of the detached tire by the right-rear tire. Thus, this test was judged to be unacceptable according to the safety performance criteria presented in MASH. A summary of the safety performance evaluation is provided in Table 6.
Table 6. Summary of Safety Performance Evaluation Results

<table>
<thead>
<tr>
<th>Evaluation Factors</th>
<th>Evaluation Criteria</th>
<th>Test No. MGSC-5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>A.</strong> 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>U</td>
</tr>
<tr>
<td>Structural Adequacy</td>
<td><strong>D.</strong> 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 5.3 and Appendix E of MASH.</td>
<td>U</td>
</tr>
<tr>
<td></td>
<td><strong>F.</strong> The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td>
<td>U</td>
</tr>
<tr>
<td></td>
<td><strong>H.</strong> Occupant Impact Velocities (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td><strong>Occupant Impact Velocity Limits, ft/s (m/s)</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Component</td>
<td>Preferred</td>
</tr>
<tr>
<td></td>
<td>Longitudinal and Lateral</td>
<td>30 ft/s (9.1 m/s)</td>
</tr>
<tr>
<td></td>
<td><strong>I.</strong> The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td><strong>Occupant Ridedown Acceleration Limits (g’s)</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Component</td>
<td>Preferred</td>
</tr>
<tr>
<td></td>
<td>Longitudinal and Lateral</td>
<td>15.0 g’s</td>
</tr>
</tbody>
</table>

S – Satisfactory   U – Unsatisfactory   NA - Not Available
7 REFERENCES


8 APPENDICES
Appendix A. Material Specifications
Figure A-1. W6x8.5 Post Material Certification, Test No. MGSC-5
# Certified Analysis

<table>
<thead>
<tr>
<th>Description</th>
<th>Spec Cl.</th>
<th>YY</th>
<th>Heat Code/Kest #</th>
<th>Yield</th>
<th>T8</th>
<th>Elong</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Ni</th>
<th>Co</th>
<th>Cu</th>
<th>Cr</th>
<th>Ve</th>
<th>ACW</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 9/16&quot; Post Above</td>
<td>A-709</td>
<td>12479900</td>
<td>40,600</td>
<td>69,100</td>
<td>23.3</td>
<td>0.190</td>
<td>0.960</td>
<td>0.033</td>
<td>0.830</td>
<td>0.430</td>
<td>0.04</td>
<td>0.300</td>
<td>0.004</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 9/16&quot; 12 Plat. Hole</td>
<td>M-180 A</td>
<td>5831.06</td>
<td>71,200</td>
<td>77,000</td>
<td>23.0</td>
<td>0.051</td>
<td>0.730</td>
<td>0.016</td>
<td>0.015</td>
<td>0.012</td>
<td>0.071</td>
<td>0.00</td>
<td>0.351</td>
<td>0.000</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stein Policy No. LG-002.

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

ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36

ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.

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

NUTS COMPLY WITH ASTM A-363 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

3/4" Dia Cable 6X19 Zinc Coated Swaged End Aisi C-1035 Steel Annealed Stud 1" Dia ASTM 449 Aashto M30, Type II Breaking Strength - 49100 LB

State of Texas, County of Collin 
Notary Public: 
Commission Expires: 
Trinity Highway
Certified By: Quality Assurance

Figure A-2. W6x8.5 Post Material Certification, Test No. MGSC-5
<table>
<thead>
<tr>
<th>HEAT#</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Tensile</th>
<th>Yield</th>
<th>Elong.</th>
<th>Quantity</th>
<th>Class</th>
<th>Type</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>3390</td>
<td>0.21</td>
<td>0.8</td>
<td>0.013</td>
<td>0.007</td>
<td>0.01</td>
<td>81650</td>
<td>62520</td>
<td>20.76</td>
<td>160</td>
<td>2</td>
<td>12GA 12FT6IN/3FT11/2IN WB T2</td>
<td></td>
</tr>
</tbody>
</table>

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-163, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-183, unless otherwise stated.
All other galvanized material conforms with ASTM A-123 & ASTM-505.
All steel used in the manufacture of Domestic Origin. "Steel & Bars Rolled in the United States"
All Bolts and Nuts are of Domestic Origin.

By:
Andrew Ariz
Vice President of Sales and Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by

Dennis M. Baston
Notary Public, State of Ohio
My Commission Expires February 24, 2008

Figure A-3. W-Beam Material Certification, Test No. MGSC-5
Certified Test Report

NORTH STAR BLUESCOPE STEEL LLC
6767 County Road 9
Delta, Ohio 43515
Telephone: (888) 822-2112

Customer:
Lawson Steel, Inc.
3238 E. 82nd St.
Cleveland, OH 44104

Customer P.O.: 021336
Cust. Ref/Part # n/a

Order Number 171137
Line Item Number 1
Heat Number 111813
Coll Number 842536

Ordered Width (mm/in) 1454.150 / 57.250
Ordered Gauge (mm/in) 2.438 / 0.086
Material Description ASTM A568, 1018 CQ Modified
Production Date/Time Mar 1 2008 5:41PM

Heat Chemical Analysis (wt%)

<table>
<thead>
<tr>
<th>Type</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Al</th>
<th>Cu</th>
<th>Ni</th>
<th>Mo</th>
<th>Sn</th>
<th>N</th>
<th>B</th>
<th>V</th>
<th>Nb</th>
<th>Ti</th>
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</thead>
<tbody>
<tr>
<td>Heat</td>
<td>0.19</td>
<td>0.73</td>
<td>0.012</td>
<td>0.003</td>
<td>0.03</td>
<td>0.02</td>
<td>0.09</td>
<td>0.04</td>
<td>0.03</td>
<td>0.01</td>
<td>0.00</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.002</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Mechanical Test Report

All mechanical tests are performed on a sample from the tail of a coil.

<table>
<thead>
<tr>
<th>Yield Strength</th>
<th>Tensile Strength</th>
<th>% Elongation in 2 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>64,860 psi</td>
<td>83,230 psi</td>
<td>23.5%</td>
</tr>
</tbody>
</table>

This material has been produced and tested in accordance with each of the following applicable standards: ASTM E 1800-96, ASTM E 415-98a, ASTM A 751-01, ASTM A 370-03a, JIS Z2201:1996, JIS Z2241:1996. This report certifies that the above test results are representative of those contained in the records of North Star BlueScope Steel LLC for the material identified in this test report and is intended to comply with the requirements of the material description. North Star BlueScope Steel LLC is not responsible for the inability of this material to meet specific applications. Any modifications to this certification as provided negate the validity of this test report. All reproductions must have the written approval of North Star BlueScope Steel. This product was manufactured, melted, cast, and hot-rolled (min. 3:1 reduction ratio), entirely within the U.S.A at North Star BlueScope Steel LLC, Delta, Ohio. This material was not exposed to Mercury or any alloy which is liquid at ambient temperature during processing or while in North Star BlueScope Steel LLC possession. Test equipment calibration certificates are available upon request. NIST traceability is established through test equipment calibration certificates which are available upon request. Uncertainty calculations are calculated in accordance with NIST standards and are maintained at a 4:1 ratio in accordance with NIST standards. Uncertainty data is available upon request.

Tim Mitchell
Manager Quality Assurance and Technology

Date Issued: Mar 12, 2008 11:00:32
Revision#: 01

Figure A-4. W-Beam Material Certification, Test No. MGSC-5
JULY 28TH, 2008

TRINITY INDUSTRIES
PLANT # 55
425 E. O'CONNOR
LIMA, OHIO 45801

ATTN: MR. KEITH HAMBURG

ENCLOSED ARE THE NECESSARY COMPLIANCE CERTIFICATES FOR
YOUR PURCHASE ORDER # 126446 B RELEASE # 26. THESE
CERTIFICATES ARE FOR YOUR PART # 003000G (1,000) PCS 3/4" X 6'6"
DOUBLE SWAGE GUARD RAIL ASSEMBLIES. THEY SHOW THE
DOMESTICITY OF ALL MATERIAL USED, MELTED AND MANUFACTURED IN
THE USA.

VERY TRULY YOURS

[Signature]

JOE CARPENTER
OFFICE / CUSTOMER SERVICE MGR

Figure A-5. Anchor Cable Certificate of Compliance, Test No. MGSC-5
CERTIFICATION OF COMPLIANCE

This is to certify that the diameter, strand construction, minimum breaking strength, and wire coating weights for RP122260 3/4 6x19W RR A741 CL-A SC-US produced on SJR2227 are in accordance with ASTM A741-98(2003) titled "Standard Specification for Zinc Coated Steel Wire Rope and Fittings for Highway Guard Rail".

All wire and rope manufacturing processes occurred in the United States. All steel used was melted and manufactured in the United States.

ACTUAL TEST DATA

<table>
<thead>
<tr>
<th>MEASURED ROPE DIAMETER:</th>
<th>.750</th>
</tr>
</thead>
<tbody>
<tr>
<td>STRAND CONSTRUCTION:</td>
<td>19 WARRINGTON 1-6-(6+6)</td>
</tr>
<tr>
<td>BREAKING STRENGTH:</td>
<td>69,000 pounds Req'd. 42,800 pounds</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ZINC COATING WEIGHTS (Class A):</th>
<th>Wire Dia.</th>
<th>Min. Oz/ft²</th>
<th>Avg. Oz/ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>.395&quot;</td>
<td>N/A</td>
<td>.42</td>
<td></td>
</tr>
<tr>
<td>.460&quot;</td>
<td>.40</td>
<td>.43</td>
<td></td>
</tr>
<tr>
<td>.540&quot;</td>
<td>.40</td>
<td>.63</td>
<td></td>
</tr>
<tr>
<td>.610&quot;</td>
<td>.40</td>
<td>.45</td>
<td></td>
</tr>
</tbody>
</table>

WIRE ROPE CORPORATION OF AMERICA, INC.

[Signature]

Administrator Engineering Information

Figure A-6. Anchor Cable Certificate of Compliance, Test No. MGSC-5
Certificate of Compliance

Report of Chemical Analysis and Physical Tests

Customer: The Commercial Group
G-1427 E Judi Road
Burton, MI 48529

Order No. 156E132

Figure A-7. Anchor Cable Certificate of Compliance, Test No. MGSC-5

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Description</th>
<th>Tensile Strength</th>
<th>WL Test</th>
<th>Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>001</td>
<td>0.0350 Galvanized Wire</td>
<td>334</td>
<td>273,000</td>
<td>85</td>
</tr>
<tr>
<td>002</td>
<td>0.0460 Galvanized Wire</td>
<td>443</td>
<td>267,000</td>
<td>55</td>
</tr>
<tr>
<td>003</td>
<td>0.0540 Galvanized Wire</td>
<td>628</td>
<td>278,000</td>
<td>54</td>
</tr>
</tbody>
</table>

The material covered by this certification was manufactured and tested in accordance with specifications as listed above. We certify that representative samples of the material have been tested and the results confirm to the requirements outlined in these specifications.

Signed: [Signature]

The chemical, physical, or mechanical tests reported above are correct as contained in the records of the corporation.

October 30, 2009
MwRSF Report No. TRP-03-221-09
Figure A-8. Anchor Cable Certificate of Compliance, Test No. MGSC-5
### CHEMICAL ANALYSIS

<table>
<thead>
<tr>
<th>Heat Number</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>Si</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>Al</th>
<th>V</th>
<th>Si</th>
<th>Co</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>905610</td>
<td>0.78</td>
<td>0.54</td>
<td>0.026</td>
<td>0.016</td>
<td>0.23</td>
<td>0.16</td>
<td>0.06</td>
<td>0.17</td>
<td>2.00</td>
<td>0.001</td>
<td>0.0002</td>
<td>0.006</td>
</tr>
</tbody>
</table>

### MECHANICAL PROPERTIES

<table>
<thead>
<tr>
<th>Property</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
<th>Std. Dev</th>
<th>Coef</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate Tensile (FY)</td>
<td>161380</td>
<td>167980</td>
<td>164960</td>
<td>2603</td>
<td>10</td>
</tr>
<tr>
<td>Reduction in Area (%)</td>
<td>11.9</td>
<td>16.9</td>
<td>15.4</td>
<td>4.3</td>
<td>10</td>
</tr>
<tr>
<td>Repeatability</td>
<td>0.004</td>
<td>0.006</td>
<td>0.008</td>
<td>0.001</td>
<td>10</td>
</tr>
</tbody>
</table>

All melting and manufacturing processes of the material subject to this test certificate occurred in the United States of America.

This material has been produced and tested in accordance with the requirements of the applicable specifications. We hereby certify that the above test results represent those contained in the records of this company.

---

Figure A-9. Anchor Cable Certificate of Compliance, Test No. MGSC-5
Figure A-10. Anchor Cable Certificate of Compliance, Test No. MGSC-5

<table>
<thead>
<tr>
<th>Metal Number</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Al</th>
<th>V</th>
<th>B</th>
<th>C</th>
<th>Ni</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>50211/1</td>
<td>0.79</td>
<td>0.57</td>
<td>0.005</td>
<td>0.013</td>
<td>0.17</td>
<td>6.14</td>
<td>0.05</td>
<td>0.007</td>
<td>0.008</td>
<td>0.004</td>
<td>0.002</td>
<td>0.003</td>
<td>0.004</td>
<td>0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ultimate (ksi)</th>
<th>Yield (ksi)</th>
<th>%</th>
<th>Grade</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>141690</td>
<td>26.7</td>
<td>318</td>
<td>.007</td>
</tr>
<tr>
<td>Maximum</td>
<td>146520</td>
<td>39.1</td>
<td>318</td>
<td>.007</td>
</tr>
<tr>
<td>Average</td>
<td>143487</td>
<td>33.2</td>
<td>318</td>
<td>.007</td>
</tr>
<tr>
<td>Std Dev</td>
<td>1247</td>
<td>2.7</td>
<td>600</td>
<td>.000</td>
</tr>
<tr>
<td>Count</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

ALL MELTING AND MANUFACTURING PROCESSES OF THE MATERIAL SUBJECT TO THIS TEST CERTIFICATE OCCURRED IN THE UNITED STATES OF AMERICA.

THIS MATERIAL HAS BEEN PRODUCED AND TESTED IN ACCORDANCE WITH THE REQUIREMENTS OF THE APPLICABLE SPECIFICATIONS. WE HEREBY CERTIFY THAT THE ABOVE TEST RESULTS REPRESENT THOSE CONTAINED IN THE RECORDS OF THE COMPANY.

Mark Zimmerman

Quality Assurance Department
Figure A-11. Anchor Cable Certificate of Compliance, Test No. MGSC-5
<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>0.07</td>
<td>1.25</td>
<td>0.017</td>
<td>0.02</td>
<td>0.013</td>
<td>99.9</td>
</tr>
<tr>
<td>Avg</td>
<td>0.07</td>
<td>1.25</td>
<td>0.017</td>
<td>0.02</td>
<td>0.013</td>
<td>99.9</td>
</tr>
<tr>
<td>Max</td>
<td>0.07</td>
<td>1.25</td>
<td>0.017</td>
<td>0.02</td>
<td>0.013</td>
<td>99.9</td>
</tr>
</tbody>
</table>

**MECHANICAL PROPERTIES**

<table>
<thead>
<tr>
<th>Property</th>
<th>Tensile</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>16150</td>
<td>800</td>
</tr>
<tr>
<td>Units</td>
<td>lbf/in²</td>
<td>psi</td>
</tr>
</tbody>
</table>

**Test No. MGSC-5**

Figure A-12. Anchor Cable Certificate of Compliance.
Figure A-13. Anchor Cable Certificate of Compliance, Test No. MGSC-5
Figure A-14. Anchor Cable Certificate of Compliance, Test No. MGSC-5
Figure A-15. Anchor Cable Certificate of Compliance, Test No. MGSC-5
Figure A-16. Anchor Cable Certificate of Compliance, Test No. MGSC-5
Figure A-17. Concrete Material Certification, Test No. MGSC-5
**Figure A-18. Reinforcing Steel Material Certification, Test No. MGSC-5**
<table>
<thead>
<tr>
<th>Name</th>
<th>Address</th>
<th>Phone</th>
<th>Fax</th>
</tr>
</thead>
</table>

**Concrete Industries Inc.**

123 Main Street, Anytown USA

Phone: 555-1234
Fax: 555-4321

**Concrete Inc.**

456 Main Street, Anytown USA

Phone: 555-3210
Fax: 555-2100

**Concrete Industries Inc.**

789 Main Street, Anytown USA

Phone: 555-9876
Fax: 555-6789

**Concrete Inc.**

012 Main Street, Anytown USA

Phone: 555-6543
Fax: 555-4321

**Concrete Industries Inc.**

321 Main Street, Anytown USA

Phone: 555-7890
Fax: 555-0987

**Concrete Inc.**

543 Main Street, Anytown USA

Phone: 555-1234
Fax: 555-4321

**Concrete Industries Inc.**

987 Main Street, Anytown USA

Phone: 555-5432
Fax: 555-3210
Appendix B. Static Soil Tests
Figure B-1. Soil Strength, Initial Calibration Tests
Figure B-2. Static Soil Test, Test No. MGSC-5 Static
Appendix C. Vehicle Center of Gravity Determination
Figure C-1. Vehicle Mass Distribution, Test No. MGSC-5
Appendix D.  Vehicle Deformation Records
## Figure D-1. Floor Pan Deformation Data – Set 1, Test No. MGSC-5

### Table: Floor Pan Deformation Data – Set 1, Test No. MGSC-5

<table>
<thead>
<tr>
<th>POINT</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>X'</th>
<th>Y'</th>
<th>Z'</th>
<th>DEL X</th>
<th>DEL Y</th>
<th>DEL Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28.75</td>
<td>29.25</td>
<td>-0.75</td>
<td>28.75</td>
<td>29.25</td>
<td>NA</td>
<td>0</td>
<td>0</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>2</td>
<td>31.5</td>
<td>25.25</td>
<td>-0.75</td>
<td>31.5</td>
<td>25.5</td>
<td>NA</td>
<td>0</td>
<td>0.25</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>3</td>
<td>31.5</td>
<td>19.25</td>
<td>-0.75</td>
<td>31.5</td>
<td>19</td>
<td>NA</td>
<td>0</td>
<td>-0.25</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>4</td>
<td>27.25</td>
<td>10.75</td>
<td>-0.25</td>
<td>27</td>
<td>10.5</td>
<td>NA</td>
<td>-0.25</td>
<td>-0.25</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>5</td>
<td>27</td>
<td>30</td>
<td>-2.75</td>
<td>27.5</td>
<td>29.5</td>
<td>NA</td>
<td>0</td>
<td>-0.5</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>6</td>
<td>28.75</td>
<td>26.5</td>
<td>-3</td>
<td>29</td>
<td>26.25</td>
<td>NA</td>
<td>0.25</td>
<td>-0.25</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>7</td>
<td>30.5</td>
<td>20.5</td>
<td>-4.25</td>
<td>30.5</td>
<td>20</td>
<td>NA</td>
<td>0</td>
<td>-0.5</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>8</td>
<td>25.75</td>
<td>11</td>
<td>-0.5</td>
<td>25.5</td>
<td>11</td>
<td>NA</td>
<td>-0.25</td>
<td>0</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>9</td>
<td>26</td>
<td>30.5</td>
<td>-5</td>
<td>26.25</td>
<td>30</td>
<td>NA</td>
<td>0.25</td>
<td>-0.5</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>10</td>
<td>26.5</td>
<td>25.25</td>
<td>-5.5</td>
<td>26.5</td>
<td>25.5</td>
<td>NA</td>
<td>0</td>
<td>0.25</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>11</td>
<td>26.5</td>
<td>20</td>
<td>-6</td>
<td>26.25</td>
<td>19.5</td>
<td>NA</td>
<td>-0.25</td>
<td>-0.5</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>12</td>
<td>24.5</td>
<td>11.5</td>
<td>-1.25</td>
<td>24.5</td>
<td>12</td>
<td>NA</td>
<td>0</td>
<td>0.5</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>13</td>
<td>22.5</td>
<td>8.75</td>
<td>-1.25</td>
<td>22.25</td>
<td>8.5</td>
<td>NA</td>
<td>-0.25</td>
<td>-0.25</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>14</td>
<td>20.5</td>
<td>27.5</td>
<td>-8.75</td>
<td>20.5</td>
<td>27</td>
<td>NA</td>
<td>0</td>
<td>-0.5</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>15</td>
<td>20.25</td>
<td>22.75</td>
<td>-9.25</td>
<td>20.25</td>
<td>22.25</td>
<td>NA</td>
<td>0</td>
<td>-0.5</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>16</td>
<td>19.75</td>
<td>14.25</td>
<td>-5.75</td>
<td>19.5</td>
<td>14</td>
<td>NA</td>
<td>-0.25</td>
<td>-0.25</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>17</td>
<td>17.5</td>
<td>7.5</td>
<td>-3</td>
<td>17.5</td>
<td>7.75</td>
<td>NA</td>
<td>0</td>
<td>0.25</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>18</td>
<td>15.25</td>
<td>2.5</td>
<td>-3.5</td>
<td>15.25</td>
<td>2.5</td>
<td>NA</td>
<td>0</td>
<td>0</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>19</td>
<td>15.25</td>
<td>27.75</td>
<td>-9</td>
<td>15.25</td>
<td>27.25</td>
<td>NA</td>
<td>0</td>
<td>-0.5</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>20</td>
<td>12.5</td>
<td>21</td>
<td>-9.5</td>
<td>12.5</td>
<td>20.5</td>
<td>NA</td>
<td>0</td>
<td>-0.5</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>21</td>
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<td>15.5</td>
<td>-10</td>
<td>12.5</td>
<td>15.25</td>
<td>NA</td>
<td>0</td>
<td>-0.25</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>22</td>
<td>9.5</td>
<td>6.75</td>
<td>-4</td>
<td>9.25</td>
<td>6.75</td>
<td>NA</td>
<td>-0.25</td>
<td>0</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>23</td>
<td>9.25</td>
<td>1.75</td>
<td>-4.25</td>
<td>9</td>
<td>1.75</td>
<td>NA</td>
<td>-0.25</td>
<td>0</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>24</td>
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<td>28.25</td>
<td>-4.75</td>
<td>0.5</td>
<td>28.25</td>
<td>NA</td>
<td>0</td>
<td>0</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>25</td>
<td>0.75</td>
<td>21.75</td>
<td>-5.25</td>
<td>0.75</td>
<td>21.5</td>
<td>NA</td>
<td>0</td>
<td>-0.25</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>26</td>
<td>1</td>
<td>15</td>
<td>-6</td>
<td>0.75</td>
<td>14.75</td>
<td>NA</td>
<td>-0.25</td>
<td>-0.25</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>27</td>
<td>1.25</td>
<td>7.75</td>
<td>-3.75</td>
<td>1.25</td>
<td>6</td>
<td>NA</td>
<td>0</td>
<td>0.25</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>28</td>
<td>1.25</td>
<td>2</td>
<td>-4</td>
<td>1.25</td>
<td>2</td>
<td>NA</td>
<td>0</td>
<td>0</td>
<td>#VALUE!</td>
</tr>
<tr>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>0</td>
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<tr>
<td>31</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: If impact is on driver side need to enter negative number for Y.
### Figure D-2. Floor Pan Deformation Data – Set 2, Test No. MGSC-5

<table>
<thead>
<tr>
<th>POINT</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>X'</th>
<th>Y'</th>
<th>Z'</th>
<th>DEL X</th>
<th>DEL Y</th>
<th>DEL Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>54.5</td>
<td>27.75</td>
<td>-1.5</td>
<td>NA</td>
<td>NA</td>
<td>-0.75</td>
<td>#VALUE!</td>
<td>#VALUE!</td>
<td>0.75</td>
</tr>
<tr>
<td>2</td>
<td>54.5</td>
<td>21.75</td>
<td>-1.5</td>
<td>NA</td>
<td>NA</td>
<td>-0.5</td>
<td>#VALUE!</td>
<td>#VALUE!</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>50.25</td>
<td>13.25</td>
<td>-1</td>
<td>NA</td>
<td>NA</td>
<td>0.5</td>
<td>#VALUE!</td>
<td>#VALUE!</td>
<td>1.5</td>
</tr>
<tr>
<td>4</td>
<td>50.5</td>
<td>32.5</td>
<td>0.5</td>
<td>NA</td>
<td>NA</td>
<td>2</td>
<td>#VALUE!</td>
<td>#VALUE!</td>
<td>1.5</td>
</tr>
<tr>
<td>5</td>
<td>51.75</td>
<td>29</td>
<td>-3.25</td>
<td>NA</td>
<td>NA</td>
<td>-3</td>
<td>#VALUE!</td>
<td>#VALUE!</td>
<td>0.25</td>
</tr>
<tr>
<td>6</td>
<td>53.5</td>
<td>23</td>
<td>-3.5</td>
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Occupant Compartment Deformation Index (OCDI)

Test No.: MGSC-5
Vehicle Type: Ram 1500 Q.C.

OCDI = XXABCDEFGHI

XX = location of occupant compartment deformation

A = distance between the dashboard and a reference point at the rear of the occupant compartment, such as the top of the rear seat or the rear of the cab on a pickup

B = distance between the roof and the floor panel

C = distance between a reference point at the rear of the occupant compartment and the motor panel

D = distance between the lower dashboard and the floor panel

E = interior width

F = distance between the lower edge of right window and the upper edge of left window

G = distance between the lower edge of left window and the upper edge of right window

H = distance between bottom front corner and top rear corner of the passenger side window

I = distance between bottom front corner and top rear corner of the driver side window

Severity Indices

0 - if the reduction is less than 3%
1 - if the reduction is greater than 3% and less than or equal to 10%
2 - if the reduction is greater than 10% and less than or equal to 20%
3 - if the reduction is greater than 20% and less than or equal to 30%
4 - if the reduction is greater than 30% and less than or equal to 40%

where,
1 = Passenger Side
2 = Middle
3 = Driver Side

Location:

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<th>Post-Test (in.)</th>
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Note: Maximum severity index for each variable (A-I) is used for determination of final OCDI value

Figure D-3. Occupant Compartment Deformation Index (OCDI), Test No. MGSC-5
Distance from C.G. to reference line - $L_{REF}$: 105 (2667)

Width of contact and induced crush - Field L: 27.25 (692)
Crush measurement spacing interval (L/5) - 1t: 5.45 (138)
Distance from center of vehicle to center of Field L - $D_{FL}$: 25.625 (651)

Width of Contact Damage: 27.25 (692)
Distance from center of vehicle to center of contact damage - $D_{C}$: 25.75 (654)

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Figure D-4. Exterior Vehicle Crush (NASS) - Front, Test No. MGSC-5
Figure D-5. Exterior Vehicle Crush (NASS) - Side, Test No. MGSC-5
Appendix E. Accelerometer and Rate Transducer Data Plots
Figure E-1. 10-ms Average Longitudinal Deceleration (EDR-3), Test No. MGSC-5
Figure E-2. Longitudinal Occupant Impact Velocity (EDR-3), Test No. MGSC-5
Figure E-3. Longitudinal Occupant Displacement (EDR-3), Test No. MGSC-5
Figure E-4. 10-ms Average Lateral Deceleration (EDR-3), Test No. MGSC-5
Figure E-5. Lateral Occupant Impact Velocity (EDR-3), Test No. MGSC-5
Figure E-6. Lateral Occupant Displacement (EDR-3), Test No. MGSC-5
Figure E-7. 10-ms Average Longitudinal Deceleration (EDR-4), Test No. MGSC-5
Figure E-8. Longitudinal Occupant Impact Velocity (EDR-4), Test No. MGSC-5
Figure E-10. 10-ms Average Lateral Deceleration (EDR-4), Test No. MGSC-5
Figure E-11. Lateral Occupant Impact Velocity (EDR-4), Test No. MGSC-5
Figure E-12. Lateral Occupant Displacement (EDR-4), Test No. MGSC-5
Figure E-13. Vehicle Angular Displacements (EDR-4), Test No. MGSC-5
Figure E-14. 10-ms Average Longitudinal Deceleration (DTS), Test No. MGSC-5
Figure E-15. Longitudinal Occupant Impact Velocity (DTS), Test No. MGSC-5
Figure E-17. 10-ms Average Lateral Deceleration (DTS), Test No. MGSC-5
Figure E-18: Lateral Occupant Impact Velocity (DTS), Test No. MGSC-5
Figure E-19. Lateral Occupant Displacement (DTS), Test No. MGSC-5
Figure E-20. Vehicle Angular Displacements (DTS), Test No. MGSC-5
END OF DOCUMENT