Test Report No. 608431-01-1&2
Test Report Date: October 2018

MASH TESTS 3-34 AND 3-35 ON THE 31-INCH BURIED-IN-BACKSLOPE TERMINAL COMPATIBLE WITH MGS GUARDRAIL

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16. Abstract

Buried (in backslope) terminal designs for beam guardrail were developed under National
Cooperative Highway Research Program (NCHRP) Report 350 criteria 27½-inch high guardrail systems.
Some states have modified this design so that it could be used with 31-inch high guardrail systems. Other
agencies are hesitant to use this design for 31-inch high guardrail until it is crash tested or deemed acceptable
for use by Federal Highway Administration.

The purpose of this research was to evaluate the safety performance of a 31-inch Buried-in-Backslope
(BIB) terminal attached to a Midwest Guardrail System (MGS) in accordance with American Association of
State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH)
evaluation criteria. The proposed BIB terminal design successfully met the MASH evaluation criteria for
MASH Tests 3-34 and 3-35.
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INTRODUCTION

1.1 PROBLEM STATEMENT

Buried (in backslope) terminal designs for beam guardrail were developed under National Cooperative Highway Research Program (NCHRP) Report 350 criteria for 27¾-inch high guardrail systems (1). When properly designed and located, this type of anchor eliminates the possibility of an end-on impact with the barrier terminal and minimizes the likelihood of vehicular intrusion behind the barrier. Some states desire to have a modified BIB design that is compatible with 31-inch high guardrail systems.

The purpose of this research was to perform full-scale crash tests and evaluate the performance of a 31-inch BIB terminal design attached to an MGS guardrail system.

1.2 BACKGROUND

A W-beam guardrail can be terminated by burying the end of the rail element into a soil berm. This type of guardrail termination installation is referred to as a “Buried-In-Backslope end terminal” (hereinafter “BIB”). BIB terminal designs for W-beam guardrail were developed under NCHRP Report 350 criteria for 27-inch high guardrail systems.

With the satisfactory performance of the modified G4(1S) W-beam guardrail system with timber blockouts, the Federal Highway Administration (FHWA) decided to evaluate two terminal designs for the steel-post W-beam guardrail with similar modification (i.e., timber blockouts). Texas A&M Transportation Institute (TTI) evaluated two BIB end terminals for use with modified G4(1S) W-beam guardrails (3). Tests were conducted in accordance with NCHRP Report 350, and involved a 2000P vehicle impacting the terminal at a nominal impact speed and angle of 62 mi/h and 20°, respectively. The BIB end terminal for the W-beam guardrail was tested in two configurations: one with a ditch and the other with a drop inlet. The top of the rail was 27 inches high, as measured from the shoulder grade, and the guardrail end was anchored to a concrete block buried in the backslope.

In previous tests, for the ditch configuration, the earth was graded away from the shoulder at a 1V:10H slope for 6 ft, followed by a 3-ft wide ditch, then by a 1V:2H backslope. For the drop inlet configuration, the earth was graded away from the shoulder at a 1V:10H slope for 9 ft, followed by a 1V:2H backslope. Both installations met evaluation criteria set forth for NCHRP Report 350 test designation 3-35. There was minimal deformation and no intrusion into the occupant compartment. The occupant risk factors were all well within the recommended limits.

Subsequently, the buried terminal design was also successfully tested on installations with a 1V:6H foreslope forming a V-ditch with a 1V:4H backslope and over a 1V:4H foreslope forming a V-ditch with a 1V:2H backslope (4). These tests were intended primarily to evaluate the ability of the device to contain and redirect a 2000P pickup truck (structural adequacy criteria). The tests performed were NCHRP Report 350 test designation 3-35, with a 2000P...
vehicle impacting the beginning of the length of need of the terminal at a nominal speed and impact angle of 62 mi/h and 20°, respectively.

The BIB terminal with a 1V:6H ditch contained and redirected the vehicle. Maximum deformation of the occupant compartment was 1.77 inches. The terminal performed acceptably for NCHRP Report 350 test designation 3-35. The BIB terminal with a 1V:4H slope contained and redirected the vehicle. Maximum deformation of the occupant compartment was 4.9 inches. The terminal performed acceptably for NCHRP Report 350 test designation 3-35.


In recent years, guardrail heights have increased to 31 inches in many states. Considering the increase in guardrail height to 31 inches, it was advisable that the BIB terminal design for a 27¾-inch high guardrail be modified to satisfy NCHRP Report 350 criteria for a 31-inch high guardrail. The BIB design offers the advantage of shielding guardrail ends from direct vehicle impact, thus reducing the potential for penetration behind the end terminal and/or for the guardrail to penetrate the vehicle.

A previous study funded by the Roadside Safety Pooled Fund Group was conducted with the objective to identify design modifications necessary to adapt a buried terminal design for 27¾-inch guardrail for use with a 31-inch guardrail system, and to assess impact performance criteria in accordance with NCHRP Report 350 criteria (5). Results from the computer simulation of Test 3-35 on the 31-inch high buried-in-backslope terminal indicate that all applicable NCHRP Report 350 evaluation criteria were met. Finite element (FE) computer simulations indicated the 31-inch high buried-in-backslope terminal would have very similar behavior to that of the 27¾-inch high system. In fact, the 31-inch rail height improved vehicle stability throughout the entire impact event, and occupant risk indices were well below the limiting values recommended in NCHRP Report 350.

1.3 OBJECTIVE

The purpose of this research was to evaluate the safety performance of a 31-inch BIB terminal attached to a Midwest Guardrail System (MGS) in accordance with American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH) evaluation criteria. Two full-scale crash tests were performed according to MASH Test Level 3 (TL-3). The first full-scale crash test, MASH Test 3-35, involved a 5000-lb pickup truck impacting the BIB at 62 mi/h nominal speed and at a nominal angle of 25° with respect to the roadway orientation. This test is intended to evaluate the strength and capacity of the terminal system. The second full-scale test, MASH Test 3-34, involved a 2420-lb passenger vehicle impacting the terminal at 62 mi/h nominal speed at a nominal angle of 15° with respect to the roadway orientation. This test assesses occupant risk as well as the likelihood for the small passenger car to underride the terminal system. Both tests were assessed according to the evaluation criteria set forth in MASH for TL-3 terminals.
Chapter 2. SYSTEM DETAILS

2.1. TEST ARTICLE AND INSTALLATION DETAILS

The test installation consisted of a guardrail with a BIB Terminal on the upstream end and a Texas Department of Transportation (TxDOT) Downstream Anchor Terminal (DAT) Terminal on the downstream end, for a total installation length of 242 ft 7 inches. The guardrail was flared across a V-ditch and its end was anchored to three 72-inch long steel posts using a special connection bracket that was buried in the backslope (see Sheet 5 of 6 in Appendix A). The installation used standard 12 gauge W-beam guardrail with the splices mid-span between the posts. All posts in the installation were spaced at 75 inches, except the two 37½-inch spaces at posts 1 to 2 and 2 to 3 in the BIB Terminal anchorage section. The W-beam guardrail was attached to 72-inch long W6×8.5 wide flange guardrail posts embedded in soil and nominal 6×8-inch timber blockouts using 10-inch long button head guardrail bolts such that the top of the guardrail was at 31 inches above grade.

The DAT Terminal and guardrail were placed parallel to an existing concrete apron, with the front of the rail aligned with the break point of “V” profile ditch. The ditch had a 72-inch wide, 4-to-1 foreslope that initiated from the pavement edge, and a 2-to-1 backslope. The bottom of the V-ditch crossed the rail terminal between posts 9 and 10.

The guardrail between posts 1, 2, 3, and 4 (numbered sequentially from the end anchor) is flared back in a 4-to-1 ratio. The guardrail between posts 4 and 6 is flared back in a 6-to-1 ratio; between posts 6 and 10 in an 8-to-1 ratio; and between posts 10 and 22 in a 13 to 1 ratio. In addition, the guardrail between post 10 and post 1 is tapered from a height of 31 inches to 15 inches, as measured from the top of the rail to the pavement grade. This places the top of the rail at post 1 12 inches below the surface of the soil. The guardrail, beginning at post 10, was parallel to the travel way with the top of the rail at a height of 31 inches.

Posts 1 through 3 and 22 through 39 were 72 inches long. Posts 4 through 21 were 96 inches long. A W-beam rub rail extended from post 4 to post 21. The rub rail was mounted to the steel guardrail posts with a 2-inch guardrail bolt. A 3-inch vertical gap was maintained between the W-beam guardrail and the rub rail. The upstream end of the rub rail was connected to post 4 with a special connection bracket and the downstream end of the rub rail was connected to the back of post 21 with a ½ inch diameter by 5-inch long bolt.

Figure 2.1 presents overall information on the BIB Terminal, and Figure 2.2 provides photographs of the installation. Appendix A provides further details of the BIB Terminal.

2.2. MATERIAL SPECIFICATIONS

Material certification documents for the materials used to install/construct the BIB Terminal are on file at TTI Proving Ground.
Figure 2.1. Details of the 31-inch BIB Terminal.
2.3. SOIL CONDITIONS

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

In accordance with Appendix B of MASH, soil strength was measured the day of the crash test. During installation of the BIB terminal for full-scale crash testing, two W6×16 posts were installed in the immediate vicinity of the BIB terminal utilizing the same fill materials and installation procedures used in the test installation and the standard dynamic test. Table B.1 in
Appendix B presents minimum soil strength properties established through the dynamic testing performed in accordance with MASH Appendix B. As determined by the tests summarized in Appendix B, Table B.1, the minimum post loads required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, are 3940 lb, 5500 lb, and 6540 lb, respectively (90% of static load for the initial standard installation).

On the day of Test No. 608431-1-1, April 30, 2018, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 6717 lbf, 7121 lbf, and 7121 lbf, respectively. Table B.2 in Appendix B shows the strength of the backfill material in which the BIB Terminal was installed met minimum MASH requirements.

On the day of Test No. 608431-1-2, June 1, 2018, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 4494 lbf, 5202 lbf, and 5555 lbf, respectively. Table B.3 in Appendix B shows the strength of the backfill material in which the BIB Terminal was installed met the minimum MASH requirement at 5 inches, but did not meet minimum MASH requirements at 10 inches and 15 inches. The location where the two W6×16 pull posts were installed for soil strength measurements was roughly 100 ft upstream of the BIB impact location. The soil at this location had a significantly higher moisture content than the soil in the ditch in which the guardrail system was installed. The researchers decided to excavate in the ditch adjacent to a post in the vicinity of the impact location to verify and compare the soil moisture. The soil in the ditch appeared drier than the location where the two W6×16 pull posts were installed, and close to optimum moisture content. The difference was attributed to the fact that the area upstream of the ditch where the two W6×16 pull posts were installed retained rain water, while the ditch in which the guardrail and BIB terminal were installed allowed for the same water to drain faster. After discussions with the sponsor, the researchers decided to perform the crash test.
Chapter 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1. CRASH TEST PERFORMED / MATRIX

Table 3.1 shows the recommended tests and evaluation criteria for evaluating the impact performance of terminals in MASH. MASH Tests 3-34 and 3-35 were performed on the BIB terminal. The crash tests and data analysis procedures were in accordance with guidelines presented in MASH.

Table 3.1 Test Conditions and Evaluation Criteria Specified for MASH TL-3 Non-Gating Terminals.

<table>
<thead>
<tr>
<th>Test Designation</th>
<th>Test Vehicle</th>
<th>Impact Conditions</th>
<th>Evaluation Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Speed (mi/h)</td>
<td>Angle (deg.)</td>
</tr>
<tr>
<td>3-30</td>
<td>1100C</td>
<td>62</td>
<td>0</td>
</tr>
<tr>
<td>3-31</td>
<td>2270P</td>
<td>62</td>
<td>0</td>
</tr>
<tr>
<td>3-32</td>
<td>1100C</td>
<td>62</td>
<td>5-15</td>
</tr>
<tr>
<td>3-33</td>
<td>2270P</td>
<td>62</td>
<td>5-15</td>
</tr>
<tr>
<td>3-34</td>
<td>1100C</td>
<td>62</td>
<td>15</td>
</tr>
<tr>
<td>3-35</td>
<td>2270P</td>
<td>62</td>
<td>25</td>
</tr>
<tr>
<td>3-36</td>
<td>2270P</td>
<td>62</td>
<td>25</td>
</tr>
<tr>
<td>3-37b</td>
<td>1100C</td>
<td>62</td>
<td>25</td>
</tr>
<tr>
<td>3-38</td>
<td>1500A</td>
<td>62</td>
<td>0</td>
</tr>
</tbody>
</table>

Tests 3-30, 3-31, 3-32, and 3-33 are intended to evaluate occupant risk, vehicle stability and vehicle trajectory for head-on or oblique impacts on the end of the terminal system. In the case of the BIB system, there is no exposed end that can be impacted, therefore these tests are considered not relevant.

Test 3-36 is designed to examine the behavior of terminals when attached to rigid barriers or other very stiff features. In the case of the BIB, there is no rigid back-up structure attached to the terminal, therefore this test is considered not relevant.

Test 3-37 (a or b) examines the behavior of terminals during reverse-direction impacts. For post-and-beam terminals utilizing a breakaway cable system, the 1100C is generally the critical vehicle for this test (Test 3-37b). The BIB system doesn’t include a breakaway cable system that needs to be released. Also, the rubrail of the BIB system helps prevent interaction with posts during a reverse direction impact. In addition, the BIB system flaring away from the roadway reduces the effective impact angle and impact severity for a reverse direction hit. For these reasons, test 3-37b is considered not relevant.
Test 3-38 is intended to evaluate the performance of crash cushions and end terminals during impacts by mid-size vehicles. Since the BIB is not a staged device, this test is considered not relevant.

The crash tests reported herein were performed in accordance with MASH Tests 3-34 and 3-35 for non-gating terminals.

*MASH* defines the CIP for Test 34 as the point “where the behavior of these devices (i.e. the BIB terminal) changes from gating or capturing to redirection.” With that in mind, the researchers selected the location that maximizes under-riding potential for the 1100C vehicle, as well as maximizes interaction between the passenger car and test installation. The target impact point for *MASH* Test 3-34 was selected to be 19 inches downstream of post 9, which was the point where the installation crosses the ditch bottom.

*MASH* indicates that for Test 35, “a 2270P vehicle is directed into the system at the beginning of the LON at an impact angle of 25 degrees”. The AASHTO Roadside Design Guide defines the beginning of the LON for all buried-in-backslope designs as “the point where the installation crosses the ditch bottom”. Therefore, the target impact point for *MASH* Test 3-35 was 19 inches downstream of post 9, which is the point where the installation crosses the ditch bottom.

![Figure 3.1. Target CIP for MASH Tests 3-34 and 3-35 on BIB Terminal.](image)

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

### 3.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-3 and 5-1 of *MASH* were used to evaluate the crash tests reported herein. The test conditions and evaluation criteria required for
MASH TL-3 non-gating terminals are listed in Table 3.1, and the substance of the evaluation criteria described in Table 3.2. An evaluation of each of the crash test results is presented in detail under the section Assessment of Test Results.

**Table 3.2. Evaluation Criteria Required for MASH TL-3 Non-Gating Terminals.**

<table>
<thead>
<tr>
<th>Evaluation Factors</th>
<th>Evaluation Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural Adequacy</strong></td>
<td>A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td>
</tr>
<tr>
<td></td>
<td>D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</td>
</tr>
<tr>
<td><strong>Occupant Risk</strong></td>
<td>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td>
</tr>
<tr>
<td></td>
<td>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.</td>
</tr>
<tr>
<td></td>
<td>I. The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</td>
</tr>
</tbody>
</table>
Chapter 4. TEST CONDITIONS

4.1. TEST FACILITY

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

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

4.2 VEHICLE TOW AND GUIDANCE SYSTEM

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

4.3 DATA ACQUISITION SYSTEMS

4.3.1 Vehicle Instrumentation and Data Processing

Each test vehicle was 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, which measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra-small, solid state units designed for crash test service. The TDAS Pro hardware
and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 16 channels is capable of providing precision amplification, scaling, and filtering based on transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 values per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit 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 initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

Each of the TDAS Pro units is returned to the factory annually for complete recalibration and all instrumentation used in the vehicle conforms to all specifications outlined by SAE J211. All accelerometers are calibrated annually by means of an ENDEVCO® 2901, precision primary vibration standard. This standard and its support instruments are checked annually and receive a National Institute of Standards Technology (NIST) traceable calibration. The rate transducers used in the data acquisition system receive a calibration via a Genisco Rate-of-Turn table. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are also made any time data are suspect. Acceleration data is 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 low-pass digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals, 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).

4.3.2 Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the front seat on the impact side of the 1100C vehicle. The dummy was not instrumented.

According to MASH, use of a dummy in the 2270P vehicle is optional. Use of the dummy in the 2270P vehicle is recommended for tall rails to evaluate the “potential for an occupant to extend out of the vehicle and come into direct contact with the test article.” Although this
information is reported, it is not part of the impact performance evaluation. A dummy was placed in the front seat of the 2270P vehicle on the impact side and restrained with lap and shoulder belts.

4.3.3 Photographic Instrumentation Data Processing

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

- One overhead with a field of view perpendicular to the ground and directly over the impact point;
- One placed 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 on each of the impacting vehicles was activated by a pressure-sensitive tape switch to indicate the instant of contact with the BIB terminal. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.
5.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

*MASH* Test 3-34 involves an 1100C vehicle weighing 2420 lb ±55 lb impacting the beginning of length of need of the terminal at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 15° ±1.5°. The target impact point for *MASH* Test 3-34 on the BIB Terminal was at the rail location where the system crosses the ditch (approximately 19.0 inches downstream of post 9).

The 2009 Kia Rio* used in the test weighed 2427 lb, and the actual impact speed was 64.1 mi/h. The vehicle left the roadway at 14.5°, however, due to the vehicle’s interaction with the slope as it traversed into the ditch, actual impact angle as it contacted the terminal was 17.8° to the roadway (24.9° effective angle with the tangent of the rail at impact point). The actual impact point was 18.5 inches downstream of post 9. Minimum target impact severity (IS) was ≥19 kip-ft, and actual IS was 31 kip-ft (59 kip-ft using 24.9° effective angle).

5.2 WEATHER CONDITIONS

*MASH* Test 3-34 on the BIB Terminal was performed on the afternoon of June 1, 2018. Weather conditions at the time of testing were as follows: wind speed: 9 mi/h; wind direction: 229° (vehicle was traveling in a southwesterly direction); temperature: 89°F; relative humidity: 66 percent.

5.3 TEST VEHICLE

Figures 5.1 and 5.2 show the 2009 Kia Rio used for the crash test. The vehicle’s test inertia weight was 2427 lb, and its gross static weight was 2592 lb. The height to the lower edge of the vehicle bumper was 7.75 inches, and height to the upper edge of the bumper was 21.5 inches. Table C.1 in Appendix C1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

* Figure 5.1. BIB Terminal/Test Vehicle Geometrics for Test No. 608431-01-2.

* A test vehicle model older than 2012 was used, based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the year model, this vehicle met the *MASH* requirements.
5.4 TEST DESCRIPTION

The test vehicle was traveling at an impact speed of 64.1 mi/h when it contacted the BIB Terminal 18.5 inches downstream of post 9, at an impact angle of 17.8° with respect to the roadway (24.9° effective angle with the tangent of the rail at impact point). Table 5.1 lists events that occurred during Test No. 608431-01-2. Figure C.1 in Appendix C2 present sequential photographs during the test.

Table 5.1. Events during Test No. 608431-01-2.

<table>
<thead>
<tr>
<th>TIME (s)</th>
<th>EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.013</td>
<td>Post 9 begins to deflect toward the field side</td>
</tr>
<tr>
<td>0.027</td>
<td>Post 10 begins to deflect toward the field side</td>
</tr>
<tr>
<td>0.037</td>
<td>Vehicle begins to redirect</td>
</tr>
<tr>
<td>0.046</td>
<td>Right front corner of bumper contacts post 10</td>
</tr>
<tr>
<td>0.048</td>
<td>Post 11 begins to deflect toward the field side</td>
</tr>
<tr>
<td>0.073</td>
<td>Right front corner of bumper contacts post 10</td>
</tr>
<tr>
<td>0.074</td>
<td>Post 12 begins to deflect toward the field side</td>
</tr>
<tr>
<td>0.097</td>
<td>Post 13 begins to deflect toward the field side</td>
</tr>
<tr>
<td>0.119</td>
<td>Right front corner of bumper contacts post 11</td>
</tr>
<tr>
<td>0.168</td>
<td>Rear of vehicle contacts rail element</td>
</tr>
<tr>
<td>0.175</td>
<td>Vehicle becomes parallel with the guardrail</td>
</tr>
<tr>
<td>0.199</td>
<td>Right front corner of bumper contacts blockout at post 12</td>
</tr>
<tr>
<td>0.363</td>
<td>Vehicle loses contact with the guardrail while traveling at exit speed and angle of 49.9 mi/h and 6.7° relative to tangent section of guardrail.</td>
</tr>
</tbody>
</table>

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in MASH. After loss of contact with the barrier, the vehicle came to rest 303 ft downstream of the impact and 54 ft toward traffic lanes.
5.5 DAMAGE TO TEST INSTALLATION

Figures 5.3 through 5.5 show the damage to the BIB Terminal, and Table 5.2 lists damage. Working width was 25.3 inches at a height of 32.0 inches. Maximum dynamic deflection during the test was 19.9 inches, and maximum permanent deformation was 5.5 inches.

Figure 5.3. BIB Terminal after Test No. 608431-01-2.

Figure 5.4. Posts 9 through 11 after Test No. 608431-01-2.
Table 5.2. Damage to BIB Terminal after Test No. 608431-01-2.

<table>
<thead>
<tr>
<th>POST NO.</th>
<th>DAMAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-7</td>
<td>No noticeable damage</td>
</tr>
<tr>
<td>8</td>
<td>Soil around post disturbed</td>
</tr>
<tr>
<td>9</td>
<td>1.5 inch gap on traffic side; 0.4 inch gap on field side; leaning 86° toward field side</td>
</tr>
<tr>
<td>10</td>
<td>3.0 inch gap traffic side; 1.25 inch gap field side; post leaning 79° toward field side</td>
</tr>
<tr>
<td>11</td>
<td>4.5 inch gap traffic side; leaning 75° toward field side &amp; 80° downstream; rail released from blockout; rubrail bolt tore through flange</td>
</tr>
<tr>
<td>12</td>
<td>0.75 inch gap on traffic side; 0.5 inch gap on field side; leaning 86° toward field side</td>
</tr>
<tr>
<td>13</td>
<td>0.25 inch gap on traffic side; 0.5 inch gap on field side; leaning 89° toward field side</td>
</tr>
<tr>
<td>14-40</td>
<td>No damage</td>
</tr>
</tbody>
</table>

5.6 VEHICLE DAMAGE

Figure 5.6 shows the damage sustained by the vehicle. The front bumper, hood, right front fender, right front tire and rim, right front strut, right front and rear doors, right rear tire, right rear quarter panel, and rear bumper were damaged. The windshield sustained stress cracking at the right lower corner. Maximum exterior crush to the vehicle was 8.0 inches in the
side plane at the right front corner at bumper height. No occupant compartment deformation or intrusion was noted. Figure 5.7 shows the interior of the vehicle. Tables C.2 and C.3 in Appendix C1 provide exterior crush and occupant compartment measurements.

![Figure 5.6. Test Vehicle after Test No. 608431-01-2.](image)

![Figure 5.7. Interior of Test Vehicle after Test No. 608431-01-2.](image)

5.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and are shown in Table 5.3. Figure 6.8 summarizes these data and other pertinent information from the test. Figure C.2 in Appendix C3 shows the vehicle angular displacements, and Figures C.3 through C.8 in Appendix C4 show accelerations versus time traces.
### Table 5.3. Occupant Risk Factors for Test No. 608431-01-2.

<table>
<thead>
<tr>
<th>Occupant Risk Factor</th>
<th>Value</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Occupant Impact Velocity (OIV)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal</td>
<td>14.1 ft/s</td>
<td>at 0.1169 s on right side of interior</td>
</tr>
<tr>
<td>Lateral</td>
<td>20.3 ft/s</td>
<td></td>
</tr>
<tr>
<td><strong>Occupant Ridedown Accelerations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal</td>
<td>7.5 g</td>
<td>0.1546 - 0.1646 s</td>
</tr>
<tr>
<td>Lateral</td>
<td>8.5 g</td>
<td>0.1180 - 0.1280 s</td>
</tr>
<tr>
<td><strong>Theoretical Head Impact Velocity (THIV)</strong></td>
<td></td>
<td>at 0.1134 s on right side of interior</td>
</tr>
<tr>
<td></td>
<td>26.0 km/h</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.2 m/s</td>
<td></td>
</tr>
<tr>
<td><strong>Post Head Deceleration (PHD)</strong></td>
<td>10.3 g</td>
<td>0.1409 - 0.1509 s</td>
</tr>
<tr>
<td><strong>Acceleration Severity Index (ASI)</strong></td>
<td>0.96</td>
<td>0.0684 - 0.1184 s</td>
</tr>
<tr>
<td><strong>Maximum 50-ms Moving Average</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal</td>
<td>−5.7 g</td>
<td>0.0374 - 0.0874 s</td>
</tr>
<tr>
<td>Lateral</td>
<td>−7.4 g</td>
<td>0.0316 - 0.0816 s</td>
</tr>
<tr>
<td>Vertical</td>
<td>−2.8 g</td>
<td>0.1933 - 0.2433 s</td>
</tr>
<tr>
<td><strong>Maximum Roll, Pitch, and Yaw Angles</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roll</td>
<td>17°</td>
<td>0.4214 s</td>
</tr>
<tr>
<td>Pitch</td>
<td>6°</td>
<td>2.7930 s</td>
</tr>
<tr>
<td>Yaw</td>
<td>44°</td>
<td>2.7908 s</td>
</tr>
</tbody>
</table>
Figure 5.8. Summary of Results for MASH Test 3-34 on BIB Terminal.

* Angle at roadway departure; Impact angle at contact with terminal with respect to roadway; Effective impact angle with respect to tangent of flare at contact.
** IS at impact angle at contact with terminal with respect to roadway; IS at effective impact angle with respect to tangent of flare at impact.
Chapter 6. *MAST TEST 3-35 (CRASH TEST NO. 608431-01-1)*

6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

*MAST* Test 3-35 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the beginning of the length of need of the terminal at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. The target impact point for *MAST* Test 3-35 on the BIB terminal was at rail location where the system crosses the ditch (19 inches ±1 ft downstream of post 9).

The 2012 Dodge RAM 1500 pickup truck used in the test weighed 5035 lb, and the actual impact speed was 63.3 mi/h. The vehicle left the roadway at 25.4°, however, due to the vehicle’s interaction with the slope as it traversed into the ditch, actual impact angle as it contacted the terminal was 27.2° to the roadway (34.3° effective angle with the tangent of the rail at impact point). The actual impact point was 19.6 inches downstream of post 9. Minimum target IS was ≥106 kip-ft, and actual IS was 141 kip-ft (214 kip-ft using 34.3° effective angle).

6.2 WEATHER CONDITIONS

The test was performed on the morning of April 30, 2018. Weather conditions at the time of testing were as follows: wind speed: 7 mi/h; wind direction: 180° (vehicle was traveling in a southwesterly direction); temperature: 73°F; relative humidity: 76 percent.

6.3 TEST VEHICLE

Figures 6.1 and 6.2 show the 2012 Dodge RAM 1500 pickup truck used for the crash test. The vehicle’s test inertia weight was 5035 lb, and its gross static weight was 5200 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle’s center of gravity was 28.38 inches. Tables D.1 and D.2 in Appendix D1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 6.1. BIB Terminal/Test Vehicle Geometrics for Test No. 608431-01-1.
6.4 TEST DESCRIPTION

The test vehicle was traveling at an impact speed of 63.3 mi/h when it contacted the BIB Terminal 19.6 inches downstream of post 9 at an impact angle of 27.2° with respect to the roadway (34.3° effective angle with the tangent of the rail at impact point). Table 6.1 lists events that occurred during Test No. 608431-01-1. Figures D.1 and D.2 in Appendix D2 present sequential photographs during the test.

Table 6.1. Events during Test No. 608431-01-1.

<table>
<thead>
<tr>
<th>TIME (s)</th>
<th>EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
<td>Vehicle makes contact with terminal downstream of Post 9</td>
</tr>
<tr>
<td>0.048</td>
<td>Vehicle begins to redirect</td>
</tr>
<tr>
<td>0.078</td>
<td>Front right tire blows out hitting base of post 10</td>
</tr>
<tr>
<td>0.141</td>
<td>Rear left tire is airborne and off of pavement</td>
</tr>
<tr>
<td>0.192</td>
<td>Right rear of vehicle makes contact with rail between posts 9 and 10</td>
</tr>
<tr>
<td>0.223</td>
<td>Vehicle becomes parallel with terminal</td>
</tr>
<tr>
<td>0.655</td>
<td>Vehicle loses contact with terminal while traveling at 36.0 mi/h and 11.8°</td>
</tr>
<tr>
<td>1.118</td>
<td>Vehicle front left tire makes contact with pavement</td>
</tr>
<tr>
<td>1.700</td>
<td>Vehicle touches ground</td>
</tr>
</tbody>
</table>

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in MASH. After loss of contact with the barrier, the vehicle came to rest 167 ft downstream of the impact and 3 ft toward traffic lanes.
6.5 DAMAGE TO TEST INSTALLATION

Figures 6.3 through 6.5 show damage to the BIB Terminal, and Table 6.2 lists damage. Working width was 62.7 inches at a height of 54.7 inches. Maximum dynamic deflection during the test was 51.4 inches.

Figure 6.3. BIB Terminal after Test No. 608431-01-1.
Figure 6.4. Damage at Posts 9 through 15 after Test No. 608431-01-1.
Figure 6.5. Rail Tears after Test No. 608431-01-1.

Table 6.2. Damage to BIB Terminal after Test No. 608431-01-1.

<table>
<thead>
<tr>
<th>POST NO.</th>
<th>DAMAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>No noticeable damage</td>
</tr>
<tr>
<td>5</td>
<td>Soil disturbed; 0.25 inch gap on downstream side; blockout rotated 5°</td>
</tr>
<tr>
<td>6</td>
<td>Soil disturbed</td>
</tr>
<tr>
<td>7</td>
<td>Soil disturbed; 0.25 inch gap on traffic side; post leaning 89° toward field side</td>
</tr>
<tr>
<td>8</td>
<td>1.5 inch gap traffic side; 0.5 inch gap field side; 85° toward field side</td>
</tr>
<tr>
<td>9</td>
<td>5.0 inch gap traffic side; 2.0 inch gap field side; post leaning 75° toward field side</td>
</tr>
<tr>
<td>10</td>
<td>Post released from both rail elements; post leaning 50° toward field side</td>
</tr>
<tr>
<td>11</td>
<td>Post released from top rail element; post leaning 48° toward field side</td>
</tr>
<tr>
<td>--</td>
<td>4.5-inch tear in rub rail at joint between posts 11 and 12</td>
</tr>
<tr>
<td>12</td>
<td>Post released from both rail elements; post leaning 85° toward field side / 45° downstream</td>
</tr>
<tr>
<td>13</td>
<td>Post released from both rail elements; post leaning 85° toward field side / 45° downstream</td>
</tr>
<tr>
<td>14</td>
<td>Post released from both rail elements; post leaning 75° toward field side / 74° downstream</td>
</tr>
<tr>
<td>15</td>
<td>Post released from rub rail; 1.0 inch gap on traffic side; post leaning 88° twd field side</td>
</tr>
<tr>
<td>16</td>
<td>0.25 inch gap on traffic side; post leaning 89° toward field side</td>
</tr>
<tr>
<td>41</td>
<td>0.12 inch gap on downstream side</td>
</tr>
</tbody>
</table>
6.6 VEHICLE DAMAGE

Figure 6.6 shows the damage sustained by the vehicle. The front bumper grill, right front tire and rim, right front and rear doors, rear exterior bed, right rear tire and rim, and rear bumper were damaged. Maximum exterior crush to the vehicle was 10.0 inches in the front plane at the right front corner at bumper height. No occupant compartment deformation or intrusion was noted. Figure 6.7 shows the interior of the vehicle. Tables D.3 and D.4 in Appendix D1 provide exterior crush and occupant compartment measurements.

![Figure 6.6. Test Vehicle after Test No. 608431-01-1.](image)

![Figure 6.7. Interior of Test Vehicle for Test No. 608431-01-1.](image)

6.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and are shown in Table 6.3. Figure 6.8 summarizes these data and other pertinent information from the test. Figure D.3 in Appendix D3 shows the vehicle angular displacements, and Figures D.4 through D.9 in Appendix D4 show accelerations versus time traces.
Table 6.3. Occupant Risk Factors for Test No. 608431-01-1.

<table>
<thead>
<tr>
<th>Occupant Risk Factor</th>
<th>Value</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Occupant Impact Velocity (OIV)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal</td>
<td>17.4 ft/s</td>
<td>at 0.1424 s on right side of interior</td>
</tr>
<tr>
<td>Lateral</td>
<td>16.4 ft/s</td>
<td></td>
</tr>
<tr>
<td><strong>Occupant Ridedown Accelerations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal</td>
<td>5.4 g</td>
<td>0.1424 - 0.1524 s</td>
</tr>
<tr>
<td>Lateral</td>
<td>8.8 g</td>
<td>0.2327 - 0.2427 s</td>
</tr>
<tr>
<td><strong>Theoretical Head Impact Velocity (THIV)</strong></td>
<td>24.8 km/h</td>
<td>at 0.1360 s on right side of interior</td>
</tr>
<tr>
<td></td>
<td>6.9 m/s</td>
<td></td>
</tr>
<tr>
<td><strong>Post Head Deceleration (PHD)</strong></td>
<td>9.2 g</td>
<td>0.2260 - 0.2360 s</td>
</tr>
<tr>
<td><strong>Acceleration Severity Index (ASI)</strong></td>
<td>0.83</td>
<td>0.2454 - 0.2954 s</td>
</tr>
<tr>
<td><strong>Maximum 50-ms Moving Average</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal</td>
<td>−5.3 g</td>
<td>0.0726 - 0.1226 s</td>
</tr>
<tr>
<td>Lateral</td>
<td>−7.0 g</td>
<td>0.2258 - 0.2758 s</td>
</tr>
<tr>
<td>Vertical</td>
<td>2.4 g</td>
<td>0.2424 - 0.2924 s</td>
</tr>
<tr>
<td><strong>Maximum Roll, Pitch, and Yaw Angles</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roll</td>
<td>6°</td>
<td>0.1959 s</td>
</tr>
<tr>
<td>Pitch</td>
<td>3°</td>
<td>0.8693 s</td>
</tr>
<tr>
<td>Yaw</td>
<td>36°</td>
<td>0.7859 s</td>
</tr>
</tbody>
</table>
**General Information**

<table>
<thead>
<tr>
<th>Test Agency</th>
<th>Texas A&amp;M Transportation Institute (TTI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Standard Test No.</td>
<td>MASH Test 3-35</td>
</tr>
<tr>
<td>TTI Test No.</td>
<td>608431-01-1</td>
</tr>
<tr>
<td>Test Date</td>
<td>2018-04-30</td>
</tr>
</tbody>
</table>

**Test Article**

<table>
<thead>
<tr>
<th>Type</th>
<th>Terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Buried-in-Backslope Terminal</td>
</tr>
<tr>
<td>Installation Length</td>
<td>242 ft 7 inches</td>
</tr>
<tr>
<td>Material or Key Elements</td>
<td>W-Beam Terminal flared back at 4 different angles, for total setback of 14 ft, 31-inch rail height to the paved road; splice between posts: 4:1 foreslope: 2:1 backslope; W-beam rubrail</td>
</tr>
</tbody>
</table>

**Soil Type and Condition**

| AASHTO M147-65(2004), grading B Soil (crushed limestone), Damp |

**Test Vehicle**

<table>
<thead>
<tr>
<th>Type/Designation</th>
<th>2270P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make and Model</td>
<td>2012 Dodge RAM 1500 Pickup</td>
</tr>
<tr>
<td>Curb</td>
<td>4968 lb</td>
</tr>
<tr>
<td>Test Inertial</td>
<td>5035 lb</td>
</tr>
<tr>
<td>Dummy</td>
<td>165 lb</td>
</tr>
<tr>
<td>Gross Static</td>
<td>5200 lb</td>
</tr>
</tbody>
</table>

**Impact Conditions**

<table>
<thead>
<tr>
<th>Speed</th>
<th>63.3 mi/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle*</td>
<td>25.4° / 27.2° / 34.3°</td>
</tr>
<tr>
<td>Location/Orientation</td>
<td>19.6 inches dwnstrm of post 9</td>
</tr>
<tr>
<td>Impact Severity**</td>
<td>141 kip-ft / 214 kip-ft</td>
</tr>
</tbody>
</table>

**Exit Conditions**

<table>
<thead>
<tr>
<th>Speed</th>
<th>36.0 mi/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle</td>
<td>11.8°</td>
</tr>
</tbody>
</table>

**Occupant Risk Values**

<table>
<thead>
<tr>
<th>Longitudinal OIV</th>
<th>17.4 ft/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral OIV</td>
<td>16.4 ft/s</td>
</tr>
<tr>
<td>Longitudinal Ridedown</td>
<td>5.4 g</td>
</tr>
<tr>
<td>Lateral Ridedown</td>
<td>8.8 g</td>
</tr>
<tr>
<td>THIV</td>
<td>24.8 km/h</td>
</tr>
<tr>
<td>PHD</td>
<td>9.2 g</td>
</tr>
<tr>
<td>ASI</td>
<td>0.83</td>
</tr>
<tr>
<td>Max. 0.050-s Average Longitudinal</td>
<td>-5.3 g</td>
</tr>
<tr>
<td>Max. 0.050-s Average Lateral</td>
<td>-7.0 g</td>
</tr>
<tr>
<td>Max. 0.050-s Average Vertical</td>
<td>2.4 g</td>
</tr>
</tbody>
</table>

**Post-Impact Trajectory**

<table>
<thead>
<tr>
<th>Stopping Distance</th>
<th>167 ft dwnstrm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Yaw Angle</td>
<td>36°</td>
</tr>
<tr>
<td>Maximum Pitch Angle</td>
<td>3°</td>
</tr>
<tr>
<td>Maximum Roll Angle</td>
<td>6°</td>
</tr>
<tr>
<td>Vehicle Snagging</td>
<td>No</td>
</tr>
<tr>
<td>Vehicle Pocketing</td>
<td>No</td>
</tr>
</tbody>
</table>

**Test Article Deflections**

<table>
<thead>
<tr>
<th>Dynamic</th>
<th>51.4 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent</td>
<td>51.4 inches</td>
</tr>
<tr>
<td>Working Width</td>
<td>62.7 inches</td>
</tr>
<tr>
<td>Height of Working Width</td>
<td>54.7 inches</td>
</tr>
</tbody>
</table>

**Vehicle Damage**

<table>
<thead>
<tr>
<th>VDS</th>
<th>01RFQ5</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDC</td>
<td>01FREW4</td>
</tr>
<tr>
<td>Max. Exterior Deformation</td>
<td>10.0 inches</td>
</tr>
<tr>
<td>OCDI</td>
<td>RF000000</td>
</tr>
<tr>
<td>Max. Occupant Compartment Deformation</td>
<td>None</td>
</tr>
</tbody>
</table>

---

* Angle at roadway departure; Impact angle at contact with terminal with respect to roadway; Effective impact angle with respect to tangent of flare at contact.

** IS at impact angle at contact with terminal with respect to roadway; IS at effective impact angle with respect to tangent of flare at impact.

**Figure 6.8. Summary of Results for MASH Test 3-35 on BIB Terminal.**
Chapter 7. CONCLUSIONS AND IMPLEMENTATION

7.1 ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed in accordance with MASH Tests 3-34 and 3-35 for non-gating terminals. An assessment of the tests based on the applicable safety evaluation criteria for MASH Tests 3-34 and 3-35 is provided in Tables 7.1 and 7.2, respectively.

7.2 CONCLUSIONS

The BIB Terminal performed acceptably for MASH Tests 3-34 and 3-35 for non-gating terminals.

7.3 IMPLEMENTATION*

Two tests were performed to evaluate the proposed design for a TL-3 BIB Terminal compatible with an MGS guardrail system. They represent the tests considered necessary to demonstrate MASH compliance of the device. The TL-3 BIB Terminal system met MASH requirements and is considered MASH compliant. It is considered suitable for implementation at V-ditch locations with a 4:1 or flatter foreslope where a MASH TL-3 BIB Terminal system is needed and/or desired.

* The opinions/interpretations identified/expressed in this section of the report are outside the scope of TTI Proving Ground’s A2LA Accreditation.
<table>
<thead>
<tr>
<th>MASH Test 3-34 Evaluation Criteria</th>
<th>Test Results</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural Adequacy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td>
<td>The BIB Terminal contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 19.9 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>No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area.</td>
<td>Pass</td>
</tr>
<tr>
<td>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</td>
<td>No occupant compartment deformation or intrusion occurred.</td>
<td></td>
</tr>
<tr>
<td>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td>
<td>The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 17° and 6°, respectively.</td>
<td>Pass</td>
</tr>
<tr>
<td>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.</td>
<td>Longitudinal OIV was 14.1 ft/s, and lateral OIV was 20.3 ft/s.</td>
<td>Pass</td>
</tr>
<tr>
<td>I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</td>
<td>Maximum longitudinal occupant ridedown acceleration was 7.5 g, and maximum lateral occupant ridedown acceleration was 8.5 g.</td>
<td>Pass</td>
</tr>
</tbody>
</table>
Table 7.2. Performance Evaluation Summary for MASH Test 3-35 on BIB Terminal.

<table>
<thead>
<tr>
<th>Test Agency: Texas A&amp;M Transportation Institute</th>
<th>Test No.: 608431-01-1</th>
<th>Test Date: 2018-04-30</th>
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<tbody>
<tr>
<td>MASH Test 3-35 Evaluation Criteria</td>
<td>Test Results</td>
<td>Assessment</td>
</tr>
<tr>
<td><strong>Structural Adequacy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td>
<td>The BIB Terminal contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 51.4 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>No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area.</td>
<td>Pass</td>
</tr>
<tr>
<td>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</td>
<td>No occupant compartment deformation or intrusion occurred.</td>
<td></td>
</tr>
<tr>
<td>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td>
<td>The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 6° and 3°, respectively.</td>
<td>Pass</td>
</tr>
<tr>
<td>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.</td>
<td>Longitudinal OIV was 17.4 ft/s, and lateral OIV was 16.4 ft/s.</td>
<td>Pass</td>
</tr>
<tr>
<td>I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</td>
<td>Maximum longitudinal occupant ridedown acceleration was 5.4 g, and maximum lateral occupant ridedown acceleration was 8.8 g.</td>
<td>Pass</td>
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REFERENCES


### SI* (MODERN METRIC) CONVERSION FACTORS

#### APPROXIMATE CONVERSIONS TO SI UNITS

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<thead>
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<th>Symbol</th>
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*NOTE: volumes greater than 1000L shall be shown in m³*

| **MASS** | | | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or metric ton") | Mg (or “t") |

**TEMPERATURE (exact degrees)**

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<tr>
<td>or (F-32)/1.8</td>
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**FORCE and PRESSURE or STRESS**

| lbf | poundforce | 4.45 | newtons | N |
| lbf/in² | poundforce per square inch | 6.89 | kilopascals | kPa |

#### APPROXIMATE CONVERSIONS FROM SI UNITS

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<thead>
<tr>
<th>Symbol</th>
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<th>Multiply By</th>
<th>To Find</th>
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**TEMPERATURE (exact degrees)**

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<th>Celsius</th>
<th>°F</th>
<th>Fahrenheit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.8C+32</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FORCE and PRESSURE or STRESS**

| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lb/in² |

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

1b. TxDOT Downstream Anchor Terminal. See attached Drawing #GF 9(31) DAT-14.

1c. 75" Post spacing typical for LoN and Terminal unless otherwise indicated.
Terminal Details - Elevation

- 12 ga. W-beam, 9'-4"-1/2" span

**Detail D**
- Scale 1:10
- See 3a

- Buried in Backslope Anchor Plate
- Recessed Guardrail Nut
- Bolt, 7/8 x 2" hex (x 4), See 3a
- Plate Washer (x 4)
  - 1 3/4" x 1 3/4" x 3/16" with Ø1" hole
- Nut, 7/8 hex
- 10" Guardrail Bolt FBB03
- Bolt, 5/8 x 2" hex (x 4)
- 2" Guardrail Bolt FBB02

**Section E-E**
- Post 1
  - Typ @ Posts 1-3
  - Scale 1:30

**Section F-F**
- Scale 1:50

**Section G-G**
- Timber Blockout, for W-section Post PDB-01b

**Post 7**
- Typ @ Posts 5-20
- Scale 1:30

---

3a. Recessed Guardrail Nuts typical on all 5/8" Bolts. Anchor Plate and hardware are typical on top rail at Posts 1 - 3, and rub rail at Post 4. Field drill Ø1" holes in Guardrail as needed for 7/8 Bolts at Posts 1 - 4. Hex Head bolts are ASTM A307.

3b. Rail height changes 16" from Post 10 to 1 to achieve 12" of soil coverage at Post 1.
Terminal Details - Plan
Ditch and Backslope edges hidden for clarity

Length of Need
24 22 20
K

200

Ditch Bottom

13:1
74'-10"

24'-9/1/2"

8'-10-1/4"**

6.1

12'-4"

8:1

24'-9/1/2"

12'-1"

13'-11-3/4"**

4.1

1-1/4" Guardrail Bolt
FBB01
Typ x 8 at each Rail joint

2018-10-03

Detail K
Scale 1 : 20

12 ga. W-beam, 9'-4-1/2" span

Rail Joints between Posts - Typical in LoN and Buried in Backslope Terminal

Detail J
Scale 1 : 5

Bolt, 5/8 x 5" hex
FBX16a

Washer, USS 5/8 Flat

Pipe Sleeve Spacer
FMM04

Field drill Ø3/4 hole in Post

75"

See Detail D and Note 3a on previous sheet.

Detail H
Scale 1 : 20

12 ga. W-beam, 9'-4-1/2" span

4a. * These dimensions indicate the offset to the back of the Rail at Posts 1, 4, 6, and 10.
Buried in Backslope Anchor Plate
Plate, 14" x 1/2" x 14"
ASTM A36
GENERAL NOTES
1. The detail shown is the minimum length of need (LDN) for a DAT connected to a concrete rail.
2. The rail section of the end post is supported by the shelf angle bracket, the rail element is not attached.
3. The foundation tubes shall not project more than 3 1/2" above the finished grade.
4. All hardware for DAT shall be ASTM A325 unless otherwise shown.
5. Refer to GF (31) sheet for terminal connection details.

ELEVATION

DOWNSTREAM ANCHOR TERMINAL (DAT)

Only for downstream use when located outside the horizontal clearance area of opposing traffic.

MONO STRIP INSTALLATION

If a new strip is required with the DAT installation, the cut-out area around the steel foundation tube and the two channel strands shall require a full pour at foundation tubes.

### (DAT) PARTS LIST

<table>
<thead>
<tr>
<th>PART</th>
<th>QTY</th>
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<tr>
<td>DAT Foundation Tube</td>
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<tr>
<td>DAT Terminal Post</td>
<td>2</td>
</tr>
<tr>
<td>Channel Strut</td>
<td>2</td>
</tr>
<tr>
<td>Terminal Rail Element</td>
<td>1</td>
</tr>
<tr>
<td>Shelf Angle Bracket</td>
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</tr>
<tr>
<td>BCT Bearing Plate</td>
<td>1</td>
</tr>
<tr>
<td>BCT Post Sleeve</td>
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</tr>
<tr>
<td>Guardrail Anchor Bracket</td>
<td>1</td>
</tr>
<tr>
<td>Guardrail Anchor Bracket</td>
<td>1</td>
</tr>
<tr>
<td>Round B C E End Section</td>
<td>1</td>
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<tr>
<td>BCT Cable Anchor</td>
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<tr>
<td>Recessed Nut, Guardrail</td>
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<tr>
<td>1 1/2&quot; Button Head Bolt</td>
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</tr>
<tr>
<td>1 1/2&quot; Button Head Bolt</td>
<td>4</td>
</tr>
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<td>3/4&quot; x 2 1/2&quot; Hex Head Bolt</td>
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<td>2</td>
</tr>
<tr>
<td>3/4&quot; Flat Washer</td>
<td>16</td>
</tr>
</tbody>
</table>
NOTES: 1. ALL FILLETS SHALL HAVE A MINIMUM RADIUS OF 1/16 [2].
   THE BOLT SHOULD BE TRIMMED BACK.

---

DESIGNATOR L T (MIN)
FBB01 1-1/4 [32] 1-1/8 [28]
FBB02 2 [51] 1-3/4 [44]
FBB03 10 [254] 4 [102]
FBB04 18 [457] 4 [102]
FBB05 25 [635] 4 [102]

---

GUARDRAIL BOLT AND RECESSSED NUT

---

FBB01-05

---
SPECIFICATIONS
The geometry and material specifications for this oval shoulder button-headed bolt and hex nut are found in AASHTO M 180. The bolt shall have 5/8-11 [M16x2] threads as defined in ANSI B1.1 [ANSI B1.13M] for Class 2A [6g] tolerances. Bolt material shall conform to ASTM A307 Grade A [ASTM F 568M Class 4.6], with a tensile strength of 60 ksi [400 MPa] and yield strength of 36 ksi [240 MPa]. Material for corrosion-resistant bolts shall conform to ASTM A325 Type 3 [ASTM F 568M Class 8.8.3], with tensile strength of 120 ksi [830 MPa] and yield strength of 92 ksi [660 MPa]. This bolt material has corrosion resistance comparable to ASTM A588 steels. Metric zinc-coated bolt heads shall be marked as specified in ASTM F 568 Section 9 with the symbol “4.6.”

Nuts shall have ANSI B1.1 Class 2B [ANSI B1.13M Class 6h] 5/8-11 [M16x2] threads. The geometry of the nuts, with the exception of the recess shown in the drawing, shall conform to ANSI B18.2.2 [ANSI B18.2.4.1M Style 1] for zinc-coated hex nuts (shown in drawing) and ANSI B18.2.2 [ANSI B18.2.4.6M] for heavy hex corrosion-resistant nuts (not shown in drawing). Material for zinc-coated nuts shall conform to the requirements of AASHTO M 291 (ASTM A 563) Grade A [AASHTO M 291M (ASTM A 563M) Class 5], and material for corrosion-resistant nuts shall conform to the requirements of AASHTO M 291 (ASTM A 563) Grade C3 [AASHTO M 291M (ASTM A 563M) Class 8S3].

When zinc-coated bolts and nuts are required, the coating shall conform to either AASHTO M 232 (ASTM A 153/A 153M) for Class C or AASHTO M 298 (ASTM B 695) for Class 50. Zinc-coated nuts shall be tapped over-size as specified in AASHTO M 291 (ASTM A 563) [AASHTO M 291M (ASTM A 563M)], except that a diametrical allowance of 0.020 inch [0.510 mm] shall be used instead of 0.016 inches [0.420 mm].

<table>
<thead>
<tr>
<th>Designator</th>
<th>Stress Area of Threaded Bolt Shank</th>
<th>Min. Bolt Tensile Strength</th>
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Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

INTENDED USE
These bolts and nuts are used in numerous guardrail and median barrier designs.
PIPE SLEEVE SPACER

<table>
<thead>
<tr>
<th>DESIGNATOR</th>
<th>NOMINAL DIAMETER</th>
<th>D</th>
<th>L</th>
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<tr>
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<td>35</td>
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<td>21</td>
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W-BEAM TIMBER BLOCKOUT

1994

PLAN (a)

PLAN (b)

SIDE

FRONT

3/4 [20] D HOLE

3/4 [20] D HOLE

PDB01a-b

SHEET NO. DATE:
1 of 2 6/30/2005
SPECIFICATIONS
Blockouts shall be made of timber with a stress grade of at least 1160 psi [8 MPa]. Grading shall be in accordance with the rules of the West Coast Lumber Inspection Bureau, Southern Pine Inspection Bureau, or other appropriate timber association. Timber for blockouts shall be either rough-sawn (unplaned) or S4S (surfaced four sides) with nominal dimensions indicated. The variation in size of blockouts in the direction parallel to the axis of the bolt holes shall not be more than ± ¼ inch [6 mm]. Only one type of surface finish shall be used for posts and blockouts in any one continuous length of guardrail.

All timber shall receive a preservation treatment in accordance with AASHTO M 133 after all end cuts are made and holes are drilled.

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

INTENDED USE
Blockout PDB01a is used with wood post PDE01 or PDE02 in the SGR04b strong-post W-beam guardrail and the SGM04b median barrier. Blockout PDB01b is routed to be used with steel post PWE01 or PWE02 in the SGR04c guardrail and the SGM04a median barrier.

W-BEAM TIMBER BLOCKOUT

<table>
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<th>PDB01a-b</th>
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<tr>
<td>SHEET NO.</td>
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<td>2 of 2</td>
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4-Space W-Beam Guardrail

RWM04a-b

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4 Equal Post Hole Spacings 0.952.5 EA

24x30 Splice Bolt Slots (Typ)
20x65 Post Bolt Slot (Typ)

The Cross-Sectional Dimensions of This Part Are the Same As Part RWM02a (Sheet 3 of 4).

1994
SPECIFICATIONS
Corrugated sheet steel beams shall conform to the current requirements of AASHTO M180. The section shall be manufactured from sheets with a nominal width of 483 mm. Guardrail RWM04a shall conform to AASHTO M180 Class A and RWM04b shall conform to Class B. Corrosion protection may be either Type II (zinc-coated) or Type IV (corrosion resistant steel). Corrosion resistant steel should conform to ASTM A606 for Type IV material and shall not be zinc-coated, painted or otherwise treated. Inertial properties are calculated for the whole cross-section without a reduction for the splice bolt holes.

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Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

INTENDED USE
This corrugated sheet steel beam is used as a rail element in transition systems STB02 and STB03 or when a reduced post spacing is desired in the SGR02, SGR04a-b, SGM02, and SGM04a-b.

4-SPACE W-BEAM GUARDRAIL
RWM04a-b

<table>
<thead>
<tr>
<th>SHEET NO.</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 of 2</td>
<td>04-01-95</td>
</tr>
</tbody>
</table>
72" Wide-Flange Guardrail Post
WB x 8.5 - ASTM A36
Zinc-coated according to ASTM A123

Elevation Views

Section A-A
### Table B.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.

<table>
<thead>
<tr>
<th>Date</th>
<th>Test Facility and Site Location</th>
<th>In Situ Soil Description (ASTM D2487)</th>
<th>Fill Material Description (ASTM D2487) and sieve analysis</th>
<th>Description of Fill Placement Procedure</th>
<th>Bogie Weight</th>
<th>Impact Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016-11-05</td>
<td>TTI Proving Ground, 3100 SH 47, Bryan, TX 77807</td>
<td>Sandy gravel with silty fines</td>
<td>AASHTO Grade B Soil-Aggregate (see sieve analysis above)</td>
<td>6-inch lifts tamped with a pneumatic compactor</td>
<td>5009 lb</td>
<td>20.5 mph</td>
</tr>
</tbody>
</table>

#### Dynamic Test Installation Details

- **Dynamic Setup**
- **Post-Test Photo**
- **Static Load Test**

#### Static Load Test Installation Details

- **Displacement (inch)**
- **Load (lb)**

#### Comparison of Load vs. Displacement at 25-inch height

![Graph comparing load vs. displacement](image)

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

![Graph of percent finer vs. grain size](image)

#### Bogie Data

- Dynamic Post Load
- Required Dynamic
- Static Pull

![Bogie Data Diagram](image)
Table B.2. Test Day Static Soil Strength Documentation for Test No. 608431-01-1.

Date................................................................. 2018-04-30 for Test No. 608431-01-1
Test Facility and Site Location ........................................ TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487) .......................... Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis .. AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure ......................... 6-inch lifts tamped with a pneumatic compactor

Static Load Setup

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

Comparison of Static Load Test Results and Required Minimum:
Load versus Displacement at 26 Inch Height

<table>
<thead>
<tr>
<th>Displacement (in)</th>
<th>Load (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>4500</td>
</tr>
<tr>
<td>15</td>
<td>7000</td>
</tr>
<tr>
<td>15</td>
<td>7000</td>
</tr>
</tbody>
</table>

Static Load Setup
### Table B.3. Test Day Static Soil Strength Documentation for Test No. 608431-01-2.

<table>
<thead>
<tr>
<th>Date</th>
<th>2018-06-01 for Test No. 608431-01-2</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>

![Static Load Setup Image]

![Percent Finer Vs. Grain Size of Fill Soil for Dynamic and Static Load Tests Image]
APPENDIX C. MASH TEST 3-34 (CRASH TEST NO. 608431-01-2)

C1 VEHICLE PROPERTIES AND INFORMATION


<table>
<thead>
<tr>
<th>Date</th>
<th>Test No.</th>
<th>VIN No.</th>
<th>Year</th>
<th>Make</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018-06-01</td>
<td>608431-1-2</td>
<td>KNADE223896502932</td>
<td>2009</td>
<td>KIA</td>
<td>RIO</td>
</tr>
</tbody>
</table>

Tire Inflation Pressure: 32 PSI  Odometer: 157778  Tire Size: 185/65R14

Describe any damage to the vehicle prior to test: None

- Denotes accelerometer location.

NOTES: None

Engine Type: 4 cylinder  Engine CID: 1.6 L

Transmission Type:
- ☑ Auto or ☑ Manual
- ☑ FWD  ☑ RWD  ☑ 4WD

Optional Equipment: None

Dummy Data:
- Type: 50th percentile male
- Mass: 165 lb
- Seat Position: Passenger Seat

Geometry: inches

<table>
<thead>
<tr>
<th>A</th>
<th>F</th>
<th>66.38</th>
<th>33.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>G</td>
<td>51.50</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>H</td>
<td>165.75</td>
<td>36.49</td>
</tr>
<tr>
<td>D</td>
<td>I</td>
<td>34.00</td>
<td>7.75</td>
</tr>
<tr>
<td>E</td>
<td>J</td>
<td>98.75</td>
<td>21.50</td>
</tr>
</tbody>
</table>

Wheel Center Ht Front: 11.00  Wheel Center Ht Rear: 11.00

GVWR Ratings: Mass: lb  Curb  Test Inertial  Gross Static

Front 1718  M_{front}  1572  1530  1615
Back 1874  M_{rear}  903  897  977
Total 3638  M_{Total}  2475  2427  2592

Allowable TIM = 2420 lb ±55 lb | Allowable GSM = 2585 lb ±55 lb

Mass Distribution:

| lb  | LF   | 766  | RF   | 764  | LR   | 433  | RR   | 464  |

TR No. 608431-01-1&2  2018-10-03
Table C.2. Exterior Crush Measurements for Test No. 608431-01-2.

<table>
<thead>
<tr>
<th>Date: 2018-06-01</th>
<th>Test No.: 608431-1-2</th>
<th>VIN No.: KNADE223896502932</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year: 2009</td>
<td>Make: KIA</td>
<td>Model: RIO</td>
</tr>
</tbody>
</table>

**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 $C_1$ to $C_4$ 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>Width** (CDC)</th>
<th>Max*** Crush</th>
<th>Field L**</th>
<th>$C_1$</th>
<th>$C_2$</th>
<th>$C_3$</th>
<th>$C_4$</th>
<th>$C_5$</th>
<th>$C_6$</th>
<th>±D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AT FT BUMPER</td>
<td>16</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>2</td>
<td>ABOVE FT BUMPER</td>
<td>16</td>
<td>8</td>
<td>27</td>
<td>1.5</td>
<td>3.5</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>±56</td>
<td></td>
</tr>
</tbody>
</table>

*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 C.3. Occupant Compartment Measurements for Test No. 608431-01-2.

<table>
<thead>
<tr>
<th>Date: 2018-06-01</th>
<th>Test No.: 608431-1-2</th>
<th>VIN No.: KNADE223896502932</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year: 2009</td>
<td>Make: KIA</td>
<td>Model: RIO</td>
</tr>
</tbody>
</table>

**OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT**

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
<th>Differ.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>67.50</td>
<td>67.50</td>
<td>0.00</td>
</tr>
<tr>
<td>A2</td>
<td>67.25</td>
<td>67.25</td>
<td>0.00</td>
</tr>
<tr>
<td>A3</td>
<td>67.75</td>
<td>67.75</td>
<td>0.00</td>
</tr>
<tr>
<td>B1</td>
<td>40.50</td>
<td>40.50</td>
<td>0.00</td>
</tr>
<tr>
<td>B2</td>
<td>39.00</td>
<td>39.00</td>
<td>0.00</td>
</tr>
<tr>
<td>B3</td>
<td>40.50</td>
<td>40.50</td>
<td>0.00</td>
</tr>
<tr>
<td>B4</td>
<td>36.25</td>
<td>36.25</td>
<td>0.00</td>
</tr>
<tr>
<td>B5</td>
<td>36.00</td>
<td>36.00</td>
<td>0.00</td>
</tr>
<tr>
<td>B6</td>
<td>36.25</td>
<td>36.25</td>
<td>0.00</td>
</tr>
<tr>
<td>C1</td>
<td>26.00</td>
<td>26.00</td>
<td>0.00</td>
</tr>
<tr>
<td>C2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>C3</td>
<td>26.00</td>
<td>26.00</td>
<td>0.00</td>
</tr>
<tr>
<td>D1</td>
<td>9.50</td>
<td>9.50</td>
<td>0.00</td>
</tr>
<tr>
<td>D2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>D3</td>
<td>9.50</td>
<td>9.50</td>
<td>0.00</td>
</tr>
<tr>
<td>E1</td>
<td>51.50</td>
<td>51.50</td>
<td>0.00</td>
</tr>
<tr>
<td>E2</td>
<td>51.00</td>
<td>51.00</td>
<td>0.00</td>
</tr>
<tr>
<td>F</td>
<td>51.00</td>
<td>51.00</td>
<td>0.00</td>
</tr>
<tr>
<td>G</td>
<td>51.00</td>
<td>51.00</td>
<td>0.00</td>
</tr>
<tr>
<td>H</td>
<td>37.50</td>
<td>37.50</td>
<td>0.00</td>
</tr>
<tr>
<td>I</td>
<td>37.50</td>
<td>37.50</td>
<td>0.00</td>
</tr>
<tr>
<td>J*</td>
<td>51.00</td>
<td>51.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

*Lateral area across the cab from driver’s side kickpanel to passenger’s side kickpanel.*
Figure C.1. Sequential Photographs for Test No. 608431-01-2 (Overhead and Frontal Views).
Figure C.1. Sequential Photographs for Test No. 608431-01-2 (Overhead and Frontal Views) (Continued).
**NOTE:** Data started 0.207 s prior to impact with terminal.

Figure C.2. Vehicle Angular Displacements for Test No. 608431-01-2.
NOTE: Data started 0.207 s prior to impact with terminal.

Figure C.3. Vehicle Longitudinal Accelerometer Trace for Test No. 608431-01-2
(Accelerometer Located at Center of Gravity).
NOTE: Data started 0.207 s prior to impact with terminal.

Figure C.4. Vehicle Lateral Accelerometer Trace for Test No. 608431-01-2
(Accelerometer Located at Center of Gravity).
**NOTE:** Data started 0.207 s prior to impact with terminal.

Figure C.5. Vehicle Vertical Accelerometer Trace for Test No. 608431-01-2
(Accelerometer Located at Center of Gravity).
NOTE: Data started 0.207 s prior to impact with terminal.

Figure C.6. Vehicle Longitudinal Accelerometer Trace for Test No. 608431-01-2 (Accelerometer Located Rear of Center of Gravity).
NOTE: Data started 0.207 s prior to impact with terminal.

Figure C.7. Vehicle Lateral Accelerometer Trace for Test No. 608431-01-2 (Accelerometer Located Rear of Center of Gravity).
NOTE: Data started 0.207 s prior to impact with terminal.
# APPENDIX D. MASH TEST 3-35 (CRASH TEST NO. 608431-01-1)

## D1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 608431-01-1.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>2018-04-30</td>
</tr>
<tr>
<td>Test No.</td>
<td>608431-1-1</td>
</tr>
<tr>
<td>VIN No.</td>
<td>1C6RD6FP46S168775</td>
</tr>
<tr>
<td>Year</td>
<td>2012</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>265/70 R 17</td>
</tr>
<tr>
<td>Tread Type</td>
<td>HIGHWAY</td>
</tr>
<tr>
<td>Tire Inflation Pressure</td>
<td>35 PSI</td>
</tr>
<tr>
<td>Odometer</td>
<td>217692</td>
</tr>
<tr>
<td>Note any damage to the vehicle prior to test</td>
<td>NONE</td>
</tr>
</tbody>
</table>

- Denotes accelerometer location.

### NOTES:

- Engine Type: V-8
- Engine CID: 4.7 L
- Transmission Type: Auto or Manual
- Optional Equipment: NONE
- Dummy Data: Type: 50 percentile male, Mass: 165 lb, Seat Position: Passenger Side

### Geometry:

<table>
<thead>
<tr>
<th>A</th>
<th>F</th>
<th>K</th>
<th>P</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>78.50</td>
<td>40.00</td>
<td>20.00</td>
<td>3.00</td>
<td>27.00</td>
</tr>
<tr>
<td>B</td>
<td>G</td>
<td>L</td>
<td>Q</td>
<td>V</td>
</tr>
<tr>
<td>74.00</td>
<td>28.38</td>
<td>30.00</td>
<td>30.50</td>
<td>29.75</td>
</tr>
<tr>
<td>C</td>
<td>H</td>
<td>M</td>
<td>R</td>
<td>W</td>
</tr>
<tr>
<td>227.50</td>
<td>61.80</td>
<td>68.50</td>
<td>18.00</td>
<td>61.80</td>
</tr>
<tr>
<td>D</td>
<td>I</td>
<td>N</td>
<td>S</td>
<td>X</td>
</tr>
<tr>
<td>44.00</td>
<td>11.75</td>
<td>68.00</td>
<td>13.00</td>
<td>77.00</td>
</tr>
<tr>
<td>E</td>
<td>J</td>
<td>O</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>140.50</td>
<td>27.00</td>
<td>46.00</td>
<td>77.00</td>
<td></td>
</tr>
</tbody>
</table>

Wheel Center Height Front: 14.75 inches, Wheel Well Clearance (Front): 6.00 inches, Bottom Frame Height - Front: 12.00 inches, Wheel Center Height Rear: 14.75 inches, Wheel Well Clearance (Rear): 9.25 inches, Bottom Frame Height - Rear: 25.50 inches

### GVWR Ratings:

<table>
<thead>
<tr>
<th></th>
<th>Mass: lb</th>
<th>Curb Test Inertial</th>
<th>Gross Static</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
<td>3700 M&lt;sub&gt;front&lt;/sub&gt;</td>
<td>2825</td>
<td>2807</td>
</tr>
<tr>
<td>Back</td>
<td>3900 M&lt;sub&gt;rear&lt;/sub&gt;</td>
<td>2143</td>
<td>2228</td>
</tr>
<tr>
<td>Total</td>
<td>6700 M&lt;sub&gt;total&lt;/sub&gt;</td>
<td>4968</td>
<td>5035</td>
</tr>
</tbody>
</table>

Mass Distribution:

|   | LF: 1373 | RF: 1434 | LR: 1153 | RR: 1075 |

<table>
<thead>
<tr>
<th>Date</th>
<th>2018-04-30</th>
<th>Test No.</th>
<th>608431-1-1</th>
<th>VIN: 1C6RD6FP4GS168775</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>2012</td>
<td>Make:</td>
<td>DODGE</td>
<td>Model: RAM 1500</td>
</tr>
<tr>
<td>Body Style</td>
<td>QUAD CAB</td>
<td>Mileage</td>
<td>217692</td>
<td></td>
</tr>
<tr>
<td>Engine</td>
<td>4.7L V-8</td>
<td>Transmission</td>
<td>AUTOMATIC</td>
<td></td>
</tr>
<tr>
<td>Fuel Level</td>
<td>EMPTY</td>
<td>Ballast</td>
<td>133 lb</td>
<td>(440 lb max)</td>
</tr>
<tr>
<td>Tire Pressure</td>
<td>Front: 35 psi</td>
<td>Rear: 35 psi</td>
<td>Size: 265/70 R 17</td>
<td></td>
</tr>
</tbody>
</table>

**Measured Vehicle Weights:** (lb)

<table>
<thead>
<tr>
<th>LF</th>
<th>1373</th>
<th>RF</th>
<th>1434</th>
<th>Front Axle</th>
<th>2807</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR</td>
<td>1153</td>
<td>RR</td>
<td>1075</td>
<td>Rear Axle</td>
<td>2228</td>
</tr>
<tr>
<td>Left</td>
<td>2526</td>
<td>Right</td>
<td>2509</td>
<td>Total: 5035</td>
<td></td>
</tr>
</tbody>
</table>

Wheel Base: 140.50 inches  Track: F: 68.50 inches  R: 68.00 inches

148 ±12 inches allowed  Track = (F+R)/2 = 67 ±1.5 inches allowed

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

<table>
<thead>
<tr>
<th>X</th>
<th>62.17 inches</th>
<th>Rear of Front Axle (63 ±4 inches allowed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>-0.12 inches</td>
<td>Left - Right + of Vehicle Centerline</td>
</tr>
<tr>
<td>Z</td>
<td>28.38 inches</td>
<td>Above Ground (minimum 28.0 inches allowed)</td>
</tr>
</tbody>
</table>

Hood Height: 46.00 inches  Front Bumper Height: 27.00 inches

43 ±6 inches allowed

Front Overhang: 40.00 inches  Rear Bumper Height: 30.00 inches

39 ±3 inches allowed

Overall Length: 227.50 inches

237 ±13 inches allowed
### Table D.3. Exterior Crush Measurements for Test No. 608431-01-1.

**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>( \frac{X1 + X2}{2} )</td>
</tr>
<tr>
<td>&lt; 4 inches</td>
<td></td>
</tr>
<tr>
<td>≥ 4 inches</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Measure \( C_1 \) to \( C_5 \) 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>Undamaged Damage</th>
<th>Field L**</th>
<th>( C_1 )</th>
<th>( C_2 )</th>
<th>( C_3 )</th>
<th>( C_4 )</th>
<th>( C_5 )</th>
<th>±D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Front Plane at bumper height</td>
<td>18</td>
<td>10</td>
<td>25</td>
<td>10</td>
<td>1.5</td>
<td>4</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>Side Plane above bumper height</td>
<td>18</td>
<td>8</td>
<td>48</td>
<td>1</td>
<td>2</td>
<td>3.5</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

*Table taken from National Accident Sampling System (NASS).*

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

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

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

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

**Note:** Use as many lines/columns as necessary to describe each damage profile.
Table D.4. Occupant Compartment Measurements for Test No. 608431-01-1.

<table>
<thead>
<tr>
<th>Date: 2018-04-30</th>
<th>Test No.: 608431-1-1</th>
<th>VIN No.: 1C6RD6FP46S168775</th>
</tr>
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<tbody>
<tr>
<td>Year: 2012</td>
<td>Make: DODGE</td>
<td>Model: RAM 1500</td>
</tr>
</tbody>
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**OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT**

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
<th>Differ.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>65.00</td>
<td>65.00</td>
<td>0.00</td>
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<tr>
<td>A2</td>
<td>63.00</td>
<td>63.00</td>
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<td>A3</td>
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</tr>
<tr>
<td>B1</td>
<td>45.00</td>
<td>45.00</td>
<td>0.00</td>
</tr>
<tr>
<td>B2</td>
<td>38.00</td>
<td>38.00</td>
<td>0.00</td>
</tr>
<tr>
<td>B3</td>
<td>45.00</td>
<td>45.00</td>
<td>0.00</td>
</tr>
<tr>
<td>B4</td>
<td>39.50</td>
<td>39.50</td>
<td>0.00</td>
</tr>
<tr>
<td>B5</td>
<td>43.00</td>
<td>43.00</td>
<td>0.00</td>
</tr>
<tr>
<td>B6</td>
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<td>0.00</td>
</tr>
<tr>
<td>C1</td>
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<td>6.00</td>
<td>0.00</td>
</tr>
<tr>
<td>C2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
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<tr>
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<td>0.00</td>
</tr>
<tr>
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<tr>
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<tr>
<td>I</td>
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</tr>
<tr>
<td>J*</td>
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<td>0.00</td>
</tr>
</tbody>
</table>

* Lateral area across the cab from driver’s side kickpanel to passenger’s side kickpanel.
Figure D.1. Sequential Photographs for Test No. 608431-01-1 (Overhead and Frontal Views).
Figure D.1D.1. Sequential Photographs for Test No. 608431-01-1 (Overhead and Frontal Views) (Continued).
Figure D.2. Sequential Photographs for Test No. 608431-01-1 (Rear View).
Figure D.3. Vehicle Angular Displacements for Test No. 608431-01-1.
Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 608431-01-1
(Accelerometer Located at Center of Gravity).
Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 608431-01-1 (Accelerometer Located at Center of Gravity).
Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 608431-01-1
(Accelerometer Located at Center of Gravity).
Figure D.7. Vehicle Longitudinal Accelerometer Trace for Test No. 608431-01-1
(Accelerometer Located Rear of Center of Gravity).
Figure D.8. Vehicle Lateral Accelerometer Trace for Test No. 608431-01-1 (Accelerometer Located Rear of Center of Gravity).
Figure D.9. Vehicle Vertical Accelerometer Trace for Test No. 608431-01-1 (Accelerometer Located Rear of Center of Gravity).