MASH TL-4 EVALUATION OF THE TxDOT TYPE C2P BRIDGE RAIL

Crash testing performed at:
TTI Proving Ground
3100 SH 47, Building 7091
Bryan, TX 77807

Test Report 9-1002-15-2 Rev.1
Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
Federal Highway Administration and the Texas
Department of Transportation
The objective of this research was to evaluate the impact performance of the Texas Department of Transportation (TxDOT) Type C2P Bridge Rail according to the safety-performance evaluation guidelines included in the American Association of State Highway and Transportation Officials Manual for Assessing Safety Hardware (MASH) for Test Level Four (TL-4). This report describes the TxDOT Type C2P Bridge Rail, documents the impact performance of the bridge rail system according to MASH TL-4 evaluation criteria for longitudinal barriers, and presents recommendations regarding implementation.

MASH Tests 4-10 and 4-11 evaluate a barrier’s ability to successfully contain and redirect passenger vehicles and evaluate occupant risk. MASH Test 4-12 evaluates the structural adequacy of the bridge rail. All three tests were performed on the TxDOT Type C2P Bridge Rail.

For Test 4-12, the post welds were not properly fabricated according to the project design drawings. As a result, some post welds in the immediate impact area did rupture from the MASH Test 4-12 truck impact. These ruptured post welds did aggravate the stability of the single unit truck during the test. For subsequent tests, the posts were welded correctly as per the project drawings. The bridge rail posts, with the correct post welds, should only improve the performance of the single unit truck. The TxDOT Type C2P Bridge Rail performed acceptably for MASH TL-4.
MASH TL-4 EVALUATION OF THE TXDOT TYPE C2P BRIDGE RAIL

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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. 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. This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Roger P. Bligh, P.E. #78550.

TTI PROVING GROUND DISCLAIMER

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

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Page 20, 27, and 36 added in windshield deformation information under the vehicle damage section.
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Chapter 1. INTRODUCTION

1.1. PROBLEM

The current research was conducted under a project that 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. Such safety devices help 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 various site conditions, placement locations, and a changing vehicle fleet. Periodically, there is a need to assess the compliance of existing safety devices with current evaluation and testing criteria and develop new devices that address identified needs.

Under this project, TxDOT identified roadside safety issues and prioritized these for investigation. Each roadside safety issue is addressed with a separate work plan and test report.

1.2. OBJECTIVES/SCOPE OF RESEARCH

The objective of this research was to evaluate the impact performance of the TxDOT Type C2P Bridge Rail according to the safety-performance evaluation guidelines included in the American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH) for Test Level Four (TL-4) (1). This report describes the TxDOT Type C2P Bridge Rail, documents the impact performance of the bridge rail system according to MASH TL-4 evaluation criteria for longitudinal barriers, and presents recommendations on implementation.
Chapter 2. SYSTEM DETAILS

2.1. TEST ARTICLE AND INSTALLATION DETAILS

The test installation consisted of three 144-ft long (post-to-post) horizontal steel rails mounted on a 148-ft long concrete curb. Each rail was comprised of four 39-ft 10-inch long (40-ft long nominal) segments. The overall height of the bridge rail system was 42 inches above the bridge deck. The upper rail was comprised of a 4½-inch outside diameter (OD) × $\frac{3}{16}$-inch wall thickness round hollow structural section (HSS4.500×0.1875), and the middle and lower rails were each 6-inch × 2-inch × $\frac{1}{4}$-inch wall thickness rectangular hollow structural sections (HSS6.00×2.00×0.250). Nineteen 32-inch tall posts were equally spaced at 8 ft along the length of the installation. The posts were anchored to the top of a 9-inch tall steel reinforced concrete curb.

2.1.1 Horizontal Rail Members

The upper rail element was comprised of an HSS4.500×0.1875 fabricated from ASTM A500 grade B material. The horizontal centerline of the round upper rail was 39¾ inches above the bridge deck. The middle and lower rail elements were each comprised of HSS6.00×2.00×0.250 fabricated from ASTM A500 grade B material. The horizontal centerlines of the middle and lower rails were 27 inches and 17 inches above the bridge deck, respectively.

To facilitate attaching the rails to the posts, each rail contained five pairs of 1 $\frac{1}{16}$-inch diameter holes on 4½-inch centers on the field side located every 96 inches along the length of the rail. The rails were attached to the posts with $\frac{1}{2}$-inch diameter ASTM A36 steel U-bolts with 2 inches of 13 UNC threads on 3½-inch long legs bent at 4½-inch centers. The bolts were inserted through the 1 $\frac{1}{16}$-inch diameter holes in the rail and through the post, then secured with 2-inch square × $\frac{5}{16}$-inch thick ASTM A36 plate washers containing a centered $\frac{9}{16}$-inch diameter hole, a lock washer, and a $\frac{1}{2}$-inch, 13 UNC heavy hex nut (see Appendix A and/or B, drawing sheet 8 of 14 for details)

For test 1 with the small car and test 2 with the pickup truck, the most upstream four post locations of the installation were not used, so the fifth post location was numbered as post 1. The 2-inch wide rail expansion joints were centered 32 inches upstream of the centerlines of posts 6 and 11 of 15 posts. Each of the three rail sections were attached to five posts. The most upstream rail section had a 31-inch overhang preceding post 1, and the most downstream rail section had a 5-ft 3-inch overhang beyond post 15 (see Figure 2-1 and Appendix A)

For test 3 with the single unit truck, the three rail expansion joints for the four rail sections were each centered 32 inches upstream of the centerlines of posts 6, 11, and 16 of 19 posts. The most upstream three rail sections at posts 1 through 15 were each attached to five posts, with a 31-inch overhang preceding post 1, and the remaining downstream rail section at posts 16 through 19 was attached to four posts (16, 17, 18, and 19) with a 13 ft-3 inch overhang beyond post 19 (see Figure 2-2 and Appendix B)
Figure 2-1. General Layout of the TxDOT Type C2P Bridge Rail for Test No. 490026-4-1 and 4-2.
Figure 2-2. General Layout of the TxDOT Type C2P Bridge Rail for Test No. 490026-4-3.
The rail sections were connected with internal splice sections that matched the internal profile of the rails. The splice sections for the top rail were 28-inch long \( \times \) 4-inch OD \( \times \frac{3}{4}\)-inch thick round HSS fabricated from ASTM A500 grade B material with a \( \frac{3}{4}\)-inch diameter locating pin located mid-span. The splice sections for the middle and bottom rails were 28-inch long welded rectangular tubes measuring 5\(\frac{3}{8}\)-inches wide \( \times \) 1\(\frac{3}{8}\)-inches tall \( \times \frac{3}{16}\)-inch thick fabricated from ASTM A36 steel plate. These splice tubes also contained a \(\frac{3}{8}\)-inch diameter locating pin at mid-span (see Appendix A and/or B, drawing sheet 6 of 14 for details).

### 2.1.2 Picket Panels

Eighteen picket panels were attached to the field side of the bridge rail system, one between each of the 19 posts. Each panel measured 73\(\frac{3}{8}\) inches long \( \times \) 29\(\frac{3}{8}\)-inches high, and had thirteen \(\frac{3}{8}\)-inch square vertical steel bars evenly spaced at 6 inches along the length. Three horizontal members connected the pickets. The top longitudinal member was a 2-inch \( \times \) 1\(\frac{1}{2}\)-inch \( \times \frac{3}{16}\)-inch thick angle oriented with the 2-inch leg vertical and on the field side of the pickets. The middle and bottom horizontal members were 1\(\frac{1}{2}\)-inch \( \times \) \(\frac{3}{8}\)-inch thick steel plate positioned 13\(\frac{3}{4}\) inches and 23\(\frac{3}{8}\) inches below the top of the top angle. The middle and bottom horizontal members were positioned on the traffic side of the pickets. Fifteen picket sections had three \(\frac{9}{16}\)-inch diameter bolt holes located 3\(\frac{9}{16}\) inches, 33\(\frac{9}{16}\) inches, and 69\(\frac{9}{16}\) inches from the end of each middle and bottom horizontal plate (providing 30-inch and 36-inch spacings). The three picket sections located at the sleeved expansion joints had \(\frac{9}{16}\)-inch wide \( \times \) 3\(\frac{3}{4}\)-inch long slots (instead of \(\frac{9}{16}\)-inch diameter holes) centered at the same locations. All picket materials were ASTM A36 steel. Each picket panel was secured to the middle and lower rails with six \(\frac{1}{2}\) \( \times \) 1\(\frac{1}{2}\) -13 UNC ASTM A325 bolts, two \(\frac{1}{2}\)-inch SAE hardened washers, and \(\frac{1}{2}\)-inch heavy hex nuts. The rails were constructed with 2-inch diameter hardware access holes on the bottom near the field side at each picket panel bolt location. Similar holes were field cut in the internal splice sections as needed, and 2-inch long bolts were used at these locations. The top horizontal angle was not connected to the round top rail (see Appendix A and/or B, drawing sheet 5 and 7 of 14 for details).

### 2.1.3 Bridge Rail Posts

Fabricated steel posts, each 32 inches in overall height, supported the three rails atop the curb at 19 locations equally spaced at 8 ft along the test installation. Each post was a built-up welded structure comprised of two 9-inch wide \( \times \) 31\(\frac{3}{4}\)-inch tall \( \times \frac{3}{4}\)-inch thick side plates on 12\(\frac{1}{2}\)-inch centers welded to a base plate. The base plate was 14-inches wide \( \times \) 12-inches deep \( \times \frac{3}{4}\)-inch thick. Three rail bolting plates, each 2 inches wide \( \times \frac{3}{4}\) inch thick, were welded between the side plates. A \(\frac{3}{8}\)-inch square vertical bar picket was welded to the field side of the middle and bottom rail plates. The front of each side plate was located 2\(\frac{1}{2}\) inches back from the edge of the baseplate. Each side plate contained two rectangular notches, each 3\(\frac{3}{4}\) inches deep \( \times \) 2\(\frac{3}{8}\) inches high, that received the rail bolting plates and the middle/lower rail elements. The traffic side face of the middle and lower rails projected 3\(\frac{1}{2}\) inches beyond the side plates, and was flush with the face of the curb.

The base plate contained two pairs of 1\(\frac{3}{4}\)-inch diameter anchor bolt holes located 2\(\frac{3}{8}\) inches and 7\(\frac{3}{8}\) inches from the front edge (traffic side) of the base plate and spaced on 4-inch centers about the centerline of the post. The base plates and post side plates were fabricated from ASTM A572.
grade 50 material, and the pickets and rail bolting plates were fabricated from ASTM A36 material (see Appendix A and/or B, drawing sheet 3 and 4 of 14 for details).

In addition to the 12 existing anchor bolt sets, 7 new anchor bolt assemblies (for posts 13 through 19) were cast into the extended concrete curb. Four \(\frac{7}{8}\)-inch diameter \(\times\) 11\(\frac{1}{2}\)-inch long ASTM A193 grade B7 threaded rods were located in \(\frac{15}{16}\)-inch diameter holes in an 11-inch long \(\times\) 6\(\frac{1}{2}\)-inch wide \(\times\) \(\frac{3}{4}\)-inch thick ASTM A36 steel anchor plate and supported by heavy hex nuts welded to the underside. Anchor bolt threads projected 2\(\frac{1}{2}\) inches above the top of the concrete curb. Each post was secured to the curb with a \(\frac{7}{8}\)-inch diameter heavy hex nut and \(\frac{7}{8}\)-inch SAE hardened washer on each anchor bolt (see Appendix A and/or B, drawing sheet 9 of 14 for details).

### 2.1.3.1 Bridge Rail Post Interim Repairs

The first test was test 3 with the single unit truck (MASH 4-12), followed by test 2 with the pickup truck (MASH 4-11), and finally test 1 with the small car (MASH 4-10). During test 3, the base plate welds failed at posts 5, 6, and 7 (refer to Section 7.5). Prior to test 2, the base plates for all 15 posts used for the remaining two tests were removed and new base plates of the same design were welded to the posts.

### 2.1.4 Concrete Curb and Bridge Deck

An existing steel reinforced concrete curb, bridge deck, and support wall from a previous bridge rail installation was used for the upstream 92-ft of the 148-ft installation length used for testing and evaluation of the TxDOT Type C2P Bridge Rail. On the downstream end of the installation, an additional 56 ft of curb, bridge deck, and sub-grade footer wall was constructed off of the existing concrete apron at the TTI Proving Ground facility. The curb was installed in three regions: A) an extension of the existing curb approximately 6-ft long; B) a new curb, deck, and sub-grade footer wall approximately 12 ft long; and C) a new curb, deck, sub-grade footer wall, and moment slab approximately 38 ft long.

The top of the curb was 9 inches above the finished grade of the bridge deck, and was 14 inches wide.

The cantilevered deck was constructed on top of a 12-inch thick \(\times\) 3-ft deep vertical footer wall. The deck emulated the overhang of a bridge deck and was 8-inch thick \(\times\) 30-inch wide. A 14-inch wide \(\times\) 9-inch tall curb with \(\frac{3}{4}\)-inch chamfered corners was cast on top of the deck. The field side of the bridge deck extended 1\(\frac{1}{2}\) inches beyond the field side of the curb (see Appendix A and/or B, drawing sheet 10 of 14 for details).

In the new deck region A, the bridge deck was extended laterally approximately 4 ft to the existing concrete apron.

In the new deck region B, the vertical footer wall was extended longitudinally and the bridge deck was extended laterally approximately 5\(\frac{1}{2}\) ft over the new footer wall to the existing concrete apron (see Appendix A, drawing sheet 10 of 14 for details)

In the new deck region C, the vertical footer wall was extended farther longitudinally and the bridge deck was extended laterally approximately 14\(\frac{1}{2}\) ft over the new footer wall to create a new moment slab that was joined to the existing concrete apron (see Appendix A, drawing sheet 12 of 14 for details)
The bridge deck and moment slab extension were secured to the existing concrete apron via 24-inch long × ¾-inch diameter joint bars that were set a minimum of 6 inches deep in holes drilled horizontally into the edge of the apron 3½ inches below grade and 24 inches on center. The joint bars were secured into the apron using Hilti RE500 epoxy according to the manufacturer’s instructions. The curb extension was similarly connected with four joint bars (see Appendix A and/or B, drawing sheet 10 and 11 of 14 for details).

The ¾-inch diameter (#5) deck stirrups and transverse reinforcing steel bars were spaced on 6-inch longitudinal centers (except as noted) for the length of the curb. Also, a pair of #5 Z bars secured each anchor bolt assembly in the curb. Additional concrete reinforcement details can be found in Appendix A and/or B, drawing sheets 10 through 14.

Concrete cover over the reinforcing steel was 2 inches on the top of the deck, 1¼ inches at the bottom of the deck, and 1½ inches on the top and sides of the curb. Junctions of the steel reinforcing bars were field wire-tied as necessary.

Figure 2-1 and Figure 2-2 present overall information on the TxDOT Type C2P Bridge Rail, and Figure 2-3 provides photographs of the installation. Appendices A and B provide further details of the TxDOT Type C2P Bridge Rail.

### 2.2. MATERIAL SPECIFICATIONS

The specified minimum unconfined compressive strength for the bridge deck and curb concrete were 4000 psi. The average unconfined compressive strength of the concrete in the bridge wall was 4586 psi at 46 days of age. The average unconfined compressive strength of the concrete in the bridge deck was 4539 psi at 34 days of age. The average unconfined compressive strength of the concrete in the curb was 3850 psi at 15 days of age.

Reinforcement of the bridge deck and curb was comprised of ASTM A615 grade 60 rebar with specified minimum yield strength of 60 ksi.

Epoxied connections were installed with Hilti RE500 epoxy anchoring system according to the manufacturer’s instructions.

Appendix C provides material certification documents for the materials used to install/construct the TxDOT Type C2P Bridge Rail.
Figure 2-3. TxDOT Type C2P Bridge Rail prior to First Test 4-12.
Chapter 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1. CRASH TEST MATRIX

According to MASH, three tests are recommended to evaluate bridge rails for MASH Test Level 4 (TL-4). Details of these tests are described below:

**MASH Test 4-10** involves a 2420-lb passenger car (1100C) impacting the critical impact point (CIP) of the length-of-need (LON) of the bridge rail while traveling at an impact speed and angle of 62 mi/h and 25 degrees, respectively.

**MASH Test 4-11** involves a 5000-lb pickup truck (2270P) impacting the CIP of the LON of the bridge rail while traveling at an impact speed and angle of 62 mi/h and 25 degrees, respectively.

**MASH Test 4-12** involves a 22046-lb single unit truck (10000S) impacting the CIP of the LON of the bridge rail while traveling at an impact speed and angle of 56 mi/h and 15 degrees, respectively.

MASH Tests 4-10 and 4-11 evaluate a barrier’s ability to successfully contain and redirect passenger vehicles and evaluate occupant risk. MASH Test 4-12 evaluates the structural adequacy of the bridge rail. All three tests were performed on the TxDOT Type C2P Bridge Rail. The target CIP for each test was determined according to the information provided in MASH and is summarized in Figure 3-1 through Figure 3-3.

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

![Figure 3-1. Target CIP for MASH Test 4-10 on TxDOT Type C2P Bridge Rail.](image)
3.2. EVALUATION CRITERIA

The crash test results for each test were evaluated in accordance with the criteria presented in MASH. The impact performance of the TxDOT Type C2P Bridge Rail was judged based on the following factors:

- Structural adequacy, which is judged on the ability of the TxDOT Type C2P Bridge Rail to contain and redirect the vehicle.

- Risk of occupant compartment deformation or intrusion by detached elements, fragments, or other debris from the test article, which evaluates the potential risk of hazard to occupants, and, to some extent, other traffic, pedestrians, or workers in construction zones, if applicable.

- Occupant risk values, for which longitudinal and lateral occupant impact velocity and ridedown accelerations for the 1100C and 2270P vehicles must be within the limits specified in MASH, and determines the risk of injury to the occupants.

- Post-impact vehicle trajectory, which considers 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 tests reported herein. These criteria are listed in further detail under the assessment of each crash test.
Chapter 4. TEST CONDITIONS

4.1 TEST FACILITY

The full-scale crash tests reported herein were performed at the TTI Proving Ground, an International Standards Organization (ISO) 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 TTI Proving Ground is a 2000-acre complex of research and training facilities located 8 miles northwest of the main 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 that are 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 Type C2P Bridge Rail 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

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 2:1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released and ran unrestrained. The vehicles remained freewheeling (i.e., no steering or braking inputs) until they cleared the immediate area of the test site, after which the brakes were activated, if needed, to bring the test vehicles 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 and initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

Each of the TDAS Pro units is returned to the factory annually for complete recalibration. Accelerometers and rate transducers are also calibrated annually with traceability to the National Institute for Standards and Technology. All accelerometers are calibrated annually according to SAE J211 4.6.1 by means of an ENDEVCO® 2901, precision primary vibration standard. This device and its support instruments are returned to the factory annually for a National Institute of Standards Technology (NIST) traceable calibration. 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 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 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. However, it is recommended a dummy be used when testing “any longitudinal barrier with a height greater than or equal to 33 inches.” 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. Since the rail height of the TxDOT Type C2P Bridge Rail was
42 inches, a dummy was placed in the front seat of the 2270P vehicle on the impact side and restrained with lap and shoulder belts.

MASH does not recommend or require use of a dummy in the 10000S vehicle. However, for informational purposes, an H3 instrumented dummy provided by the National Highway Traffic Safety Association (NHTSA) was positioned in the driver’s seat and restrained with lap and shoulder belts. Measurements and photographs were taken per NHTSA protocol for use in studying dummy interactions within large vehicles.

4.3.3 Photographic Instrumentation Data Processing

Photographic coverage of each 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.
- 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 TxDOT Type C2P Bridge Rail. The flashbulb was visible from each camera to synchronize timing from the impact event. The videos from these high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-digital video camera and still cameras recorded and documented conditions of each test vehicle and the installation before and after each test.
Chapter 5.  *MASH TEST 4-10 (CRASH TEST NO. 490026-4-1)*

5.1  **TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS**

*MASH* Test 4-10 involves an 1100C vehicle weighing 2425 lb ±55 lb impacting the CIP of the TxDOT Type C2P Bridge Rail at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target CIP for *MASH* Test 4-10 on the TxDOT Type C2P Bridge Rail was 43\(\frac{3}{16}\) inches upstream of the centerline of post 11. The 2010 Kia Rio used in the test weighed 2433 lb, and the actual impact speed and angle were 63.0 mi/h and 25.7 degrees, respectively. The actual impact point was 45 inches upstream of the centerline of post 11. Minimum target impact severity (IS) was 51 kip-ft, and actual IS was 61 kip-ft.

5.2  **WEATHER CONDITIONS**

The test was performed on the morning of July 20, 2016. Weather conditions at the time of testing were as follows: wind speed: 3 mi/h; wind direction: 183 degrees (vehicle was traveling in a northwesterly direction); temperature: 90°F; relative humidity: 63 percent.

5.3  **TEST VEHICLE**

A 2010 Kia Rio, shown in Figure 5-1 and Figure 5-2, was used for the crash test. The vehicle’s test inertia weight was 2433 lb, and its gross static weight was 2598 lb. The height to the lower edge of the vehicle bumper was 7.75 inches and the height to the upper edge of the vehicle bumper was 21.0 inches. Table D-1 in Appendix D1 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. TxDOT Type C2P Bridge Rail/Test Vehicle Geometrics for Test No. 490026-4-1.*
5.4 TEST DESCRIPTION

As the 2010 Kia Rio was traveling at an impact speed of 63.0 mi/h, the left front corner of the bumper contacted the TxDOT Type C2P Bridge Rail 45 inches upstream of post 11 at an impact angle of 25.7 degrees. At 0.005 s after impact, the left front tire contacted the curb, and at 0.019 s, the hood contacted the middle horizontal rail element. The left front tire deformed at 0.022 s as the rim began traveling on the top surface of the curb, and the vehicle began to redirect at 0.032 s. At 0.040 s, the driver door opened slightly at the top near the roof, and at 0.050 s, cracks in the windshield began to radiate up and out from the left lower corner. The glass of the driver door began to dislodge from the frame of the window at 0.055 s, and the left front tire deflated at 0.064 s. At 0.089 s, the head of the dummy contacted the dislodged window glass, and at 0.101 s, the glass shattered as the dummy’s head remained in contact with the door glass. The head of the dummy began to return to the vehicle interior at 0.132 s (the dummy’s head did not contact the bridge rail), and the vehicle was traveling parallel with the installation at 0.178 s. At 0.350 s, the vehicle lost contact with the installation while traveling at an exit speed and exit angle of 49.5 mi/h and 9.7 degrees, respectively. Figures D-1 and D-2 in Appendix C2 present sequential photographs during the test.

For a bridge rail, it is desirable that the vehicle be redirected and exit the barrier within the exit box criteria (not less than 32.8 ft for cars and pickups). Brakes on the vehicle were applied 1.8 s after impact. The vehicle yawed counterclockwise and came to rest 174 ft downstream of impact and 2 ft toward the field side of the bridge rail. The 1100C vehicle exited within the exit box criteria defined in MASH.

5.5 DAMAGE TO TEST INSTALLATION

Figure 5-3 shows the damage to the TxDOT Type C2P Bridge Rail. The traffic face of the bridge rail was marred and scuffed, as was the traffic face and top of the curb. Working width was 14.0 inches. Maximum dynamic deflection during the test was 0.8 inch, and there was no notable maximum permanent deformation after the test.
Figure 5-3. TxDOT Type C2P Bridge Rail after Test No. 490026-4-1.
5.6 VEHICLE DAMAGE

Figure 5-4 shows the damage sustained by the vehicle. The front bumper, hood, left front tire and rim, left front strut and tower, left front fender, left front door and window glass, left rear door, left rear quarter panel, and rear bumper were damaged. The windshield was cracked in the left lower corner, and cracks radiated upward and toward the center, and deformation of the windshield was significantly less than 3 inches. Maximum exterior crush to the vehicle was 13.0 inches in the side plane at the left front corner at bumper height. Maximum occupant compartment deformation was 4.0 inches in the left front firewall area near the toe pan. Figure 5-5 shows the interior of the vehicle. Tables C-2 and C-3 in Appendix D1 provide exterior crush and occupant compartment measurements.

![Test Vehicle after Test No. 490026-4-1.]

Figure 5-4. Test Vehicle after Test No. 490026-4-1.

Before Test

After Test

Figure 5-5. Interior of Test Vehicle for Test No. 490026-4-1.

5.7 OCCUPANT RISK FACTORS

Data from the accelerometers located at the vehicle center of gravity were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity (OIV) was 26.2 ft/s at 0.071 s, the highest 0.010-s occupant ridedown acceleration was 2.8 g from
0.949 to 0.959 s, and the maximum 0.050-s average acceleration was −14.9 g between 0.014 and 0.064 s. In the lateral direction, the occupant impact velocity was 33.1 ft/s at 0.071 s, the highest 0.010-s occupant ridedown acceleration was 8.2 g from 0.199 to 0.209 s, and the maximum 0.050-s average was 19.7 g between 0.010 and 0.060 s. Theoretical Head Impact Velocity (THIV) was 46.0 km/h or 12.8 m/s at 0.069 s; Post-Impact Head Decelerations (PHD) was 8.5 g between 0.199 and 0.209 s; and Acceleration Severity Index (ASI) was 2.81 between 0.044 and 0.094 s. Figure 5-6 summarizes these data and other pertinent information from the test. Figures 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.

5.8 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable MASH safety evaluation criteria for MASH test 4-10 is provided below.

5.8.1 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 Type C2P Bridge Rail contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 0.8 inch. (PASS)

5.8.2 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: 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. (PASS)

Maximum occupant compartment deformation was 4.0 inches in the left front firewall area. (PASS)
Figure 5-6. Summary of Results for MASH Test 4-10 on TxDOT Type C2P Bridge Rail.
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 were 6 degrees and 5 degrees, respectively. (PASS)

H. Occupant impact velocities should satisfy the following:

*Longitudinal and Lateral Occupant Impact Velocity*

<table>
<thead>
<tr>
<th>Preferred</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 ft/s</td>
<td>40 ft/s</td>
</tr>
</tbody>
</table>

Results: Longitudinal OIV was 26.2 ft/s, and lateral OIV was 33.1 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:

*Longitudinal and Lateral Occupant Ridedown Accelerations*

<table>
<thead>
<tr>
<th>Preferred</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 g</td>
<td>20.49 g</td>
</tr>
</tbody>
</table>

Results: Maximum longitudinal ridedown acceleration was 2.8 g, and maximum lateral ridedown acceleration was 8.2 g. (PASS)
Chapter 6. *MASH Test 4-11 (Crash Test No. 490026-4-2)*

6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

*MASH* Test 4-11 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the CIP of the TxDOT Type C2P Bridge Rail at an impact speed of 62.2 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target CIP for *MASH* Test 4-11 on the TxDOT Type C2P Bridge Rail was 51½ inches upstream of the centerline of post 6. The 2011 Dodge RAM 1500 pickup truck used in the test weighed 5048 lb, and the actual impact speed and angle were 62.9 mi/h and 24.5 degrees, respectively. The actual impact point was 47½ inches upstream of the centerline of post 6. Minimum target impact severity was 106 kip-ft, and actual IS was 115 kip-ft.

6.2 WEATHER CONDITIONS

The test was performed on the morning of July 13, 2016. Weather conditions at the time of testing were as follows: wind speed: 14 mi/h; wind direction: 199 degrees (vehicle was traveling in a northwesterly direction); temperature: 92°F; relative humidity: 64 percent.

6.3 TEST VEHICLE

A 2011 Dodge RAM 1500 pickup truck, shown in Figure 6-1 and Figure 6-2, was used for the crash test. The vehicle’s test inertia weight was 5048 lb, and its gross static weight was 5213 lb. The height to the lower edge of the vehicle bumper was 11.75 inches and the height to the upper edge of the vehicle bumper was 26.0 inches. The height to the center of gravity of the vehicle was 28.3 inches. Tables E-1 and E-2 in Appendix E1 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. TxDOT Type C2P Bridge Rail/Test Vehicle Geometrics for Test No. 490026-4-2.](image-url)
6.4 TEST DESCRIPTION

As the 2011 Dodge RAM 1500 pickup truck was traveling at an impact speed of 62.9 mi/h, the left front corner of the bumper contacted the TxDOT Type C2P Bridge Rail 47½ inches upstream of the centerline of post 6 at an impact angle of 24.5 degrees. At 0.014 s after impact, the left front tire contacted the curb, and at 0.018 s, the hood and grill contacted the middle horizontal rail element. The left front tire began to climb the curb at 0.024 s, and the tire deflated at 0.028 s. At 0.038 s, the vehicle began to redirect, and at 0.042 s, a crack formed on the field side of the curb at post 6. The door opened near the roof at 0.058 s, and the head of the dummy contacted the door glass at 0.096 s. At 0.103 s, cracks began to radiate up and out from the left lower corner of the windshield, and at 0.106 s, the door glass in the driver door shattered. The head of the dummy was at maximum extent outside the vehicle at 0.134 s but did not contact the bridge rail. The vehicle began traveling parallel with the installation at 0.169 s. The dummy began retracting into the interior of the vehicle at 0.172 s, and the rear of the vehicle contacted the bridge rail at 0.180 s. At 0.340 s, the vehicle lost contact with the installation traveling at an exit speed and exit angle of 50.5 mi/h and 8.1 degrees, respectively. Figures E-1 and E-2 in Appendix E2 present sequential photographs during the test.

For a bridge rail, it is desirable that the vehicle be redirected and exit the barrier within the exit box criteria (not less than 32.8 ft for cars and pickups). Brakes on the vehicle were applied at 1.8 s after impact. The vehicle yawed counterclockwise and came to rest against a secondary barrier 220 ft downstream of impact and 1 ft toward the traffic side of the bridge rail. The 2270P vehicle exited within the exit box criteria defined in MASH.

6.5 DAMAGE TO TEST INSTALLATION

Figure 6-3 shows the damage to the TxDOT Type C2P Bridge Rail. No damage to the posts was noted. Small cracks in the curb radiated from the anchor bolts at post 5, and larger cracks radiated from the anchor bolts at post 6. Working width was 14.0 inches. Maximum dynamic deflection during the test was 2.5 inches, and maximum permanent deformation was 1.4 inches.
6.6 VEHICLE DAMAGE

Figure 6-4 shows the damage sustained by the vehicle. The front bumper, grill, hood, left front tire and rim, left upper and lower A-arms, left front fender, left front door and window glass, left rear door, left rear cab corner, left rear exterior bed, left rear tire and rim, left rear bumper, and left rear tailgate were damaged. The windshield sustained stress cracks radiating form the lower left corner of the A-pillar, and there was no deformation to the windshield. Maximum exterior crush to the vehicle was 13.0 inches in the side plane at the left front corner at bumper height. Maximum occupant compartment deformation was 2.25 inches in the instrument.
panel area. Figure 6-5 shows the interior of the vehicle. Tables E-3 and E-4 in Appendix E1 provide exterior crush and occupant compartment measurements.

Figure 6-4. Test Vehicle after Test No. 490026-4-2.

Figure 6-5. Interior of Test Vehicle for Test No. 490026-4-2.

6.7 OCCUPANT RISK FACTORS

Data from the accelerometers located at the vehicle center of gravity were digitized for evaluation of occupant risk. In the longitudinal direction, the OIV was 18.4 ft/s at 0.094 s, the highest 0.010-s occupant ridedown acceleration was 3.0 g from 0.200 to 0.210 s, and the maximum 0.050-s average acceleration was –9.9 g between 0.032 and 0.082 s. In the lateral direction, the occupant impact velocity was 29.5 ft/s at 0.094 s, the highest 0.010-s occupant ridedown acceleration was 9.5 g from 0.222 to 0.232 s, and the maximum 0.050-s average was 15.3 g between 0.042 and 0.092 s. THIV was 38.7 km/h or 10.7 m/s at 0.091 s; PHD was 9.9 g between 0.222 and 0.232 s; and ASI was 2.03 between 0.062 and 0.112 s. Figure 6-6 summarizes these data and other pertinent information from the test. Figure E-3 in Appendix E3 shows the vehicle angular displacements, and Figures E-4 through E-9 in Appendix E4 show accelerations versus time traces.
Figure 6-6. Summary of Results for MASH Test 4-11 on TxDOT Type C2P Bridge Rail.
6.8 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable MASH safety evaluation criteria for MASH test 4-11 is provided below.

6.8.1 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 Type C2P Bridge Rail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 2.5 inches. (PASS)

6.8.2 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 \( \leq 4.0 \) inches; windshield = \( \leq 3.0 \) inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan \( \leq 9.0 \) inches; forward of A-pillar \( \leq 12.0 \) inches; front side door area above seat \( \leq 9.0 \) inches; front side door below seat \( \leq 12.0 \) inches; floor pan/transmission tunnel area \( \leq 12.0 \) inches).

Results: 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. (PASS)

Maximum occupant compartment deformation was 2.25 inches in the instrument panel area. (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 collision event. Maximum roll and pitch angles were 5 degrees and 4 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><strong>Preferred</strong></td>
</tr>
<tr>
<td>30 ft/s</td>
</tr>
</tbody>
</table>

Results: Longitudinal OIV was 18.4 ft/s, and lateral OIV was 29.5 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><strong>Preferred</strong></td>
</tr>
<tr>
<td>15 g</td>
</tr>
</tbody>
</table>

Results: Maximum longitudinal ridedown acceleration was 3.0 g, and maximum lateral ridedown acceleration was 9.5 g. (PASS)
Chapter 7. *MASH TEST 4-12 (CRASH TEST NO. 490026-4-3)*

7.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

*MASH* Test 4-12 involves a 10000S vehicle weighing 22,000 lb ±660 lb impacting the CIP of the TxDOT Type C2P Bridge Rail at an impact speed of 56 mi/h ±2.5 mi/h and an angle of 15 degrees ±1.5 degrees. The CIP for *MASH* Test 4-12 on the TxDOT Type C2P Bridge Rail was 5 ft (60 inches) upstream of centerline of post 6. The 2004 International 4200 single-unit box van truck used in the test weighed 22,220 lb, and the actual impact speed and angle were 58.4 mi/h and 15.3 degrees, respectively. The actual impact point was 63 inches upstream of centerline of post 6. Minimum target impact severity was 142 kip-ft, and actual IS was 176 kip-ft.

7.2 WEATHER CONDITIONS

The test was performed on the morning of June 27, 2016. Weather conditions at the time of testing were as follows: wind speed: 2 mi/h; wind direction: 198 degrees (vehicle was traveling in a northwesterly direction); temperature: 91°F; relative humidity: 54 percent.

7.3 TEST VEHICLE

A 2004 International 4200 single-unit box van truck, shown in Figure 7-1 and Figure 7-2, was used for the crash test. Test inertia weight of the test vehicle was 22,220 lb, and its gross static weight was 22,385 lb. The height to the lower edge of the vehicle front bumper was 19.25 inches and height to the upper edge of the vehicle front bumper was 34.0 inches. Table F-1 in Appendix F1 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 7-1. TxDOT Type C2P Bridge Rail/Test Vehicle Geometrics for Test No. 490026-4-3.](image-url)
7.4 TEST DESCRIPTION

As the 2004 International 4200 single-unit box van truck was traveling at an impact speed of 58.4 mi/h, the left front corner of the bumper contacted the middle horizontal rail element of the TxDOT Type C2P Bridge Rail 63 inches upstream of centerline of post 6 at an impact angle of 15.3 degrees. At 0.008 s after impact, the left front fender of the vehicle contacted the top horizontal rail element, and at 0.009 s, the left front tire contacted the lower rail element. The left front tire contacted the curb at 0.011 s, and the tire began to climb the curb at 0.025 s. At 0.063 s, the cab of the vehicle began to redirect, and at 0.098 s, the left lower corner of the box contacted the top horizontal rail element. The box of the vehicle began to redirect at 0.110 s, and the base plate at post 5 began to lift off the curb at 0.234 s. At 0.235 s, the left lower rear corner of the box contacted the top horizontal rail element, and at 0.242 s, the box was traveling parallel with the installation. The weld at the connection between post 5 and the base plate began to rupture at 0.257 s, and the cab of the vehicle was traveling parallel with the installation at 0.270 s. At 0.294 s, post 5 was at maximum dynamic angle of 23 degrees toward the field side, and at 0.408 s, the left rear lower corner of the box lifted upward off the top horizontal rail element. Between 0.500 s and 0.600 s, the vehicle was traveling at 54.1 mi/h as it left the view of the overhead camera. The left front corner of the box contacted the top horizontal rail element at 0.580 s, and the left rear corner of the box contacted the top horizontal rail element a second time at 0.838 s. At 1.278 s, the left upper corner of the box contacted the top horizontal rail element, and at 1.739 s, the left rear upper corner of the box contacted the top horizontal rail element. Figures F-1 and F-2 in Appendix F2 present sequential photographs during the test.

For a bridge rail, it is desirable that the vehicle be redirected and exit the barrier within the exit box criteria (not less than 65.6 ft for vehicles other than cars and pickups). Brakes on the vehicle were not applied. The vehicle rode off the end of the bridge rail while traveling approximately parallel with the bridge rail. As the vehicle lost contact with the bridge rail, the vehicle rolled clockwise and came to rest on its left side 240 ft downstream of impact and 6 ft toward the traffic side of the bridge rail. The 10000S vehicle exited within the exit box criteria defined in MASH.
7.5 DAMAGE TO TEST INSTALLATION

Figure 7-3 shows the damage to the TxDOT Type C2P Bridge Rail. The welds failed at the base plates of post 5, 6, and 7. It was determined that the welds were not constructed correctly by the fabricator. After the welds failed at Posts 5, 6, and 7, the post plates rotated toward the field side 10 degrees, 13 degrees, and 7 degrees, respectively. The picket section between posts 5 and 6 released at the center and downstream locations but remained attached to the rail. Cracks radiated through the curb at posts 3 and 4, through the curb and deck at posts 5, 6, and 7, and through the curb at post 8. Working width was 62.3 inches. Maximum dynamic deflection during the test was 11.4 inches. Maximum permanent deformation as 7.25 inches at the joint between posts 5 and 6.

Figure 7-3. TxDOT Type C2P Bridge Rail after Test No. 490026-4-3.
7.6 VEHICLE DAMAGE

Figure 7-4 shows the damage sustained by the vehicle. The front bumper, hood, left front tire and rim, left battery box, left steps, left door and vent glass, left side of the cargo box, left rear outer tire and rim, and roof were damaged. The windshield sustained stress cracks during the test, and there was no deformation to the windshield. Maximum exterior crush to the vehicle was 14.0 inches in the side plane at the left front corner at bumper height. No occupant compartment deformation was noted. Figure 7-5 shows the interior of the vehicle.

Figure 7-4. Test Vehicle after Test No. 490026-4-3.

Figure 7-5. Interior of Test Vehicle for Test No. 490026-4-3.

7.7 OCCUPANT RISK FACTORS

Data from accelerometers located near the near the center of gravity were digitized only for information purposes. In the longitudinal direction, the OIV was 6.2 ft/s at 0.212 s, the highest 0.010-s occupant ridedown acceleration was 3.6 g from 0.260 to 0.270 s, and the maximum 0.050-s average acceleration was –1.8 g between 0.048 and 0.098 s. In the lateral direction, the occupant impact velocity was 15.1 ft/s at 0.212 s, the highest 0.010-s occupant
ridedown acceleration was 8.0 g from 0.278 to 0.288 s, and the maximum 0.050-s average was 5.4 g between 0.111 and 0.161 s. THIV was 17.8 km/h or 4.9 m/s at 0.206 s; PHD was 8.0 g between 0.278 and 0.288 s; and ASI was 0.61 between 0.136 and 0.186 s. Figure 7-6 summarizes these data and other pertinent information from the test. Figure F-3 in Appendix F3 shows the vehicle angular displacements, and Figures F-4 through F-9 in Appendix F4 show accelerations versus time traces.

7.8 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable MASH safety evaluation criteria for MASH test 4-12 is provided below.

7.8.1 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 Type C2P Bridge Rail contained and redirected the 10000S vehicle. Although the welds partially failed on several posts in the impact region (due to incorrect weldment by the fabricator), the vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 11.4 inches. (PASS)

7.8.2 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: No detached elements, fragments, or other debris from the bridge rail was present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. (PASS)

No deformation or intrusion into the occupant compartment occurred. (PASS)
Figure 7-6. Summary of Results for MASH Test 4-12 on TxDOT Type C2P Bridge Rail.
G. It is preferable, although not essential, that the vehicle remain upright during and after the collision.

Results: After losing contact with the bridge rail, the vehicle yawed counterclockwise and rolled onto its left side.
Chapter 8. SUMMARY AND CONCLUSIONS

8.1 ASSESSMENT OF TEST RESULTS

An assessment for each MASH test performed on the TxDOT Type C2P Bridge Rail is provided below.

8.1.1 MASH Test 4-10 (Crash Test No. 490026-4-1)

The TxDOT Type C2P Bridge Rail contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 0.8 inch. 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. Maximum occupant compartment deformation was 4.0 inches in the left front firewall area. The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 6 degrees and 5 degrees, respectively. Occupant risk factors were within the limits specified in MASH.

8.1.2 MASH Test 4-11 (Crash Test No. 490026-4-2)

The TxDOT Type C2P Bridge Rail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 2.5 inches. 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. Maximum occupant compartment deformation was 2.25 inches in the instrument panel area. The 2270P vehicle remained upright during and after collision event. Maximum roll and pitch angles were 5 degrees and 4 degrees, respectively. Occupant risk factors were within the preferred limits specified in MASH.

8.1.3 MASH Test 4-12 (Crash Test No. 490026-4-3)

The TxDOT Type C2P Bridge Rail contained and redirected the 10000S vehicle. Although the welds partially failed on several posts in the impact region (due to poor weld penetration during fabrication), the vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 11.4 inches. No detached elements, fragments, or other debris from the bridge rail was present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. No deformation or intrusion into the occupant compartment occurred. After losing contact with the bridge rail, the vehicle yawed counterclockwise and rolled onto its left side.

8.2 CONCLUSIONS

For MASH Test 4-12, the post welds were not properly fabricated according to the project design drawings. As a result, some post welds in the immediate impact area did rupture from the MASH Test 4-12 truck impact. These ruptured post welds did aggravate the stability of the single unit truck during the test. For subsequent tests, the posts were welded correctly as per the project
drawings. The bridge rail posts, with the correct post welds, should only improve the performance of the single unit truck.*

Table 8-1 through Table 8-3 show that the TxDOT Type C2P Bridge Rail performed acceptably for MASH TL-4.

* The opinions expressed in this paragraph are outside the scope of TTI Proving Ground’s A2LA Accreditation.
Table 8-1. Performance Evaluation Summary for MASH Test 4-10 on TxDOT Type C2P Bridge Rail.

<table>
<thead>
<tr>
<th>Structural Adequacy</th>
<th>Test Results</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<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 Type C2P Bridge Rail contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 0.8 inch.</td>
<td>Pass</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Occupant Risk</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<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></td>
<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></td>
</tr>
<tr>
<td></td>
<td>Maximum occupant compartment deformation was 4.0 inches in the left front firewall area.</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 were 6 degrees and 5 degrees, respectively.</td>
<td>Pass</td>
</tr>
<tr>
<td></td>
<td></td>
<td></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 OIV was 26.2 ft/s, and lateral OIV was 33.1 ft/s.</td>
<td>Pass</td>
</tr>
<tr>
<td></td>
<td></td>
<td></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 2.8 g, and maximum lateral ridedown acceleration was 8.2 g.</td>
<td>Pass</td>
</tr>
</tbody>
</table>
### Table 8-2. Performance Evaluation Summary for MASH Test 4-11 on TxDOT Type C2P Bridge Rail.

<table>
<thead>
<tr>
<th>MASH Test 4-11 Evaluation Criteria</th>
<th>Test Results</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural Adequacy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td>
<td>The TxDOT Type C2P Bridge Rail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 2.5 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 5.3 and Appendix E of MASH.</td>
<td>Maximum occupant compartment deformation was 2.25 inches in the instrument panel area.</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 collision event. Maximum roll and pitch angles were 5 degrees and 4 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 OIV was 18.4 ft/s, and lateral OIV was 29.5 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 3.0 g, and maximum lateral ridedown acceleration was 9.5 g.</td>
<td>Pass</td>
</tr>
</tbody>
</table>
### Table 8-3. Performance Evaluation Summary for MASH Test 4-12 on TxDOT Type C2P Bridge Rail.

<table>
<thead>
<tr>
<th>Structural Adequacy</th>
<th>Test Agency: Texas A&amp;M Transportation Institute</th>
<th>Test No.: 490026-4-3</th>
<th>Test Date: 2016-06-27</th>
<th>Test Results</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. <strong>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</strong></td>
<td>The TxDOT Type C2P Bridge Rail contained and redirected the 10000S vehicle. Although the welds partially failed on several posts in the impact region (due to poor weld penetration during fabrication), the vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 11.4 inches.</td>
<td>Pass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Occupant Risk</strong></td>
<td><strong>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.</strong></td>
<td>No detached elements, fragments, or other debris from the bridge rail was present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area.</td>
<td>Pass</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</strong></td>
<td>No deformation or intrusion into the occupant compartment occurred.</td>
<td>Pass</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>G. It is preferable, although not essential, that the vehicle remain upright during and after collision.</strong></td>
<td>After losing contact with the bridge rail, the vehicle yawed counterclockwise and rolled onto its left side.</td>
<td>Not Required</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Chapter 9. IMPLEMENTATION PLAN

The TxDOT Type C2P Bridge Rail, as tested and reported herein, met all the strength and impact performance requirements of MASH TL-4. Based on these testing results, the researchers consider the TxDOT Type C2P Bridge Rail suitable for implementation on bridges on which a MASH TL-4 barrier is desired.
REFERENCES

APPENDIX A.
DETAILS OF THE TXDOT TYPE C2P BRIDGE RAIL USED IN TEST NOS. 490026-1 AND 42

1a. Place Picket Panels with slots at Rail splice locations. Picket Panels with round holes go at all other locations.
1b. Tolerance on all fabricated parts is ±1/8" unless otherwise indicated.
Rail Parts List

Holes were field-cut on the Splice Sections to allow access to the 1/2" hardware. 2" long bolts were used at these locations.

Section C-C
Scale 1 : 10

Detail D
Scale 1 : 20

2a. Place Splice Sections with Pins on Field Side.

2b. Ø1/2" Bolts are ASTM A325. Ø7/8" Bolts are ASTM A449.

<table>
<thead>
<tr>
<th>#</th>
<th>Part Name</th>
<th>Qty.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Post for 42&quot; Picket Rail</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>Picket Rail Panel, with slots</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Picket Rail Panel, with holes</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>Rectangular Rail</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Round Rail</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Splice Section for Round Rail</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Splice Section for Rectangular Rail</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>U-bolt for Picket Rail</td>
<td>45</td>
</tr>
<tr>
<td>9</td>
<td>Plate Washer for U-bolt</td>
<td>90</td>
</tr>
<tr>
<td>10</td>
<td>Washer, 1/2 SAE Hardened</td>
<td>168</td>
</tr>
<tr>
<td>11</td>
<td>Nut, 1/2 heavy hex</td>
<td>174</td>
</tr>
<tr>
<td>12</td>
<td>Bolt, 1/2&quot; x 1 1/2&quot; hex</td>
<td>84</td>
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<tr>
<td>13</td>
<td>Washer, 1/2 Lock</td>
<td>90</td>
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<tr>
<td>14</td>
<td>Washer, 7/8 SAE Hardened</td>
<td>60</td>
</tr>
<tr>
<td>15</td>
<td>Nut, 7/8 heavy hex</td>
<td>60</td>
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<td>#</td>
<td>Body Name</td>
<td>Description</td>
</tr>
<tr>
<td>----</td>
<td>------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>16</td>
<td>Base Plate</td>
<td>Plate, 12” x 3/4”</td>
</tr>
<tr>
<td>17</td>
<td>Side Plate</td>
<td>Plate, 9” x 3/4”</td>
</tr>
<tr>
<td>18</td>
<td>Rail Plate, Top</td>
<td>Plate, 2” x 3/4”</td>
</tr>
<tr>
<td>19</td>
<td>Rail Plate, Bot and Mid</td>
<td>Plate, 2” x 3/4”</td>
</tr>
<tr>
<td>20</td>
<td>Picket</td>
<td>Plate, 5/8” x 5/8”</td>
</tr>
</tbody>
</table>
Post Parts
(See Table, previous sheet, for Picket details)

Base Plate
Plate, 12" x 3/4"
ASTM A572 Grade 50

Rail Plate, Top
Plate, 2" x 3/4"
ASTM A36 Steel
Slots, 15/16" x 1-3/4"
Typical both Rail Plates

Rail Plate, Bot and Mid
Plate, 2" x 3/4"
ASTM A36 Steel

Side Plate
Plate, 9" x 3/4"
ASTM A572 Grade 50
Section E-E

Elevation View
from Field Side

Isometric Views

Plate, 5/8" x 5/8" x 28-7/8"
ASTM A36

Plate, 1 1/2" x 3/8" x 73-1/8"
ASTM A36

Typ

6"

29-7/8"

16-1/8"

6"

3-3/16"

1/4"

3/16"

Slot, 9/16" x 3-1/2"
(3 Panels)

9/16" Hole
(12 Panels)

1/4" Typ

Typ

5a. Need 18 Panels total, 3 with Slots and 15 with holes at same location.
6a. Check Splice Sleeve for Rectangular Rail for loose fit in Rectangular Rail after fabrication is completed.
Rectangular Rail
HSS 6" x 2" x 1/4"
ASTM A500 Grade B

Plan View
(see 7a)

Elevation View

Section J-J
Scale 1 : 5

Detail K
Scale 1 : 10

Detail I
Scale 1 : 10

7a. Please note that the Plan View and Detail I are showing the Rail from the top. The holes are on bottom.
8a. Dimension is approximate. Rod is 10" long before bending.
**Anchor Bolt Assembly**

B7 Threaded Rod, Ø7/8" x 11 1/2"
Typ x 4
(thread not shown for clarity)

Nut, 7/8 heavy hex
Typ x 4

Anchor Plate

Isometric Views

**Anchor Plate**
Plate, 6 1/2" x 1/4" x 11"
ASTM A36 Steel

Ø 15/16" Typical
Previous Concrete

10a. Tie Bars spaced at 24", and welded to existing rebar protruding from the runway (not shown here).
10b. All Rebar is grade 60. Minimum lap distance is 17" for Ø1/2" bars and 21" for Ø5/8" bars.
10b. Concrete is TxDOT Class S (4000 psi). Chamfer edges of Deck and Curb 3/4" as shown.

Detail N
Scale 1 : 10

Z-bar (in pairs at each Post location)

Z-bar (in pairs at each Post location)

Bottom Transverse L at 18"

Deck Stirrup at 6"
New Concrete

11a. Drill minimum 6" into existing concrete and secure Joint Bars with Hilti RE-500 epoxy, according to manufacturer's instructions.

11b. Long Tie Bars spaced at 24" and welded to existing rebar protruding from the runway (not shown here).
12a. Drill minimum 6" into existing concrete and secure Joint Bars with Hilti RE-500 epoxy, according to manufacturer's instructions. Space at 24".

Section S-S
(see sheet 10 for all other details for Region C)
Rebar Details - 1

Tie Bar
total length = 30 7/16"

Long Tie Bar

3

5/8"

3-3/4"

24"

8"

20"

3-3/4"

5/8"

Bottom Transverse L

2

5/8"

24"

3-3/4"

33"

30 7/16"

3-3/4"

5/8"

5/8"

33"

37"

72 7/16"

Top Transverse L

36

6

3-3/4"

3-3/4"

24"

37"

64 7/16"

13a. The numeral in the hexagon denotes the quantity needed for each bar.
Rebar Details - 2

4 Rebar, #4 in new Wall

Deck Stirrup
- total length ≈ 44 7/8"

112

Z-bar
- total length ≈ 30 1/16"

14

Joint Bar

20-3/4"

21-1/4"

17-10"

5/8"

5/8"

5/8"

5/8"

11"

14-3/8"

14-1/2"

27-3/4"

6-5/8"

6-5/8"

6-5/8"

6-5/8"

6-5/8"

6-5/8"

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6-5/8"

6-5/8"
APPENDIX B. DETAILS OF THE TXDOT TYPE C2P BRIDGE RAIL USED IN TEST NOS. 490026-4-3

1a. Place Picket Panels with slots at Rail splice locations. Picket Panels with round holes go at all other locations.

1b. Tolerance on all fabricated parts is ±1/8" unless otherwise indicated.

Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project 490026-4-3 42" Picket Rail 2016-07-20
Drawn By GES Scale:1:200 Sheet 1 of 14 Test Installation

Test Installation

Plan View

Elevation View

Section A-A

Detail B

Scale 1 : 20

Scale 1 : 20

(some dims rounded to nearest 1/8")

Typical each joint

Nut, 7/8 heavy hex
Typical x 4 at each Post
Washer, 7/8 SAE Hardened

© 2022-06-29
Holes were field-cut on the Splice Sections to allow access to the 1/2" hardware. 2" long bolts were used at these locations.

**Rail Parts**

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<th>Qty.</th>
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<tr>
<td>2</td>
<td>Picket Rail Panel, with slots</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Picket Rail Panel, with holes</td>
<td>12</td>
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<td>4</td>
<td>Rectangular Rail</td>
<td>6</td>
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<tr>
<td>5</td>
<td>Round Rail</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Splice Section for Round Rail</td>
<td>2</td>
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<td>7</td>
<td>Splice Section for Rectangular Rail</td>
<td>4</td>
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<td>8</td>
<td>U-bolt for Picket Rail</td>
<td>45</td>
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<tr>
<td>9</td>
<td>Plate Washer for U-bolt</td>
<td>90</td>
</tr>
<tr>
<td>10</td>
<td>Washer, 1/2 SAE Hardened</td>
<td>168</td>
</tr>
<tr>
<td>11</td>
<td>Nut, 1/2 heavy hex</td>
<td>174</td>
</tr>
<tr>
<td>12</td>
<td>Bolt, 1/2” x 1 1/2” hex</td>
<td>84</td>
</tr>
<tr>
<td>13</td>
<td>Washer, 1/2 Lock</td>
<td>90</td>
</tr>
<tr>
<td>14</td>
<td>Washer, 7/8 SAE Hardened</td>
<td>60</td>
</tr>
<tr>
<td>15</td>
<td>Nut, 7/8 heavy hex</td>
<td>60</td>
</tr>
</tbody>
</table>

**Section C-C**

Scale 1 : 10

2a. Place Splice Sections with Pins on Field Side.

2b. Ø1/2" Bolts are ASTM A325. Ø7/8" Bolts are ASTM A449.
Post Parts

<table>
<thead>
<tr>
<th>#</th>
<th>Body Name</th>
<th>Description</th>
<th>Length</th>
<th>MATERIAL</th>
<th>Qty</th>
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<td>Base Plate</td>
<td>Plate, 12&quot; x 3/4&quot;</td>
<td>14&quot;</td>
<td>ASTM A572 Grade 50</td>
<td>1</td>
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<tr>
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<td>Side Plate</td>
<td>Plate, 9&quot; x 3/4&quot;</td>
<td>31 1/4&quot;</td>
<td>ASTM A572 Grade 50</td>
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<tr>
<td>18</td>
<td>Rail Plate, Top</td>
<td>Plate, 2&quot; x 3/4&quot;</td>
<td>11 3/4&quot;</td>
<td>ASTM A36 Steel</td>
<td>1</td>
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<tr>
<td>19</td>
<td>Rail Plate, Bot and Mid</td>
<td>Plate, 2&quot; x 3/4&quot;</td>
<td>14&quot;</td>
<td>ASTM A36 Steel</td>
<td>2</td>
</tr>
<tr>
<td>20</td>
<td>Picket</td>
<td>Plate, 5/8&quot; x 5/8&quot;</td>
<td>27 3/4&quot;</td>
<td>ASTM A36 Steel</td>
<td>1</td>
</tr>
</tbody>
</table>

Detail E
Scale 1 : 5

Elevation Views

Isometric View
Post Parts
(See Table, previous sheet, for Picket details)

Base Plate
Plate, 12" x 3/4"
ASTM A572 Grade 50

Rail Plate, Top
Plate, 2" x 3/4"
ASTM A36 Steel

Slots, 15/16" x 1-3/4"
Typical both Rail Plates

Rail Plate, Bot and Mid
Plate, 2" x 3/4"
ASTM A36 Steel

Side Plate
Plate, 9" x 3/4"
ASTM A572 Grade 50

Roadside Safety and
Physical Security Division -
Proving Ground

Project 490025-4 / 1-2 42" Picket Rail
2016-07-18
Drawn By GES Scale 1:5 Sheet 4 of 14 Post Parts
5a. Need 18 Panels total, 3 with Slots and 15 with holes at same location.
6a. Check Splice Sleeve for Rectangular Rail for loose fit in Rectangular Rail after fabrication is completed.
Rectangular Rail
HSS 6" x 2" x 1/4"
ASTM A500 Grade B

Plan View
(see 7a)

Elevation View

Section J-J
Scale 1 : 5

Detail K
Scale 1 : 10

Detail I
Scale 1 : 10

7a. Please note that the Plan View and Detail I are showing the Rail from the top. The holes are on bottom.
**Round Rail**

HSS Round 4 1/2” x 3/16”
ASTM A500 Grade B
Elevation View

**Section L-L**
Scale 1 : 5

**Detail M**
Scale 1 : 5

- Φ1-1/16”
  - Field side only

**Plate Washer for U-bolt**
Plate, 2” x 5/16” x 2”
ASTM A36 Steel
Scale 1 : 2

**U-bolt for Picket Rail**
Φ 1/2” ASTM A36 Steel
Scale 1 : 2

8a. Dimension is approximate. Rod is 10” long before bending.
Anchor Bolt Assembly

B7 Threaded Rod, Ø7/8" x 11 1/2"
Typ x 4
(threads not shown for clarity)

Nut, 7/8 heavy hex
Typ x 4

Anchor Plate

Isometric Views

Anchor Plate
Plate, 6 1/2" x 1/4" x 11"
ASTM A36 Steel

Ø15/16" Typical
10a. Tie Bars spaced at 24", and welded to existing rebar protruding from the runway (not shown here).

10b. All Rebar is grade 60. Minimum lap distance is 17" for Ø1/2" bars and 21" for Ø5/8" bars.

10b. Concrete is TxDOT Class S (4000 psi). Chamfer edges of Deck and Curb 3/4" as shown.

Z-bar (in pairs at each Post location)
Lap 9" with laps centered on Posts.

Z-bar (in pairs at each Post location)

12"

Bottom Transverse L at 18"

4"

2"

8"

17"

2" cover

1-1/4" cover

3/4"

5/8"

5-1/2"

2-3/4"

1-1/2"

1-1/2"

10-3/8"

9-5/8"

5-5/8"

Top Transverse L at 8"

Deck Stirrup at 6"

Ø1/2" longitudinal rebar, at 9" and as shown

Tie Bar (see 10a)

Ø5/8" longitudinal rebar, at 12" and as shown

Scale 1:10

Section O-O

Previous Concrete

Roadside Safety and Physical Security Division - Proving Ground

Project 490025-4 / 1-2  42" Picket Rail  2016-07-18
Drawn By GES  Scale:1:120  Sheet 10 of 14  Previous Concrete
New Concrete

11a. Drill minimum 6" into existing concrete and secure Joint Bars with Hilti RE-500 epoxy, according to manufacturer's instructions.

11b. Long Tie Bars spaced at 24" and welded to existing rebar protruding from the runway (not shown here).
12a. Drill minimum 6" into existing concrete and secure Joint Bars with Hilti RE-500 epoxy, according to manufacturer's instructions. Space at 24".
Rebar Details - 1

Tie Bar
- total length = 30 7/16"  

Long Tie Bar
- total length = 42 7/16"

Top Transverse L
- total length = 72 7/16"

Bottom Transverse L
- total length = 64 7/16"

13a. The numeral in the hexagon denotes the quantity needed for each Bar.
Rebar Details - 2

4. Rebar, #4 in new Wall

19. Joint Bar

112. Deck Stirrup
   total length ≈ 44 7/8"  

14. Z-bar
   total length ≈ 30 1/16"

76. Moment Slab Transverse Bar

14a. The numeral in the hexagon denotes the quantity needed for each Bar.
APPENDIX C. SUPPORTING CERTIFICATION DOCUMENTS

CONCRETE COMPRESSION TEST REPORT

Report Number: A1161016.0010
Service Date: 06/09/16
Report Date: 06/28/16 Revision 1 - 15-day results
Task: PO #490026-4

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

Project
Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1161016

Material Information
Specified Strength: 4,000 psi @ 28 days
Mix ID:
Supplier: Martin Marietta Materials
Batch No.: 1237
Truck No.: 7130

Sample Information
Sample Date: 06/09/16
Sample Time: 1:320
Sampled By: Randolph E. Rehrbach
Weather Conditions: Clear, light wind
Accumulative Yards: 5,555
Batch Size (cy): 5.5
Placement Method: Direct Discharge
Water Added Before: Not Specified
Water Added After: Not Specified
Sample Location: West end
Placement Location: Curb

Field Test Data
Test | Result | Specification
--- | --- | ---
Slump (in): | 4 3/4 | Not Specified
Air Content (%): | Not Specified | Not Specified
Concrete Temp. (F): | 92 | 40 - 95
Ambient Temp. (F): | 91 | 40 - 95
Plastic Unit Wt. (pcf): | Not Specified | Not Specified

Laboratory Test Data

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<th>Avg Diam.</th>
<th>Area (sq in)</th>
<th>Date Received</th>
<th>Date Tested</th>
<th>Age at Test (days)</th>
<th>Maximum Load (lbs)</th>
<th>Compressive Strength (psi)</th>
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<td>07/07/16</td>
<td>28</td>
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Average (15 days): 3,850

Comments: Not tested for plastic unit weight.

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

Terracon Rep.: Randolph E. Rehrbach
Reported To: Start/Stop: 1230-1415

Report Distribution:
(1) Texas Transportation Institute, Gary Gerke
(1) Terracon Consultants, Inc., Nicole Fasbinder

Reviewed By: Mark E. Dornak, P.E.
Project Manager

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

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

**5.7.2 Concrete Break**

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<tr>
<th>Doc. No.</th>
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<td>2012-09-17</td>
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<td>Page:</td>
<td>1 of 1</td>
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Revised by: G. E. Schroeder
Approved by: C. E. But

---

**Project No.:** 490026-4

**Placment:** W4C

**Casting Date:** 2016-05-13

**Mix Design P.S.I.:** 4000

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Printed name of Technician taking sample: GLENN SCHROEDER
Signature of Technician taking sample: [Signature]
Printed name of Technician breaking sample: EDWIN HANG
Signature of Technician breaking sample: [Signature]
### Quality Policy Form

**Concrete Break**

- **TR No.:** 9-1002-15-2
- **Doc. No.:** QPF 5.7.2
- **Revision Date:** 2012-09-17
- **Page:** 1 of 1

**Revised by:** G. E. Schroeder

**Approved by:** C. E. But

**Project No.:** 490026.4

**Placement:** DECK

**Casting Date:** 2016-05-25

**Mix Design P.S.I.:** 4000

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<th>Yards</th>
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<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

**Printed name of Technician taking sample:**

**Signature of Technician taking sample:**

**Printed name of Technician breaking sample:**

**Signature of Technician breaking sample:**

### Break Date

<table>
<thead>
<tr>
<th>Break Date</th>
<th>Cylinder Age</th>
<th>Truck No.</th>
<th>Total Load (Pounds)</th>
<th>PSI Break</th>
<th>Average</th>
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<tbody>
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<td>2016-06-27</td>
<td>34 days</td>
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<td>131,000</td>
<td>4133</td>
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<td>125,000</td>
<td>4921</td>
<td>4539</td>
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# MATERIAL USED

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<tr>
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<th>DATE RECEIVED</th>
<th>DESCRIPTION</th>
<th>GRADE</th>
<th>YIELD</th>
<th>TENSILE</th>
<th>SUPPLIER</th>
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<tr>
<td>15-044</td>
<td>2016-04-12</td>
<td>Rebar, #5 x 20'</td>
<td>60</td>
<td>63.8 ksi</td>
<td>102.5 ksi</td>
<td>CMC Steel</td>
</tr>
<tr>
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<td>60</td>
<td>none given</td>
<td></td>
<td>CMC Steel</td>
</tr>
<tr>
<td>15-049</td>
<td>2016-05-31</td>
<td>Ø7/8 x 11-1/2 Rod</td>
<td>B7</td>
<td>125000</td>
<td>138000</td>
<td>Mack Bolt &amp; Steel</td>
</tr>
<tr>
<td>15-050</td>
<td>2016-05-31</td>
<td>Nut, 7/8 Heavy Hex</td>
<td>2H</td>
<td></td>
<td></td>
<td>Mack Bolt &amp; Steel</td>
</tr>
<tr>
<td>15-051</td>
<td>2016-05-31</td>
<td>Washer, 7/8 flat</td>
<td>SAE</td>
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<td>Mack Bolt &amp; Steel</td>
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<tr>
<td>15-053</td>
<td>2016-06-20</td>
<td>Rail Parts</td>
<td></td>
<td></td>
<td>see attached</td>
<td>Rik-Mar</td>
</tr>
</tbody>
</table>
CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT

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

William VanDerWaal
Quality Assurance/Reliability Manager

TR No. 9-1002-15-2

HEAT NO.: 3060965
SECTION: REBAR 16MM (#5) 20"'
420/60 B096
GRADE: ASTM A615-14 Gr 420/60
ROLL DATE: 01/20/2016
MELT DATE: 01/17/2016

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<th>Value</th>
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<tr>
<td>Mn</td>
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</tr>
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<td>P</td>
<td>0.012%</td>
</tr>
<tr>
<td>S</td>
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</tr>
<tr>
<td>Si</td>
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<tr>
<td>Cu</td>
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<tr>
<td>Cr</td>
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</tr>
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<td>Ni</td>
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</tr>
<tr>
<td>Mo</td>
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</tr>
<tr>
<td>V</td>
<td>0.000%</td>
</tr>
<tr>
<td>Cb</td>
<td>0.003%</td>
</tr>
<tr>
<td>Sn</td>
<td>0.009%</td>
</tr>
<tr>
<td>Al</td>
<td>0.003%</td>
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Yield Strength test 1 | 63.8ksi
Tensile Strength test 1 | 102.5ksi
Elongation test 1 | 16%
Elongation Gage Lth test 1 | 8IN
Bend Test Diameter | 2.188IN
Bend Test | Passed

THIS MATERIAL IS FULLY KILLED, 100% MELTED AND MANUFACTURED IN THE USA. WITH NO WELD REPAIR OR MERCURY CONTAMINATION IN THE PROCESS.

REMARKS:

02/18/2016 17:55:00

Page 1 OF 1
<table>
<thead>
<tr>
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<tr>
<td>P</td>
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<tr>
<td>S</td>
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<tr>
<td>Si</td>
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<tr>
<td>Ca</td>
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</tr>
<tr>
<td>Cr</td>
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</tr>
<tr>
<td>Ni</td>
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</tr>
<tr>
<td>Mo</td>
<td>0.038%</td>
</tr>
<tr>
<td>V</td>
<td>0.000%</td>
</tr>
<tr>
<td>Cb</td>
<td>0.002%</td>
</tr>
<tr>
<td>Sn</td>
<td>0.015%</td>
</tr>
<tr>
<td>Al</td>
<td>0.001%</td>
</tr>
</tbody>
</table>

**CERTIFIED MILL TEST REPORT**

For additional copies call 830-372-9771

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

William VanderWaal
Quality Assurance/Reliability Manager

**HEAT NO.:** 3062573
**SECTION:** REBAR 13MM (#4) 20'0"
**GRADE:** ASTM A615-14 Gr 420/60
**ROLL DATE:** 04/06/2016
**MELT DATE:** 04/01/2016

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<td>Mn</td>
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<tr>
<td>P</td>
<td>0.012%</td>
</tr>
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<td>0.043%</td>
</tr>
<tr>
<td>Si</td>
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<tr>
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<td>Mo</td>
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<td>V</td>
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<tr>
<td>Sn</td>
<td>0.015%</td>
</tr>
<tr>
<td>Al</td>
<td>0.001%</td>
</tr>
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**Delivery #:** 81766737
**BOL #:** 71582102
**CUST PO #:** 712289
**CUST P/N:** 5524200
**DLVRY LBS / HEAT:** 35056.000 LB
**DLVRY PCS / HEAT:** 2624 EA

THIS MATERIAL IS FULLY KILLED, 100% MELTED AND MANUFACTURED IN THE USA, WITH NO WELD REPAIR OR MERCURY CONTAMINATION IN THE PROCESS.

**REMARKS:**

04/06/2016 16:01:44
Page 1 OF 1
We certify that the material or fasteners supplied were manufactured, sampled, tested and inspected in accordance with the specification and other requirements designated in the purchase order and was found to meet those requirements. While in our possession, the material did not come in contact with mercury. The recording of false, fictitious or fraudulent statements or entries on this document may be punishable as a felony under Federal Statute.

Material Number: 60372
Batch: 0000431559 / Quantity: 2 EA
Heat Number: 6613040020

Specification / Description:
TFL STUDS
ASTM A193 B7
.875-9 X 11.500 MEASURED OVERALL LENGTH

<table>
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<th>Unit</th>
<th>Value</th>
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<tr>
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<td>6613040020</td>
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<tr>
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<td>China</td>
</tr>
<tr>
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</tr>
<tr>
<td>Chromium Content</td>
<td>%</td>
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<tr>
<td>Manganese Content</td>
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<tr>
<td>Molybdenum Content</td>
<td>%</td>
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<tr>
<td>Phosphorus Content</td>
<td>%</td>
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<td>Sulfur Content</td>
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<tr>
<td>Tensile Strength</td>
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<td>Yield Strength</td>
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<td>125000</td>
</tr>
<tr>
<td>Elongation</td>
<td>%</td>
<td>20.000</td>
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<tr>
<td>Reduction of Area</td>
<td>%</td>
<td>58.000</td>
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<tr>
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<tr>
<td>Tempering Temperature</td>
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B&G Manufacturing Company, Inc. Quality Certificate  Date: 05/27/2016

Page 2 of 3
Macro Etch Testing - Pass
MACRO CENTER SEGREGATION - ASTM E381-01 C2
MACRO RANDOM CONDITION - ASTM E381-01 R2
MACRO SUBSURFACE CONDITION - ASTM E381-01 S2
Condition - Quenched and Tempered
Condition - Stress Relieved

If you have any questions concerning this document, please contact our customer service dept at 215-996-3301.

Certification Service Specialist: Amanda Culp
B&G Manufacturing Company, Inc. Quality Certificate

Date: 05/27/2016

Material Number: 60372
Batch: 0000431561 / Quantity: 48 EA
Heat Number: 4104544

Specification / Description
TFL STUDS
ASTM A193 B7
.875-9 X 11.500 MEASURED OVERALL LENGTH

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<td>Molybdenum Content</td>
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<td>Sulfur Content</td>
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<tr>
<td>Condition</td>
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<td>Stress Relieved</td>
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</tbody>
</table>

If you have any questions concerning this document, please contact our customer service dept at 215-996-3301.

Certification Service Specialist: Amanda Culp

15-049
Stelfast Inc.
22979 Stelfast Parkway
Strongsville, Ohio
44149

Issued To: Mack Bolt, Steel & Machine
5875 Hwy 21 East
BRYAN, TX
77808

Quantity: 150
Part #: A2HHO0875C
Description: 7/8-9 Hvy Hs Nut 2H

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<th>S</th>
<th>Si</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
<th>B</th>
<th>Ni</th>
<th>Cu</th>
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</tbody>
</table>

Chemical Analysis

We hereby certify that the above data is a true copy of the data furnished to us by the producing mill or the data resulting from tests performed in approved laboratories. Stelfast does not certify to customer's part number.

This certificate applies to the product shown on this document, as supplied by Stelfast Inc. Alterations to the product by our customer or a third party will render this certificate void.

David Biss
Quality Manager

May 25, 2016
Stelfast Inc.
22979 Stelfast Parkway
Strongsville, Ohio
44149

Issued To: Mack Bolt, Steel & Machine
5875 Hwy 21 East
BRYAN, TX
77808

Quantity: 750
Part #: DHW0008750
Description: 7/8 Hardened Washer F436

Chemical Analysis

<table>
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<th>S</th>
<th>Si</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
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</table>

Mechanical Properties

Hardness (Core)  39 - 44 HRC

We hereby certify that the above data is a true copy of the data furnished to us by the producing mill or the data resulting from tests performed in approved laboratories. Stelfast does not certify to customer's part numbers.

This certificate applies to the product shown on this document, as supplied by Stelfast Inc. Alterations to the product by our customer or a third party will render this certificate void.

David Biss
Quality Manager
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<th>HEAT</th>
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<th>Si</th>
<th>Cu</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Al</th>
<th>V</th>
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<th>Ti</th>
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**Chemical Composition**

- **TEST OF THE PRODUCT**

<table>
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<th>HEAT</th>
<th>SLAB / PLATE NO.</th>
<th>THICKNESS (Inch)</th>
<th>Y. STRENGTH (ksi)</th>
<th>T. STRENGTH (ksi)</th>
<th>ELONG.</th>
<th>T. ELONG.</th>
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**Tested Product**

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<th>WIDTH (Inch)</th>
<th>LARGE (Inch)</th>
<th>ORDER</th>
<th>ITEM</th>
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<td>240.0000</td>
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<td>3030 94303752</td>
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</tr>
</tbody>
</table>

All heats and sizes are fully aluminum killed with fine grain practice. DIN EN 10204 § 3.1 compliant.

**Country of Origin:** Mexico

**Issued:** COIA110

**END OF DATA**
## Material Test Report

**Texas Tubular Products**  
P.O. Box 0388, F.M. 250 North, Lone Star, TX 75668  
**Material Test Report**  
Results relate only to items tested. Test report not to be reproduced except in its entirety.

In accordance with EN 10204 - Type 3.1

**Sold To:**  
DELTA STEEL INC.  
2000 N 170TH E AVE.  
TULSA OK 74116

**Mtr#:** 4016  
**Customer Order Number:** DHO-146395  
**Date:** 4/29/2016

**Product:** 4.5 .188 8.67#

**Specification:** ASTM A500/A500M-13 Grade B, ERW

Melted and Manufactured in the U.S.A.

### Chemical Analysis, % (Heat Analysis)

<table>
<thead>
<tr>
<th>Heat Number</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
</tr>
</thead>
</table>
| ASTM583     | 0.2 | 0.46| 0.014| 0.005| 0.03| 0.08| 0.03| 0.06| 0.01| 0.005

### Mechanical Properties

<table>
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<tr>
<th>Test</th>
<th>Dir</th>
<th>Loc</th>
<th>Yield</th>
<th>Tensile</th>
<th>Elong %</th>
<th>Hydrotest 5 sec. hold</th>
<th>Flattening</th>
<th>UT N10 Notch</th>
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<tbody>
<tr>
<td>1</td>
<td>L</td>
<td>B</td>
<td>64.1</td>
<td>74.8</td>
<td>27</td>
<td>N/A</td>
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<td>N/A</td>
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<tr>
<td>2</td>
<td>T</td>
<td>B</td>
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<tr>
<td>3</td>
<td>T</td>
<td>W</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**WE HEREBY VERIFY THAT THE ABOVE INFORMATION IS CORRECT AS CONTAINED IN THE RECORDS OF TEXAS TUBULAR PRODUCTS**

By: Vice-President Friedman Industries Inc.  
Texas Tubular Products Division  
01/04/10

**TTM-05210**  
**ROUND TUBING**  
**CR: A-500 GR B**  
**6/10/16**
## CERTIFICADO DE CALIDAD / MILL TEST REPORT

**CLIENTE/SOLD TO:** Triple S Steel Supply Co.  
PO Box 21119  
Houston TX C.P. 77226

**DESTINATARIOSHIP TO:** Triple S - Irvington Whs  
PO Box 21119  
Houston TX C.P. 77022

**FACTURA/BROKER:**  
1200060678

**FECHA/DATE:** 11/17/2015

### PROPIEDADES FÍSICAS / MECHANICAL PROPERTIES

<table>
<thead>
<tr>
<th>O.C./P.O.</th>
<th>PEDIDO/ ORDER</th>
<th>ROLLO/ COIL</th>
<th>LOTE/ PACKAGE</th>
<th>PROPRIEDADES FÍSICAS / MECHANICAL PROPERTIES</th>
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<tbody>
<tr>
<td>HOU-167987</td>
<td>30039108-20</td>
<td>0011069329</td>
<td>0011130578</td>
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<td>0011137941</td>
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<td>0011137941</td>
<td>TENSIL (kSI) 66 61 47 64 25 A500 HX-B HR Gr 205610 Made in Mexico</td>
</tr>
</tbody>
</table>

### RESPONSABLES

Imprimido/Printed by: Info. Prolamsa  
11/17/2015 19:51:51  
Pági/n: 1

Emitted by: Luis de Alvarado  
Coord. De Laboratorio

### RECTANGULAR TUBING

6x2x1/4 x 40
### Datos del Cliente / Solicitado

- **Nombre:** Acanos Ramos Ariza
- **Dirección:** Carrera 100 N° 8-40, 1232, Bogotá, Colombia
- **Teléfono:** +57 314 743 8943
- **Correo Electrónico:** ""
<table>
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<tr>
<th>CHEMICAL COMPOSITION</th>
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<tbody>
<tr>
<td>C</td>
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<td>Min.</td>
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<td>0.26</td>
<td>0.08</td>
<td>0.11</td>
<td>0.020</td>
<td>0.033</td>
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<tr>
<td>Tensile</td>
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<td>Stress (ksi)</td>
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<td>COMMENTS / NOTES</td>
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</tbody>
</table>

The above figures are certified chemical and physical test results as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in Canada. CMTR complies with EN 10204 3.1.

MANNY ROGOLLO
QUALITY ASSURANCE MGR.

BRIAN YALAMANCHILI
QUALITY DIRECTOR
| SERIE       | PRODUCT   | COLADA | GRADO | "LE" | "UT" | PE | LEUT | C | Mn | Si | P  | S  | Cu | Cr | Ni | Mo | Sn | V  | Nb | Al | CEQ |
|------------|-----------|--------|-------|------|------|----|------|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1201511252018 | SOL 201 1-1/2x3/8 | 000003152426 | ANSA328-50 | 51255 | 73521 | 30 | 0.7 | 0.18 | 0.18 | 0.23 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| 1201511252009 | SOL 201 1-1/2x3/8 | 000003152426 | ANSA328-50 | 51255 | 73521 | 30 | 0.7 | 0.18 | 0.18 | 0.23 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| 1201511252004 | SOL 201 1-1/2x3/8 | 000003152426 | ANSA328-50 | 51255 | 73521 | 30 | 0.7 | 0.18 | 0.18 | 0.23 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| 1201511252005 | SOL 201 1-1/2x3/8 | 000003152426 | ANSA328-50 | 51255 | 73521 | 30 | 0.7 | 0.18 | 0.18 | 0.23 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| 1201512163021 | ANG 2 11x1.8 | 000003152960 | ANSA328-50 | 51300 | 72500 | 29 | 0.71 | 0.18 | 0.18 | 0.23 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| 1201512163032 | ANG 2 11x1.8 | 000003152960 | ANSA328-50 | 51300 | 72500 | 29 | 0.71 | 0.18 | 0.18 | 0.23 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| 1201512163028 | ANG 2 11x1.8 | 000003152960 | ANSA328-50 | 51300 | 72500 | 29 | 0.71 | 0.18 | 0.18 | 0.23 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| 1201512163021 | ANG 2 11x1.8 | 000003152960 | ANSA328-50 | 51300 | 72500 | 29 | 0.71 | 0.18 | 0.18 | 0.23 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |

*Las unidades expresadas en L.E. y U.T son en PSI. La composición química está expresada en % en peso.*

*The units expressed in L.E. and U.T are in PSI. The chemical composition is expressed in % by weight.*

Certificamos que el producto aquí descrito, cumple y ha sido
fabricado, muestreado, probado e inspeccionado de acuerdo
con los requisitos aplicables de la especificación:

ASTM A5/ A5M-13 a (2014); AS29 / AS29M; ASME SA-6/SA-6M

We certify that the product above mentioned complies with and has
been manufactured, tested and inspected in accordance
with applicable requirements of specifications:

ASTM A5/ A5M-13 a (2014); AS29 / AS29M; ASME SA-6/SA-6M.

Gerente de Aseguramiento de Calidad

F. G. C. L. C. M. REV. 4-06-2014
**CERTIFIED MATERIAL TEST REPORT**

**CUSTOMER SHIP TO**
TRIPLE S STEEL SUPPLY  
6000 JENSEN DR  
HOUSTON, TX 77026-1113  
USA

**CUSTOMER BILL TO**
TRIPLE S STEEL  
6000 JENSEN DR  
HOUSTON, TX 77026-1119  
USA

**SALES ORDER**
3585736/000020

**BILL OF LADING**
1321-000003835

**DATE**
04/03/2016

**BILLBOARD**
1321-000003835

**GRADE**
GGMULTI

**SHAPE / SIZE**
Angle / 2X1 1/2X3/16

**LENGTH**
20'00"

**WEIGHT**
2,968 LBS

**HEAT / BATCH**
54149200/03

**CUSTOMER PURCHASE ORDER NUMBER**
8801469975

**BILL OF LADING**
1321-000003835

**DATE**
04/03/2016

**METAL CHEMICAL COMPOSITION**
- C: 0.16
- Mn: 0.68
- P: 0.014
- S: 0.038
- Si: 0.19
- Cu: 0.34
- Ni: 0.13
- Cr: 0.14
- Mo: 0.040
- V: 0.016
- Nb: 0.002
- S: 0.015

**MECHANICAL PROPERTIES**
- Elong.: 29.00
- UTS: 8000
- UTS: 74733
- UTS: 513
- UTS: 55343
- YS: 382

**GEOMETRIC CHARACTERISTICS**
- 25.00

**COMMENTS / NOTES**
This grade meets the requirements for the following grades:
CSA Grades: G40.21M, G40.21A
AASHTO Grades: M270-36, M270-30
ASME Grades: SA36

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

**SIGNATURES**

- **QA Director**
  - Bhaskar Valamanchi

- **Quality Assurance**
  - Jordan Foster
MATERIAL CERTIFICATION

Shipper's/No.  33944

Customer Information:
Triple S Steel
P.O. Box 21119
Houston, TX 77226

Ship To:
Dallas / Fort Worth Prime Stock
3201 N. Sylvania Avenue BLDG 105
817-222-1603  Shelley
Fort Worth, TX 76111

Shipped Date: 4/14/2016 12:00:00AM

<table>
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<th>Item Description</th>
<th>Vendor Item #</th>
<th>Order Number</th>
<th>Qty Shipped</th>
<th>C</th>
<th>Mo</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Yield Strength</th>
<th>Tensile Strength</th>
<th>Elongation</th>
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<td>3.000 x 3.000 x 1/4 x 240</td>
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<td>0.002</td>
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<td>26</td>
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<td>Customer PO #: TXN-3195</td>
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<td>Grade: ASTM A500 B/C Rev 10a</td>
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<tr>
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<td>4.000 x 4.000 x 1/4 x 288</td>
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<tr>
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<td>Grade: ASTM A500 B/C Rev 10a</td>
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</tr>
</tbody>
</table>

Comments:
- All items above were Melted and Manufactured in the U.S.A.
- Mercury free.
- The material test results meeting ASTM A500 B and/or B/C Rev 10a also meet the requirements for ASTM A500 B Rev 10 and Rev 13.
- Material that meets A500 B and B/C Rev 10a also meet the requirements for A513.
- Pipe sizes above meet ASTM A53 Grade B Non-Hydro Type E / A500 Grade B tensile requirements only.

171 Cleage Dr. Birmingham, Alabama 35217
(205) 520-0238, 1-800-956-5440 Fax (205) 520-9573 -
C:\Users\gwilliams\AppData\Roaming\Waysy\AgilityDocs\MATCERTIF\base.RPT
DELTA STEEL, INC.

Sold By:
INDEPENDENCE TUBE CORPORATION
6226 W. 74th St
Chicago, IL 60638
Tel: 708-496-0380
Fax: 708-563-1850

Sold To:
1 - DELTA STEEL INC-HOUSTON
P.O. BOX 2289
HOUSTON, TX 77252

Purchase Order No: DHO-145785
Sales Order No: MAR 302224 - 2
Bill of Lading No: MAR 176204 - 3

Ship To:
1 - DELTA STEEL, INC.
7355 ROUNDHOUSE LANE
HOUSTON, TX 77078

Certificate No: MAR 409637
Test Date: 2/29/2016

CERTIFICATE of ANALYSIS and TESTS
Customer Part No:
ROUND A600 GRADE B(C)
4.000"OD (3.5"NPS)X SCH40 X 42' BUNDLE

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<th>Heat Seq.</th>
<th>Mill</th>
<th>Heat</th>
<th>Y/T Ratio</th>
<th>Pieces</th>
<th>Weight</th>
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<td>0.8707</td>
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Mill #: 6
Heat #: D01629
Carbon Eq.: 0.2746
Heat Source: MELTED AND MANUFACTURED IN THE USA

C | Mn | P | S | Si | Al | Cu | Cr | Mo | V | Ni | Nb | Co
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<td>0.0010</td>
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</tbody>
</table>

Sn | N | B | Ti
<table>
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<tbody>
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<td>0.0030</td>
<td>0.0005</td>
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LEED Information (based on the most recent LEED information from the producing mill)

Method | Location | Recycled Content | Post Consumer | Post Industrial |
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<td>Gary Works, IN</td>
<td>36.9%</td>
<td>19.8%</td>
<td>14.4%</td>
</tr>
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Certification:
I certify that the above results are a true and correct copy of records prepared and maintained by Independence Tube Corporation. Sworn this day, 2/29/2016.

WE PROUDLY MANUFACTURE ALL OUR PRODUCT IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED, AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.
MATERIAL IDENTIFIED AS A500 GRADE B(C) MEETS BOTH ASTM A500 GRADE B AND A500 GRADE C SPECIFICATIONS.

CURRENT STANDARDS:
A252-10
A500/A500M-13
A513-12
ASTM A55/A55M-12 | ASME SA-53/SA-53M-13
A847/A847M-14
A1055/A1055M-15

Page - 1
## APPENDIX D.  MASH TEST 4-10 (CRASH TEST NO. 490026-4-1)

### D1  VEHICLE PROPERTIES AND INFORMATION

#### Table D-1. Vehicle Properties for Test No. 490026-4-1.

<table>
<thead>
<tr>
<th>Date:</th>
<th>2016-07-20</th>
<th>Test No.:</th>
<th>490026-4-1</th>
<th>VIN No.:</th>
<th>KNADH4A31A6679041</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year:</td>
<td>2010</td>
<td>Make:</td>
<td>Kia</td>
<td>Model:</td>
<td>Rio</td>
</tr>
<tr>
<td>Tire Inflation Pressure:</td>
<td>32 psi</td>
<td>Odometer:</td>
<td>101244</td>
<td>Tire Size:</td>
<td>185/65R14</td>
</tr>
</tbody>
</table>

Describe any damage to the vehicle prior to test: None

- Denotes accelerometer location.

**NOTES:** None

Engine Type: 4 cylinder

Engine CID: 1.6 liter

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

Optional Equipment: None

**Geometry:** inches

<table>
<thead>
<tr>
<th>A</th>
<th>66.38</th>
<th>F</th>
<th>33.00</th>
<th>K</th>
<th>10.75</th>
<th>P</th>
<th>4.12</th>
<th>U</th>
<th>15.10</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>57.50</td>
<td>G</td>
<td>-----</td>
<td>L</td>
<td>25.00</td>
<td>Q</td>
<td>22.50</td>
<td>V</td>
<td>20.75</td>
</tr>
<tr>
<td>C</td>
<td>165.75</td>
<td>H</td>
<td>35.35</td>
<td>M</td>
<td>57.75</td>
<td>R</td>
<td>15.50</td>
<td>W</td>
<td>35.35</td>
</tr>
<tr>
<td>D</td>
<td>34.00</td>
<td>I</td>
<td>7.75</td>
<td>N</td>
<td>57.10</td>
<td>S</td>
<td>7.50</td>
<td>X</td>
<td>102.25</td>
</tr>
<tr>
<td>E</td>
<td>97.75</td>
<td>J</td>
<td>21.00</td>
<td>O</td>
<td>28.25</td>
<td>T</td>
<td>66.20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Wheel Center Ht Front 11.00

Wheel Center Ht Rear 11.00

**GVWR Ratings:**

<table>
<thead>
<tr>
<th>Front</th>
<th>1918</th>
<th>M&lt;sub&gt;front&lt;/sub&gt;</th>
<th>1598</th>
<th>1562</th>
<th>Gross Static</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back</td>
<td>1874</td>
<td>M&lt;sub&gt;rear&lt;/sub&gt;</td>
<td>895</td>
<td>871</td>
<td>1046</td>
</tr>
<tr>
<td>Total</td>
<td>3638</td>
<td>M&lt;sub&gt;Total&lt;/sub&gt;</td>
<td>2493</td>
<td>2433</td>
<td>2598</td>
</tr>
</tbody>
</table>

**Mass Distribution:**

| lb  | LF: 770 | RF: 792 | LR: 445 | RR: 426 |

**Engine Type:**

- 4 cylinder

**Engine CID:**

- 1.6 liter

**Transmission Type:**

- Manual
- FWD
- RWD
- 4WD

**Optional Equipment:** None

**Dummy Data:**

- Type: 50<sup>th</sup> percentile male
- Mass: 165 lb
- Seat Position: Driver seat
Table D-2. Exterior Crush Measurements for Test No. 490026-4-1.

<table>
<thead>
<tr>
<th>Date: 2016-07-20</th>
<th>Test No.: 490026-4-1</th>
<th>VIN No.: KNADH4A31A6679041</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year: 2010</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></td>
<td>Bowing: B1</td>
</tr>
<tr>
<td></td>
<td>X1</td>
</tr>
<tr>
<td></td>
<td>X2</td>
</tr>
</tbody>
</table>

End shift at frame (CDC)

Bowing constant

\[
\frac{X1 + X2}{2} = ______
\]

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>20</td>
<td>12</td>
<td>30</td>
<td>12</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>-15</td>
</tr>
<tr>
<td>2</td>
<td>Side plane at bumper ht</td>
<td>20</td>
<td>13</td>
<td>52</td>
<td>0</td>
<td>4</td>
<td>4.5</td>
<td>7.5</td>
<td>10.5</td>
<td>13</td>
<td>+50</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 D-3. Occupant Compartment Measurements for Test No. 490026-4-1.

<table>
<thead>
<tr>
<th>Date:</th>
<th>Test No.: 490026-4-1</th>
<th>VIN No.: KNADH4A31A6679041</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year: 2010</td>
<td>Make: Kia</td>
<td>Model: Rio</td>
</tr>
</tbody>
</table>

**OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT**

<table>
<thead>
<tr>
<th></th>
<th>Before (inches)</th>
<th>After (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>67.25</td>
<td>67.00</td>
</tr>
<tr>
<td>A2</td>
<td>67.25</td>
<td>67.25</td>
</tr>
<tr>
<td>A3</td>
<td>67.50</td>
<td>67.50</td>
</tr>
<tr>
<td>B1</td>
<td>40.50</td>
<td>38.75</td>
</tr>
<tr>
<td>B2</td>
<td>36.75</td>
<td>36.25</td>
</tr>
<tr>
<td>B3</td>
<td>40.50</td>
<td>40.00</td>
</tr>
<tr>
<td>B4</td>
<td>36.00</td>
<td>36.00</td>
</tr>
<tr>
<td>B5</td>
<td>36.00</td>
<td>36.00</td>
</tr>
<tr>
<td>B6</td>
<td>36.00</td>
<td>36.00</td>
</tr>
<tr>
<td>C1</td>
<td>26.50</td>
<td>22.50</td>
</tr>
<tr>
<td>C3</td>
<td>26.50</td>
<td>26.50</td>
</tr>
<tr>
<td>D1</td>
<td>9.50</td>
<td>8.00</td>
</tr>
<tr>
<td>D3</td>
<td>9.50</td>
<td>9.50</td>
</tr>
<tr>
<td>E1</td>
<td>51.50</td>
<td>52.75</td>
</tr>
<tr>
<td>E2</td>
<td>51.12</td>
<td>51.75</td>
</tr>
<tr>
<td>F</td>
<td>51.00</td>
<td>51.00</td>
</tr>
<tr>
<td>G</td>
<td>51.00</td>
<td>51.00</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>49.50</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. 490026-4-1 (Overhead and Frontal Views).
Figure D-1. Sequential Photographs for Test No. 490026-4-1 (Overhead and Frontal Views) (Continued).
Figure D-2. Sequential Photographs for Test No. 490026-4-1 (Rear View).
Figure D-3. Vehicle Angular Displacements for Test No. 490026-4-1.
**Figure D-4. Vehicle Longitudinal Accelerometer Trace for Test No. 490026-4-1**

(Accelerometer Located at Center of Gravity).
Figure D-5. Vehicle Lateral Accelerometer Trace for Test No. 490026-4-1 (Accelerometer Located at Center of Gravity).
Z Acceleration at CG

Figure D-6. Vehicle Vertical Accelerometer Trace for Test No. 490026-4-1 (Accelerometer Located at Center of Gravity).
Figure D-7. Vehicle Longitudinal Accelerometer Trace for Test No. 490026-4-1 (Accelerometer Located Rear of Center of Gravity).
Y Acceleration Rear of CG

Test Number: 490026-4-1
Test Standard Test Number: MASH Test 4-10
Test Article: TxDOT 42-inch Picket Rail
Test Vehicle: 2010 Kia Rio
Inertial Mass: 2433 lb
Gross Mass: 2598 lb
Impact Speed: 63.0 mi/h
Impact Angle: 25.7 degrees

Figure D-8. Vehicle Lateral Accelerometer Trace for Test No. 490026-4-1
(Accelerometer Located Rear of Center of Gravity).
Figure D-9. Vehicle Vertical Accelerometer Trace for Test No. 490026-4-1
(Accelerometer Located Rear of Center of Gravity).
APPENDIX E.  MASH TEST 4-11 (CRASH TEST NO. 490026-4-2)

E1 VEHICLE PROPERTIES AND INFORMATION

Table E-1. Vehicle Properties for Test No. 490026-4-2.

<table>
<thead>
<tr>
<th>Date: 2016-07-13</th>
<th>Test No.: 490026-4-2</th>
<th>VIN No.: 1D7RB16P1B5550752</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year: 2011</td>
<td>Make: Dodge</td>
<td>Model: RAM 1500</td>
</tr>
<tr>
<td>Tire Size: 265/70R17</td>
<td>Tire Inflation Pressure: 35 psi</td>
<td></td>
</tr>
<tr>
<td>Tread Type: Highway</td>
<td>Odometer: 120216</td>
<td></td>
</tr>
</tbody>
</table>

Note any damage to the vehicle prior to test: None

Denotes accelerometer location.

NOTES: None

Engine Type: V-8
Engine CID: 4.7 liter

Transmission Type: x Auto or ___ Manual
___ FWD  x RWD  ___ 4WD

Optional Equipment: None

Dummy Data:
Type: 50th percentile male
Mass: 165 lb
Seat Position: Driver seat

Geometry: inches

<table>
<thead>
<tr>
<th>A</th>
<th>78.50</th>
<th>F</th>
<th>41.50</th>
<th>K</th>
<th>20.00</th>
<th>P</th>
<th>3.00</th>
<th>U</th>
<th>26.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>75.00</td>
<td>G</td>
<td>28.30</td>
<td>L</td>
<td>29.25</td>
<td>Q</td>
<td>30.50</td>
<td>V</td>
<td>29.50</td>
</tr>
<tr>
<td>C</td>
<td>231.00</td>
<td>H</td>
<td>62.20</td>
<td>M</td>
<td>68.50</td>
<td>R</td>
<td>18.00</td>
<td>W</td>
<td>62.20</td>
</tr>
<tr>
<td>D</td>
<td>49.50</td>
<td>I</td>
<td>11.75</td>
<td>N</td>
<td>68.00</td>
<td>S</td>
<td>13.00</td>
<td>X</td>
<td>78.45</td>
</tr>
<tr>
<td>E</td>
<td>140.50</td>
<td>J</td>
<td>26.00</td>
<td>O</td>
<td>45.50</td>
<td>T</td>
<td>77.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Wheel Center Height Front: 14.75
Wheel Well Clearance (Front): 6.00
Bottom Frame Height - Front: 17.50

Wheel Center Height Rear: 14.75
Wheel Well Clearance (Rear): 9.25
Bottom Frame Height - Rear: 25.50

GVWR Ratings:
Front: 3700  Mfront: 2874  Test Inertial: 2813  Gross Static: 2898
Back: 3900  Mrear: 2037  2235  2315
Total: 6700  MTotal: 4911  5048  5213

Allowable Range for TIM and GSM = 5000 lb ±110 lb

Mass Distribution:
1415
1398
1118
1117

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)
Table E-2. Measurements of Vehicle Vertical CG for Test No. 490026-4-2.

<table>
<thead>
<tr>
<th>Date: 2016-07-13</th>
<th>Test No.: 490026-4-2</th>
<th>VIN: 1D7RB16P1B5550752</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year: 2011</td>
<td>Make: Dodge</td>
<td>Model: RAM 1500</td>
</tr>
<tr>
<td>Body Style: Quad Cab</td>
<td>Mileage: 120216</td>
<td></td>
</tr>
<tr>
<td>Engine: 4.7 liter V-8</td>
<td>Transmission: Automatic</td>
<td></td>
</tr>
<tr>
<td>Fuel Level: Empty</td>
<td>Ballast: 212 lb</td>
<td>(440 lb max)</td>
</tr>
<tr>
<td>Tire Pressure: Front: 35 psi</td>
<td>Rear: 35 psi</td>
<td>Size: 265/70R17</td>
</tr>
</tbody>
</table>

**Measured Vehicle Weights:** (lb)

| LF: 1415 | RF: 1398 | Front Axle: 2813 |
| LR: 1118 | RR: 1117 | Rear Axle: 2235  |
| Left: 2533 | Right: 2515 | Total: 5048 |

Wheel Base: 140.5 inches | Track: F: 68.5 inches | R: 68 inches
148 ±12 inches allowed | Track = (F+R)/2 = 67 ±1.5 inches allowed

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

| X: 62.21 inches | Rear of Front Axle: 63 ±4 inches allowed |
| Y: -0.12 inches | Left - Right + of Vehicle Centerline |
| Z: 28.3 inches | Above Ground: 28.0 inches allowed (minimum) |

Hood Height: 45.50 inches | Front Bumper Height: 26.00 inches
43 ±4 inches allowed

Front Overhang: 41.50 inches | Rear Bumper Height: 29.25 inches
39 ±3 inches allowed

Overall Length: 231.00 inches
237 ±13 inches allowed
Table E-3. Exterior Crush Measurements for Test No. 490026-4-2.

Date: 2016-07-13      Test No.: 490026-4-2      VIN No.: 1D7RB16P1B5550752
Year: 2011           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>Bowing constant</td>
</tr>
</tbody>
</table>
| End shift at frame (CDC) | \[
| (check one) | \[
| < 4 inches ____ | \[
| \geq 4 inches ____ | \[

**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</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>( \pm D )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Front plane at bumper ht</td>
<td>20</td>
<td>11</td>
<td>25</td>
<td>11</td>
<td>7</td>
<td>3</td>
<td>2.5</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Side plane at bumper ht</td>
<td>20</td>
<td>13</td>
<td>70</td>
<td>1</td>
<td>2</td>
<td>6.25</td>
<td>8</td>
<td>10</td>
<td>13</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 E-4. Occupant Compartment Measurements for Test No. 490026-4-2.

Date: 2016-07-13  Test No.: 490026-4-2  VIN No.: 1D7RB16P1B5550752  Year: 2011  Make: Dodge  Model: RAM 1500

**OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT**

<table>
<thead>
<tr>
<th></th>
<th>Before (inches)</th>
<th>After (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>65.25</td>
<td>63.00</td>
</tr>
<tr>
<td>A2</td>
<td>63.25</td>
<td>63.25</td>
</tr>
<tr>
<td>A3</td>
<td>65.25</td>
<td>65.25</td>
</tr>
<tr>
<td>B1</td>
<td>44.75</td>
<td>44.75</td>
</tr>
<tr>
<td>B2</td>
<td>38.00</td>
<td>38.00</td>
</tr>
<tr>
<td>B3</td>
<td>44.75</td>
<td>44.75</td>
</tr>
<tr>
<td>B4</td>
<td>39.50</td>
<td>39.50</td>
</tr>
<tr>
<td>B5</td>
<td>43.00</td>
<td>43.00</td>
</tr>
<tr>
<td>B6</td>
<td>39.50</td>
<td>39.50</td>
</tr>
<tr>
<td>C1</td>
<td>28.00</td>
<td>27.00</td>
</tr>
<tr>
<td>C2</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>C3</td>
<td>25.25</td>
<td>25.25</td>
</tr>
<tr>
<td>D1</td>
<td>11.25</td>
<td>11.25</td>
</tr>
<tr>
<td>D2</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>D3</td>
<td>11.25</td>
<td>11.25</td>
</tr>
<tr>
<td>E1</td>
<td>58.75</td>
<td>61.75</td>
</tr>
<tr>
<td>E2</td>
<td>63.50</td>
<td>65.50</td>
</tr>
<tr>
<td>E3</td>
<td>63.50</td>
<td>63.50</td>
</tr>
<tr>
<td>E4</td>
<td>63.25</td>
<td>63.25</td>
</tr>
<tr>
<td>F</td>
<td>59.00</td>
<td>59.00</td>
</tr>
<tr>
<td>G</td>
<td>59.00</td>
<td>59.00</td>
</tr>
<tr>
<td>H</td>
<td>37.00</td>
<td>37.00</td>
</tr>
<tr>
<td>I</td>
<td>37.00</td>
<td>37.00</td>
</tr>
<tr>
<td>J*</td>
<td>23.50</td>
<td>21.50</td>
</tr>
</tbody>
</table>

*Lateral area across the cab from driver’s side kickpanel to passenger’s side kickpanel.*
Figure E-1. Sequential Photographs for Test No. 490026-4-2 (Overhead and Frontal Views).
Figure E-1. Sequential Photographs for Test No. 490026-4-2 (Overhead and Frontal Views) (Continued).
Figure E-2. Sequential Photographs for Test No. 490026-4-2 (Rear View).
**Figure E-3. Vehicle Angular Displacements for Test No. 490026-4-2.**
X Acceleration at CG

Test Number: 490026-4-2
Test Standard Test Number: MASH Test 4-11
Test Article: TxDOT 42 - inch Picket Rail
Test Vehicle: 2011 Dodge RAM 1500
Inertial Mass: 5048 lb
Gross Mass: 5213 lb
Impact Speed: 62.9 mi/h
Impact Angle: 24.5 degrees

Figure E-4. Vehicle Longitudinal Accelerometer Trace for Test No. 490026-4-2
(Accelerometer Located at Center of Gravity).
**Y Acceleration at CG**

Test Number: 490026-4-2  
Test Standard Test Number: MASH Test 4-11  
Test Article: TxDOT 42 - inch Picket Rail  
Test Vehicle: 2011 Dodge RAM 1500  
Inertial Mass: 5048 lb  
Gross Mass: 5213 lb  
Impact Speed: 62.9 mi/h  
Impact Angle: 24.5 degrees  

**Figure E-5. Vehicle Lateral Accelerometer Trace for Test No. 490026-4-2**  
(Accelerometer Located at Center of Gravity).
Figure E-6. Vehicle Vertical Accelerometer Trace for Test No. 490026-4-2
(Accelerometer Located at Center of Gravity).
Figure E-7. Vehicle Longitudinal Accelerometer Trace for Test No. 490026-4-2
(Accelerometer Located Rear of Center of Gravity).
Figure E-8. Vehicle Lateral Accelerometer Trace for Test No. 490026-4-2 (Accelerometer Located Rear of Center of Gravity).
Figure E-9. Vehicle Vertical Accelerometer Trace for Test No. 490026-4-2
(Accelerometer Located Rear of Center of Gravity).
APPENDIX F.  MASH TEST 4-12 (CRASH TEST NO. 490026-4-3)

F1  VEHICLE PROPERTIES AND INFORMATION

Table F-1. Vehicle Properties for Test No. 490026-4-3.

Date: 2016-06-27  Test No.: 490026-4-3  VIN No.: 1HTMPAFN24H662565
Year: 2004  Make: International  Model: 4200
Odometer: 103161  Tire Size Front: 275/80R22.5  Tire Size Rear: 275/80R22.5

Vehicle Geometry: inches

A  Front Bumper Width: 92.00
B  Overall Height: 133.50
C  Overall Length: 330.25
D  Rear Overhang: 89.50
E  Wheel Base: 204.75
F  Front Overhang: 36.00
G  C.G. Height: 
H  C.G. Horizontal Dist. w/Ballast: 132.87
I  Front Bumper Bottom: 19.25
J  Front Bumper Top: 34.00
K  Rear Bumper Bottom: 
L  Rear Frame Top: 37.50
M  Front Track Width: 80.00
N  Roof Width: 71.00
O  Hood Height: 59.50
P  Bumper Extension: 1.00
Q  Front Tire Width: 39.00
R  Front Wheel Width: 23.00
S  Bottom Door Height: 37.25
T  Overall Width: 96.00
U  Cab Length: 106.00
V  Trailer/Box Length: 226.00
W  Gap Width: 2.25
X  Overall Front Height: 98.50
Y  Roof-Hood Distance: 30.00
Z  Roof-Box Height Difference: 41.00
AA  Rear Track Width: 73.00
BB  Ballast Center of Mass: 61.50
CC  Cargo Bed Height: 50.00

More information needed on next page
Table F-1. Vehicle Properties for Test No. 490026-4-3 (Continued).

<table>
<thead>
<tr>
<th>Date:</th>
<th>2016-06-27</th>
<th>Test No.:</th>
<th>490026-4-3</th>
<th>VIN No.:</th>
<th>1HTMPAFN24H662565</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year:</td>
<td>2004</td>
<td>Make:</td>
<td>International</td>
<td>Model:</td>
<td>4200</td>
</tr>
</tbody>
</table>

**WEIGHTS**

<table>
<thead>
<tr>
<th>(lb or kg)</th>
<th>CURB</th>
<th>TEST INERTIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>( W_{\text{front axle}} )</td>
<td>6110</td>
<td>7800</td>
</tr>
<tr>
<td>( W_{\text{rear axle}} )</td>
<td>6250</td>
<td>14420</td>
</tr>
<tr>
<td>( W_{\text{TOTAL}} )</td>
<td>12360</td>
<td>22220</td>
</tr>
</tbody>
</table>

*Allowable Range for CURB = 13,200 ±2200 lb | Allowable Range for TIM = 22,046 ±660 lb*

Ballast: 10287 (lb) (as-needed)

(See MASH Section 4.2.1.2 for recommended ballasting)

**Mass Distribution**

<table>
<thead>
<tr>
<th>(lb or kg)</th>
<th>LF: 4030</th>
<th>RF: 3770</th>
<th>LR: 7350</th>
<th>RR: 7070</th>
</tr>
</thead>
</table>

Engine Type: VT

Engine Size: 365

Transmission Type:

\[ x \] Auto or \[ ___ \] Manual

\[ ___ \] FWD \[ x \] RWD \[ ___ \] 4WD

Accelerometer Locations (inches)

\( x^2 \quad y \quad z^2 \)

Front: \[ 132.80 \quad 0 \quad 49.00 \]

Over 5th Wheel: \[ 239.00 \quad 0 \quad 49.00 \]

Describe any damage to the vehicle prior to test:

None

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

- 4612 lb block; H=30 inches, W=60 inches; L=30 inches
- 5270 lb block; H=60 inches; W=60 inches; L=30 inches
- Centered in middle of bed
- 61.5 inches to center of block to ground
- Four 5/16-inch cable per block

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2 Referenced to the front axle
3 Above ground

TR No. 9-1002-15-2 128 2022-06-29
Figure F-1. Sequential Photographs for Test No. 490026-4-3 (Overhead and Frontal Views).
Figure F-1. Sequential Photographs for Test No. 490026-4-3 (Overhead and Frontal Views) (Continued).
Figure F-2. Sequential Photographs for Test No. 490026-4-3 (Rear View).
Figure F-3. Vehicle Angular Displacements for Test No. 490026-4-3.

Axes are vehicle-fixed.
Sequence for determining orientation:
1. Yaw.
2. Pitch.
3. Roll.
Figure F-4. Vehicle Longitudinal Accelerometer Trace for Test No. 490026-4-3
(Accelerometer Located at Horizontal Center of Gravity).
Figure F-5. Vehicle Lateral Accelerometer Trace for Test No. 490026-4-3
(Accelerometer Located at Horizontal Center of Gravity).
Figure F-6. Vehicle Vertical Accelerometer Trace for Test No. 490026-4-3 (Accelerometer Located at Horizontal Center of Gravity).
Figure F-7. Vehicle Longitudinal Accelerometer Trace for Test No. 490026-4-3 (Accelerometer Located Rear of Horizontal Center of Gravity).
Figure F-8. Vehicle Lateral Accelerometer Trace for Test No. 490026-4-3
(Accelerometer Located Rear of Horizontal Center of Gravity).
Figure F-9. Vehicle Vertical Accelerometer Trace for Test No. 490026-4-3
(Accelerometer Located Rear of Horizontal Center of Gravity).