

MASH TEST 3-21 ON TL-3 THRIE BEAM TRANSITION WITHOUT CURB



Test Report 9-1002-12-3

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE COLLEGE STATION, TEXAS

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16. Abstract

This project evaluated the impact performance of a modified TxDOT thrie beam transition to rigid concrete barrier without a curb element below the transition rail. In a previous test described in TxDOT Research Report 0-4564, a thrie beam transition without curb failed to meet *NCHRP Report 350* performance criteria. However, it could not be discerned whether the vehicle instability observed in that test was attributable to the missing curb or the rotation of the thrie beam transition rail into the sloped face of the concrete safety shape rail at the bridge end connection point.

A transition design without curb would reduce the complexity of the field installations and would provide an option for dealing with different drainage requirements at bridge ends. A fabricated steel blockout was incorporated into the transition system to keep the three beam rail and terminal connector in a vertical plane at its connection to the concrete bridge rail.

The modified three beam transition without curb failed to meet *MASH* TL-3 requirements due to rollover of the impacting vehicle. Further discussions as to the possible cause of the failure are described within the report.

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DISCLAIMER

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

TTI PROVING GROUND DISCLAIMER

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



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CHAPTER 1. INTRODUCTION

1.1 INTRODUCTION

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

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

1.2 BACKGROUND

Current roadside safety barriers can be generalized into a two categories. The first category includes rigid barriers such as permanent concrete median barriers. The second category includes flexible barriers such as metal beam guard fence. These barriers are highly effective in redirecting errant vehicles; however, they have significantly different deflection characteristics. Approach guardrail is often attached to a bridge rail to shield motorists from hazards at the bridge end and those underlying the bridge. A transition system is needed to transition the stiffness between the two systems to avoid impact performance issues such as pocketing and snagging on the rigid end of the bridge parapet.

In May 1998, Midwest Roadside Safety Facility (MwRSF) released a report detailing the design and testing of "Two Approach Guardrail Transitions for Concrete Safety Shape Barriers." This research was funded by the Midwest State's Regional Pooled Fund Program. The report details the design and testing of both steel and wood post options for transitioning W-beam guardrail to a concrete safety shape barrier. Two key features of these nested thrie beam transition designs include a curb under the transition rail near the concrete parapet end and a steel offset block that allows the thrie beam to be vertically connected to the sloped face of the concrete parapet without having to twist the thrie beam section. Both designs met National Cooperative Highway Research Program (NCHRP) *Report 350 (1)* evaluation criteria for Test Level 3 (TL-3).

In October 2003, TxDOT requested that Texas A&M Transportation Institute (TTI) evaluate a modified TL-3 nested thrie beam transition. The first modification was to eliminate the curb from under the transition rail. Second, the fabricated steel offset block under the terminal connector was removed. Instead, the nested thrie beam and terminal connector was twisted to match and connect directly to the sloped face of the concrete safety shape parapet.

TxDOT requested these modifications to reduce fabrication and installation complexity and cost. The modified transition system failed to meet *NCHRP Report 350* TL-3 performance criteria. The impacting vehicle overturned as it exited the transition system. It could not be conclusively determined which modification contributed more to the vehicle instability.

The American Association of State Highway and Transportation Officials (AASHTO) published the *Manual for Assessing Safety Hardware (MASH)* in October 2009 (2). *MASH* supersedes *NCHRP Report 350* as the recommended guidance for the safety performance evaluation of roadside safety features. In October 2006, MwRSF published Research Report TRP-03-175-06. This report documents a successful *MASH* TL-3 crash test (Test Designation 3-21) on the original nested thrie beam transition design. This test was performed as part of NCHRP Project 22-14 (2).

Subsequently, TxDOT requested that a *MASH* test be performed to evaluate the impact performance of a modified TxDOT thrie beam transition to rigid concrete barrier without a curb element below the transition rail. A transition design without curb would reduce the complexity of the field installations and would provide an option for dealing with different drainage requirements at bridge ends. The difference between the previous failed transition test and the proposed design is that a fabricated steel blockout was incorporated into the transition system to keep the thrie beam rail and terminal connector in a vertical plane at its connection to the concrete bridge rail.

1.3 OBJECTIVES/SCOPE OF RESEARCH

This project evaluated the impact performance of a modified transition design for approach W-beam guardrail to a rigid concrete bridge rail without a curb element beneath the transition rail. The test was performed in accordance with *MASH* guidelines following the impact conditions for Test Designation 3-21.

CHAPTER 2. SYSTEM DETAILS

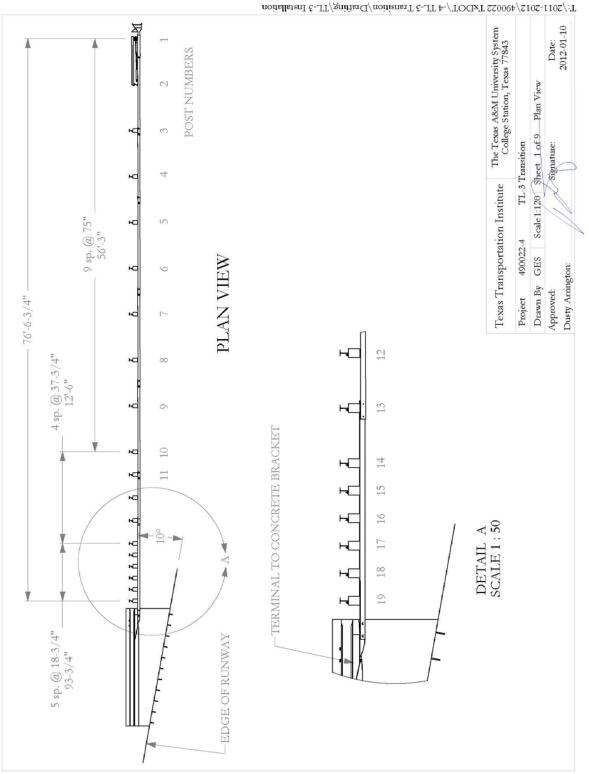
2.1 TEST ARTICLE DESIGN AND CONSTRUCTION

A total installation length of 92 ft-6³/₄ inch was installed to fully evaluate the bridge rail to metal beam guard fence transition according to *MASH* TL-3 impact conditions. A 16-ft single slope concrete bridge rail served as a surrogate bride rail parapet end condition. The remaining 76 ft-6³/₄ inches was constructed of metal beam guard fence. This length includes a TL-3 approved terminal and the TL-3 transition itself. A generic overall diagram of the test installation can be found in Figures 2.1 and 2.2. A full set of shop/fabrication drawings can be found in Appendix A.

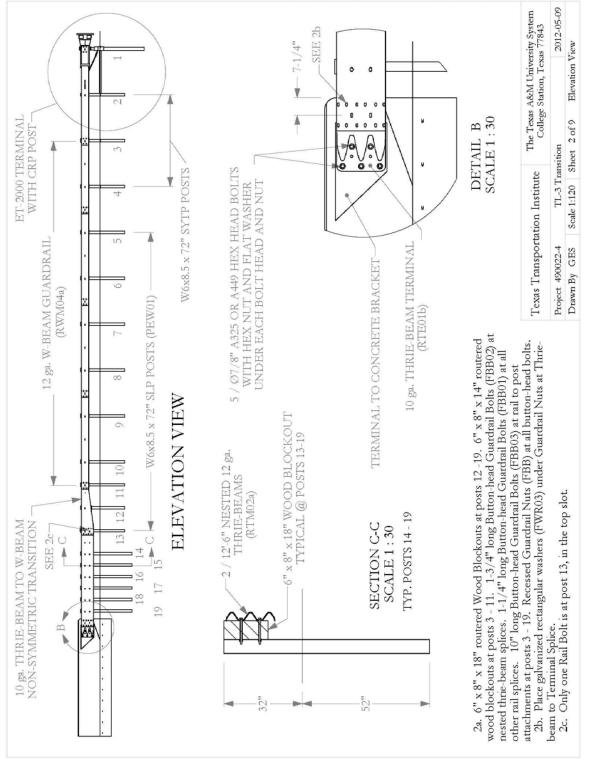
The surrogate bridge rail parapet was constructed according to TxDOT 36-inch single slope traffic rail (SSTR) bridge rail standards found on the TxDOT standards website (http://www.dot.state.tx.us). As the standard suggests, the barrier is a 36-inch tall wall with a 79 degree constant slope traffic face. The barrier is $7\frac{1}{2}$ inches wide at the top of the barrier and $14\frac{1}{2}$ inches wide at the bottom of the barrier at the end of the parapet. The barrier is cast atop an 18-inch thick moment slab designed to withstand a *MASH* TL-4 impact. The concrete used in constructing the parapet and moment slab met/exceeded TxDOT Class C (3600 psi) specifications. The barrier toe was chamfered at the end of the parapet. The chamfer was $13\frac{3}{8}$ inches tall and 36 inches long. A total of five 1-inch holes were cast into the parapet to allow for the attachment of the 10 gauge thrie-beam terminal end shoe (RTE01b) and a custom $\frac{1}{4}$ -inch thick adapter plate using five $\frac{7}{8}$ -inch A325 bolts.

The reinforcement in the parapet included the following according to TxDOT SSTR barrier standards. "S-bars" and "U-bars" are placed every 5 inches along the length of the parapet. A total of eight #4 bars (½-inch) were equally spaced along the face of the parapet. The 18-inch deck was reinforced with two distinct rebar mats each containing #5 bars spaced every 6 inches perpendicular to the parapet and #4 bars spaced every 9 inches parallel to the parapet. The first mat maintained a 3-inch cover from the bottom of the moment slab. The second mat maintained a 2-inch cover from the top of the moment slab.

The metal beam guard fence was constructed using a total of 19 posts that were numbered from 1 to 19 starting with the ET-2000 Terminal control release post (CRP) anchor post. Posts 1 and 2 were installed as part of the standard 31-inch ET-2000 Terminal. Posts 3 through 11 are installed as part of a standard 12 gauge W-Beam Guardrail (RWM04a). Each post in this section is a 72-inch long W6×8.5 SLP (PEW01) attached to the 12 gauge rail element using an 8-inch wood blockout. The posts in this section were placed at the mid-span of the guardrail (not at a splice). Between posts 11 and 13, a 10 gauge thrie beam to W-beam nonsymmetric transition segment is used and is supported by a 72-inch long W6×8.5 SLP. Between Post 13 and the end of the bridge parapet, a nested 12 gauge thrie beam (RTM02a) configuration is used and is supported by 84-inch long W6×8.5 posts with 6×8×18-inch wood blockouts. A 10 gauge thrie-beam end shoe (RTE01b) was used to connect the nested thrie beam to the $\frac{1}{4}$ -inch thick adapter plate.







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Figure 2.3. TxDOT TL-3 Transition Installation before Test No. 490022-4.

The adapter plate is constructed using $\frac{1}{4}$ -inch steel plate. The adapter is 21 inches tall and 40 inches wide. The adapter plate allows for a 4-inch blockout at the top of the plate and tapers down to a 0-inch blockout distance. Quarter-inch thick stiffener plates are then welded to the back of the plate to stiffen the plate.

2.2 MATERIAL SPECIFICATIONS

As discussed in section 2.1, the concrete used to construct the concrete parapet meets/exceeds TxDOT Class C (3600 psi) specifications. All steel plates and structural members meet A36 material specifications. All standard American Road and Transportation Builders Association (ARTBA) parts meet/exceed material specifications associated with their assigned classification numbers.

2.3 SOIL CONDITIONS

The TxDOT TL-3 Transition was installed in standard soil meeting AASHTO standard specifications for "Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses," designated M147-65(2004), grading B.

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test (see Appendix C, Table C1). During installation of the TxDOT TL-3 Transition for full-scale crash testing, two standard W6×16 posts were installed in the immediate vicinity of the TxDOT TL-3 Transition, utilizing the same fill materials and installation procedures used in the standard dynamic test (see Appendix C, Table C2).

As determined in the tests shown in Appendix C, Table C2, the minimum post load required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, is 3940 lb, 5500 lb, and 6540 lb, respectively (90 percent of static load for the initial standard installation). On the day of the test, April 14, 2009, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 8121 lbf, 7303 lbf, and 6909 lbf, respectively. The strength of the backfill material met minimum requirements.

CHAPTER 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 CRASH TEST MATRIX

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

MASH Test Designation 3-20: A 2425-lb vehicle impacting the critical impact point (CIP) of the length of need (LON) of the barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. This test investigates a barrier's ability to successfully contain and redirect a small passenger vehicle.

MASH Test Designation 3-21: A 5000-lb pickup truck impacting the CIP of the LON of the barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. This test investigates a barrier's ability to successfully contain and redirect light trucks and sport utility vehicles.

Based on the geometry and strength of the transition design, the project team concluded that Test 3-20 was not warranted. The test reported here corresponds to Test 3-21 of *MASH* (5000-lb pickup, 62 mi/h, 25 degrees).

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

3.2 EVALUATION CRITERIA

The crash test was evaluated in accordance with the criteria presented in *MASH*. The performance of the TxDOT TL-3 Transition is judged on the basis of three factors: structural adequacy, occupant risk, and post impact vehicle trajectory. Structural adequacy is judged upon the ability of the TxDOT TL-3 Transition to contain and redirect the vehicle, or bring the vehicle to a controlled stop in a predictable manner. Occupant risk criteria evaluate the potential risk of hazard to occupants in the impacting vehicle, and to some extent, other traffic, pedestrians, or workers in construction zones, if applicable. Post-impact vehicle trajectory is assessed to determine potential for secondary impact with other vehicles or fixed objects, creating further risk of injury to occupants of the impacting vehicle and/or risk of injury to occupants in other vehicles. The appropriate safety evaluation criteria from Table 5-1 of *MASH* were used to evaluate the crash test reported here and are listed in further detail under the assessment of the crash test.

CHAPTER 4. CRASH TEST PROCEDURES

4.1 TEST FACILITY

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

The Texas A&M Transportation Institute Proving Ground is a 2000-acre complex of research and training facilities located 10 miles northwest of the main campus of Texas A&M University. The site, formerly an Air Force base, has large expanses of concrete runways and parking aprons well-suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for construction and testing of the T131RC Bridge Rail evaluated under this project was along the edge of an out-of-service apron. The apron consists of an unreinforced jointed-concrete pavement in 12.5 ft \times 15 ft blocks nominally 6 inches deep. The apron is over 60 years old, and the joints have some displacement, but are otherwise flat and level.

4.2 VEHICLE TOW AND GUIDANCE PROCEDURES

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

4.3 DATA ACQUISITION SYSTEMS

4.3.1 Vehicle Instrumentation and Data Processing

The 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 that measure the x, y, and z axis of vehicle acceleration are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors measuring vehicle roll, pitch, and yaw rates are ultra-small size, solid state units 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 the 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 are 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.

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, the program computes the maximum average accelerations over 50-ms intervals in each of the three directions. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals and then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact.

4.3.2 Anthropomorphic Dummy Instrumentation

According to *MASH*, the use of a dummy in the 2270P vehicle is optional. Researchers did not use any dummy in the test with the 2270P vehicle.

4.3.3 Photographic Instrumentation and Data Processing

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

CHAPTER 5. CRASH TEST RESULTS

5.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-21 involves a 2270P vehicle weighing 5000 lb ±100 lb and impacting the bridge rail transition at an impact speed of 62.2 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target impact point of 93 inches upstream of concrete parapet was determined through Barrier VII simulations and the tables found within *MASH* for determining CIP. The 2006 Dodge Ram 1500 pickup truck used in the test weighed 5002 lb and the actual impact speed and angle were 62.6 mi/h and 23.9 degrees, respectively. The actual impact point was 89.0 inches upstream of the concrete parapet. Target impact severity (IS) was calculated at 115.1 kip*ft, and actual IS was calculated at 107.6 kip*ft, which was 6.5 percent less than target IS (acceptable limit for IS is not less than 8 percent of target IS).

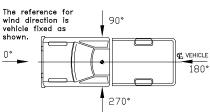
5.2 TEST VEHICLE

A 2006 Dodge Ram 1500 pickup truck, shown in Figure 5.1, was used for the crash test. Test inertia weight of the vehicle was 5002 lb, and its gross static weight was 5002 lb. The height to the lower edge of the vehicle bumper was 13.7 inches, and it was 25.38 inches to the upper edge of the bumper. Tables D1 and D2 in Appendix D give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be unrestrained just prior to impact.

5.3 WEATHER CONDITIONS

The test was performed on the morning of May 14, 2012. Weather conditions at the time of testing were: wind speed: 2 mi/h; wind direction:

206 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 80°F, relative humidity: 58 percent.



5.4 TEST DESCRIPTION

The 2006 Dodge Ram 1500 pickup truck, traveling at an impact speed of 62.6 mi/h, impacted the TxDOT TL-3 Transition 89.0 inches upstream of the concrete parapet at an impact angle of 23.9 degrees. At 0.010 s after impact, the vehicle began to redirect, and at 0.012 s, the thrie-beam guardrail and posts on either side of impact began to deflect toward the field side. The right front tire contacted the concrete parapet at 0.101 s, and the right front tire and wheel rim separated from the vehicle. At 0.168 s, the vehicle was traveling parallel with the transition at a speed of 52.7 mi/h. The rear of the vehicle contacted the transition at 0.176 s. At 0.316 s, the vehicle lost contact with the transition and was traveling at an exit speed and angle of 52.3 mi/h and 16.2 degrees. As the vehicle exited the transition, it rolled onto its right side and came to rest 208.4 ft downstream of impact and 75.0 ft toward traffic lanes. Figures E1 and E2 in Appendix E show sequential photographs of the test period.





Figure 5.1. Vehicle before Test No. 490022-4.

5.5 DAMAGE TO TEST INSTALLATION

Figures 5.2 and 5.3 show damage to the TxDOT TL-3 Transition. The soil was disturbed around post 1 and posts 10 through 12. Post 13 was leaning toward the field side and downstream 0.5 degree (from upright), and there was a gap of 0.25 inch between the edge of the soil and the traffic side of the post. Post 14 was deflected toward the field side 1.12 inches and was leaning 6 degrees toward the field side and 1 degree downstream. Post 15 was deflected toward the field side 1.62 inches and leaning toward field side 6 degrees and downstream 3 degrees. Post 16 was deflected toward the field side 2.0 inches and leaning toward the field side 5 degrees and downstream 7 degrees. Post 17 was deflected toward the field side 1.9 inches and was leaning toward the field side 4 degree and downstream 4 degrees. Post 18 was deflected toward the field side 1.5 inches and leaning toward the field side 5 degrees and downstream 3 degrees. Post 19 was deflected toward the field side 1.4 inches and leaning toward the field side 7 degrees and downstream 6 degrees. Maximum permanent deformation of the thrie beam rail element was 4.5 inches at the top ridge, 3.9 inches at the middle ridge, and 6.5 inches at the bottom ridge. Total length of contact of the vehicle with the thrie beam rail element was 149.0 inches. Working width was 22.8 inches and maximum dynamic deflection of the top of the rail element was 5.9 inches.

5.6 VEHICLE DAMAGE

As shown in Figure 5.4, the 2270P vehicle was damaged in the right front and right side. The right frame rail, right front upper and lower A-arms, right front upper and lower ball joints, and right outer tie rods were deformed. Also damaged were the front bumper, hood, grill, right front fender, right front tire and wheel rim, right front door and door glass, right rear door, right exterior bed, rear bumper, tailgate, and right rear wheel rim. Maximum exterior crush to the vehicle was 170.0 inches in the front plane at the right front corner at bumper height. Maximum occupant compartment deformation was 3.75 inches in the lateral area across the occupant compartment in the kickpanel area near the front passenger's feet. Figure 5.5 shows the occupant compartment before and after the test. Tables D3 and D4 of Appendix D present the exterior and interior crush measurement.

5.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 16.4 ft/s at 0.099 s, the highest 0.010-s occupant ridedown acceleration was 14.4 Gs from 0.114 to 0.124 s, and the maximum 0.050-s average acceleration was -8.9 Gs between 0.075 and 0.125 s. In the lateral direction, the occupant impact velocity was 27.6 ft/s at 0.099 s, the highest 0.010-s occupant ridedown acceleration was 9.0 Gs from 0.103 to 0.113 s, and the maximum 0.050-s average was -13.6 Gs between 0.043 and 0.093 s. Theoretical Head Impact Velocity (THIV) was 34.9 km/h or 9.7 m/s at 0.097 s; Post-Impact Head Decelerations (PHD) was 16.2 Gs between 0.114 and 0.124 s; and Acceleration Severity Index (ASI) was 1.63 between 0.044 and 0.094 s. Figure 5.6 summarizes these data and other pertinent information from the test. Vehicle angular displacements and accelerations versus time traces are presented in Appendix F, Figures F1 through F7.



Figure 5.2. TxDOT TL-3 Transition/Vehicle after Test No. 490022-4.



Figure 5.3. TxDOT TL-3 Transition after Test No. 490022-4.



Figure 5.4. Vehicle after Test No. 490022-4.

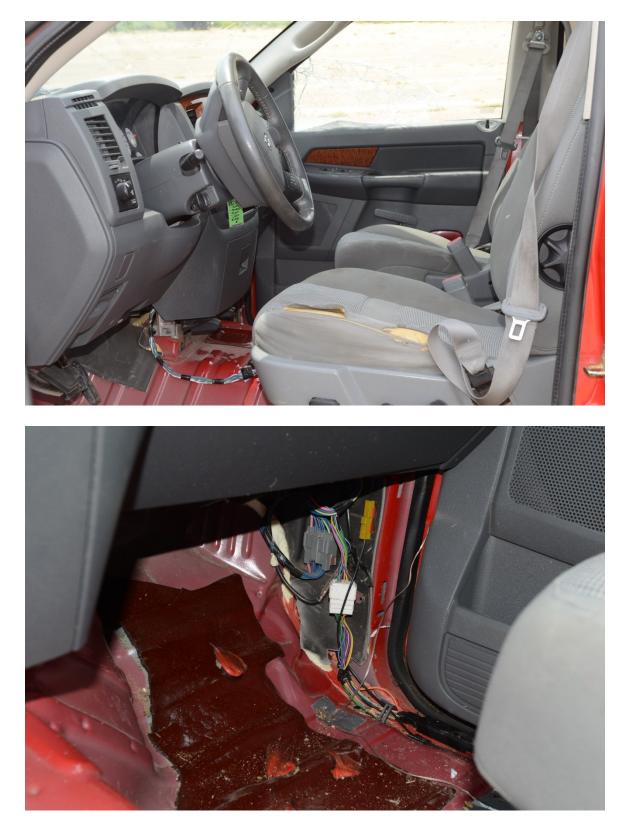


Figure 5.5. Interior of Vehicle after Test No. 490022-4.

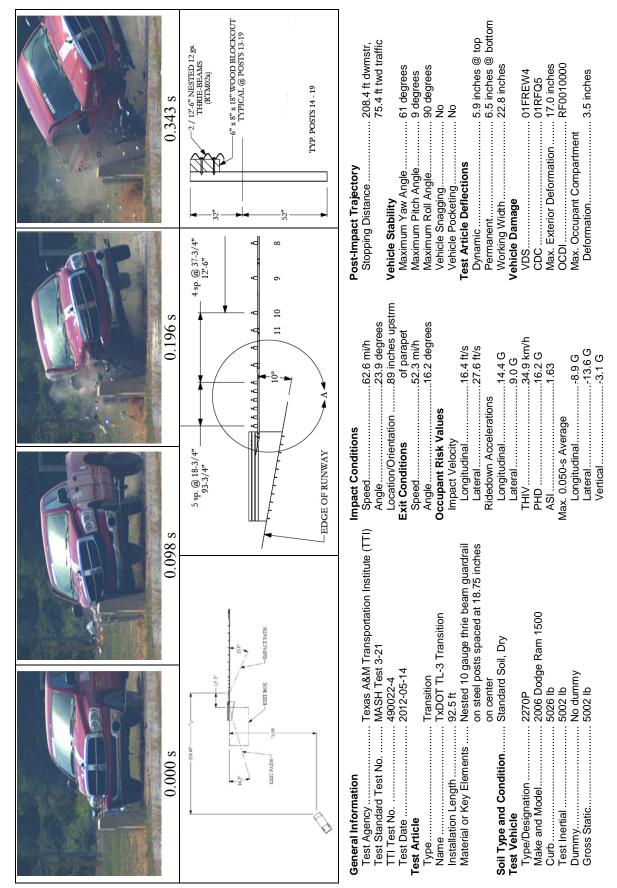


Figure 5.6. Summary of Results for MASH Test 3-21 on the TxDOT TL-3 Transition.

CHAPTER 6. SUMMARY AND CONCLUSIONS

6.1 ASSESSMENT OF TEST RESULTS

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

6.1.1 Structural Adequacy

- *A.* Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.
- <u>Results</u>: The TxDOT TL-3 Transition contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the metal rail element was 7.9 inches. (PASS)

6.1.2 Occupant Risk

D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.

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

- Results: No detached elements, fragments, or other debris was 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 3.75 inches in the lateral area across the occupant compartment in the kickpanel area near the front passenger's feet. (PASS)
- *F.* The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.
- <u>Results</u>: The 2270P vehicle rolled 90 degrees onto its right side after exiting the transition. (FAIL)

Н.	Occupant impact velocities sho	uld satisfy the following:
	Longitudinal and Lateral C	ccupant Impact Velocity
	<u>Preferred</u>	<u>Maximum</u>
	30 ft/s	40 ft/s

<u>Results</u>: Longitudinal occupant impact velocity was 16.4 ft/s, and lateral occupant impact velocity was 27.6 ft/s. (PASS)

Ι.	Occupant ridedown acceleration	ons should satisfy the following:
	Longitudinal and Lateral C	Occupant Ridedown Accelerations
	<u>Preferred</u>	<u>Maximum</u>
	15.0 Gs	20.49 Gs

<u>Results</u>: Longitudinal ridedown acceleration was 14.4 G, and lateral ridedown acceleration was 9.0 G. (PASS)

6.1.3 Vehicle Trajectory

For redirective devices, the vehicle shall exit the barrier within the exit box. Report vehicle rebound distance and velocity for crash cushions.

<u>Result</u>: The 2270P vehicle exited within the exit box. (PASS)

6.2 CONCLUSIONS

The TxDOT TL-3 Transition did not perform acceptably for *MASH* test 3-21 due to vehicle rollover (see Table 6.1). There were indications of wheel snagging on the end of the concrete parapet that may have contributed to destabilization of the vehicle.

6.3 **RECOMMENDATIONS***

The researchers suggest that the following are possible design changes may improve the performance of the system. First, a short curb may be placed at the end of the parapet under the rail to help prevent the wheel snagging. This is consistent with previous design details; however, the researchers feel the length may be reduced to help with the draining problems that prompted this test. Second, the steel blockout at the end of the parapet could be increased in depth to offset the rail to decrease the amount of snagging. Finally, the posts in the nested section of the guardrail could be strengthened by using a larger size post and increasing the embedment depth. This would serve to further stiffen the transition and reduce dynamic deflection. Some previous studies suggest that excessive deflection in the transition region can induce vehicle instability. However, if the system becomes too stiff, the upstream end of the transition section may need to be redesigned and evaluated. Further development, analysis, and full-scale crash testing would be required to evaluate any of these proposed modifications.

^{*} TTI Proving Ground's A2LA scope of accreditation does not cover recommendations. These recommendations were provided by the engineering research team.

Te	Test Agency: Texas A&M Transportation Institute	Test No.: 490022-4 Te	Test Date: 2012-05-14
	MASH Test 3-21 Evaluation Criteria	Test Results	Assessment
$\frac{Str}{A}$.	<u>Structural Adequacy</u> A. Test article should contain and redirect the vehicle or	The TxDOT TL-3 Transition contained and	
	bring the vehicle to a controlled stop; the vehicle	redirected the 2270P vehicle. The vehicle did	
	should not penetrate, underride, or override the	not penetrate, underride, or override the	Pass
	installation although controlled lateral deflection of	installation. Maximum dynamic deflection of	
	the test article is acceptable	the metal rail element was 7.9 inches.	
$\frac{O_{C}}{O}$	Occupant Risk		
Ū.	Detached elements, fragments, or other debris from	No detached elements, fragments, or other debris	
	the test article should not penetrate or show potential	was present to penetrate or show potential for	
	for penetrating the occupant compartment, or present	penetrating the occupant compartment, or to	Pass
	an undue hazard to other traffic, pedestrians, or	present hazard to others in the area.	
	personnel in a work zone.		
	Deformations of or intersions into the occurrent	Maximum occupant compartment deformation	
	Deformations of, or initiations into ine occupanti commatiment chould not everal limits cot fouth	was 3.75 inches in the lateral area across the	Dage
	compariment should not exceed timus set form	occupant compartment in the kickpanel area near	I 435
	in Section 5.5 and Appendix E of MASH.	the front passenger's feet.	
F.	The vehicle should remain upright during and after	The 2270P vehicle rolled 90 degrees onto its	
	collision. The maximum roll and pitch angles are not	right side after exiting the transition.	Fail
	to exceed 75 degrees.		
H.	Longitudinal and lateral occupant impact velocities	Longitudinal occupant impact velocity was	
	should fall below the preferred value of 30 ft/s, or at	16.4 ft/s, and lateral occupant impact velocity	Pass
	least below the maximum allowable value of 40 ft/s.	was 27.6 ft/s.	
Ι.	Longitudinal and lateral occupant ridedown	Longitudinal ridedown acceleration was 14.4 G,	
	accelerations should fall below the preferred value of	and lateral ridedown acceleration was 9.0 G.	Dage
	15.0 Gs, or at least below the maximum allowable		F 435
	value of 20.49 Gs.		
Ve_{i}	Vehicle Trajectory		
	For redirective devices, the vehicle shall exit the	The 2270P vehicle exited within the exit box.	Pass
	barrier within the exit box (not less than 32.8 ft).		

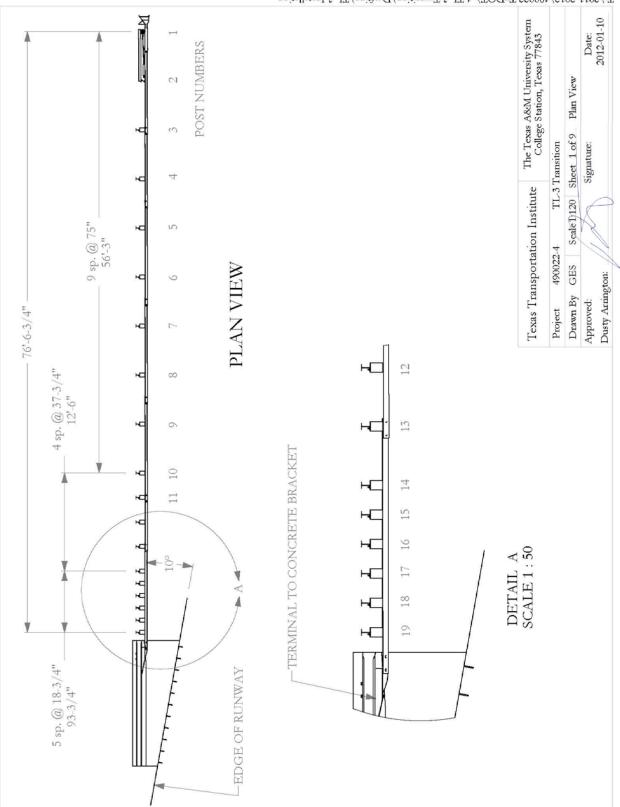
Table 6.1. Performance Evaluation Summary for MASH Test 3-21 on the TxDOT TL-3 Transition.

CHAPTER 7. IMPLEMENTATION STATEMENT

The modified transition system without curb did not meet the impact performance requirements of *MASH*. Consequently, no implementation is recommended at this time. Several possible design modifications are presented to mitigate the vehicle instability observed in the test. One or more if these modifications can be analyzed and evaluated at the discretion of TxDOT.

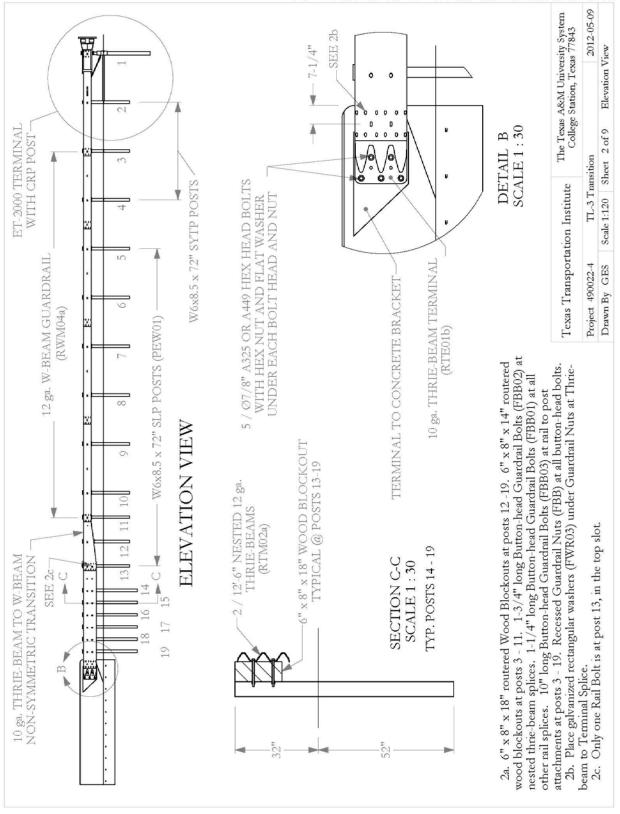
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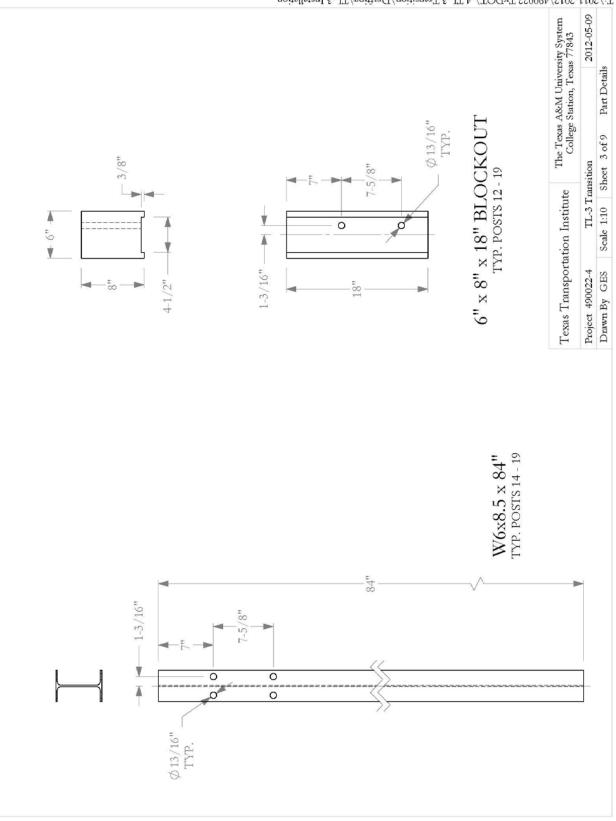
- 1. H. E. Ross, D. L. Sicking, R. A. Zimmer, and J. D. Michie. "Recommended Procedures for the Safety Performance Evaluation." *NCHRP Report 350*. National Academy Press, Washington, D.C., National Cooperative Highway Research Program, 1993.
- 2. AASHTO, *Manual for Assessing Safety Hardware*, American Association of State Highway and Transportation Officials, Washington, D.C., 2009.



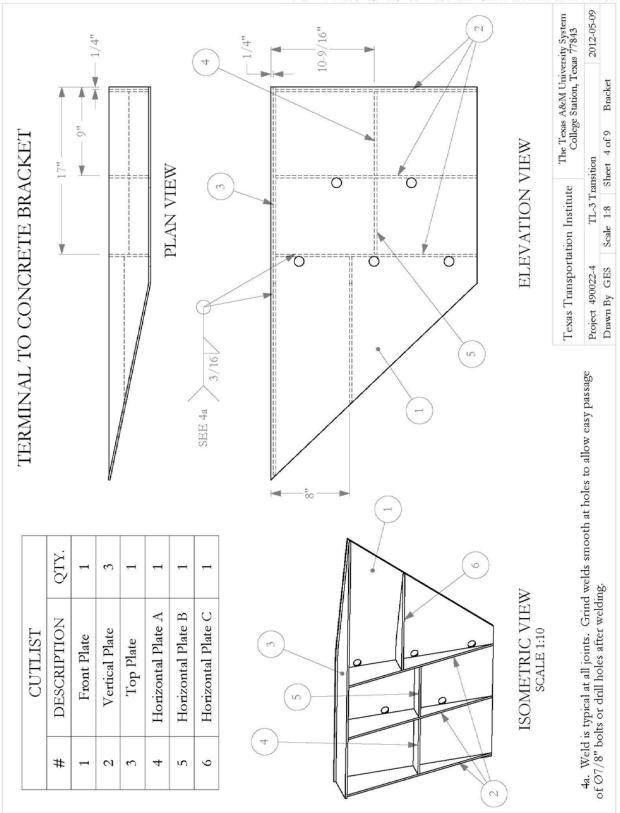
APPENDIX A. DETAILS OF THE TXDOT TL-3 TRANSITION

T:/2012/490022 TxDOT/-4 TL-2 Transition/Drafting/TL-3 Transition



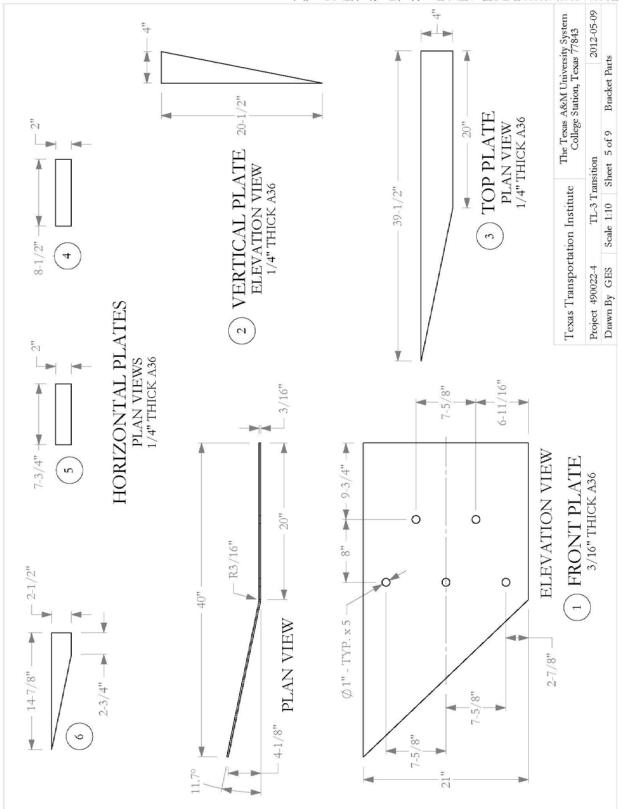


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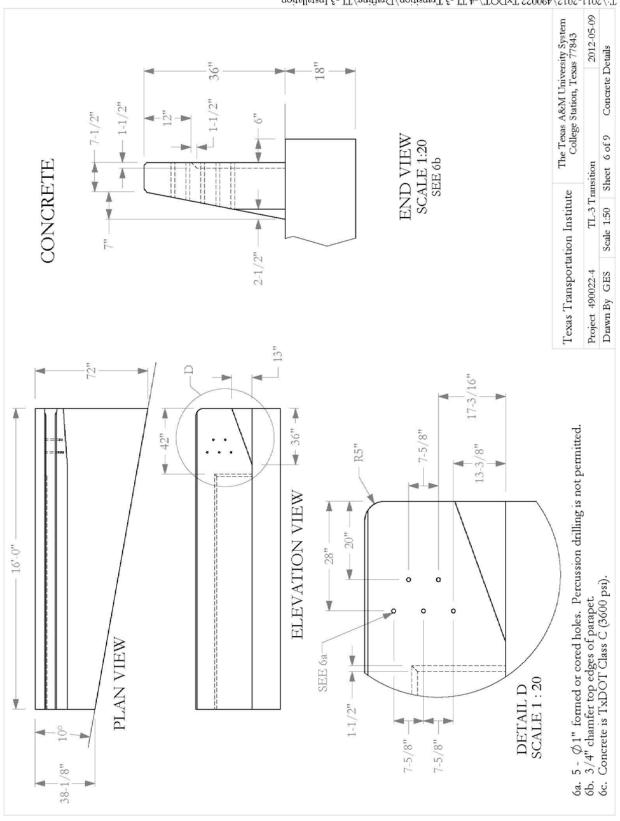




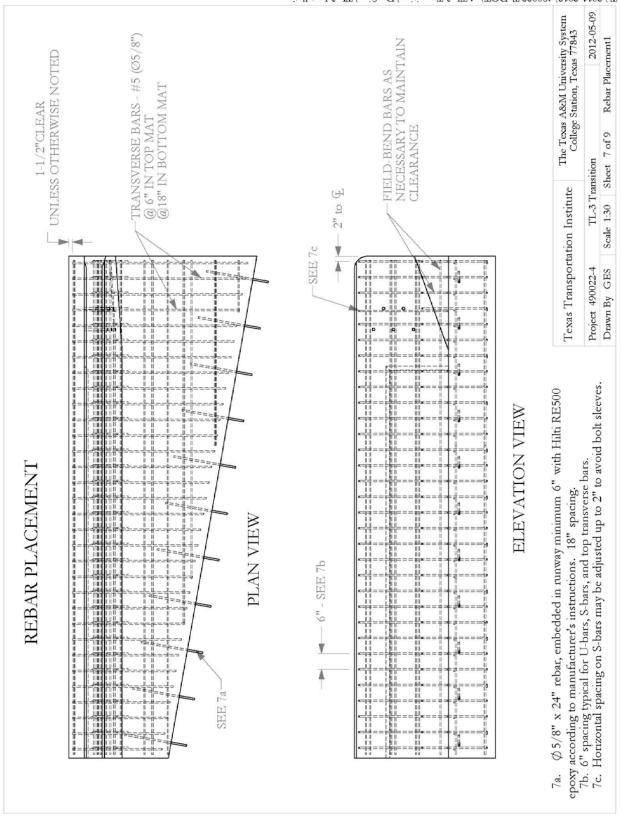
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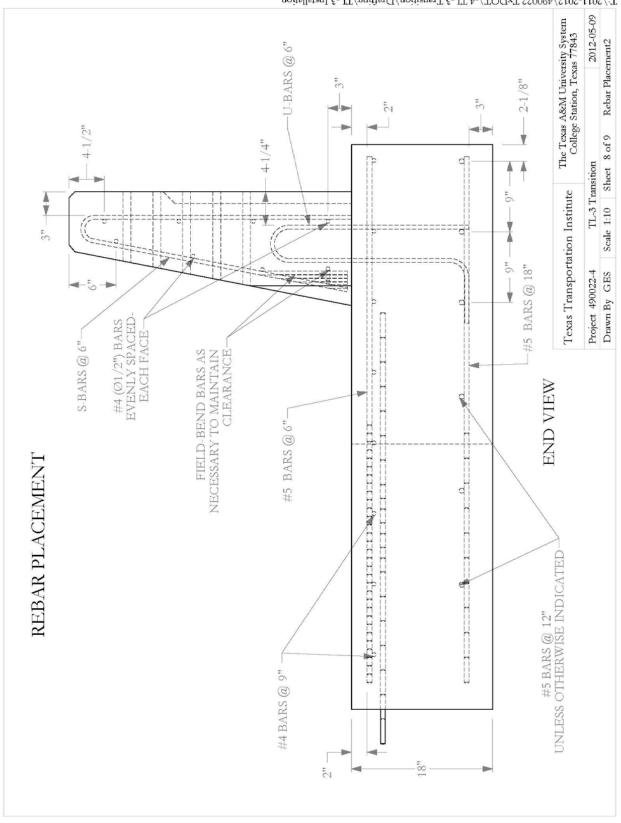


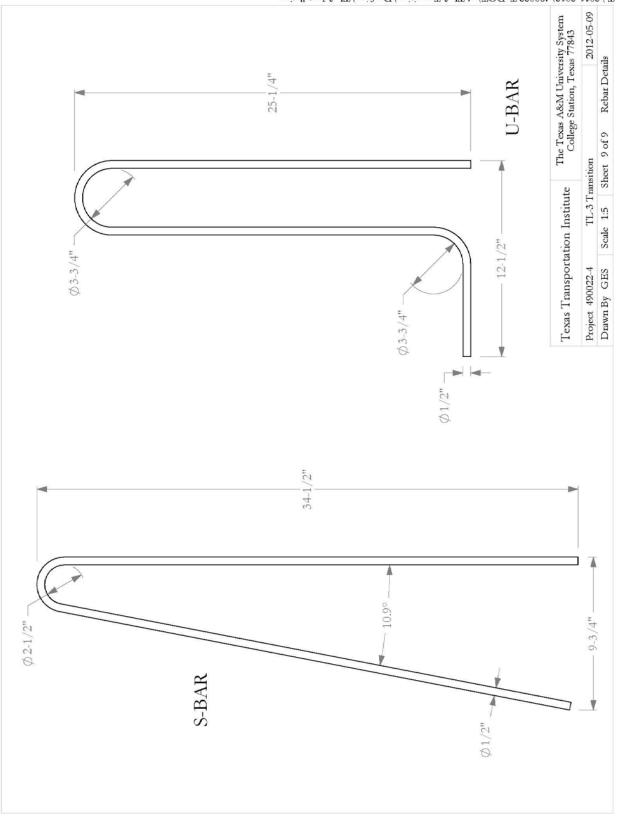
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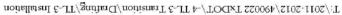


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TR No. 9-1002-12-4

APPENDIX B. CERTIFICATION DOCUMENTATION

MATERIAL USED

TEST NUMBER 490022-4

TEST NAME TL-3 Transition

DATE 2012-05-14

DATE RECEIVED	ITEM NUMBER	DESCRIPTION	SUPPLIER	HEAT #
2012-02-08	Parts-16	Guardrail Parts	Trinity	see file
2012-02-23	Rebar 04-26	1/2" x 20' gr 60	CMC-Sheplers	3029770
2012-02-23	Rebar 05-15	5/8" x 20' grd 60	CMC-Sheplers	3028494

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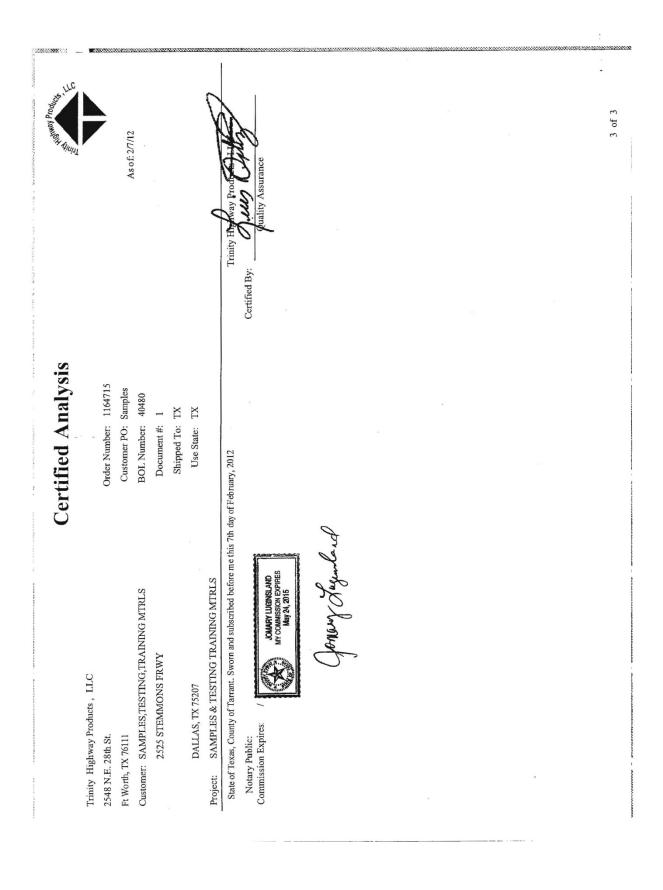
to post of the second s	Print Date: 27/12 Project: SAMPLES & TESTING TTI ET-2000 GILCHRIST/SHI Shipped To: TX Use State: TX	S EXTRUDER TERMINAL **	-002.	ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT ALL GUADRALIA MERICA STEEL MEETS ASTIM 36 ALL CONTROSS PROCESSIES OF THE STRUCT ON HAIO, ALL STRUCTURED NA LOS AND COMPLIES WITH HAS THA STRUCTURED AND THIS AND COMPLIES WITH HAS THA STRUCTURED AND THIS AND COMPLIES WITH HAS THA STRUCTURED AND SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTIM A-353 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTIM A-133, UNLESS OTHERWISE STATED. NOTS COMPLY WITH ASTIM F-436 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTIM A-133, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTIM F-436 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTIM F-3239. SITEM CALLE GAYS OTHER WIGH DE DID ALST CLOSS STEEL ANVAILED IN ACCORDANCE WITH ASTIM F-3239. STRUCTH0100.LB STRUCTH010.LB STRUCTH0100.LB STRUCTH0100.LB STRUCTH0100.LB STRUCTH0100.LB STRUCTH0100.LB STRUCTH0100.LB STRUCTH010.LB STRUCTH0100.LB STRUCTH010.LB STRUCTH0100.LB STRUCTH0100.LB STRUCTH0100.LB STRUCTH0100.LB STRUCTH0100.LB STRUCTH0100.LB STRUCTH0100.LB STRUCTH010.LB STRUCTH010.LB STRUCTH010.LB STRUCTH010.LB STRUCTH010.LB STRUCTH010.LB STRUCTH010.LB STRUCTH010.LB STRUCTH010.LB STRUCTH010.LB STRUCTH010.LB S	2 of 2
and a submitted of the second s	Sales Order: 1164772 Customer PO: TTI-ET 2000 BOL # 40479 Document # 1	Trinity Highway Products, LLC pliance For Trinity Industries, Inc. ** E.T. PLU NCHRP Report 350 Compliant	Highway Products , LLC Storage Stain Policy No. LG-002 tecording to manufactures specifications	RED IN USA AND COMPLIES WITH T UCTURAL STEEL MEETS ASTM A36 E PERFORMED IN USA AND COMPLIES V STM-123, UNLESS OTHER WISE STAT VS AND ARE GALVANIZED IN ACCOR VS AND ARE GALVANIZED IN ACCOR ION AND/OR F-844 AND ARE GALVA ION AND AND AND AND AND ARE GALVA ION AND AND AND AND AND AND AND AND AND AN	
Trinity Highway Products , LLC 2548 N.E. 28th St. Ft Worth, TX 76111	Customer: SAMPLES, TESTING, TRAINING MTRLS 2525 STEMMONS FRWY DALLAS, TX 75207	Certificate Of Comp	Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain I TL -3 or TL-4 COMPLIANT when installed according to manufactures specifications	ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 ALL COATNRS PROCESSES OF THE STEEL OR INON ARE PREVORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT ALL GALVANIZED MATERIAL CONFORMS WITH ASTM 4-30 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-133, UNLESS OTHER WITS COMPLY WITH ASTM 4-30 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-133, UNLESS OTHER WITS COMPLY WITH ASTM 7-30 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-133, UNLESS OTHER WITS COMPLY WITH ASTM 7-30 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-133, UNLESS OTHER WITS COMPLY WITH ASTM 7-30 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-133, UNLESS OTHER WITS COMPLY WITH ASTM 7-30 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-133, UNLESS OTHER WITS COMPLY WITH ASTM 7-30 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM 7-33, UNLESS OTHER WITS COMPLY WITH ASTM 7-30 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM 7-33, UNLESS OTHER WITS COMPLY WITH ASTM 7-30 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM 7-33, UNLESS OTHER WITS COMPLY WITH ASTM 7-30 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM 7-33, UNLESS OTHER WITS COMPLY WITH ASTM 7-30 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM 7-33, UNLESS OTHER WITS COMPLY WITH ASTM 7-30 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM 7-33, UNLESS OTHER WITS TO A CONTROL WITH ASTM 7-30 MAGDE END ASIC CONTROL WITH ASTM 7-30 SPECIFICATION AND/OR F-344 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM 7-233, WASTMAGED END ASIC CONTROL WITH ASTM 7-30 MAGDE END ASIC C	

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2548 N.E. 28th St.					Order Nı	Order Number: 1164715	5							
Ft Worth, TX 76111					Custom	Customer PO: Samples	10					As of: 2/7/12	2	
SAMP	Customer: SAMPLES, TESTING, TRAINING MTRLS	MTRLS			BOL N	BOL Number: 40480					•		1	
2525 S	2525 STEMMONS FRWY				Docur	Document #: 1								
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DALLA	DALLAS, TX 75207				Use	Use State: TX								
SAMP	SAMPLES & TESTING TRAINING MTRLS	NG MTRLS												
Qty Part #	Description	Spec (CL	ΥY	TY Heat Code/ Heat #	Yield	ST	Elg C	Mn	P S	Si Cu	C	Cr Vn ACW	CW
11G	S/	A-500		2	202248	53,600	75,500	29.0 0.190	29.0 0.190 0.780 0.011 0.020 0.120 0.120	1 0.020 0.	120 0.120	1	0.00 0.050 0.002	4
		M-180	۷	2	101800	50,000	73,300	30.0 0.190		0.750 0.012 0.002 0.020 0.120	0.020 0.120		0.000 0.070 0.002	4
		M-180	V	2	101802	51,800	74,700	29.0 0.190		0.770 0.009 0.002 0.020 0.120	0.020 0.120		0.002	4
		M-180	Y	2	101804	54,500	75,800	28.0 0.190		011 0.002 0	0.020 0.120		050 0.002	4
		M-180	۷	2	102475	58,700	79,800	25.0 0.200		0.820 0.010 0.010 0.007 0.130	0.007 0.130		050 0.000	4
		M-180	V	2	102476	58,100	77,900	26.0 0.190		0.750 0.009 0.001 0.020 0.130	0.020 0.130		060 0.002	4
		M-180	V	2	202249	51,800	74,500	30.0 0.190		0.790 0.010 0.002 0.020 0.120	0.020 0.120		0.000 0.050 0.002	4
		M-180	A	2	202250	54,100	76,100	27.0 0.200		0.820 0.012 0.002 0.020 0.120	0.020 0.120	0.000 0.050	050 0.003	4
		M-180	V	2	202938	57,600	80,400	25.0 0.190		0.830 0.009 0.001 0.020 0.130	0.020 0.130		050 0.003	4
		M-180	A	2	202939	56,800	78,400	25.0 0.190	0.770 0.0	0.770 0.009 0.004 0.020 0.130	0.020 0.130		0.000 0.050 0.003	4
533G	6'0 POST/8.5/DDR	A-36			1017017	53,642	71,899	26.8 0.110	26.8 0.110 0.960 0.008 0.038 0.180 0.260	8 0.038 0	.180 0.260		0.00 0.090 0.004	4
533G		A-36			1017007	53,613	72,244	25.7 0.120	25.7 0.120 0.930 0.012 0.040 0.180 0.360	2 0.040 0	.180 0.360		0.00 0.140 0.003	4
533G		A-36			1016666	56,666	73,288	29.7 0.110	29.7 0.110 0.940 0.013 0.037 0.190 0.320	3 0.037 0	.190 0.320		0.00 0.150 0.004	4
533G		A-36			1017003	55,742	71,204	24.3 0.100	24.3 0.100 0.950 0.014 0.046 0.180 0.300	4 0.046 0	.180 0.300		0.00 0.160 0.004	4
980G	TI0/END SHOE/SLANT	A-36			125745	58,100	66,100	31.9 0.050	31.9 0.050 0.570 0.012 0.003 0.030 0.100	2 0.003 0	.030 0.100		0.01 0.050 0.000	4
4 12227G	T12/12'6/3'1.5:6@1'6.75/S	M-180	A	2	150054	61,580	80,600	25.0 0.190	25.0 0.190 0.720 0.010 0.003 0.010 0.130	0 0.003 0	010 0.130		0.00 0.060 0.001	4
12 14784G	7'0 POST/8.5#/3HT	A-36			1014849	50,787	69,032	25.6 0.100	25.6 0.100 0.960 0.015 0.037 0.180 0.310	15 0.037 0	.180 0.310		0.00 0.180 0.003	4
14784G		A-36			1014844	53,141	69,983	28.3 0.110	28.3 0.110 0.960 0.010 0.037 0.180 0.330	10 0.037 0	0.180 0.330		0.00 0.110 0.003	4
14784G		A-36			1014840	57,069	73,001	30.4 0.110	30.4 0.110 0.960 0.010 0.035 0.170 0.320 0.00 0.150 0.004	10 0.035 0	0.170 0.320	0.00 0.1	150 0.004	4
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Traine J Highene Products, LLC 3:451K 2:8h:S. The Chantene: 11(61:1) 1:46112 TESTING; TRANING MTRLS Channene: 11(61:1) 1:406m; XY 2:01 1:225 STEIDMONS FRWY Domment #: 1 2:225 STEIDMONS FRWY Domment #: 1 2:225 STEIDMONS FRWY DOMMEN: 2:25 STEIDMONS FRWY DOMMEN: 4010 2:225 STEIDMONS FRWY DOMMEN: 2:25 STEIDMONS FRWY DOM END FRW DOM		Certified Analysis	l Analy	Sis			AT PININ
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Customer PO: Samples BOL Number: 40480 BOL Number: 40480 Document #: 1 Shipped To: TX LS TX Ls Shipped To: TX LS TX Ls Shipped To: TX LS TX Ls Shipped To: TX LS TX Ls Shipped To: TX LS TX Ls Shipped To: TX LS TX Ls Shipped To: TX LS 1014813 TX Ls Shipped To: Shipped	2548 N.E. 28th St.	Order Nu	umber: 116471	5			
BOL Number: 4040 Document #: 1 Stipped To: TX Jack State: Jack State: Jack State: Jack Jack Jack Jack <t< td=""><td>Ft Worth, TX 76111</td><td>Custom</td><td>er PO: Samples</td><td>-</td><td></td><td>Veo</td><td>6-2171.12</td></t<>	Ft Worth, TX 76111	Custom	er PO: Samples	-		Veo	6-2171.12
3255 STEIMMONS FR.WY Decement #. 1 SAMPLAS, YT 5207 Sampla To: TX DALLAS, IX 75207 Use State: TX SAMPLAS A TESTING TRAINING MTRLS Use State: TX 17386 Deterpline Spe CL TX Intercedention TA Spe Sp	Customer: SAMPLES, TESTING, TRAINING MTRLS	BOL N	umber: 40480			n ev	1. 21 11 12
BMILAS, IX 75307 SAMPLES A. TISTING TRALNING MTELS JOALAS, IX 75307 Use State: TX SAMPLES & TISTING TRALNING MTELS JOALAS, IX 75307 Use State: TX JOALAS, IX 75307 Use State: TX JOALAS, IX 75307 JOAL TALINING MTELS JOALAS, IX 75307 JOAL TALINING MTELS JOAL AND TRALINING MTELS JOAL TALINING MTELS JOAL ON TALINING MTELS JOAL TALINING MTELS JOAL ON TALINING MTELS JOAL ON TO JOAL ON TOJ	2525 STEMMONS FRWY	Docun	nent #: 1				
DALLAS, TX 7520TLue Shut: TXSAMPLES & TESTING MTRLSAMPLES A TESTING MTRLSSAMPLES & TESTING TRAINING MTRLSImage: Sample Set Set Set Set Set Set Set Set Set Se		Shipp	ed To: TX				
SAMPLES & TESTING TRAINING MTRLS Part# Description Spec Ct TY Ref To	DALLAS, TX 75207	Use					
Spic CI TY Heat Code/ Heat # Yield TS Ex C M F S S C	SAMPLES & TESTING TRA						
A-36 1014813 55,191 72,737 297 0.110 0.950 0.010 0.035 0.130 0.00 0.120 0.000 A-36 1013730 50,397 70,003 267 0.110 0.970 0.012 0.00 0.120 0.00 0.120 0.00 R A-36 1014843 55,191 72,737 297 0.110 0.970 0.012 0.00 0.120 0.00 R M-180 B 2 24.40 66,000 77,100 313 0.061 0.001 0.001 0.001 0.001 0.001 0.00 0.00 0.00 R M-180 B 2 24.40 55,101 77,100 313 0.001 0.0	Part # Description Spec	TY Heat Code/ Heat #	Yield	TS	C Mn	s Si Cu	Ċ
A-36 101370 50,597 70,003 267 0.10 0.070 0.120 0.270 0.00 0.0140 0.00 R A-36 1014813 5,5191 72,773 297 0.110 0.905 0.110 0.00 0.012 0.00 0.012 0.00 0.012 0.00<		1014843	55,191	72,737	29.7 0.110 0.950 0.01		
(3) (3) (1) (3) (3) (1) (3) (1) (3) (1) <td>14785G 6'0 POST/8.5#/31H TX</td> <td>1013730</td> <td>50,597</td> <td>70,003</td> <td>26.7 0.110 0.970 0.01</td> <td></td> <td></td>	14785G 6'0 POST/8.5#/31H TX	1013730	50,597	70,003	26.7 0.110 0.970 0.01		
MIR M-I80 B 2 24240 66,000 77,100 33.1 0.060 1.020 0.031 <td>14786G 6'0 POST/8.5#/TRANS TX</td> <td>1014843</td> <td>161,55</td> <td>72,737</td> <td>29.7 0.110 0.950 0.01</td> <td></td> <td></td>	14786G 6'0 POST/8.5#/TRANS TX	1014843	161,55	72,737	29.7 0.110 0.950 0.01		
0 A-36 B05674 59,800 70,100 31.9 0.200 0.410 0.007 0.060 0.290 0.00 0.001 uity Highway Products , LLC Storage Stain Policy No. LG-002. WUTPACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT180, ALL STRUCTURAL STEEL MEETS ASTM A.36 EL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT" ORMS WITH ASTM-123, UNLESS OTHERWISE STATED. PECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. PECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. AGED END AISI C-1035 STEEL AND ASTM 449 ASHTO M30, TYPE II BREAKING	32218G T10/TRAN/TB:WB/ASYM/R M-180		66,000	77,100	33.1 0.060 1.250 0.01		
TL-3 or TL-4 COMPLIANT when installed according to manufactures specifications Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002. ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT. ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 ALL COATTNGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT" ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED. BOLTS COMPLY WITH ASTM A-3607 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. S1ª" DA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM -5007 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. S1ª" DA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD I" DIA ASTM 449 ASSHTO M30, TYPE II BREAKING STRENGTH - 49100 LB	35247A CONN PL 40"X20" RT MO	B056774	59,800	70,100	31.9 0.200 0.410 0.01	0 0.007 0.060 0.290 0	
Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002. ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT. ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 ALL GATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT" ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT" ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT" ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT" ALL GALVANIZED MATTERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED. BOLT'S COMPLY WITH ASTM A-367 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. NUTS COMPLY WITH ASTM A-363 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. MASTERICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS	TL -3 or TL-4 COMPLIANT when installed according to man	ufactures specifications					
ALL STEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT. ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT" ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED. BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. 3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH - 49100LB	Upon delivery, all materials subject to Trinity Highway Produc	cts, LLC Storage Stain Poli	cy No. LG-002.				
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. 34" 'DIX CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTIO M30, TYPE II BREAKING STRENGTH - 49100 LB	ALL STEEL USED WAS MELTED AND MANUFACTURED IN I ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCT ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PE ALL GALVANIZED MATERIAL CONFORMS WITH ASTN	JSA AND COMPLIES WITH TURAL STEEL MEETS AS RFORMED IN USA AND C A-123, UNLESS OTHERW	THE BUY AME STM A36 OMPLIES WITH TSE STATED.	RICA ACT. THE "BUY .	AMERICA ACT"		
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-3232. 3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD I" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH - 49100 LB	BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS A	ND ARE GALVANIZED	IN ACCORDA	NCE WITH	ASTM A-153, UNLE	SS OTHERWISE STA	TED.
	NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AI WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND 3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1 STRENGTH – 49100 LB	ND ARE GALVANIZED II //OR F-844 AND ARE GALV 035 STEEL ANNEALED STI	N ACCORDAN ANIZED IN ACC UD 1" DIA AST	CE WITH A CORDANCE M 449 AASF	STM A-153, UNLES' WITH ASTMF-2329. HTO M30, TYPE II BRE	S OTHERWISE STAT AKING	Ð.

TR No. 9-1002-12-4

2013-07-09



TR No. 9-1002-12-4

	CMC STEEL TEXAS 1 STEEL MILL DRIVE SEGUIN TX 78155-7510	EXA DRI 8155	S VE -7510	CERTIFIED MILL TEST REPORT For additional copies call 830-372-8771	TES1 I copi 2-877		are accurate and conform to the reported grade specification Denial f. debuart Daniel J. Schacht	pecification
ſ							Quality Assurance Manager	
HEAT NO.:3029770 Section: Rebar 13mm (#4) 20'0"	*4) 20'0"	s o	CMC Construction	CMC Construction Svcs College Stati	sн	CMC Construction Svcs College Stati	Delivery#: 80681077 BOL#: 70240462	
420/60		- (10650 State Hwy 30	30	-		CUST PO#: 53534v	
GRADE: ASTM A615-09b Gr 420/60 ROLL DATE: 01/22/2012	Gr 420/60	٥	College Station TX US 77845-7950	×	٩.	College Station TX US 77845-7950	CUST P/N: DLVRY LBS / HEAT: 43820.000 LB	20.000 LB
MELT DATE: 01/15/2012		⊢ 0	979 774 5900		⊢ 0 		DLVRY PCS / HEAT: 3280 EA	0 EA
Charac	Characteristic Value	Ine		Char	Characteristic	stic Value	Characteristic V	Value
	C 0.4	.45%						
	Mn 0.8	.83%						
	0	%600.						
	si 0.1	.18%						
	0	.41%	÷					
	0	.15%						
	0	.22%						
	0.0 0.0	.070% .002%	0.0			*		
	Cb 0.0	.002%						
	Sn 0.0	0.014%	1 0 -4					
Yield Strength test 1	1 6	5.7ksi						
Tensile Strength test		02.8ksi	si					
Elongation (con loth toot 1	- 0	% T						
Liongation Gage Egit (Est 1 Bend Test Diameter		750IN	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~					
Bend	· a.	Passed						

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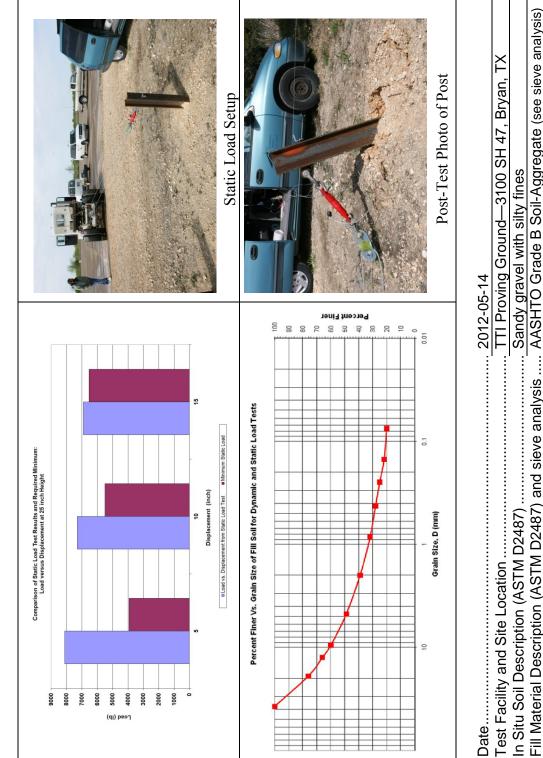
1. 4 .

We hereby certify that the test results presented here are accurate and conform to the reported grade specification Autouc Daniel J. Schacht Quality Assurance Manager	Delivery#: 80669347 BOL#: 70236513 CUST PO#: 5434V CUST P/N: DLVRY LBS / HEAT: 45990.000 LB DLVRY PCS / HEAT: 2205 EA	Characteristic Value	
We hereby certif CERTIFIED MILL TEST REPORT are accurate and confo For additional copies call 830-372-8771	College Stati S CMC Construction Svcs College Stati H 10650 State Hwy 30 P College Station TX US 77845-7950 T 979 774 5900 0	Characteristic Value	C 0.38% Mn 1.00% F 0.015% S 0.030% S 0.030% C 0.21% Cu 0.33% C 0.21% Mi 0.19% Mi 0.19% Mi 0.19% Mi 0.19% Mi 0.19% Mi 0.19% Mi 0.033% C 0.003% C 0.003% S 0.013% S 0.013%S 0.013% S 0.013%S 0.013% S 0.013% S 0.013%S 0.013% S 0.013% S 0.013%S 0.013% S 0.013% S 0.013%S 0.0
CMC STEEL TEXAS 1 STEEL MILL DRIVE SEGUIN TX 78155-7510	HEAT NO.::3028494 S CMC Construction Svcs College Stati SECTION: REBAR 16MM (#5) 20'0" 0 10650 State Hwy 30 420/60 L 10650 State Hwy 30 GRADE: ASTM A615-09b Gr 420/60 D College Station TX ROLL DATE: 11/18/2011 T 979 774 5900 MELT DATE: 11/14/2011 0 0	Characteristic Value	C 0.38% Mn 1.00% P 0.015% S 0.030% S 0.030% Cu 0.33% Cu 0.33% Cr 0.21% Ni 0.19% Mo 0.038% V 0.003% Cb 0.013% Al 0.002% Al 0.002% Al 0.002% Al 0.002% Tensile Strength test 1 68.3ksi Tensile Strength test 1 108.1ksi Elongation test 1 15% Elongation test 1 15% Bend Test Diameter 2.1881N Bend Test Diameter 2.1881N
	HEAT NO.:3028494 SECTION: REBAR 16MM 420/60 GRADE: ASTM A615-096 ROLL DATE: 11/14/2011 MELT DATE: 11/14/2011		Yield Tensile Elongation O

REMARKS :

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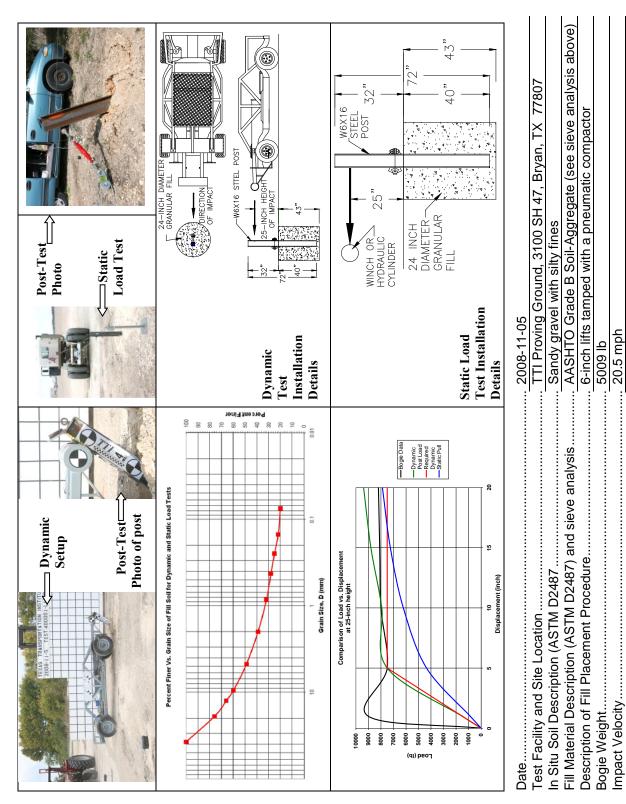


APPENDIX C. SOIL STRENGTH DOCUMENTATION

6-inch lifts tamped with a pneumatic compactor

Description of Fill Placement Procedure

Table C2. Summary of Strong Soil Test Results for Establishing Installation Procedure.



APPENDIX D. TEST VEHICLE PROPERTIES AND INFORMATION

Date: 201	2-05-11	Test No.:	490022	-4	VIN No.:	1D7HA18	323656599	981
Year: 200	6	Make:	Dodge		Model:	Ram 150	0	
Tire Size:	P265/70R1	7		Tire	Inflation Pre	ssure: 35	psi	
Tread Type:	Highway					meter: 18		
					Ouo	<u> </u>	0710	
Note any dar	nage to the ve	hicle prior to	test:					
 Denotes a 	ccelerometer l	ocation.			<₩►			
NOTES:			1		*77	⊐由∈		
			_					
Engine Type Engine CID:	: <u>V-8</u> 4.7 liter		- .	WHEEL TRACK				WHEEL WHEEL
-			<u>+ 1</u>)	
Transmissior x Auto	or	Manual		-	-0-	\succ	TEST INERTIAL C. M	
FWD	x RWD	4WD		R				4
Optional Equ	ipment:							
			- 1					
Dummy Data	1:		Ŭ J−		\bigcirc		HQ)L	-L K L
Type:	No dumr	ny	-			Lvts		
Mass: Seat Positio	on:		-	◄ — F —	►	∟ _G — Е ———		
			-		M FRONT		M REAR	
Geometry:	inches	00.00	14			c		
A 78.2		36.00	_ K_	20.50	_ P _	2.88	_ U_	28.50
B <u>75.0</u> C 223.7		28.31 60.39	_ L _ M	29.12 68.50	_ Q _ R	31.25 18.38	_ V _ W	29.50 60.50
D 47.2		13.75	N	68.00	_ K S	12.00	- <u>vv</u> - X	00.30
E 140.5		25.38	0	44.50	– в – т	77.00		
Wheel Ce	nter		Wheel W	/ell		Bottom Fra		47.40
Height F Wheel Ce		14.75 Cle	arance (Fro Wheel V		5.00	Height - F Bottom Fra		17.12
Height F	lear		earance (Re	ear)	10.25	Height - F	Rear	24.75
RANGE LIMI	T: A=78 ±2 inches	s; C=237 ±13 ind O=4	ches; E=14 3 ±4 inches	8 ±12 inches; ; M+N/2=67 ±1	F=39 ±3 inches I.5 inches	; G = > 28 incl	hes; H = 63	±4 inches;
GVWR Rati	ngs:	Mass: Ib		Curb		Inertial	Gro	oss Static
Front	3700	M _{front}		2875		2852		
Back	3900	M _{rear}		2151		2150		
Total	6700	M _{Total}		5026		5002		
Mass Distrik	oution:			(Allow	vable Range for	TIM and GSM	$= 5000 \text{ lb} \pm 1000 \text{ lb}$	110 lb)
lb	LF:	1424	RF:	1428	LR:	1066	RR:	1084

Table D1. Vehicle Properties for Test No. 490022-4.

Table D2. Vehicle Parametric Measurements for Test No. 490022-4.

Date: 2012-05	<u>-11</u> Te	st No.: <u>4</u>	90022-4	<u></u> ۱	/IN: <u>1D</u>	7HA182365659	9981	
Year: 2006		Make: D	odge		Model:	Ram 1500		
Body Style: Q	uad cab			Ν	lileage:	180713		
Engine: 4.7 lite	er V-8			Transn	nission:			
Fuel Level: Er	mpty	Balla	st: <u>120</u>) lb at fror	t of bed		(440) lb max)
Tire Pressure: F	Front: 3	85 psi	Rear	: 35	osi S	ize: 265/70R	17	
Measured Vel	hicle Wei	ghts: (I	b)					
LF:	1424		RF:	1428		Front Axle	e: 285	2
LR:	1066		RR:	1084		Rear Axle	e: 215	0
Left:	2490		Right:	2512		Tota	l: 500	2
						5000 ±	110 lb allow e	∋d
	eel Base:		inches	Track: F:		5 inches R		8 inches
	148 ±12 inch	es allow ed			Track = (F	+R)/2 = 67 ±1.5 incl	nes allow ed	
Center of Gra	vity , SAE	J874 Su	spension N	<i>l</i> ethod				
X:	60.39	in	Rear of F	ront Axle	(63 ±4 incl	nes allow ed)	_	
Y:	0.15	in	Left -	Right +	of Vehic	le Centerline	_	
Z:	28.31	in	Above Gr	ound	(minumum	28.0 inches allow e	d)	
Hood Heigh		44.50 ches allowed	inches	Front B	umper H	eight:	<u>25.38</u> i	nches
Front Overhan		36.00 ches allowed	inches	Rear B	umper H	eight:	<u>29.18</u> i	nches
Overall Length	า:	223.75	inches					

237 ±13 inches allowed

Table D3. Exterior Crush Measurements for Test No. 490022-4.

Date:	2012-05-11	Test No.:	490022-4	VIN No.:	1D7HA182365659981
Year:	2006	Make:	Dodge	Model:	Ram 1500

VEHICLE CRUSH MEASUREMENT SHEET¹

Complete Wh	en Applicable
End Damage	Side Damage
Undeformed end width	Bowing: B1 X1
Corner shift: A1	B2 X2
A2	
End shift at frame (CDC)	Bowing constant
(check one)	X1+X2 _
< 4 inches	
\geq 4 inches	

Note: Measure C_1 to C_6 from Driver to Passenger side in Front or Rear impacts – Rear to Front in Side Impacts.

a :c		Direct Damage									
Specific Impact Number	Plane* of C-Measurements	Width** (CDC)	Max*** Crush	Field L**	C1	C ₂	C ₃	C4	C5	C ₆	±D
1	Front plane at bumper ht	16.0	10.0	27	0	2	4	4	6	10	+10.5
2	Side plane at bumper ht	16.0	17.0	50	1	4			15	17	+69
	Measurements recorded										
	in inches										

¹Table 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.

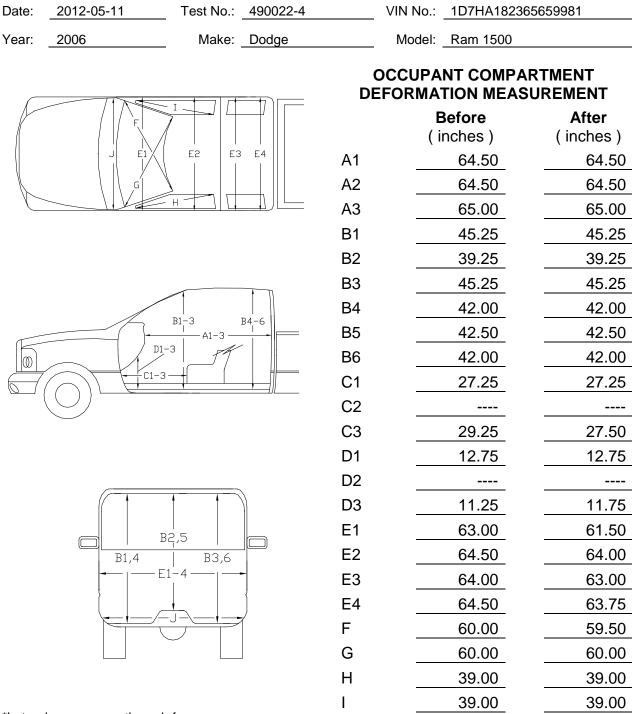


Table D4. Occupant Compartment Measurements for Test No. 490022-4.

*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

59.75

63.25

J*

APPENDIX E. SEQUENTIAL PHOTOGRAPHS

0.000 s

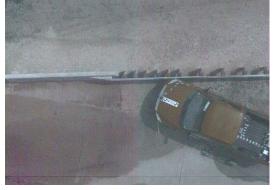
















Figure E1. Sequential Photographs for Test No. 490022-4 (Overhead and Frontal Views).

0.147 s

0.098 s





0.196s

0.245 s









Figure E1. Sequential Photographs for Test No. 490022-4 (Overhead and Frontal Views) (continued).



0.000 s



0.049 s



0.098 s



0.147 s



0.196 s



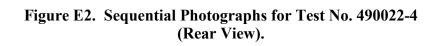
0.245 s

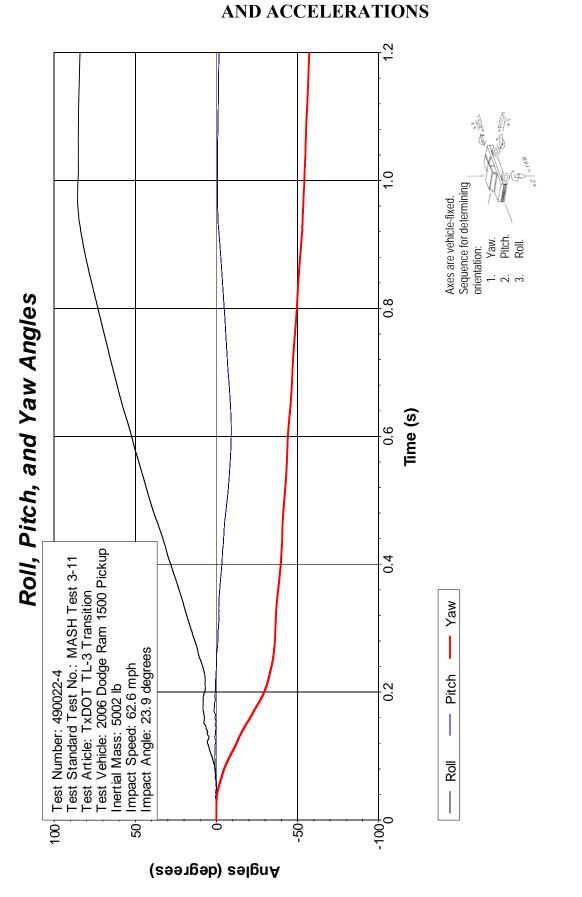


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0.343 s





APPENDIX F. VEHICLE ANGULAR DISPLACEMENTS



