DEVELOPMENT AND EVALUATION OF A MASH TL-3 31-INCH W-BEAM MEDIAN BARRIER

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TEXAS A&M TRANSPORTATION INSTITUTE
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TEXAS DEPARTMENT OF TRANSPORTATION

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

Typically, when the G4(1S) W-beam barrier is impacted in a roadside application, the W-beam rail element deforms, the support posts are displaced through the soil, and the vehicle is redirected. During the impact sequence, the rail becomes detached from the post by means of the post bolt pulling out of the rail slot as the post displaces rearward. However, in the MB4 steel post W-beam median barrier, the addition of the rear W-beam rail element provides additional lateral stiffness and post constraint. This changes the post behavior and vehicle-post interaction. In a test of the 27-inch tall MB4 median barrier, the impacting pickup truck climbed and vaulted over the barrier.

A taller 30-inch version of the MB4 W-beam median barrier (AASHTO Designation SGM06a&b) incorporates a C6×8.2 rub-rail channel to help mitigate vehicle-post snagging. However, the rub-rail may still permit the pickup to climb the barrier.

The purpose of this project was to develop and evaluate a W-beam median barrier that would meet the strength and safety performance criteria of the AASHTO Manual for Assessing Safety Hardware (MASH). A 31-inch tall W-beam median barrier with rail splices offset from the posts and 8-inch offset blocks (AASHTO Designation SGM06a) was successfully crash tested in accordance with MASH.
DEVELOPMENT AND EVALUATION OF A MASH TL-3 31-INCH W-BEAM MEDIAN BARRIER

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation, and its contents are not intended for construction, bidding, or permit purposes. In addition, the above listed agencies assume no liability for its contents or use thereof. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers’ names appear herein solely because they are considered essential to the object of this report. The engineer in charge of the project was Roger P. Bligh, P.E. (Texas, #78550).

TTI PROVING GROUND DISCLAIMER

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

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CHAPTER 1. INTRODUCTION

1.1 INTRODUCTION

The project under which the current research was conducted was set up to provide the Texas Department of Transportation (TxDOT) with a mechanism to quickly and effectively evaluate high-priority issues related to roadside safety devices. Roadside safety devices shield motorists from roadside hazards such as non-traversable terrain and fixed objects. To maintain the desired level of safety for the motoring public, these safety devices must be designed to accommodate a variety of site conditions, placement locations, and a changing vehicle fleet. Periodically, there is a need to assess the compliance of existing safety devices with current vehicle testing criteria and develop new devices that address identified needs.

Under this project, roadside safety issues were identified and prioritized for investigation. Each roadside safety issue was addressed with a separate work plan, and the results are summarized in individual test reports.

1.2 BACKGROUND

1.2.1 Previous Evaluation of 27-Inch MB4 W-Beam Median Barrier

In a National Cooperative Highway Research Program (NCHRP) project in 2008–2009, Texas A&M Transportation Institute (TTI) researchers conducted a survey of the State Departments of Transportation (DOTs) to determine usage rates for various types of non-proprietary roadside safety hardware. Additionally, they reviewed crash tests performed under NCHRP Project 22-14(02), TxDOT Project 0-5526, and numerous other projects following NCHRP Report 350 guidelines (1-15). A performance assessment of existing roadside safety devices was performed to help evaluate the impact of adopting the American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH) (16). Crash test results, engineering analyses, and engineering judgment were used to assist with the hardware evaluation. Categories of roadside features that were considered under the project include guardrails, median barriers, transitions from approach guardrail to bridge rails, breakaway sign supports, and both precast and permanent concrete barriers. Results of the performance assessment were used to develop a test prioritization scheme for evaluating compliance of selected roadside safety features with the new MASH impact performance guidelines (14).

The project panel decided to evaluate the MB4 steel post W-beam median barrier. This system was never crash tested under NCHRP Report 350 guidelines. Rather, the median barrier received FHWA acceptance based on a successful test of the “more critical” G4(1S) steel post guardrail system. Given the marginal performance of the G4(1S) guardrail system when tested following MASH guidelines under NCHRP study 22-14(02), the panel decided that this assumption should be verified through testing.
The additional constraint of the posts imposed by the double-sided G4(1S) W-beam median barrier raised concerns regarding barrier override by the 2270P vehicle and excessive occupant risk when impacted by the small passenger vehicle (1100C). The added post constraint delays release of the post from the rail, which can potentially result in vehicle climb and vaulting due to a localized drop in rail height. The delayed post release can also result in more severe wheel-post interaction and a higher level of occupant risk during the small car impact. Thus, both Test 3-10 and 3-11 were programmed for this median barrier system.

1.2.2 Test Installation Used for Evaluation of 27-Inch MB4 W-Beam Median Barrier

The MB4 W-Beam Median Barrier (AASHTO Designation SGM04a with non-steel blocks) is a 27-inch tall, strong steel post, W-beam median barrier. The median barrier is constructed using 12-gauge W-beam guardrails attached to 6 ft long W6×8.5 steel posts spaced 6 ft-3 inches on center. The W-beam guardrail elements are offset from the posts using non-steel blockouts nominally 6 inches × 8 inches × 14 inches long. Either wood or an FHWA accepted plastic blockout may be used. Wood blockouts were used in the test.

The height of the MB4 W-beam median barrier test installation was 27 inches to the top of the W-beam rail. The length of need for the installation was 100 ft. The median barrier was terminated with ET-PLUS guardrail terminals. The front (impacted) rail was constructed with 37 ft-6 inch long terminals on each end and the rear rail was constructed with 50 ft long terminals on each end. The total overall test installation length was 200 ft.

Figure 1.1 shows a cross section of the MB4 W-beam median barrier. The first test on the median barrier was with the small car (1100C vehicle). The installation was then repaired and used for the test with the pickup (2270P vehicle).

1.2.3 MASH Test 3-10 on 27-Inch G4(1S) W-Beam Median Barrier

The MB4 W-beam median barrier contained and redirected the 1100C vehicle. The vehicle did not penetrate, override, or underride the installation. Maximum dynamic deflection was 11.25 inches. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present a hazard to others in the area. Maximum occupant compartment deformation was 2.0 inches in the left front driver’s area at the level of the floor pan. The 1100C vehicle remained upright during and after the collision event. Maximum roll angle was 8 degrees. Occupant risk factors were within the limits specified in MASH. The 1100C vehicle exited the median barrier within the exit box. The G4(1S) W-beam median barrier performed acceptably when impacted by the 1100C vehicle.
1.2.4 MASH Test 3-11 on 27-Inch MB4 W-Beam Median Barrier

The MB4 W-beam median barrier did not contain or redirect the 2270P vehicle. The vehicle overrode the installation. Maximum dynamic deflection of the W-beam during the test was 23.2 inches. The impact speed and angle for this test were 64.0 mi/h and 25.1 degrees, respectively. The impact speed and angle were within the acceptable limits prescribed in MASH. However, the impact condition represented an impact severity 15.3 percent greater than the target MASH condition (62.2 mi/h and 25 degrees).

The G4(1S) W-beam median barrier did not perform acceptably when impacted by the 2270P vehicle (2007 Chevrolet Silverado pickup). The 2270P Silverado pickup truck overrode the installation.

1.2.5 MASH, FHWA, and the 27-Inch MB4 W-Beam Median Barrier

In a related effort, FHWA released a memorandum pertaining to the height of strong post W-beam guardrail installations (17). In that memorandum, FHWA recommended that state transportation agencies consider adopting a 31-inch tall guardrail system in lieu of the 27-inch high G4(1S) system. The memorandum cited research demonstrating the marginal impact performance of 27-inch high W-beam guardrail systems. Hence, the recommendation was to
adopt one of the 31-inch tall guardrail systems that has successfully passed *MASH* Test Level 3 (TL-3) performance criteria.

### 1.3 OBJECTIVES/SCOPE OF RESEARCH

This project developed and evaluated a 31-inch tall W-beam median barrier that would meet the strength and safety performance criteria of *MASH* for TL-3 impact conditions.
CHAPTER 2. SIMULATION RESULTS*

To improve the performance of the 27-inch high median W-beam, TTI researchers analyzed the failed test and incorporated design changes that have the potential of rectifying the performance of the W-beam median barrier. First, the research team developed a detailed finite element model of the W-beam median rail to calibrate the model under the MASH test previously conducted. The new Silverado vehicle model developed by the National Crash Analysis Center (18) was used to simulate the MASH 2270P test vehicle.

In the model, the post was comprised of different thicknesses to accurately represent the shape of a W6×9 steel post. A total of 18,240 shell elements were used for modeling the posts. Additionally, the W-beam model contains a more refined element mesh than the previously used W-beam models, so it can capture deformation more realistically. A total of 182,304 shell elements were used for modeling the W-beam segments (19). Figure 2.1 shows both the post and the W-beam models. The end terminals and the remaining portion of the length-of-need rail were represented by spring elements connected to each end of the modeled W-beam. These springs elements have a combined stiffness representative of typical end terminals.

![Figure 2.1. Meshing Scheme of the 8-Ft Post Model (Left) and the 12 Gauge W-Beam Rail (Right).](image)

The vehicle model used for simulation was the Chevrolet Silverado model, which was developed by NCAC. This vehicle model represents the MASH 2270P test vehicle. The finite element model for the MASH 1100C test vehicle was not available at the time this research was performed. Figure 2.2 shows the vehicle and 27-inch median W-beam barrier models.

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*TTI Proving Ground’s scope of accreditation does not include simulation.
The research team started by simulating the failed test using LS-DYNA (20) finite element code. Figure 2.3 shows the vaulting phenomena of the vehicle captured in the simulation. Hence, the model is considered corroborated with the failed MASH test 3-11 and can be used as a tool to investigate the system performance once modified.

Design modifications included increasing the rail height from 27 inches to 31 inches and moving the splice location from at-post to mid-span. Figure 2.4 shows the cross-section views of the new system design and the model.
2.1 SIMULATION RESULTS

Two simulations were conducted using LS-DYNA finite element code. One was conducted with vehicular impact at a post and the other with vehicular impact at mid-span between posts.

2.1.1 TL 3-11 Mid-Span Impact

In the first simulation case, the analysis represents vehicular impact at mid-span of the guardrail. The modified barrier system was impacted by 2270P vehicle model at 62.2 mi/h and an angle of 25 degrees. Table 2.1 provides the occupant risk assessments for this model, and vehicle behavior is shown in Figure 2.5.

The Test Risk Assessment Program (TRAP) was used to determine the maximum roll, pitch, and yaw and the specific time that the vehicle reached these values. Figure 2.6 shows the maximum roll was -16.2 degrees at 0.6014 seconds (s). The maximum pitch of the truck was -9.1 degrees at 0.7258 s, and is shown in Figure 2.7. Figure 2.8 shows the maximum yaw of the vehicle was 53.0 degrees at 0.6413 s.

The vehicle exited the system at a speed of 29.97 mi/h at time 0.745 s, and a top view at this point is provided in Figure 2.9. The maximum deflection of the guardrail system was 3.87 ft and occurred at time 0.17 s. Figure 2.10 shows an overhead view of deflection at this point. The contours of plastic strain within the W-beam at the point of maximum deflection are provided in Figure 2.11. Figure 2.12 provides the graph for angular displacements. A summary of results and sequential photos of the run are provided in Figure 2.13.
Table 2.1. TRAP Output Summary for Mid-Span Impact Case.

<table>
<thead>
<tr>
<th>Occupant Risk Factors</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact Velocity (ft/s) at 0.1695 s on left side of interior</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x-direction:</td>
<td>22.0</td>
<td>Rec: &lt;30 ft/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>y-direction:</td>
<td>-15.4</td>
<td>Max: &lt;40 ft/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>THIV (km/h):</td>
<td>26.9</td>
<td>at 0.1633 s on left side of interior</td>
<td></td>
<td></td>
</tr>
<tr>
<td>THIV (m/s):</td>
<td>7.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ridedown Acceleration (Gs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x-direction:</td>
<td>-10.6</td>
<td>(0.2471 - 0.2571 s)</td>
<td>Rec: &lt;15 Gs</td>
<td></td>
</tr>
<tr>
<td>y-direction:</td>
<td>9.9</td>
<td>(0.2959 - 0.3059 s)</td>
<td>Max: &lt;20 Gs</td>
<td></td>
</tr>
<tr>
<td>PHD (Gs):</td>
<td>11.8</td>
<td>(0.2471 - 0.2571 s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASI:</td>
<td>0.78</td>
<td>(0.1477 - 0.1977 s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. 50-millisecond (ms) Moving Average Acceleration (Gs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>x-direction:</td>
<td>-7.2</td>
<td>(0.1432 - 0.1932 s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>y-direction:</td>
<td>4.9</td>
<td>(0.1883 - 0.2383 s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>z-direction:</td>
<td>2.3</td>
<td>(0.4747 - 0.5247 s)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2.5. Views of Vehicle Behavior for Mid-Span Impact Simulation Case.

Figure 2.6. Silverado Model at Maximum Roll for Mid-Span Impact.
Figure 2.7. Silverado Model at Maximum Pitch for Mid-Span Impact.

Figure 2.8. Silverado Model at Maximum Yaw for Mid-Span Impact.

Figure 2.9. Top View of Vehicle Exit for Mid-Span Impact.
Figure 2.10. Top View of System’s Maximum Deflection for Mid-Span Impact.

Figure 2.11. Contours of W-Beam Plastic Strain for Mid-Span Impact.

Figure 2.12. Roll, Pitch, and Yaw Angle for Mid-Span Impact.
**General Information**
Test Agency: Texas A&M Transportation Institute (TTI)
Test Standard Test No.: Zephyr - 8673

**Test Article**
Material or Key Elements: Guardrail
Soil Type and Condition: Standard Soil

**Test Vehicle**
Type/Designation: 2270P
Make and Model: Chevy Silverado
Curb: 5004 lb
Test Inertial: 5004 lb
Dummy: No Dummy
Gross Static: 5004 lb

**Impact Conditions**
Speed: 62.2 mi/h
Angle: 25 degrees
Location/Orientation: Mid-span

**Exit Conditions**
Speed: 29.97 mph
Angle: ~−15.4 ft/s

**Occupant Risk Values**
Impact Velocity
Longitudinal: ~10.6 Gs
Lateral: ~9.9 Gs
THIV: ~7.5 m/s
PHD: ~11.8 Gs
ASI: ~0.78
Max. 0.050-s Average
Longitudinal: ~7.2 Gs
Lateral: ~4.9 Gs
Vertical: ~2.3 Gs

**Vehicle Stability**
Maximum Yaw Angle: ~53.0 degrees
Maximum Pitch Angle: ~−9.1 degrees
Maximum Roll Angle: ~−16.2 degrees

**Test Article Deflections**
Dynamic: ~3.87 ft

---

**Figure 2.13. Summary of Simulation Results for TL 3-11 for Mid-Span Impact.**
2.1.2 TL 3-11 At-Post Impact

The modified system was simulated under impact by the 2270P test at a post location, instead of the mid-span, using the same MASH TL 3-11 initial conditions of 62.2 mi/h and 25 degrees. Table 2.2 provides the occupant risk assessment for this model, and vehicle behavior is shown in Figure 2.14.

Table 2.2. TRAP Output Summary for At-Post Impact Case.

<table>
<thead>
<tr>
<th>Occupant Risk Factors</th>
<th>Value Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact Velocity (ft/s) at 0.1738 s on left side of interior</td>
<td></td>
</tr>
<tr>
<td>x-direction:</td>
<td>20.0</td>
</tr>
<tr>
<td>y-direction:</td>
<td>−15.4</td>
</tr>
<tr>
<td>THIV (km/hr):</td>
<td>27.1</td>
</tr>
<tr>
<td>THIV (m/s):</td>
<td>7.5</td>
</tr>
<tr>
<td>Ride down Acceleration (Gs)</td>
<td></td>
</tr>
<tr>
<td>x-direction:</td>
<td>−9.5 [0.2046 - 0.2146 s] Rec: &lt;15 Gs</td>
</tr>
<tr>
<td>y-direction:</td>
<td>9.7 [0.2896 - 0.2996 s] Max: &lt;20 Gs</td>
</tr>
<tr>
<td>PHD (G's):</td>
<td>11.8 [0.2046 - 0.2146 s]</td>
</tr>
<tr>
<td>ASI:</td>
<td>0.68 [0.1134 - 0.1634 s]</td>
</tr>
<tr>
<td>Maximum 50-ms Moving Average Acceleration (Gs)</td>
<td></td>
</tr>
<tr>
<td>x-direction:</td>
<td>−6.4 [0.1128 - 0.1628 s]</td>
</tr>
<tr>
<td>y-direction:</td>
<td>5.2 [0.2499 - 0.2999 s]</td>
</tr>
<tr>
<td>z-direction:</td>
<td>3.1 [0.3532 - 0.4032 s]</td>
</tr>
</tbody>
</table>

Figure 2.14. Views of Vehicle Behavior for At-Post Impact Simulation Case.

TRAP was used to determine the maximum roll, pitch, and yaw, as well as the specific time the vehicle reached these values. Figure 2.15 shows the maximum roll at −9.1 degrees at 0.4822 s. The maximum pitch of the truck was −9.0 degrees at 0.6507 s, which is provided in Figure 2.16. Figure 2.17 shows the maximum yaw of the vehicle at 51.0 degrees at 0.6084 s.
Figure 2.15. Silverado Model at Maximum Roll for At-Post Impact.

Figure 2.16. Silverado Model at Maximum Pitch for At-Post Impact.

Figure 2.17. Silverado Model at Maximum Yaw for At-Post Impact.
The vehicle exited the system at a speed of 31.09 mi/h at time 0.720 s, and a top view at this point is provided in Figure 2.18. The maximum deflection of the guardrail system was 3.71 ft, and occurred at time 0.12 s. Figure 2.19 shows an overhead view of deflection at this point. The contours of plastic strain within the W-beam at the point of maximum deflection are provided in Figure 2.20.

Figure 2.18. Top View of Vehicle Exit for At-Post Impact.

Figure 2.19. Top View of System’s Maximum Deflection for At-Post Impact.
2.2 SIMULATION CONCLUSIONS

Both simulation cases indicated that the 31-inch W-beam median barrier is able to contain and redirect the test vehicle, and able to pass MASH evaluation criteria presented in Tables 2.1 and 2.2. Hence, the research team used the new design for the full-scale crash testing phase of the project.
General Information
Test Agency: Texas A&M Transportation Institute (TTI)
Test Standard Test No.: Zephyr - 8359

Test Article
Material or Key Elements: Guardrail
Soil Type and Condition: Standard Soil

Test Vehicle
Type/Designation: 2270P
Make and Model: Chevy Silverado
Curb: 5004 lb
Test Inertial: 5004 lb
Dummy: No Dummy
Gross Static: 5004 lb

Impact Conditions
Speed: 62.2 mi/h
Angle: 25 degrees
Location/Orientation: At post

Exit Conditions
Speed: 31.09 mph
Angle: 

Occupant Risk Values
Impact Velocity
Longitudinal: 20.0 ft/s
Lateral: -15.4 ft/s
Ride down Accelerations
Longitudinal: -9.5 Gs
Lateral: 9.7 Gs
THIV: 7.5 m/s
PHD: 11.5 Gs
ASI: 6.68
Max. 0.050-s Average
Longitudinal: -6.4 Gs
Lateral: 5.2 Gs
Vertical: 3.1 Gs

Vehicle Stability
Maximum Yaw Angle: 51.0 degrees
Maximum Pitch Angle: -9.0 degrees
Maximum Roll Angle: -9.1 degrees
Vehicle Snagging: No
Vehicle Pocketing: No

Test Article Deflections
Dynamic: 3.71 ft

Figure 2.22. Summary of Simulation Results for TL-3-11 for At-Post Impact.
CHAPTER 3. SYSTEM DETAILS

3.1 TEST ARTICLE DESIGN AND CONSTRUCTION

The TxDOT W-Beam Median Barrier is a 31-inch tall, strong steel post, W-beam median barrier. The median barrier is constructed using 12-gauge W-beam guardrails attached to 6 ft long W6×8.5 steel posts spaced 6 ft-3 inch on center. The W-beam guardrails are offset from the posts using non-steel blockouts nominally 6 inch × 8 inch × 14 inch long. Either wood or an FHWA accepted plastic blockout may be used. For the tests presented herein, wood blockouts were used. Also, for this installation, the W-beam rail element joints were moved off the posts and centered midspan between posts.

The height of the TxDOT W-Beam Median Barrier test installation was 31 inches. The length of need for the installation was 106 ft. The median barrier was terminated with 25 ft TREND™ guardrail terminals. The TREND™ 350 Median End Terminal is a double-sided, energy-absorbing steel post terminal. The total overall test installation length was 156 ft.

Figures 3.1 and 3.2 provide a layout and cross-section of the TxDOT 31-inch W-Beam Median Barrier. Photographs of the completed installation are shown in Figure 3.3. Appendix A presents more detailed information on the barrier.

3.2 MATERIAL SPECIFICATIONS

Various certification papers and other related material are provided in Appendix B.

3.3 SOIL CONDITIONS

The TxDOT 31-inch W-Beam Median Barrier was installed in standard soil meeting AASHTO standard specifications for “Materials for Aggregate and Sol Aggregate Subbase, Base and Surface Courses,” designated M147-65(2004), grading B.

In accordance with Appendix B of MASH, soil strength was measured the day of the crash test (see Appendix C, Tables C1 and C2). During installation of the TxDOT 31-inch W-Beam Median Barrier for full-scale crash testing, two standard W6×16 posts were installed in the immediate vicinity of the TxDOT 31-inch W-Beam Median Barrier test installation, using the same fill materials and installation procedures used in the standard dynamic test (see Appendix C, Table C3).

As determined in the tests shown in Appendix C, Table C3, the minimum post load required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, is 3940 lb, 5500 lb, and 6540 lb, respectively (90 percent of static load for the initial standard installation). On the day of test no. 490023-3, June 18, 2013, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 7575 lb, 7697 lb, and 7606 lb, respectively (see
Appendix C, Table C1). On the day of test no. 490023-4, June 21, 2013, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 7272 lb, 7303 lb, and 7181 lb, respectively (see Appendix C, Table C2).
Figure 3.1. Layout of the TxDOT 31-Inch W-Beam Median Barrier.
Figure 3.2. Cross-Section of the TxDOT 31-Inch W-Beam Median Barrier.
Figure 3.3. TxDOT 31-Inch W-Beam Median Barrier before Testing.
CHAPTER 4. TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1 CRASH TEST MATRIX

According to MASH, two tests are recommended to evaluate longitudinal barriers to test level three (TL-3).

**MASH Test 3-10:** A 2425-lb vehicle impacting the critical impact point (CIP) of the length of need (LON) of the barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. This test investigates a barrier’s ability to successfully contain and redirect a small passenger vehicle.

**MASH Test 3-11:** A 5000-lb pickup truck impacting the CIP of the LON of the barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. This test investigates a barrier’s ability to successfully contain and redirect light trucks and sport utility vehicles.

Both above listed tests were performed on the TxDOT 31-inch W-Beam Median Barrier. Procedures in MASH section 2.3.2.1 were used by the research team to calculate the CIP for each test. Target CIPs were 7.95 ft upstream of post 13 for MASH test 3-10 (Test No. 490023-3), and 10.5 ft upstream of post 13 for MASH test 3-11 (Test No. 490023-4).

The crash test and data analysis procedures were in accordance with guidelines presented in MASH. Chapter 5 presents brief descriptions of these procedures.

4.2 EVALUATION CRITERIA

The crash tests were evaluated in accordance with the criteria presented in MASH. The performance of the TxDOT 31-inch W-Beam Median Barrier is judged on the basis of three factors: structural adequacy, occupant risk, and post impact vehicle trajectory. Structural adequacy is judged upon the ability of the TxDOT 31-inch W-Beam Median Barrier to contain and redirect the vehicle, or bring the vehicle to a controlled stop in a predictable manner. Occupant risk criteria evaluate the potential risk of hazard to occupants in the impacting vehicle, and, to some extent, other traffic, pedestrians, or workers in construction zones, if applicable. Post-impact vehicle trajectory is assessed to determine potential for secondary impact with other vehicles or fixed objects, creating further risk of injury to occupants of the impacting vehicle and/or risk of injury to occupants in other vehicles. The appropriate safety evaluation criteria from Table 5-1 of MASH were used to evaluate the crash test reported here, and are listed in further detail under the assessment of the crash test.
CHAPTER 5. CRASH TEST PROCEDURES

5.1 TEST FACILITY

The full-scale crash tests reported here were performed at Texas A&M Transportation Institute Proving Ground, an International Standards Organization (ISO) 17025 accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanical Testing certificate 2821.01. The full-scale crash test was performed according to TTI Proving Ground quality procedures and according to the MASH guidelines and standards.

The Texas A&M Transportation Institute Proving Ground is a 2000-acre complex of research and training facilities located 10 miles northwest of the main campus of Texas A&M University. The site, formerly an Air Force 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, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for construction and testing of the TxDOT 31-inch W-Beam Median Barrier evaluated under this project 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 apron is over 60 years old, and the joints have some displacement, but are otherwise flat and level.

5.2 VEHICLE TOW AND GUIDANCE PROCEDURES

The test vehicles were 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, 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 two-to-one speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be unrestrained. The vehicle remained free-wheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site, after which the brakes can activated, if necessary, to bring it to a safe and controlled stop.

5.3 DATA ACQUISITION SYSTEMS

5.3.1 Vehicle Instrumentation and Data Processing

The test vehicles were instrumented with a self-contained, on-board 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, that measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra small size, solid state units designs 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 values per second with a resolution of one part in 65,536. Once recorded, the data are backed up inside the unit by internal batteries should the primary battery cable be severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark as well as initiating the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The raw data are then processed by the Test Risk Assessment Program (TRAP) software to produce detailed reports of the test results. Each of the TDAS Pro units is returned to the factory annually for complete recalibration. Accelerometers and rate transducers are also calibrated annually with traceability to the National Institute for Standards and Technology. 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 occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the 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 a 60-Hz 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 of the vehicle-fixed coordinate systems 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).

5.3.2 Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver’s position of the 1100C vehicle. The dummy was uninstrumented. Use of a dummy in the 2270P vehicle is optional according to MASH, and no dummy was used in the tests with the 2270P vehicle.

5.3.3 Photographic Instrumentation and Data Processing

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed behind the installation at an angle; and a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A flashbulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked motion analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-DV camera and still cameras recorded and documented conditions of the test vehicle and installation before and after the test.
CHAPTER 6. CRASH TEST RESULTS FOR MASH TEST 3-10

6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH test 3-10 involves an 1100C vehicle weighing 2420 lb ±55 lb and impacting the TxDOT 31-inch W-Beam Median Barrier at an impact speed of 62.2 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target impact point was 21 inches upstream of post 12. The 2006 Kia Rio used in the test weighed 2444 lb, and the actual impact speed and angle were 62.2 mi/h and 25.0 degrees, respectively. The actual impact point was 22 inches upstream of post 12. Target impact severity (IS) was 55.7 kip-ft, and actual IS was 56.5 kip-ft.

6.2 TEST VEHICLE

A 2006 Kia Rio, shown in Figures 6.1 and 6.2, was used for the crash test. Test inertia weight of the vehicle was 2444 lb, and its gross static weight was 2624 lb. The height to the lower edge of the vehicle bumper was 7.12 inches, and it was 21.00 inches to the upper edge of the bumper. Tables D1 and D2 in Appendix D give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

6.3 WEATHER CONDITIONS

The test was performed on the morning of June 18, 2013. Weather conditions at the time of testing were as follows: wind speed: 6 mi/h; wind direction: 355 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 84°F, relative humidity: 72 percent.

6.4 TEST DESCRIPTION

The 2006 Kia Rio, traveling at an impact speed of 62.2 mi/h, impacted the TxDOT 31-inch W-Beam Median Barrier 22 inches upstream of post 12 at an impact angle of 25.0 degrees. At approximately 0.013 s, post 12 began to deflect toward the side opposite impact, and at 0.034 s, the left front tire contacted post 12. The W-beam on the side opposite impact began to deflect toward the side opposite impact at 0.035 s, and the vehicle began to redirect at 0.037 s. At 0.062 s, the left front tire contacted post 13, and at 0.149 s, the blockouts at post 13 separated from the post and rail element. The vehicle began traveling parallel with the installation at 0.343 s. At 0.488 s, the vehicle lost contact with the installation, however, the overhead camera failed and exit speed and angle were not attainable. Brakes on the 1100C vehicle were applied at 2.5 s after impact, the vehicle yawed counterclockwise 180 degrees and came to rest 153.3 ft downstream of impact. Figures D1 and D2 in Appendix D show sequential photographs of the test period.
Figure 6.1. Vehicle/Installation Geometrics for Test No. 490023-3.
Figure 6.2. Vehicle before Test No. 490023-3.
6.5 DAMAGE TO TEST INSTALLATION

Figures 6.3 and 6.4 show damage to the TxDOT 31-inch W-Beam Median Barrier. No apparent movement was noted at post 1 or post 26 (the end posts). Post 11 and 12 were displaced through the soil toward the side opposite impact 0.25 inch and 1.75 inches, respectively. Posts 13 and 14 were leaning 70 degrees toward the side opposite impact and the rail element on the impact side separated from the posts. Both blockouts at post 13 separated from the post and the blockout on the side opposite impact separated from post 14. Post 15 rotated 45 degrees in the soil, the blockout on impact side separated from the post, and both rail elements separated from the post. The rail element on the impact side ruptured upward two-thirds of the width of the rail element at the upstream bolts on the splice between posts 12 and 13. The length of contact of the 1100C vehicle with the rail was 22.0 ft. Maximum permanent deformation of the rail was 20.25 inches between posts 13 and 14.

6.6 VEHICLE DAMAGE

Figure 6.5 shows damage to the 1100C vehicle. The front bumper, hood, radiator and support, left front strut and tower, left front tire and wheel rim, left front fender, and left front door were damaged. The hood was pushed into the windshield, which shattered the lower portion of the windshield. Maximum exterior crush to the 1100C vehicle was 13.0 inches in the side plane at the left front corner just above bumper height. No occupant compartment deformation was noted. Figure 6.6 provides photographs of the interior of the vehicle, and Tables D1 and D2 provide exterior and occupant compartment measurements.

6.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 20.0 ft/s at 0.115 s, the highest 0.010-s occupant ridedown acceleration was 9.6 Gs from 0.172 to 0.182 s, and the maximum 0.050-s average acceleration was −7.3 Gs between 0.076 and 0.126 s. In the lateral direction, the occupant impact velocity was 17.4 ft/s at 0.115 s, the highest 0.010-s occupant ridedown acceleration was 8.3 Gs from 0.155 to 0.165 s, and the maximum 0.050-s average was 6.9 Gs between 0.038 and 0.088s. Theoretical Head Impact Velocity (THIV) was 28.0 km/h or 7.8 m/s at 0.111 s; Post-Impact Head Decelerations (PHD) was 11.0 Gs between 0.172 and 0.182 s; and Acceleration Severity Index (ASI) was 0.94 between 0.038 and 0.088 s. These data and other pertinent information from the test are summarized in Figure 6.7. Vehicle angular displacements and accelerations versus time traces are presented in Appendix D, Figures D3 through D9.
Figure 6.3. Vehicle/Installation Positions after Test No. 490023-3.
Figure 6.4. Installation after Test No. 490023-3.
Figure 6.5. Vehicle after Test No. 490023-3.
Figure 6.6. Interior of Vehicle for Test No. 490023-3.
General Information

Test Agency: Texas A&M Transportation Institute (TTI)
Test Standard Test No.: MASH Test 3-10
TTI Test No.: 490023-3
Test Date: 2013-06-18

Test Article
Type: Median Barrier
Name: TxDOT 31-inch W-Beam Median Barrier
Installation Length: 156 ft
Material or Key Elements: 12-gauge W-beam at 31 inch height on 6 ft long W6×8.5 steel posts spaced 6 ft-3 inch on center with 8 inch × 14 inch routed wood blockouts with splice midspan between posts

Soil Type and Condition: Standard soil, dry

Test Vehicle
Type/Designation: 2006 Kia Rio
Make and Model: 2006 Kia Rio
Curb: 2494 lb
Test Inertial: 2444 lb
Dummy: 180 lb
Gross Static: 2624 lb

Impact Conditions
Speed: 62.2 mi/h
Angle: 25.0 degrees
Location/Orientation: 27 inches upstrm of post 12
Impact Severity: 56.5 kip-ft

Exit Conditions
Speed: Not obtainable
Angle: Not obtainable

Occupant Risk Values
Impact Velocity
Longitudinal: 20.0 ft/s
Lateral: 17.4 ft/s
Ridedown Accelerations
Longitudinal: 8.3 G
Lateral: 9.6 G
THIV: 7.8 m/s²
PHD: 11.0 G
ASI: 0.94
Max. 0.050-s Average
Longitudinal: -7.3 G
Lateral: 6.9 G
Vertical: -3.0 G

Post-Impact Trajectory
Stopping Distance: 132.5 ft downstrm
Aligned w/cntr rail

Vehicle Stability
Maximum Yaw Angle: 36 degrees
Maximum Pitch Angle: 9 degrees
Maximum Roll Angle: 11 degrees
Vehicle Snagging: No
Vehicle Pocketing: Yes/No

Test Article Deflections
Dynamic: 25.4 inches
Permanent: 20.25 inches
Working Width: 33.6 inches
Vehicle Intrusion: 21.5 inches

Vehicle Damage
VDS: 11KFQ5
CDC: 11FLEW 4
Max. Exterior Deformation: 13.0 inches
OCDI: LF0000000
Max. Occupant Compartment Deformation: None

Figure 6.7. Summary of Results for MASH Test 3-10 on the TxDOT 31-Inch W-Beam Median Barrier.
6.1 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable MASH safety evaluation criteria is provided below.

6.1.1 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.

Results: The TxDOT 31-inch W-Beam Median Barrier contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 25.4 inches. (PASS)

6.1.2 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.

Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 inches).

Results: Three blockouts separated from posts. One blockout split apart and came to rest beneath the rail; one blockout came to rest 15 ft toward the opposite side of impact; and the third came to rest 10 ft toward traffic lanes. These blockouts did not penetrate or show potential for penetrating the occupant compartment. (PASS)

No occupant compartment deformation occurred. (PASS)

F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.

Results: The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles during the test were 11 degrees and 9 degrees, respectively. (PASS)
H. Occupant impact velocities should satisfy the following:

<table>
<thead>
<tr>
<th>Longitudinal and Lateral Occupant Impact Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preferred</td>
</tr>
<tr>
<td>30 ft/s</td>
</tr>
</tbody>
</table>

Results: Longitudinal occupant impact velocity was 20.0 ft/s, and lateral occupant impact velocity was 17.4 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:

<table>
<thead>
<tr>
<th>Longitudinal and Lateral Occupant Ridedown Accelerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preferred</td>
</tr>
<tr>
<td>15.0 Gs</td>
</tr>
</tbody>
</table>

Results: Longitudinal ridedown acceleration was 9.6 G, and lateral ridedown acceleration was 8.3 G. (PASS)

6.1.3 Vehicle Trajectory

For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).

Result: The 1100C vehicle exited within the criteria specified above. (PASS)
CHAPTER 7. CRASH TEST RESULTS FOR MASH TEST 3-11

7.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

*MASH* test 3-11 involves a 2270P vehicle weighing 5000 lb ±110 lb and impacting the TxDOT 31-inch W-Beam Median Barrier at an impact speed of 62.2 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target impact point was 10.5 ft upstream of post 13. The 2007 Dodge Ram 1500 pickup truck used in the test weighed 5017 lb and the actual impact speed and angle were 63.0 mi/h and 25.4 degrees, respectively. The actual impact point was 10.8 ft upstream of post 13. Target impact severity (IS) was 115.1 kip-ft, and actual IS was 122.5 kip-ft.

7.2 TEST VEHICLE

A 2007 Dodge Ram 1500 pickup truck, shown in Figures 7.1 and 7.2, was used for the crash test. Test inertia weight of the vehicle was 5014 lb, and its gross static weight was 5017 lb. The height to the lower edge of the vehicle bumper was 15.50 inches, and it was 28.00 inches to the upper edge of the bumper. The height to the vehicle’s center of gravity was 28.50 inches. Tables E1 and E2 in Appendix E give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

7.3 WEATHER CONDITIONS

The test was performed on the morning of June 21, 2013. Weather conditions at the time of testing were as follows: wind speed: 9 mi/h; wind direction: 173 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 87°F; relative humidity: 65 percent.

7.4 TEST DESCRIPTION

The 2007 Dodge Ram 1500 pickup truck, traveling at an impact speed of 63.0 mi/h, impacted the TxDOT 31-inch W-Beam Median Barrier 10.8 ft upstream of post 13 at an impact angle of 25.4 degrees. At approximately 0.034 s after impact, the 2270P vehicle began to redirect, and at 0.035 s, the rail element on the side opposite impact began to deform toward the side opposite impact. The left front corner of the vehicle contacted post 13 at 0.057 s, and the vehicle began traveling parallel with the installation at 0.289 s. At 0.691 s, the 2270P vehicle lost contact with the installation, however, was out of view of the overhead camera and exit speed and angle were not obtainable. Brakes on the vehicle were applied at 2.4 s after impact, and the vehicle yawed counterclockwise 136 degrees and came to rest 119.5 ft downstream of impact. Figures E1 and E2 in Appendix E show sequential photographs of the test period.
Figure 7.1. Vehicle/Installation Geometrics for Test No. 490023-4.
Figure 7.2. Vehicle before Test No. 490023-4.
7.5 DAMAGE TO TEST INSTALLATION

Figures 7.3 and 7.4 show damage to the TxDOT 31-inch W-Beam Median Barrier. Post 1 was displaced through the soil 0.5 inch at ground level on the upstream side, and no apparent movement was noted at post 26 (end posts). Posts 6 through 11 were slightly rotated, and post 11 was displaced through the soil 0.5 inch toward the side opposite impact. Post 12 was leaning downstream and toward the side opposite impact 45 degrees. Post 13 was leaning downstream 85 degrees and toward the side opposite impact 45 degrees. Posts 14 and 15 were leaning downstream 60 degrees. Post 16 was rotated slightly. The rail element on the impact side separated from posts 12 through 15, and the rail element on the side opposite impact released from posts 8 through 17. The blockouts on the impact side of posts 12 through 15 fractured and separated from the posts and rail element. The length of contact of the 2270P vehicle with the rail was 31.0 ft. Maximum permanent deformation of the rail was 29.5 inches between posts 13 and 14.

7.6 VEHICLE DAMAGE

Figure 7.5 shows damage to the 2270P vehicle. The left front tie rod, left front lower A-arm, left front frame rail, and left front hub assembly were deformed. Also damaged were the front bumper, grill, left front tire and wheel rim, left front fender, left front door, left rear door, left rear exterior bed, left rear tire, and rear bumper. Maximum exterior crush to the vehicle was 11.0 inches in the side plane at the left front corner just above bumper height. No occupant compartment deformation occurred. Figure 7.6 shows the interior of the vehicle before and after the test. Tables E3 and E4 in Appendix E present the measurements made on the vehicle.

7.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 19.0 ft/s at 0.151 s, the highest 0.010-s occupant ridedown acceleration was 10.2 Gs from 0.162 to 0.172 s, and the maximum 0.050-s average acceleration was −6.2 Gs between 0.050 and 0.100 s. In the lateral direction, the occupant impact velocity was 15.1 ft/s at 0.151 s, the highest 0.010-s occupant ridedown acceleration was 6.9 Gs from 0.192 to 0.202 s, and the maximum 0.050-s average was 4.5 Gs between 0.272 and 0.322 s. Theoretical Head Impact Velocity (THIV) was 25.3 km/h or 7.0 m/s at 0.143 s; Post-Impact Head Decelerations (PHD) was 10.2 Gs between 0.162 and 0.172 s; and Acceleration Severity Index (ASI) was 0.65 between 0.050 and 0.100 s. These data and other pertinent information from the test are summarized in Figure 7.7. Vehicle angular displacements and accelerations versus time traces are presented in Appendix E, Figures E3 through E9.
Figure 7.3. Vehicle/Installation Positions after Test No. 490023-4.
Figure 7.4. Installation after Test No. 490023-4.
Figure 7.5. Vehicle after Test No. 490023-4.
Figure 7.6. Interior of Vehicle for Test No. 490023-4.
General Information
Test Agency: Texas Transportation Institute (TTI)
Test Standard Test No.: MASH Test 3-11
TTI Test No.: 490023-4
Test Date: 2013-06-21

Test Article
Type: Median Barrier
Name: TxDOT 31-inch W-Beam Median Barrier
Installation Length: 156 ft
Material or Key Elements: 12-gauge W-beam at 31 inch height on W6×8.5 steel posts spaced 6 ft-3 inch with 6 inch × 8 inch × 14 inch routed wood blockouts with splice midspan between posts
Soil Type and Condition: Standard soil, dry

Test Vehicle
Type/Designation: 2270P
Make and Model: 2007 Dodge Ram 1500 Pickup
Curb: 4880 lb
Test Inertia: 5017 lb
Dummy: No dummy
Gross Static: 5017 lb

Impact Conditions
Speed: 63.0 mi/h
Angle: 25.4 degrees
Location/Orientation: 10.8 ft upstream of post 13
Impact Severity: 122.5 kip-ft

Exit Conditions
Speed: Not obtainable
Angle: Not obtainable

Occupant Risk Values
Impact Velocity
Longitudinal: 19.0 ft/s
Lateral: 15.1 ft/s
Ridedown Accelerations
Longitudinal: 10.2 G
Lateral: 6.9 G
THIV: 7.0 m/s
PHD: 10.2 G
ASI: 0.65
Max. 0.050-s Average
Longitudinal: -6.2 G
Lateral: 4.5 G
Vertical: 3.4 G

Post-Impact Trajectory
Stopping Distance: 119.5 ft downstrm

Vehicle Stability
Maximum Yaw Angle: 47 degrees
Maximum Pitch Angle: 11 degrees
Maximum Roll Angle: 12 degrees
Vehicle Snagging: No
Vehicle Pocketing: No

Test Article Deflections
Dynamic: 39.0 inches
Permanent: 29.5 inches
Working Width: 55.0 inches
Vehicle Intrusion: 50.3 inches

Vehicle Damage
VDS: 11LFQ3
CDC: 11FLEW3
Max. Exterior Deformation: 11.0 inches
OCDD: LF000000
Max. Occupant Compartment Deformation: None

Figure 7.7. Summary of Results for MASH Test 3-11 on the TxDOT 31-Inch W-Beam Median Barrier.
7.1 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable MASH safety evaluation criteria is provided below.

7.1.1 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.

Results: The TxDOT 31-inch W-Beam Median Barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 39.0 inches. (PASS)

7.1.2 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. Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 inches).

Results: The rail element and some blockouts separated from the posts, however, these did not penetrate nor show potential for penetrating the occupant compartment, nor did the present hazard to others in the area. (PASS)

No occupant compartment deformation occurred. (PASS)

F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.

Results: The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 11 degrees and 11 degrees, respectively. (PASS)

I. Occupant impact velocities should satisfy the following:

<table>
<thead>
<tr>
<th>Longitudinal and Lateral Occupant Impact Velocity</th>
<th>Preferred</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 ft/s</td>
<td>40 ft/s</td>
<td></td>
</tr>
</tbody>
</table>
Results: Longitudinal occupant impact velocity was 19.0 ft/s, and lateral occupant impact velocity was 15.1 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:

<table>
<thead>
<tr>
<th>Longitudinal and Lateral Occupant Ridedown Accelerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preferred</td>
</tr>
<tr>
<td>15.0 Gs</td>
</tr>
</tbody>
</table>

Results: Maximum longitudinal ridedown acceleration was 10.2 G, and maximum lateral ridedown acceleration was 6.9 G. (PASS)

7.1.3 Vehicle Trajectory

For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).

Result: The 2270P vehicle exited the installation within the limits specified above. (PASS)
CHAPTER 8. SUMMARY AND CONCLUSIONS

8.1 SUMMARY OF TEST RESULTS

8.1.1 MASH Test 3-10 (Crash Test No. 490023-3)

The TxDOT 31-inch W-Beam Median Barrier contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 25.4 inches. Three blockouts separated from posts. One blockout split apart and came to rest beneath the rail; one blockout came to rest 15 ft toward the opposite side of impact; and the third came to rest 10 ft toward traffic lanes. These blockouts did not penetrate or show potential for penetrating the occupant compartment. No occupant compartment deformation occurred. The 1100C vehicle remained upright during and after the collision event. Occupant risk factors were within the specified limits in MASH. The 1100C vehicle exited within the exit box criteria.

8.1.2 MASH Test 3-11 (Crash Test No. 490023-4)

The TxDOT 31-inch W-Beam Median Barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 39.0 inches. The rail element and some blockouts separated from the posts, however, these did not penetrate nor show potential for penetrating the occupant compartment, nor did the present hazard to others in the area. No occupant compartment deformation occurred. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 11 degrees and 11 degrees, respectively. Occupant risk factors were within the specified limits in MASH. The 2270P vehicle exited within the exit box criteria.

8.2 CONCLUSIONS

TTI researchers developed and successfully tested a 31-inch tall strong post W-beam median barrier. The barrier utilizes standard 6 ft long W6×8.5 steel posts spaced 6 ft-3 inches on center. The W-beam guardrails are offset from the posts using non-steel blockouts nominally 6 inch × 8 inch × 14 inch. The system was tested under both MASH TL 3-10 and TL 3-11 test conditions and passed all applicable MASH evaluation criteria associated with these tests as shown in Tables 8.1 and 8.2.
Table 8.1. Performance Evaluation Summary for MASH Test 3-10 on the TxDOT 31-Inch W-Beam Median Barrier.

<table>
<thead>
<tr>
<th>Test Agency: Texas Transportation Institute</th>
<th>Test No.: 490023-3</th>
<th>Test Date: 2013-06-18</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MASH Test 3-10 Evaluation Criteria</strong></td>
<td><strong>Test Results</strong></td>
<td><strong>Assessment</strong></td>
</tr>
<tr>
<td>Structural Adequacy</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 31-inch W-Beam Median Barrier contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 25.4 inches.</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>Three blockouts separated from posts. One blockout split apart and came to rest beneath the rail; one blockout came to rest 15 ft toward the opposite side of impact; and the third came to rest 10 ft toward traffic lanes. These blockouts did not penetrate or show potential for penetrating the occupant compartment.</td>
<td>Pass</td>
</tr>
<tr>
<td><em>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</em></td>
<td>No occupant compartment deformation occurred.</td>
<td>Pass</td>
</tr>
<tr>
<td>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td>
<td>The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles during the test were 11 degrees and 9 degrees, respectively.</td>
<td>Pass</td>
</tr>
<tr>
<td>H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.</td>
<td>Longitudinal occupant impact velocity was 20.0 ft/s, and lateral occupant impact velocity was 17.4 ft/s.</td>
<td>Pass</td>
</tr>
<tr>
<td>I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.</td>
<td>Longitudinal ridedown acceleration was 9.6 G, and lateral ridedown acceleration was 8.3 G.</td>
<td>Pass</td>
</tr>
<tr>
<td><strong>Vehicle Trajectory</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).</em></td>
<td>The 1100C vehicle exited within the criteria specified for the exit box.</td>
<td>Pass</td>
</tr>
</tbody>
</table>
Table 8.2. Performance Evaluation Summary for MASH Test 3-11 on the TxDOT 31-Inch W-Beam Median Barrier.

<table>
<thead>
<tr>
<th>Test Agency: Texas Transportation Institute</th>
<th>Test No.: 490023-4</th>
<th>Test Date: 2013-06-21</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MASH Test 3-11 Evaluation Criteria</strong></td>
<td><strong>Test Results</strong></td>
<td><strong>Assessment</strong></td>
</tr>
<tr>
<td>Structural Adequacy</td>
<td>The TXDOT 31-inch W-Beam Median Barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable</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 31-inch W-Beam Median Barrier contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 39.0 inches.</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>The rail element and some blockouts separated from the posts, however, these did not penetrate nor show potential for penetrating the occupant compartment, nor did the 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 5.3 and Appendix E of MASH.</td>
<td>No occupant compartment deformation occurred.</td>
<td>Pass</td>
</tr>
<tr>
<td>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td>
<td>The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 11 degrees and 11 degrees, respectively.</td>
<td>Pass</td>
</tr>
<tr>
<td>H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.</td>
<td>Longitudinal occupant impact velocity was 19.0 ft/s, and lateral occupant impact velocity was 15.1 ft/s.</td>
<td>Pass</td>
</tr>
<tr>
<td>I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.</td>
<td>Maximum longitudinal ridedown acceleration was 10.2 G, and maximum lateral ridedown acceleration was 6.9 G.</td>
<td>Pass</td>
</tr>
<tr>
<td>Vehicle Trajectory</td>
<td>The 2270P vehicle exited the installation within the limits specified above.</td>
<td>Pass</td>
</tr>
<tr>
<td>For redirective devices, the vehicle shall exit the barrier within the exit box.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 9. IMPLEMENTATION STATEMENT

A new strong steel post W-beam median barrier design was developed and tested. The TxDOT 31-inch W-Beam Median Barrier design adds a crashworthy semi-rigid median barrier alternative to TxDOT’s safety hardware standards. The design successfully met MASH impact performance criteria for both the small passenger car test (test 3-10) and pickup truck test (test 3-11). Moreover, the TxDOT 31-inch W-Beam Median Barrier design uses readily available components and does not require any new inventory.

Based on the successful crash testing, the new strong steel post W-beam median barrier design is considered ready for immediate implementation. The system is suitable for use in medians that can accommodate a dynamic deflection of 39 inches and a working width of 55 inches. This system was evaluated on flat terrain and, thus, its implementation should be on surfaces that have a grade of 1V:10H or flatter.

Full installation drawings and details for the new strong steel post W-beam median barrier design are contained herein to aid TxDOT with its incorporation into TxDOT standards.
REFERENCES


APPENDIX A. DETAILS OF THE TEST ARTICLE
## MATERIAL USED

<table>
<thead>
<tr>
<th>DATE RECEIVED</th>
<th>ITEM NUMBER</th>
<th>DESCRIPTION</th>
<th>SUPPLIER</th>
<th>HEAT #</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-06-10</td>
<td>12-Parts-01</td>
<td>Guardrail Parts</td>
<td>Trinity</td>
<td>see file</td>
</tr>
<tr>
<td>2013-06-05</td>
<td>Blockout-12-01</td>
<td>6 x 8 x 14 routed</td>
<td>Trinity</td>
<td>none</td>
</tr>
</tbody>
</table>
**Certified Analysis**

| Qty | Part# | Description                  | Spec | CL | TV | Heat Code/Heat | Yield | TS   | Elg  | C   | Mn  | P   | S   | Si  | Cu  | Cr  | Vn  | ACW |
|-----|-------|------------------------------|------|----|----|----------------|-------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|
| 10  | T1G   | 19/12/6/31/58                |      |    |    |                |       |      |      |     |     |     |     |     |     |     |     |
|     |       | M-180                        | A    | B302626 |    | 63,000         | 63,000 | 83,400 | 26.0 | 0.200 | 0.700 | 0.010 | 0.005 | 0.020 | 0.090 | 0.001 | 0.050 | 0.003 | 4   |
|     |       | M-180                        | A    | B302628 |    | 63,000         | 63,000 | 83,400 | 26.0 | 0.200 | 0.700 | 0.010 | 0.005 | 0.020 | 0.090 | 0.001 | 0.050 | 0.003 | 4   |
|     |       | M-180                        | A    | B302630 |    | 60,100         | 60,000 | 80,300 | 27.0 | 0.200 | 0.750 | 0.010 | 0.003 | 0.030 | 0.100 | 0.001 | 0.050 | 0.003 | 4   |
| 2   | 32G   | 12/12/6/38/ET2000.ANC        |      |    |    |                |       |      |      |     |     |     |     |     |     |     |     |     |
|     |       | M-180                        | A    | 223242 |    | 58,000         | 58,000 | 80,000 | 26.0 | 0.100 | 0.790 | 0.011 | 0.003 | 0.020 | 0.140 | 0.001 | 0.100 | 0.002 | 4   |
|     |       | M-180                        | A    | 2230680 |   | 60,000         | 60,000 | 85,100 | 25.0 | 0.300 | 0.720 | 0.018 | 0.003 | 0.030 | 0.100 | 0.001 | 0.060 | 0.007 | 4   |
| 25  | 533G  | 60 POST/5 DoR                | A-36 | 5905476 |   | 62,000         | 62,000 | 79,200 | 26.0 | 0.080 | 1.000 | 0.016 | 0.020 | 0.290 | 0.150 | 0.150 | 0.003 | 4   |
|     |       | A-36                         |      | 5905482 |   | 63,100         | 63,100 | 76,100 | 25.1 | 0.080 | 0.830 | 0.009 | 0.022 | 0.240 | 0.350 | 0.013 | 0.130 | 0.002 | 4   |
|     |       | A-36                         |      | 5905482 |   | 81,000         | 81,000 | 77,000 | 26.4 | 0.050 | 0.900 | 0.011 | 0.014 | 0.200 | 0.200 | 0.012 | 0.150 | 0.001 | 4   |
| 2   | 701A  | CABLE ANCHOR BREAT             | A-560 | 546000 |   | 68,255         | 68,255 | 78,404 | 25.0 | 0.200 | 0.810 | 0.013 | 0.008 | 0.013 | 0.030 | 0.006 | 0.030 | 0.001 | 4   |
| 2   | 300G  | CBL 3/4X6/CBL                | HW   |     |    |                |       |      |      |     |     |     |     |     |     |     |     |     |
| 125 | 334G  | 5/8" GR HEX NUT              | HW   | 1304580 |   | 95032          |       |      |      |     |     |     |     |     |     |     |     |     |
| 100 | 336G  | 5/8"X1.25" GR BOLT           | HW   | 1304260 |   | 1304260        |       |      |      |     |     |     |     |     |     |     |     |     |
| 25  | 350G  | 5/8"X10" GR BOLT A567         | HW   | 130419L |   | 130419L        |       |      |      |     |     |     |     |     |     |     |     |     |
| 20  | 360G  | 1" ROUND WASHER FB44         | HW   | 660119 |   | 1240119        |       |      |      |     |     |     |     |     |     |     |     |     |
| 20  | 391G  | 1" HEX NUT A563             | HW   | 1240119 |   | 1240119        |       |      |      |     |     |     |     |     |     |     |     |     |
| 25  | 677B  | PLYMR SLIC 4X7.5X14          | HW   | 4936 |   | 4936           |       |      |      |     |     |     |     |     |     |     |     |     |

**Trinity Highway Products, LLC**
2548 N.E. 28th St.
Ft Worth, TX 76111

Customer: SAMPLES, TESTING, TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207

Project: THP TEST MATERIAL
# Certified Analysis

**Trinity Highway Products, LLC**  
2548 N.E., 28th St.  
Ft Worth, TX 76111  

**Customer:** SAMPLES, TESTING, TRAINING MTRLS  
2525 STEMMONS FWY  

DALLAS, TX 75207  

**Project:** THP TEST MATERIAL  

<table>
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<tr>
<th>Order Number:</th>
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<th>Prod Ln Grp:</th>
<th>9-End Terminals (Dom)</th>
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<th>Part #</th>
<th>Description</th>
<th>Spec.</th>
<th>Cl.</th>
<th>TV</th>
<th>Heat Code/Heat</th>
<th>Yield</th>
<th>TS</th>
<th>Elg</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Cr</th>
<th>Ni</th>
<th>Al</th>
<th>Vn</th>
<th>ACW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1503G</td>
<td>69 SYT PST/5.5'/1/8 HT</td>
<td>A-36</td>
<td></td>
<td></td>
<td>11553</td>
<td>49.000</td>
<td>71.000</td>
<td>25.5</td>
<td>0.120</td>
<td>0.700</td>
<td>0.022</td>
<td>0.024</td>
<td>0.250</td>
<td>0.300</td>
<td>0.002</td>
<td>0.260</td>
<td>0.005</td>
<td>4</td>
<td></td>
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<tr>
<td>2</td>
<td>1928A</td>
<td>HHA-BRG PW/DEHDED</td>
<td>A-36</td>
<td></td>
<td></td>
<td>1024016</td>
<td>55.200</td>
<td>79.900</td>
<td>25.0</td>
<td>0.150</td>
<td>0.760</td>
<td>0.018</td>
<td>0.025</td>
<td>0.170</td>
<td>0.320</td>
<td>0.001</td>
<td>0.150</td>
<td>0.032</td>
<td>4</td>
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<tr>
<td>1</td>
<td>3373G</td>
<td>SYT-3&quot;AN STRT SL/6'6&quot;</td>
<td>A-36</td>
<td></td>
<td></td>
<td>3037297</td>
<td>55.000</td>
<td>79.900</td>
<td>32.0</td>
<td>0.260</td>
<td>0.850</td>
<td>0.010</td>
<td>0.038</td>
<td>0.190</td>
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<td>0.060</td>
<td>0.050</td>
<td>0.003</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3387A</td>
<td>ET HBA TP TOP X 2-3/4</td>
<td>A-36</td>
<td></td>
<td></td>
<td>10234567</td>
<td>57.220</td>
<td>76.037</td>
<td>28.8</td>
<td>0.120</td>
<td>0.980</td>
<td>0.021</td>
<td>0.045</td>
<td>0.180</td>
<td>0.430</td>
<td>0.001</td>
<td>0.230</td>
<td>0.003</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3387A</td>
<td>ET HBA PT 2 BTM X 6-1/2</td>
<td>A-36</td>
<td></td>
<td></td>
<td>JK12160309</td>
<td>56.096</td>
<td>74.046</td>
<td>29.6</td>
<td>0.130</td>
<td>0.650</td>
<td>0.020</td>
<td>0.040</td>
<td>0.280</td>
<td>0.270</td>
<td>0.002</td>
<td>0.110</td>
<td>0.002</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

TL -3 or TL -4 COMPLIANT when installed according to manufacturers specifications.

Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain 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 COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT".

ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123 (US DOMESTIC SHIPMENTS) ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS).

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

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

WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND OR F-444 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.

3/4" DIA CABLE GX19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA. ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH - 46000 LB.
Certified Analysis

Trinity Highway Products, LLC
2548 N.E. 28th St.
Ft Worth, TX 76111
Customer: SAMPLES, TESTING, TRAINING MTRLS
2525 STEMMONS FRWY
DALLAS, TX 75207
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Order Number: 1198833  Prod Ln Grp: 9-End Terminals (Dom)
Customer PO:
BOL Number: 47567  Ship Date:
Document #: I
Shipped To: TX
Use State: TX

State of Texas, County of Tarrant. Sworn and subscribed before me this 7th day of June, 2013
Notary Public:
Commission Expires

Certified By: Trinity Highway Products, LLC
Quality Assurance
Table C1. Test Day Static Soil Strength Documentation for Test No. 490023-3.

<table>
<thead>
<tr>
<th>Date</th>
<th>2013-06-18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Facility and Site Location</td>
<td>TTI Proving Ground – 3100 SH 47, Bryan, Tx</td>
</tr>
<tr>
<td>In Situ Soil Description (ASTM D2487)</td>
<td>Sandy gravel with silty fines</td>
</tr>
<tr>
<td>Fill Material Description (ASTM D2487) and sieve analysis</td>
<td>AASHTO Grade B Soil-Aggregate (see sieve analysis)</td>
</tr>
<tr>
<td>Description of Fill Placement Procedure</td>
<td>6-inch lifts tamped with a pneumatic compactor</td>
</tr>
</tbody>
</table>
Table C2. Test Day Static Soil Strength Documentation for Test No. 490023-4.

<table>
<thead>
<tr>
<th>Date</th>
<th>2013-06-18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Facility and Site Location</td>
<td>TTI Proving Ground – 3100 SH 47, Bryan, Tx</td>
</tr>
<tr>
<td>In Situ Soil Description (ASTM D2487)</td>
<td>Sandy gravel with silty fines</td>
</tr>
<tr>
<td>Fill Material Description (ASTM D2487) and sieve analysis</td>
<td>AASHTO Grade B Soil-Aggregate (see sieve analysis)</td>
</tr>
<tr>
<td>Description of Fill Placement Procedure</td>
<td>6-inch lifts tamped with a pneumatic compactor</td>
</tr>
</tbody>
</table>
Table C3. Summary of Strong Soil Test Results for Establishing Installation Procedure.

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

Dynamic Test Installation Details

Static Load Test Installation Details

Comparison of Load vs. Displacement at 25-inch height

Dynamic Test Setup

Post-Test Photo

Static Load Test

Percent Pass Vs. Grain Size of Fill Soil for Dynamic and Static Load Tests

Load (lb) vs. Displacement (inch)

Winch or Hydraulic Cylinder

24-Inch Diameter Granular Fill

W6X16 Steel Post
APPENDIX D.  MASH TEST 3-10 (CRASH TEST NO. 490023-3)

Table D1.  Vehicle Properties for Test No. 490023-3.

Date:  2013-06-18  Test No.:  490023-3  VIN No.:  KNADE123466137588
Year:  2006  Make:  Kia  Model:  Rio

Tire Inflation Pressure:  32 psi  Odometer:  94480  Tire Size:  185/65R14

Describe any damage to the vehicle prior to test:  

- Denotes accelerometer location.

NOTES:  

Engine Type:  4 cylinder
Engine CID:  
Transmission Type:  
  x  Auto or  Manual
  x  FWD  RWD  4WD

Optional Equipment:  

Dummy Data:  
  Type:  50th percentile male
  Mass:  180 lb
  Seat Position:  Driver

Geometry:  inches
A  66.38  F  33.00  K  11.00  P  41.12  U  16.00
B  57.75  G  ----  L  24.12  Q  22.18  V  22.00
C  165.75  H  35.23  M  57.75  R  15.38  W  38.00
D  34.00  I  7.12  N  57.12  S  7.62  X  104.00
E  98.75  J  21.00  O  30.52  T  66.12

Wheel Center Ht Front  11.00  Wheel Center Ht Rear  11.00

GVWR Ratings:  
  Mass:  lb
  Curb  1600
  Test Inertial  1572
  Gross Static  1663
Front  1918  M_{front}
Back  1874  M_{rear}
Total  3638  M_{Total}

Mass Distribution:  
  lb
  LF:  794  RF:  778  LR:  446  RR:  426
Table D2. Exterior Crush Measurements for Test No. 490023-3.

Date: 2013-06-18  Test No.: 490023-3  VIN No.: KNADE123466137588

Year: 2006  Make: Kia  Model: Rio

VEHICLE CRUSH MEASUREMENT SHEET

<table>
<thead>
<tr>
<th>End Damage</th>
<th>Side Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undeformed end width</td>
<td>Bowing: B1 X1</td>
</tr>
<tr>
<td>Corner shift: A1</td>
<td>B2 X2</td>
</tr>
<tr>
<td>A2</td>
<td></td>
</tr>
<tr>
<td>End shift at frame (CDC)</td>
<td>Bowing constant</td>
</tr>
<tr>
<td>(check one)</td>
<td></td>
</tr>
<tr>
<td>&lt; 4 inches</td>
<td></td>
</tr>
<tr>
<td>≥ 4 inches</td>
<td></td>
</tr>
</tbody>
</table>

Note: Measure C1 to C6 from Driver to Passenger Side in Front or Rear Impacts – Rear to Front in Side Impacts.

<table>
<thead>
<tr>
<th>Specific Impact Number</th>
<th>Plane* of C-Measurements</th>
<th>Direct Damage Width** (CDC)</th>
<th>Max*** Crush</th>
<th>Field L**</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>±D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Front plane at bumper ht</td>
<td>12.0</td>
<td>5.0</td>
<td>24.0</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>2</td>
<td>Front plant above bumper</td>
<td>22.0</td>
<td>13.0</td>
<td>38.0</td>
<td>0</td>
<td>3.5</td>
<td>7.0</td>
<td>9.5</td>
<td>12.0</td>
<td>13.0</td>
<td>+48</td>
</tr>
</tbody>
</table>

Measurements recorded

in inches

Table taken from National Accident Sampling System (NASS).

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

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

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

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

Note: Use as many lines/columns as necessary to describe each damage profile.
**Table D3. Occupant Compartment Measurements for Test No. 490023-3.**

<table>
<thead>
<tr>
<th></th>
<th>Before (inches)</th>
<th>After (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>68.00</td>
<td>68.00</td>
</tr>
<tr>
<td>A2</td>
<td>67.50</td>
<td>67.50</td>
</tr>
<tr>
<td>A3</td>
<td>67.50</td>
<td>67.50</td>
</tr>
<tr>
<td>B1</td>
<td>40.50</td>
<td>40.50</td>
</tr>
<tr>
<td>B2</td>
<td>36.25</td>
<td>36.25</td>
</tr>
<tr>
<td>B3</td>
<td>40.50</td>
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<tr>
<td>B4</td>
<td>36.25</td>
<td>36.25</td>
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<tr>
<td>B5</td>
<td>36.00</td>
<td>36.00</td>
</tr>
<tr>
<td>B6</td>
<td>36.25</td>
<td>36.25</td>
</tr>
<tr>
<td>C1</td>
<td>26.50</td>
<td>26.50</td>
</tr>
<tr>
<td>C2</td>
<td>----</td>
<td>----</td>
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<tr>
<td>C3</td>
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<td>D1</td>
<td>9.75</td>
<td>9.75</td>
</tr>
<tr>
<td>D2</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>D3</td>
<td>9.50</td>
<td>9.50</td>
</tr>
<tr>
<td>E1</td>
<td>48.25</td>
<td>48.25</td>
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<tr>
<td>E2</td>
<td>51.25</td>
<td>51.25</td>
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<tr>
<td>F</td>
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<td>50.50</td>
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<tr>
<td>G</td>
<td>50.50</td>
<td>50.50</td>
</tr>
<tr>
<td>H</td>
<td>36.75</td>
<td>36.75</td>
</tr>
<tr>
<td>I</td>
<td>36.75</td>
<td>36.75</td>
</tr>
<tr>
<td>J*</td>
<td>51.00</td>
<td>51.00</td>
</tr>
</tbody>
</table>

---

*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.*
Figure D1. Sequential Photographs for Test No. 490023-3 (Overhead and Frontal Views).
Figure D1. Sequential Photographs for Test No. 490023-3 (Overhead and Frontal Views) (continued).
Figure D2. Sequential Photographs for Test No. 490023-3 (Rear View).
Figure D3. Vehicle Angular Displacements for Test No. 490023-3.
Figure D4. Vehicle Longitudinal Accelerometer Trace for Test No. 490023-3
(Accelerometer Located at Center of Gravity).
Figure D5. Vehicle Lateral Accelerometer Trace for Test No. 490023-3 (Accelerometer Located at Center of Gravity).
Figure D6. Vehicle Vertical Accelerometer Trace for Test No. 490023-3 (Accelerometer Located at Center of Gravity).
Figure D7. Vehicle Longitudinal Accelerometer Trace for Test No. 490023-3 (Accelerometer Located Rear of Center of Gravity).
Figure D8. Vehicle Lateral Accelerometer Trace for Test No. 490023-3 (Accelerometer Located Rear of Center of Gravity).
Figure D9. Vehicle Vertical Accelerometer Trace for Test No. 490023-3
(Accelerometer Located Rear of Center of Gravity).
APPENDIX E. MASH TEST 3-11 (CRASH TEST NO. 490023-4)

Table E1. Vehicle Properties for Test No. 490023-4.

<table>
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<th>Date:</th>
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</thead>
<tbody>
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<td>Test No.:</td>
<td>490023-4</td>
</tr>
<tr>
<td>VIN No.:</td>
<td>1D7HA18P975246153</td>
</tr>
<tr>
<td>Year:</td>
<td>2007</td>
</tr>
<tr>
<td>Make:</td>
<td>Dodge</td>
</tr>
<tr>
<td>Model:</td>
<td>Ram 1500</td>
</tr>
<tr>
<td>Tire Size:</td>
<td>265/70R17</td>
</tr>
<tr>
<td>Tire Inflation Pressure:</td>
<td>35 psi</td>
</tr>
<tr>
<td>Tread Type:</td>
<td></td>
</tr>
<tr>
<td>Odometer:</td>
<td>137341</td>
</tr>
</tbody>
</table>

Note any damage to the vehicle prior to test:

- Denotes accelerometer location.

NOTES:

| Engine Type: | V-8 |
| Engine CID: | 4.7 liter |

Transmission Type:

- AUTO or Manual
  - FWD
  - RWD
  - 4WD

Optional Equipment:

Dummy Data:

- Type: No dummy
- Mass: |
- Seat Position: |

Geometry: inches

<table>
<thead>
<tr>
<th>A</th>
<th>78.25</th>
<th>F</th>
<th>36.00</th>
<th>K</th>
<th>20.75</th>
<th>P</th>
<th>3.88</th>
<th>U</th>
<th>28.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>75.75</td>
<td>G</td>
<td>28.50</td>
<td>L</td>
<td>29.25</td>
<td>Q</td>
<td>30.50</td>
<td>V</td>
<td>30.50</td>
</tr>
<tr>
<td>C</td>
<td>223.75</td>
<td>H</td>
<td>61.61</td>
<td>M</td>
<td>68.50</td>
<td>R</td>
<td>18.38</td>
<td>W</td>
<td>61.60</td>
</tr>
<tr>
<td>D</td>
<td>47.25</td>
<td>I</td>
<td>15.50</td>
<td>N</td>
<td>68.00</td>
<td>S</td>
<td>16.00</td>
<td>X</td>
<td>75.00</td>
</tr>
<tr>
<td>E</td>
<td>140.50</td>
<td>J</td>
<td>28.00</td>
<td>O</td>
<td>46.50</td>
<td>T</td>
<td>77.50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Wheel Center Height Front: 14.75
Wheel Center Height Rear: 14.75
Wheel Well Clearance (Front): 6.00
Wheel Well Clearance (Rear): 11.25
Bottom Frame Height - Front: 18.75
Bottom Frame Height - Rear: 26.00

GVWR Ratings:

<table>
<thead>
<tr>
<th>Front</th>
<th>3700</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back</td>
<td>3900</td>
</tr>
<tr>
<td>Total</td>
<td>6700</td>
</tr>
</tbody>
</table>

Mass Distribution:

| Ib | LF: 1433 | RF: 1384 | LR: 1096 | RR: 1104 |

TR No. 9-1002-12-8 85 2013-10-24
### Table E2. Parametric Measurements for Vertical CG on 2270P Vehicle for Test No. 490023-4.

- **Date:** 2013-06-21  
- **Test No.:** 490023-4  
- **VIN:** 1D7HA18P975246153  
- **Year:** 2007  
- **Make:** Dodge  
- **Model:** Ram 1500  
- **Body Style:** Quad Cab  
- **Mileage:** 137341  
- **Engine:** V-8  
- **Transmission:** Automatic  
- **Fuel Level:** Empty  
- **Ballast:** 176 lb (440 lb max)  
- **Tire Pressure:** Front: 35 psi  
  Rear: 35 psi  
  Size: 265/70R17  
- **Hood Height:** 46.50 inches  
- **Front Bumper Height:** 28.00 inches  
  43 ±4 inches allowed  
- **Front Overhang:** 36.00 inches  
  39 ±3 inches allowed  
- **Overall Length:** 223.75 inches  
  237 ±13 inches allowed

#### Measured Vehicle Weights (lb)

<table>
<thead>
<tr>
<th>Side</th>
<th>Weight</th>
<th>Wheel Base</th>
<th>Track</th>
</tr>
</thead>
<tbody>
<tr>
<td>LF</td>
<td>1433</td>
<td>140.5</td>
<td>68.5</td>
</tr>
<tr>
<td>RF</td>
<td>1384</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LR</td>
<td>1096</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RR</td>
<td>1104</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>2529</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>2488</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5017</td>
<td>5000 ±110 lb allowed</td>
<td></td>
</tr>
</tbody>
</table>

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

- **X:** 61.61 in  
  Rear of Front Axle (63 ±4 inches allowed)  
- **Y:** -0.28 in  
  Left - Right + of Vehicle Centerline  
- **Z:** 28.5 in  
  Above Ground (minimum 28.0 inches allowed)
Table E3. Exterior Crush Measurements for Test No. 490023-4.

Date: 2013-06-21  Test No.: 490023-4  VIN No.: 1D7HA18P975246153  Year: 2007  Make: Dodge  Model: Ram 1500

VEHICLE CRUSH MEASUREMENT SHEET

<table>
<thead>
<tr>
<th>End Damage</th>
<th>Side Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undeformed end width</td>
<td>Bowing: B1 _____ X1 _____</td>
</tr>
<tr>
<td>Corner shift: A1</td>
<td>B2 _____ X2 _____</td>
</tr>
<tr>
<td>A2</td>
<td></td>
</tr>
<tr>
<td>End shift at frame (CDC)</td>
<td>Bowing constant</td>
</tr>
<tr>
<td>(check one)</td>
<td>X1 + X2</td>
</tr>
<tr>
<td>&lt; 4 inches</td>
<td>= _____</td>
</tr>
<tr>
<td>≥ 4 inches</td>
<td></td>
</tr>
</tbody>
</table>

Note: Measure C1 to C6 from Driver to Passenger Side in Front or Rear Impacts – Rear to Front in Side Impacts.

<table>
<thead>
<tr>
<th>Specific Impact Number</th>
<th>Plane* of C-Measurements</th>
<th>Direct Damage Width** (CDC)</th>
<th>Max*** Crush</th>
<th>Field L**</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>±D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Front plane at bumper ht</td>
<td>17.0</td>
<td>10.0</td>
<td>30</td>
<td>10</td>
<td>8</td>
<td>6.5</td>
<td>3</td>
<td>1.5</td>
<td>0</td>
<td>-15</td>
</tr>
<tr>
<td>2</td>
<td>Side plane above bumper</td>
<td>20.0</td>
<td>11.0</td>
<td>60</td>
<td>0</td>
<td>1.5</td>
<td>----</td>
<td>---</td>
<td>9-</td>
<td>11</td>
<td>+72</td>
</tr>
</tbody>
</table>

Measurements recorded in inches

Table taken from National Accident Sampling System (NASS).

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

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

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

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

Note: Use as many lines/columns as necessary to describe each damage profile.
Table E4. Occupant Compartment Measurements for Test No. 490023-4.

Date: 2013-06-21  Test No.: 490023-4  VIN No.: 1D7HA18P975246153

Year: 2007  Make: Dodge  Model: Ram 1500

| OCCUPANT COMPARTMENT |
| DEFORMATION MEASUREMENT |
| Before |
| ( inches ) |
| After |
| ( inches ) |
| A1 | 64.50 |
| A2 | 64.50 |
| A3 | 65.00 |
| B1 | 45.00 |
| B2 | 39.25 |
| B3 | 45.00 |
| B4 | 42.12 |
| B5 | 44.75 |
| B6 | 42.12 |
| C1 | 29.75 |
| C2 | ---- |
| C3 | 27.50 |
| D1 | 12.75 |
| D2 | ---- |
| D3 | 11.75 |
| E1 | 62.75 |
| E2 | 64.50 |
| E3 | 64.00 |
| E4 | 64.25 |
| F | 60.00 |
| G | 60.00 |
| H | 39.00 |
| I | 39.00 |
| J* | 62.25 |

*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.*
Figure E1. Sequential Photographs for Test No. 490023-4 (Overhead and Frontal Views).
Figure E1. Sequential Photographs for Test No. 490023-4 (Overhead and Frontal Views) (continued).
Figure E2. Sequential Photographs for Test No. 490023-4 (Rear View).
Roll, Pitch, and Yaw Angles

Figure E3. Vehicle Angular Displacements for Test No. 490023-4.
Figure E4. Vehicle Longitudinal Accelerometer Trace for Test No. 490023-4 (Accelerometer Located at Center of Gravity).
Figure E5. Vehicle Lateral Accelerometer Trace for Test No. 490023-4 (Accelerometer Located at Center of Gravity).
Z Acceleration at CG

TTI Test Number: 490023-4
Test Standard Test No.: MASH 3-11
Test Article: MGS 31-inch W-Beam Median Barrier
Test Vehicle: 2007 Dodge Ram 1500 Pickup
Inertial Mass: 5017 lb
Impact Speed: 63.0 mph
Impact Angle: 25.4 degrees

Figure E6. Vehicle Vertical Accelerometer Trace for Test No. 490023-4
(Accelerometer Located at Center of Gravity).
**X Acceleration Rear of CG**

![Graph](image)

**Figure E7. Vehicle Longitudinal Accelerometer Trace for Test No. 490023-4 (Accelerometer Located Rear of Center of Gravity).**
**Figure E8. Vehicle Lateral Accelerometer Trace for Test No. 490023-4**

(Accelerometer Located Rear of Center of Gravity).
**Z Acceleration Rear of CG**

TTI Test Number: 490023-4  
Test Standard Test No.: MASH 3-11  
Test Article: MGS 31-inch W-Beam Median Barrier  
Test Vehicle: 2007 Dodge Ram 1500 Pickup  
Inertial Mass: 5017 lb  
Impact Speed: 63.0 mph  
Impact Angle: 25.4 degrees

Figure E9. Vehicle Vertical Accelerometer Trace for Test No. 490023-4  
(Accelerometer Located Rear of Center of Gravity).