TTI: 9-1002

DETERMINATION OF MINIMUM HEIGHT AND LATERAL DESIGN LOAD FOR MASH TEST LEVEL 4 BRIDGE RAILS

ISO 17025 Laboratory
Testing Certificate # 2821.01

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

Test Report No. 9-1002-5

Cooperative Research Program

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
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16. Abstract

The *Manual for Assessing Safety Hardware (MASH)* prescribes higher design vehicle impact speed and mass for test level 4 barriers compared to its predecessor *National Cooperative Highway Research Program (NCHRP) Report 350*. This has resulted in a 56 percent increase in impact severity for test level 4. The current American Association of State Highway Transportation Officials (AASHTO) *Load and Resistance Factor Design (LRFD) Bridge Specifications* require test level 4 bridge rails to have a minimum rail height of 32 inches and to be designed for a 54-kip lateral load. These requirements were based on *NCHRP Report 350* impact conditions and need to be revised for the higher impact severity under *MASH*. A recent *MASH* test 4-21 with a 32-inch tall New Jersey profile rigid concrete barrier, which performed acceptably under *NCHRP Report 350* TL-4, resulted in the vehicle rolling over the barrier.

This research had the objectives of determining the minimum rail height and lateral design impact load for *MASH* test level 4 bridge rails. Using parametric finite element analysis and subsequent crash testing, the researchers determined the minimum recommended rail height for *MASH* TL-4 impact conditions to be 36 inches. Lateral design impact load for *MASH* TL-4 test conditions was determined to be 80 kips.

A 36-inch tall Single Slope Traffic Rail (SSTR) that meets these rail height and lateral load capacity requirements was crash tested. The 36-inch tall SSTR successfully contained and redirected the impacting vehicle. Details of the simulation analysis, barrier design, full-scale crash testing, and crash test results are presented in this 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.

ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01

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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.

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 an individual test report.

This report documents research performed to determine the minimum rail height and lateral impact load for bridge rails and longitudinal barriers designed to meet test level 4 (TL-4) of the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware (MASH)* (*1*).

1.2 BACKGROUND

In 2009, *MASH* was adopted to replace *National Cooperative Highway Research Program (NCHRP) Report 350* (*2*). The TL-4 impact conditions for test 4-12 were significantly modified under *MASH*. Mass of the single unit truck design vehicle was increased from 17,640 lb to 22,050 lb. Impact speed was increased from 50 mi/h to 56 mi/h. Impact angle was maintained at 15 degrees, and the nominal center of gravity (CG) height of the vehicle ballast was reduced by 4 inches to 63 inches. Due to the increase in vehicle mass and impact velocity under *MASH* TL-4 conditions, the nominal impact severity of test 4-12 increased by approximately 56 percent compared to *NCHRP Report 350*.

The AASHTO *Load and Resistance Factor Design (LRFD) Bridge Design Specifications* require the minimum rail height for TL-4 bridge rails to be 32 inches (*3*). The lateral impact load for the strength design of these rails is specified to be 54 kips. These specifications were based on TL-4 impact conditions prescribed in *NCHRP Report 350*. Due to the significant increase in impact severity under *MASH*, there is a need to revise the minimum rail height and lateral design impact load requirements for TL-4 bridge rails.

To evaluate impact performance differences associated with the change in test level 4 conditions under *MASH*, Bullard et al. at Texas Transportation Institute (TTI) performed a *MASH* test 4-21 with a 32-inch tall New Jersey (NJ) profile rigid concrete barrier (*4*). This barrier had previously performed successfully under *NCHRP Report 350* test level 4 conditions (*5*). In the *MASH* test, the test vehicle rolled over the top of the barrier and was, therefore, not successfully contained or redirected. The result of this test was a clear indication that a 32-inch rail height is not adequate for *MASH* TL-4 bridge rails.

1.3 OBJECTIVES/SCOPE OF RESEARCH

This research sought to determine:

- The minimum acceptable rail height under *MASH* test level 4 impact conditions.
- The appropriate lateral design impact load for use with *AAHSTO LRFD* ultimate strength analysis of TL-4 bridge rails.

This report gives the details of the finite element analysis performed to determine the minimum rail height and the appropriate design load for *MASH* TL-4 barriers. Also reported are details of the TxDOT Single Slope Traffic Railing (SSTR) selected for use in a *MASH* TL-4 crash test, a description of the test performed, an assessment of the test results, and implementation recommendations.

CHAPTER 2. DESIGN AND ANALYSIS

The researchers used finite element (FE) analysis to simulate impacts of a single unit truck with a rigid barrier under *MASH* test level 4 (TL-4) impact conditions. The height of the rail was parametrically varied to arrive at the suggested minimum rail height. Researchers used the results of the FE analysis to evaluate the effect of rail height variation on vehicle kinematics and stability. A crash test was subsequently performed to verify results of the FE analysis. While performing the FE simulations, the researchers determined the lateral impact load resulting from the vehicle-barrier interaction for each rail height variation. This information was used to suggest a revised design impact load for *MASH* TL-4 bridge rails.

2.1 FINITE ELEMENT ANALYSIS

Finite element analysis was performed using LS-DYNA, which is a commercial FE software package commonly used for crashworthiness analysis (*6*). The concrete barriers were modeled with rigid material representation in all of the analyses. This was done because no significant failure or deflection of the barrier was expected due to the vehicle impact. The National Crash Analysis Center (NCAC) initially developed the single unit truck model used in the analyses and Battelle (*7*) subsequently revised it. The researchers significantly modified this model to conform to some of the key vehicle characteristics of the test vehicle used in the full-scale crash testing as described below.

2.1.1 Vehicle Model Validation

MASH specifies a maximum wheel base of 240 inches for the TL-4 single unit truck (SUT) design test vehicle. A longer wheel base tends to stabilize the vehicle by spreading its weight farther from the center of gravity (CG). Since one of the objectives of this research was to determine the minimum rail height for TL-4 bridge rails, it was important to perform FE analyses with a wheel base that represented the lower end of the spectrum of what is available in the current vehicle market and likely to be used as a crash test vehicle. This permits the greatest probability of vehicular instability when impacting a bridge rail.

Researchers found that single unit trucks with a wheel base closer to 190 inches were among the shortest available in the market. The finite element model of the SUT has a wheel base of 208 inches, which meets the *MASH* specifications, but is not the most critical in terms of vehicular instability during impact.

The recent *MASH* crash test with the 32-inch NJ profile barrier (referenced in Chapter 1) was performed using a truck with a wheel base of 188 inches, which is at the lower end of available wheel bases on SUTs (*4*). The researchers used pre-test vehicle measurements and supplemental information from the damaged test vehicle to modify the finite element model of the SUT. Major changes included reducing the wheel base, rear overhang, gap between the cab and the cargo box, and the cargo box height. Additional changes were made to improve chassis deformation and the connection between the cargo box and the chassis. The ballast shape and size, and its attachment to the vehicle were also modified to match practices and procedures at the TTI Proving Ground. After making these changes, the researchers performed an impact simulation of the modified SUT with the 32-inch NJ profile barrier using *MASH* TL-4 impact conditions. Figure 2.1 compares the simulation and crash test results.

The simulation model matched the vehicle's pitch and roll characteristics observed in the crash test reasonably well. While both simulation and test vehicles rolled over the top of the barrier, the vehicle rolled over at a faster rate in the test compared to the simulation results. With this in mind, the researchers proceeded with further analysis using the modified SUT vehicle model.

2.1.2 Rail Height Selection

The researchers investigated the effect of rail height on vehicle stability by performing finite element simulations of an SUT impacting single slope barriers of varying height. The models of the barriers were developed using rigid shell material representation. The single unit truck model impacted the barriers at a speed of 56 mi/h and an angle of 15 degrees, which are the nominal impact conditions prescribed for *MASH* test 4-12. Figure 2.2 shows the setup of a typical simulation.

An initial impact simulation was performed with a 42-inch tall single slope barrier. Since *AASHTO LRFD Design Specifications* list the 42-inch rail height as the minimum for test level 5, the researchers expected the barrier to contain and redirect the SUT in a stable manner under the less severe TL-4 conditions. Having achieved successful results with the 42-inch tall barrier, the height was gradually reduced until results of the simulation indicated significant vehicular instability and likelihood of vehicle rollover. Impact simulations were performed with barrier heights of 42, 39, 38, 37, and 36 inches. Vehicle roll, pitch, and yaw angles were determined as a function of time about a point near the center of gravity of the ballast. Figure 2.3 compares these angles.

As expected, the 42-inch rail height produced the greatest vehicular stability. Although reducing the rail height to 39 inches increased the maximum roll and pitch angles of the SUT, the vehicle was still contained and redirected in a fairly stable manner.

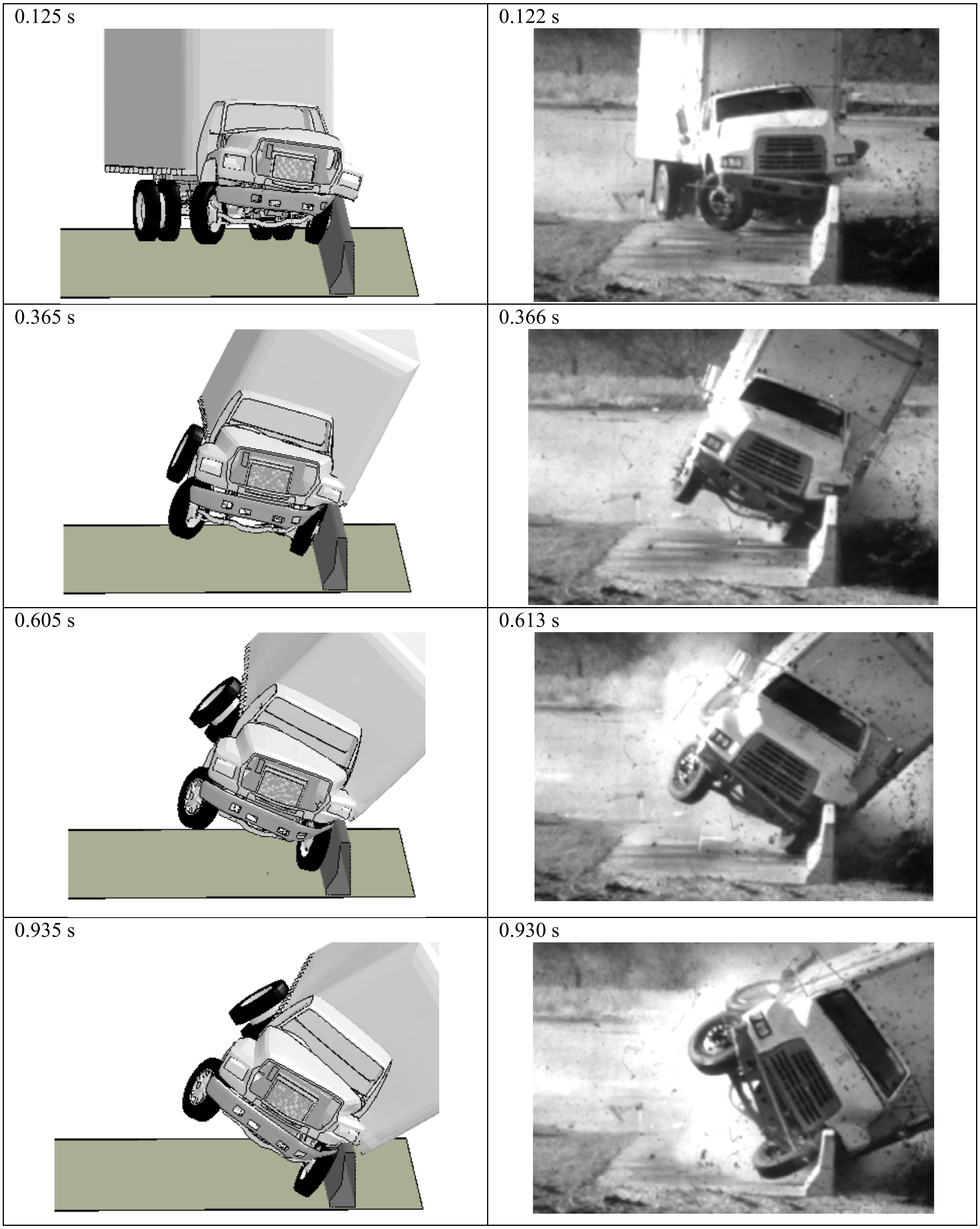


Figure 2.1. Comparison of Simulation and Crash Test Results for SUT Impact into a 32 Inch Tall NJ Barrier under MASH TL-4 Impact Conditions.

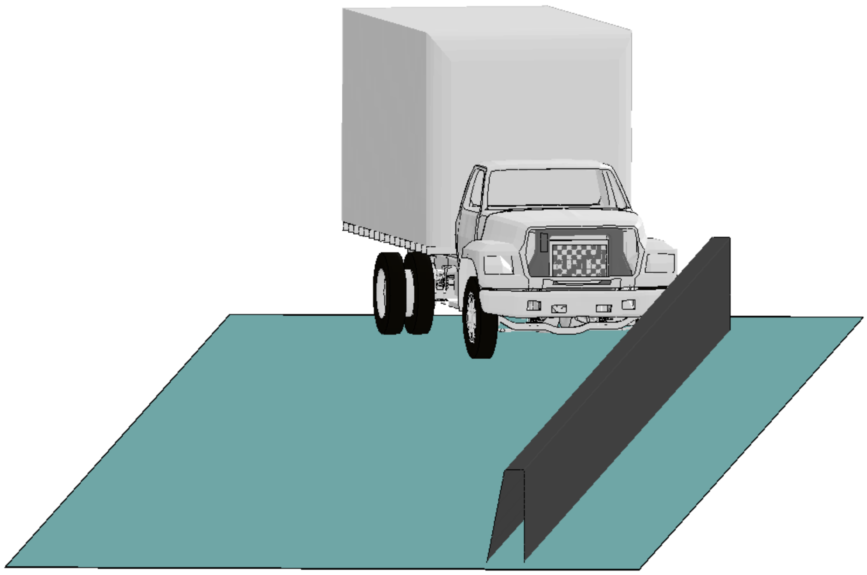


Figure 2.2. Finite Element Model of the Single Unit Truck Impacting a Rigid Single Slope Barrier under *MASH* TL-4 Impact Conditions.

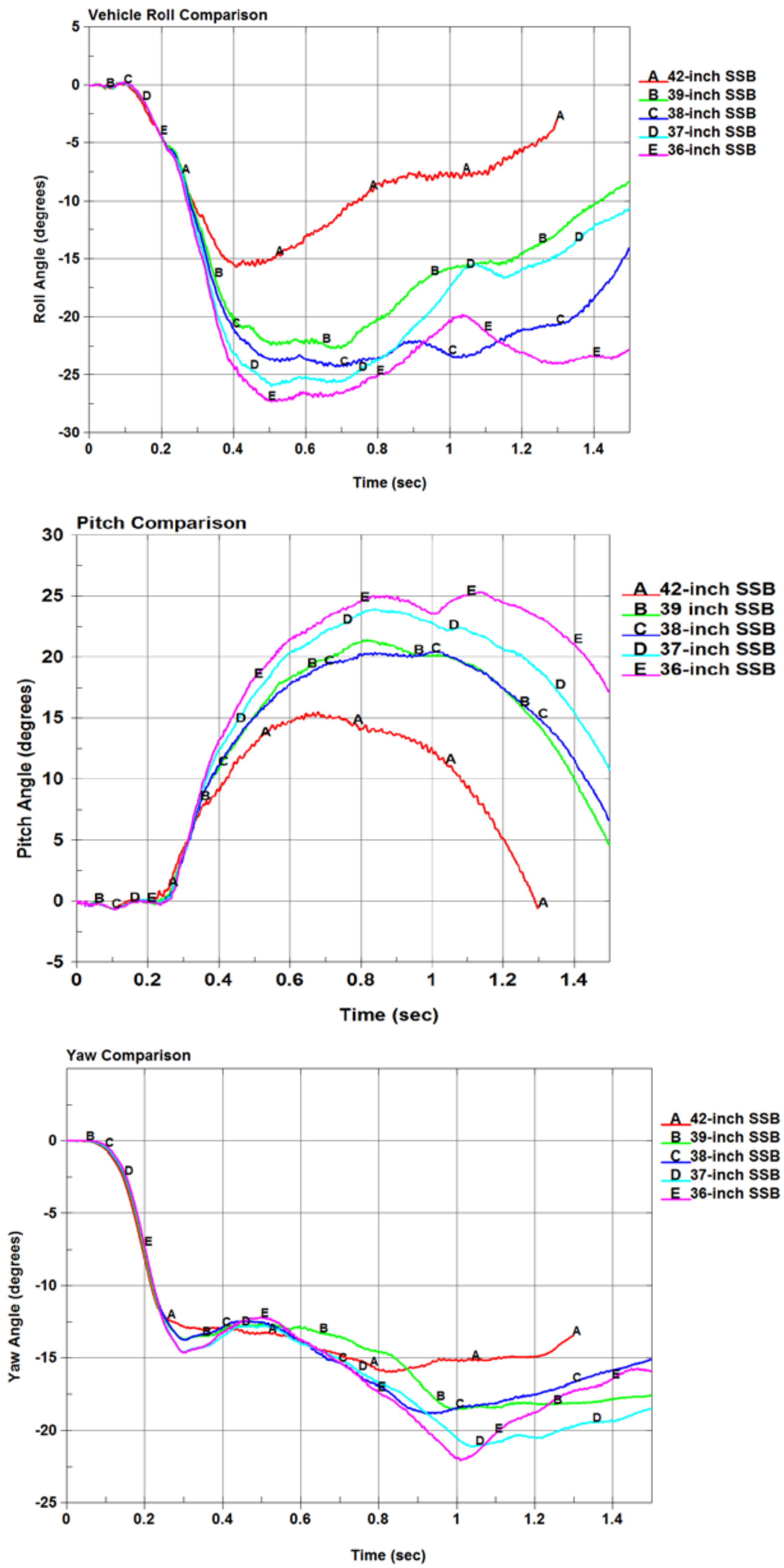


Figure 2.3. Vehicle Roll, Pitch, and Yaw Angles for *MASH* TL-4 Impacts into a Rigid Single Slope Barrier (SSB) with Various Rail Heights.

Further reducing the rail height further increased the instability of the vehicle. At 36 inches, the maximum roll and pitch at the CG of the ballast were approximately 27 and 25 degrees, respectively. This configuration was considered marginal in terms of the vehicle's stability and propensity to roll over the barrier. With a 36-inch rail height, the cross-members of the SUT's cargo box floor are significantly above the top of the rail. Simulation results showed that at a pitch of 25 degrees, the rear impact side wheels of the SUT were near the top of the rail as the vehicle yawed into the barrier. The contact between the rear wheels and the top of the barrier (shown in Figure 2.4) helped contain the SUT and prevent the cargo box from rotating over the barrier. Results indicated that any further reduction in rail height might cause the rear axle to pass over the barrier and, therefore, further reduction in height was not recommended or analyzed. It is worth noting that slightly improved kinematic behavior was observed with 37- and 38-inch rail heights. However, since this research sought to establish a minimum height for *MASH* TL-4 conditions, the 36-inch height was selected for further evaluation through a full-scale crash test.

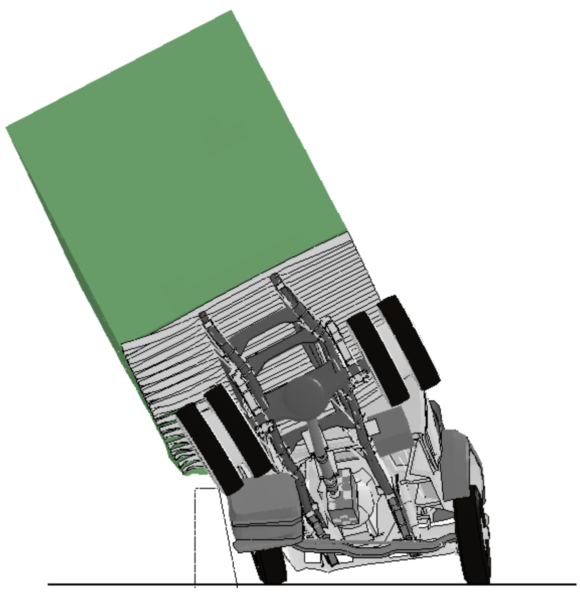


Figure 2.4. Impact of the SUT with 36-Inch Barrier (Rear View).

2.1.3 Design Load Selection

For each of the simulations performed, the researchers determined the lateral load applied to the barrier due to the impact. The load was calculated using LS-DYNA by summing the lateral contact forces applied to the barrier. Figure 2.5 shows the 50-millisecond moving average of the lateral force on the barrier for simulated rail heights of 42, 39, and 36 inches. The load curves each have two peaks. The first peak results from the initial impact of the vehicle's cab with the barrier. The second peak occurs at the time of the back-slap (i.e., when the rear axle contacts the barrier during redirection). The researchers also performed a simulation with a 32 inch tall rigid NJ profile barrier under *NCHRP Report 350* TL-4 impact conditions. Figure 2.5 plots the results of the lateral load from this simulation for comparison purposes.

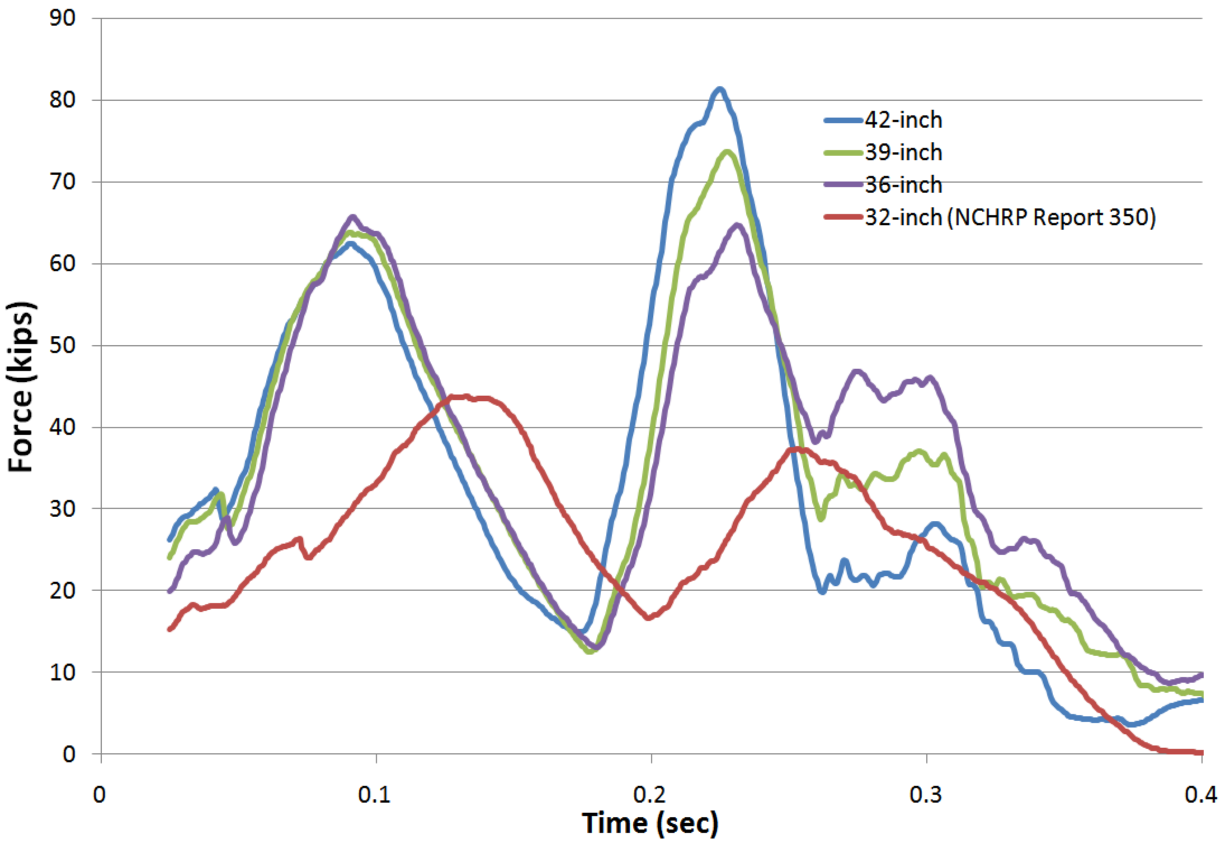


Figure 2.5. Lateral Impact Loads Resulting from Vehicle Impact with Various Rail Heights.

It can be observed that the load associated with the initial contact does not vary significantly. The load associated with the back-slap increases with rail height. A contributing factor to this increase in lateral load is the interaction of the cargo box floor with the barrier. With the SUT in a static equilibrium position, the cross-members supporting the floor of the cargo box are slightly above the 42-inch rail. However, during impact, the cargo box starts to roll towards the barrier, which causes the cross-members of the cargo box floor to impact the barrier, subsequently increasing the lateral load applied to the barrier. With a 39-inch rail height, the cross-members' interaction is still significant, even though it is reduced compared to the 42 inch rail. At 36 inches, the cross members have no significant interaction with the barrier; consequently, the peak lateral load during back-slap is slightly less that the load during initial impact of the cab (i.e., the first peak). The simulation with the 32-inch rail under *NCHRP Report 350* impact conditions also did not result in contact of the cargo box floor with the rail. However, the second peak in this case, is further reduced compared to the first peak due to significant differences in the ballast of *MASH* and *NCHRP Report 350* design vehicles.

Since the lateral load increases with rail height, the selection of a design impact load for *MASH* TL-4 rails should not correspond to the minimum rail height of 36 inches. The researchers selected the lateral load associated with a 42-inch rail height to accommodate expected variations in rail design and rail height. Thus, the recommended lateral design impact load for *MASH* TL-4 longitudinal barriers is 80 kips.

2.1.4 Concrete Bridge Rail Design

The researchers reviewed TxDOT's bridge rail standards to determine if an existing design might satisfy the recommended minimum rail height and design impact load requirements. The TxDOT Single Slope Traffic Rail (SSTR) is a 36-inch tall rigid concrete bridge rail with a single or constant slope profile. A strength analysis following the AASHTO *LRFD* yield line method indicated that the SSTR has a lateral load capacity of 80 kips, which meets the recommended capacity to accommodate a *MASH* TL-4 impact.

MASH test 4-12 was performed on the SSTR using a single unit truck with a wheel base of 187.5 inches. Details of the crash test are presented in the following chapters.

CHAPTER 3. CRASH TEST SYSTEM DETAILS

3.1 TEST ARTICLE DESIGN AND CONSTRUCTION

The test article was comprised of a single-slope rigid concrete barrier, also known as the TxDOT Single-Slope Traffic Rail (SSTR). The total length of the barrier was 150 ft. A length of 78 ft of rail was cast in place on top of an 8-inch thick concrete bridge deck cantilever. The remaining 72 ft of rail were cast on top of a 12-inch thick, 30-inch wide moment slab.

The single slope barrier was constructed with an 11-degree slope on the traffic-side face. The field side of the barrier was vertical. The barrier was 13 inches wide at the base and 7.5 inches wide at the top. The overall height of the barrier was 36 inches.

The barrier was reinforced using welded wire reinforcement. The reinforcement was comprised of 0.375-inch diameter stirrups that were bent to approximately match the profile of the barrier. The stirrups were spaced 6 inches apart over the 78-ft long bridge deck. The spacing was increased to 24 inches over the first 24 ft of rail attached to the moment slab, and then further increased to 36 inches over the last 45 ft of rail. The stirrups were welded to 10 longitudinal wires that were 0.4 inches in diameter and evenly spaced along the height of the barrier.

The 78-ft long, 8-inch thick bridge deck was reinforced with a top and bottom rebar mat. The top mat was comprised of 0.625-inch diameter (#5) transverse bars that were spaced 6 inches apart and tied to three #4 longitudinal rebars. The longitudinal rebars were spaced 9 inches apart laterally. The bottom mat was comprised of 0.625-inch diameter (#5) transverse bars spaced 18 inches apart and tied to three #5 longitudinal rebars. The bridge deck was cantilevered from an existing footing adjacent to a concrete apron. The transverse bars of the top and bottom mat in the bridge deck cantilever were welded to steel straps extending from the existing concrete footing.

The 72-ft long, 12-inch thick, 30-inch wide moment slab was reinforced using the same reinforcement scheme as the bridge deck. The slab was cast in place after excavating native soil adjacent to the concrete apron and then back-filling with compacted crushed limestone road base.

At the location of each vertical stirrup in the single-slope barrier, a 0.5-inch diameter (#4) U-shaped deck stirrup was used to connect the barrier to the underlying deck or moment slab. The U-shaped stirrup was tied to the bottom reinforcement mat of the bridge deck or moment slab and extended beyond the deck/moment slab surface.

Figures 3.1 through 3.3 show the details of the test article, Figure 3.4 has the photographs of the installation.

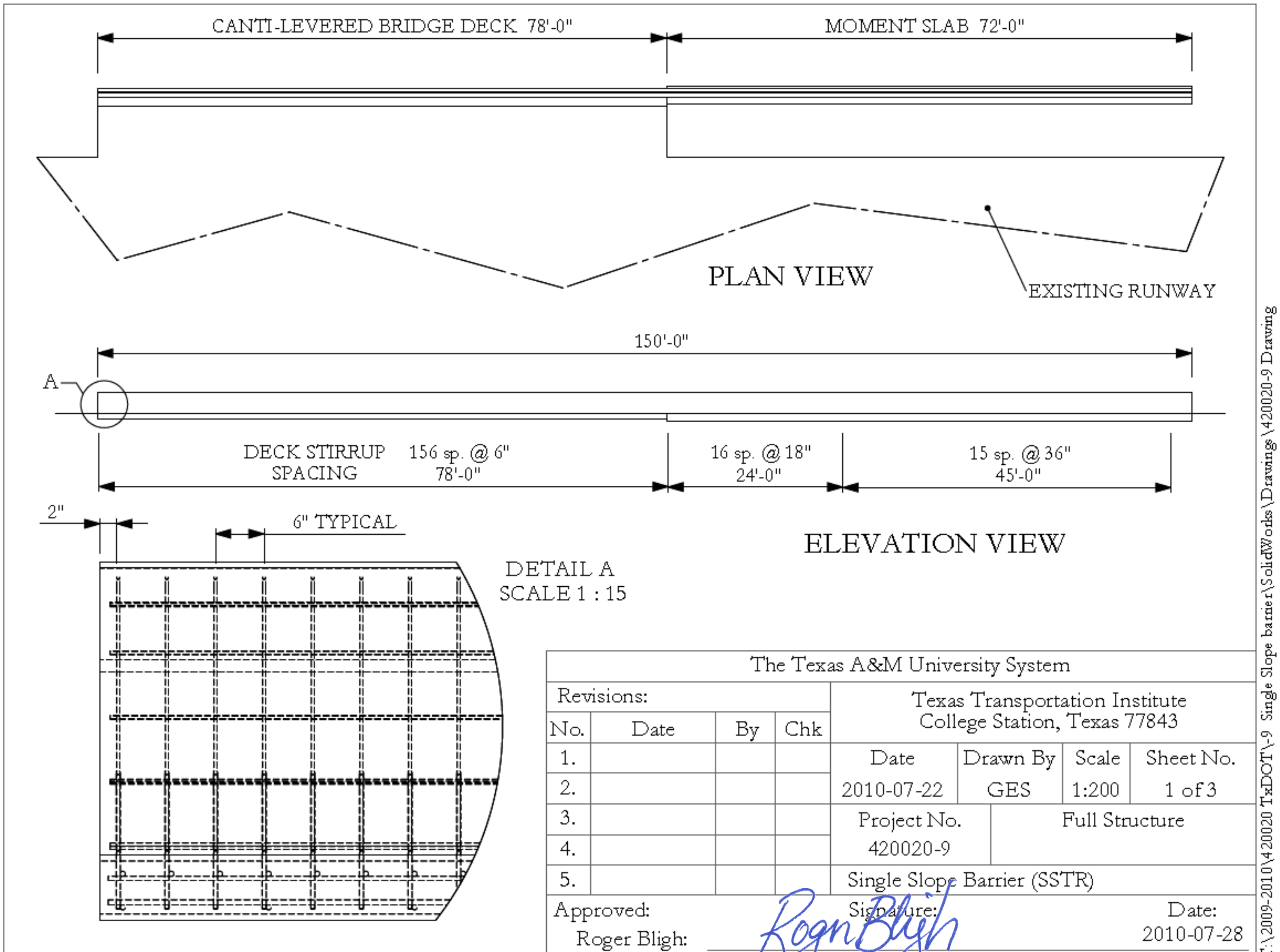


Figure 3.1. Layout of the TxDOT Single Slope Traffic Railing (SSTR).

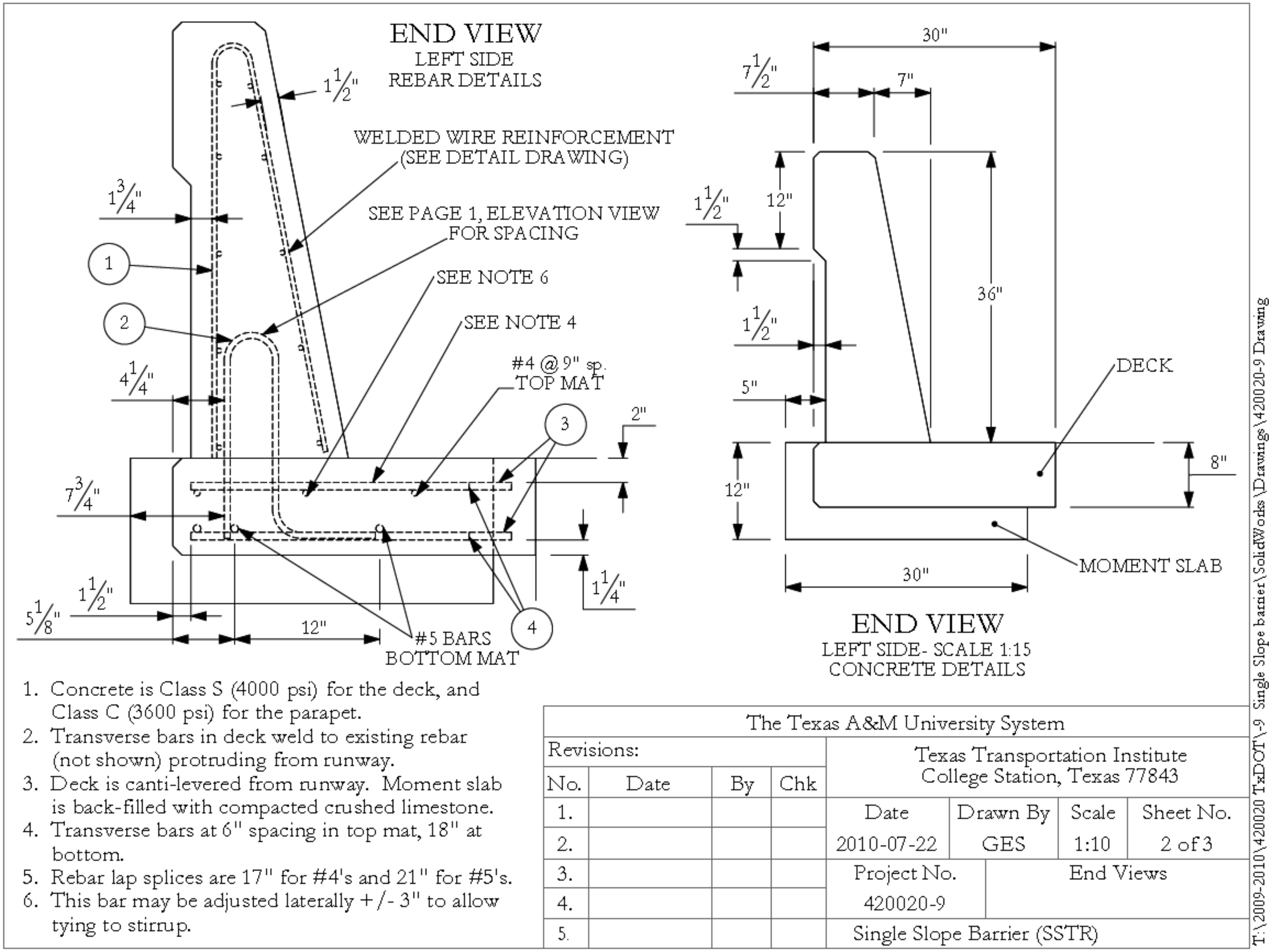


Figure 3.2. Details of the TxDOT Single Slope Traffic Railing (SSTR).

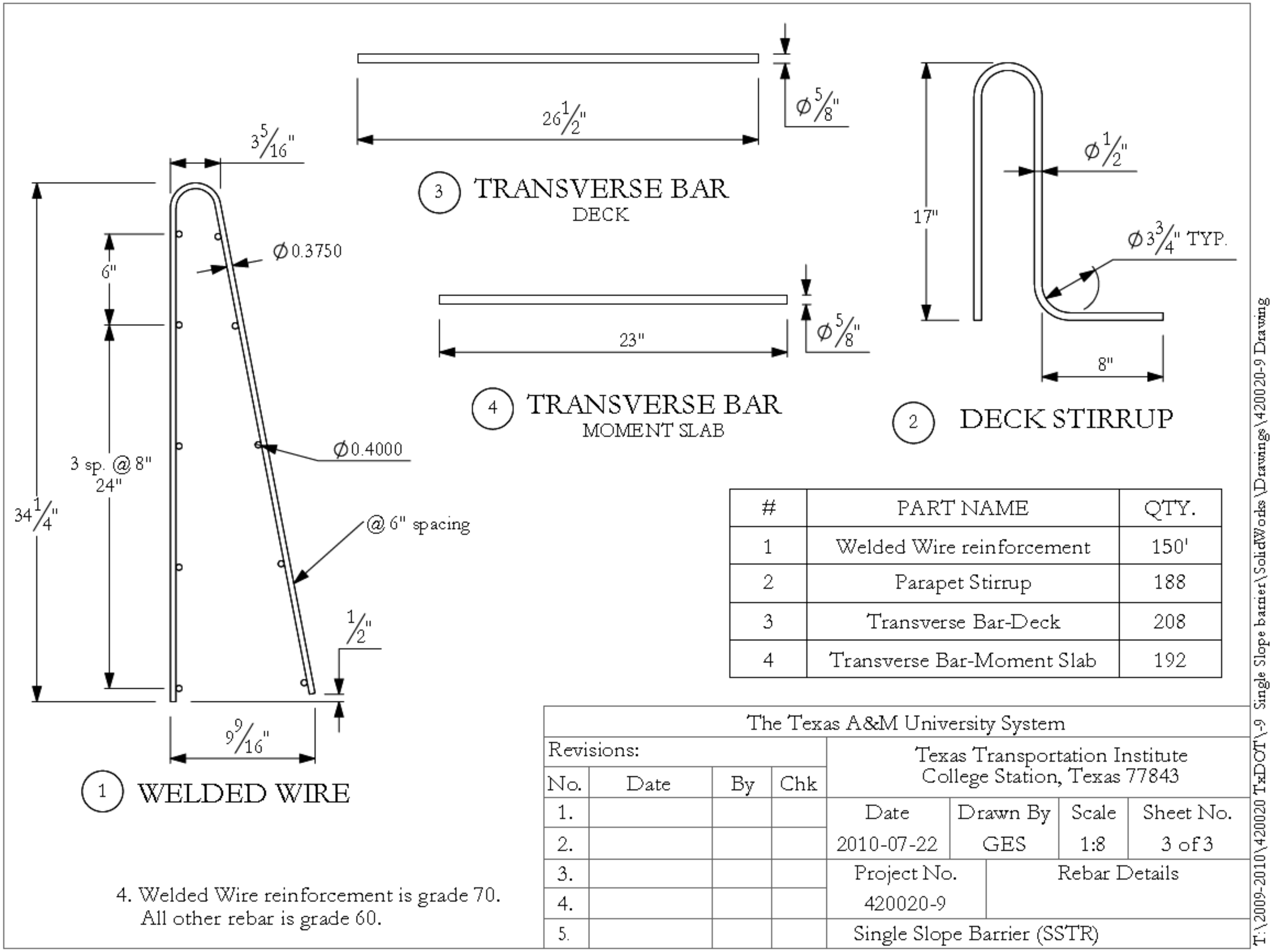


Figure 3.3. Details of the Reinforcement of the TxDOT Single Slope Traffic Railing (SSTR).

Figure 3.4. TxDOT Single Slope Traffic Railing (SSTR) before Test No. 420020-9b.

3.2 MATERIAL SPECIFICATIONS

The specified compressive strength of the concrete for the deck and the bridge rail was 4000 psi and 3600 psi, respectively. Concrete strength of the deck on the date of the test was 5167 psi, and that of the parapet was 5653 psi. Appendix A shows these test results.

All welded wire reinforcement was grade 70 steel. All other reinforcement was grade 60 steel. Appendix B provides the material properties of the reinforcement.

CHAPTER 4. TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1 CRASH TEST MATRIX

According to *MASH*, three tests are recommended to evaluate longitudinal barriers to test level four (TL-4). Details of these tests are described below.

> ***MASH* test 4-10**: A 1100C (2425 lb/1100 kg) passenger car 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 4-11**: A 2270P (5000 lb/2270 kg) 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 SUVs.
>
> ***MASH* test 4-12**: A 10000S (22,046 lb/10,000 kg) single unit truck impacting the CIP of the LON of the barrier at a nominal impact speed and angle of 56 mi/h and 15 degrees, respectively. This is a strength test for test level 4 to verify a barrier's capacity and ability to contain and redirect the single unit truck.

The test reported here corresponds to *MASH* test 4-12. Since the objective of this research was to determine the minimum rail height for *MASH* TL-4, only test 4-12 was performed to evaluate the stability of the single unit truck during the impact.

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

4.2 EVALUATION CRITERIA

The crash test was evaluated in accordance with the criteria presented in *MASH*. The performance of the TxDOT Single Slope Traffic Railing (SSTR) was 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 barrier to contain and redirect the vehicle, or bring the vehicle to a controlled stop in a predictable manner. Occupant risk criteria evaluates 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 herein. These criteria are listed in further detail under the assessment of the crash test.

CHAPTER 5. CRASH TEST PROCEDURES

5.1 TEST FACILITY

The full-scale crash test reported herein was performed at Texas Transportation Institute (TTI) Proving Ground. TTI Proving Ground is 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 as well as *MASH* guidelines and standards.

The TTI Proving Ground is a 2000-acre complex of research and training facilities located 10 miles northwest of the main campus of Texas A&M University. The site, formerly an Air Force base, has large expanses of concrete runways and parking aprons well-suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for construction and testing of the TxDOT Single Slope Traffic Railing 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 by 15 ft blocks, nominally 8–12 inches deep. The apron is over 50 years old, and the joints have some displacement, but are otherwise flat and level.

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

5.3 DATA ACQUISITION SYSTEMS

5.3.1 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. Accelerometer data is measured with an expanded uncertainty of ±1.7 percent at a confidence factor of 95 percent (k=2). Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra small size, solid state units designed for crash test service. Rate of rotation data is measured with an expanded uncertainty of 0.7 percent at a confidence factor of 95 percent (k=2). The TDAS Pro hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 16 channels is capable of providing precision amplification, scaling and filtering based on transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 values per second with a resolution of one part in 65,536. Once recorded, the data are backed up inside the unit by internal batteries should the primary battery cable be severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark as well as initiating the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The raw data are then processed by the Test Risk Assessment Program (TRAP) software to produce detailed reports of the test results. Each of the TDAS Pro units is returned to the factory annually for complete recalibration. Accelerometers and rate transducers are also calibrated annually with traceability to the National Institute for Standards and Technology.

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 ride-down acceleration. TRAP calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

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

5.3.2 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. Pressure-sensitive tape switches activated a flashbulb that was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked motion analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-DV camera and still cameras recorded and documented conditions of the test vehicle and installation before and after the test.

CHAPTER 6. CRASH TEST RESULTS

6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

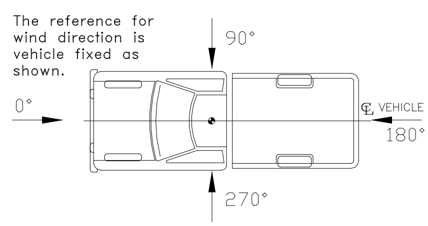
The test performed was *MASH* test 4-12. This test involves a 10000S vehicle weighing 22,046 lb ±660 lb and impacting the test article at an impact speed of 56 mi/h ±2.5 mi/h and an angle of 15 degrees ±1.5 degrees. The target impact point was 25 ft from the upstream end of the installation. The 1991 International 4700 single-unit box-van truck used in the test weighed 22,150 lb and the actual impact speed and angle were 57.2 mi/h and 16.1 degrees, respectively. The actual impact point was 24 ft downstream of the barrier.

6.2 TEST VEHICLE

A 1991 International 4700 single-unit box-van truck, shown in Figures 6.1 and 6.2, was used for the crash test. Test inertia weight of the vehicle was 22,150 lb, and its gross static weight was 22,150 lb. The height to the lower edge of the vehicle bumper was 19.0 inches, and the height to the upper edge of the bumper was 30.5 inches. Table C1 in Appendix C gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

6.3 WEATHER CONDITIONS

The test was performed on the morning of March 10, 2011. Weather conditions at the time of testing were as follows: Wind speed: 6 mi/h; wind direction: 327 degrees with respect to the vehicle (vehicle was traveling in a northeasterly direction); temperature: 59°F, relative humidity: 36 percent.



6.4 TEST DESCRIPTION

The 1991 International 4700 single-unit box-van truck, traveling at an impact speed of 57.2 mi/h, impacted the SSTR 24 ft downstream of the upstream end at an impact angle of 16.1 degrees. Shortly after contact, the bumper began to deform, and at 0.015 s, the driver's side front tire and wheel lost contact with the ground surface. The vehicle began to redirect at 0.029 s, and the tire and wheel on the front passenger side lost contact with the ground surface at 0.091 s. At 0.099 s, the front driver's side tire blew out, and at 0.230 s, the rear passenger's side tire and wheel lost contact with the ground surface. The rear of the box contacted the barrier at 0.244 s. At 0.264 s, the vehicle was traveling parallel with the barrier at a speed of 49.1 mi/h. The vehicle lost contact with the barrier at an exit speed and angle of 48.0 mi/h and 1.0 degrees, respectively. The vehicle continued to ride along the traffic face of the barrier and rode off the end. At 3.3 s after impact, the brakes on the vehicle were applied and the vehicle subsequently came to rest 185 ft downstream of the point of impact. Figures 6.1 and 6.2 in Appendix D show sequential photographs of the test period.

Figure 6.1. Vehicle and Installation Geometrics for Test No. 420020-9b.

Figure 6.2. Vehicle before Test No. 420020-9b.

6.5 DAMAGE TO TEST INSTALLATION

Figures 6.3 and 6.4 show damage to the barrier, which was cosmetic in nature. Tire marks and gouges were evident on the traffic face of the barrier. No new cracks in the concrete were noted. The barrier did not need repair after the impact.

6.6 VEHICLE DAMAGE

The 10000S vehicle sustained damage to the front left side (see Figure 6.5). The left frame rail, front axle, front U-bolts and springs, front tie rod, steering rod, left rear U-bolts and springs, and the drive shaft were all deformed. Also damaged were the front bumper, hood, left and right front tires and wheel rims, right and left fuel tanks, and left rear outer tire and wheel rim. Maximum crush of the exterior of the vehicle was approximately 12.0 inches. No notable occupant compartment deformation occurred. Figure 6.6 shows photographs of the interior of the vehicle.

6.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk for information purposes. In the longitudinal direction, the occupant impact velocity was 9.2 ft/s at 0.263 s, the highest 0.010 s occupant ridedown acceleration was 13.7 Gs from 1.602 to 1.612 s, and the maximum 0.050-s average acceleration was −6.4 Gs between 1.565 and 1.615 s. In the lateral direction, the occupant impact velocity was 11.5 ft/s at 0.263 s, the highest 0.010 s occupant ridedown acceleration was 9.0 Gs from 1.605 to 1.615 s, and the maximum 0.050 s average was 4.5 Gs between 1.566 and 1.616 s. Theoretical Head Impact Velocity (THIV) was 16.8 km/h or 4.7 m/s at 0.257 s; Post-Impact Head Decelerations (PHD) was 15.7 Gs between 1.602 and 1.612 s; and Acceleration Severity Index (ASI) was 2.42 between 1.566 and 1.616 s. Figure 6.7 summarizes these data and other pertinent information from the test. Vehicle angular displacements were not obtained due to a hardware malfunction. Appendix E, Figures E1 through E6, presents vehicle accelerations versus time traces.

Figure 6.3. After Impact Vehicle Position for Test No. 420020-9b.

Figure 6.4. Installation After Test No. 420020-9b.

Figure 6.5. Vehicle After Test No. 420020-9b.

Before Test

After Test

Figure 6.6. Interior of Vehicle for Test No. 420020-9b.

General Information

Test Agency	Texas Transportation Institute (TTI)
Test Standard Test No.	MASH Test 4-12
TTI Test No.	420020-9b
Date	2011-03-10

Test Article

Type	Bridge Rail
Name	TxDOT Single Slope Traffic Railing (SSTR)
Installation Length	150 ft
Material or Key Elements	Single-slope rigid concrete barrier, 11° slope traffic side, vertical field side, 13 inches wide at the base, 7.5 inches wide at the top, overall height 36 inches
Soil Type and Condition	Concrete Deck, Dry

Test Vehicle

Type/Designation	10000S
Make and Model	1991 International 4700 Truck
Curb	12,400 lb
Test Inertial	22,150 lb
Dummy	No dummy
Gross Static	22,150 lb

Impact Conditions

Speed	57.2 mi/h
Angle	16.1 degrees
Location/Orientation	24 ft dwnstrm of end

Exit Conditions

Speed	48.0 mi/h
Angle	1.0 degrees

Occupant Risk Values

Impact Velocity	
Longitudinal	9.2 ft/s
Lateral	11.5 ft/s
Ridedown Accelerations	
Longitudinal	13.7 G
Lateral	9.0 G
THIV	16.8 km/h
PHD	15.7 G
ASI	2.42
Max. 0.050-s Average	
Longitudinal	-6.4 G
Lateral	4.5 G
Vertical	-23.0 G

Post-Impact Trajectory

Stopping Distance	185 ft directly downstream

Vehicle Stability

Maximum Yaw Angle	Not available
Maximum Pitch Angle	Not available
Maximum Roll Angle	Not available
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	None measureable
Permanent	None measureable
Working Width	5.3 ft

Vehicle Damage

VDS	11LFQ3
CDC	11FLEW3
Max. Exterior Deformation	12 inches
OCDI	FS0000000
Max. Occupant Compartment Deformation	0

Figure 6.7. Summary of Results for *MASH* Test 4-12 on the TxDOT Single Slope Traffic Railing (SSTR).

6.8 ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable *MASH* safety evaluation criteria 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 Single Slope Traffic Railing (SSTR) contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the SSTR installation. No measureable deflection of the SSTR occurred. (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 ≤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 the 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 SSTR were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. (PASS)

No measureable occupant compartment deformation occurred. (PASS)

G. It is preferable, although not essential, that the vehicle remains upright during and after the collision.

Results: The 10000S vehicle remained upright during and after the collision event. (PASS)

CHAPTER 7. SUMMARY AND CONCLUSIONS

Due to an increase in the impact speed and vehicle mass of *MASH* test 4-12, the impact severity for test level 4 bridge rails has increased by 56 percent compared to *NCHRP Report 350*. AASHTO *LRFD Bridge Design Specifications* require test level 4 railings to have a minimum height of 32 inches and be designed to accommodate a 54-kip design impact load. These requirements are based on *NCHRP Report 350* test level 4 impact conditions. Due to the more severe impact conditions associated with *MASH* test level 4, there was a need to revise the minimum rail height and design impact load for TL-4 bridge rails.

The objective of this research was to determine the minimum acceptable rail height under *MASH* test level 4 impact conditions. Another objective was to determine the appropriate lateral design impact load for use with *AAHSTO LRFD* ultimate strength analysis of TL-4 bridge rails.

Impact simulations were performed to evaluate the stability of a 22,050-lb single unit truck impacting a rigid single slope barrier of various heights under *MASH* test 4-12 impact conditions. As the rail height decreased, the vehicle instability increased. Results of the simulation with a 36-inch rail height showed significant instability of the vehicle and the performance of the barrier was considered marginal. A rail height of 36 inches was, therefore, selected for full-scale crash testing.

LS-DYNA simulations were also used to calculate lateral loads resulting from simulated impacts of the SUT into rigid single slope barriers of various heights. Results indicated that the lateral loads for *MASH* TL-4 were significantly greater than for *NCHRP Report 350*. Due to the greater rail height now needed under *MASH*, the lateral loads were also increased by the interaction of the floor of the cargo box with the top of the rail. The researchers have based their recommendation for a lateral design impact load on a 42-inch rail height to accommodate a broader range of *MASH* TL-4 rail designs and heights. The recommended design load is 80 kips for *MASH* TL-4 rails.

MASH test 4-12 was performed on a 36-inch tall TxDOT single slope traffic rail that performed acceptably and met all relevant *MASH* criteria (see Table 7.1). The vehicle was successfully contained and redirected without any significant damage to the barrier. The phenomenon of rear wheels pitching up closer to the top of the rail as the vehicle yawed during redirection was also observed in the crash test; therefore, 36 inches is considered as the minimum rail height for *MASH* TL-4 impacts conditions.

Safety shape profiles (e.g., F-shape and NJ profile) are known to instigate significant climb and instability in passenger vehicles due to tire interaction with the toe of these barriers. However, due to a significantly greater mass and wheel radius, the effect of the toe on the stability and climb of the 22,050-lb SUT vehicle is insignificant. Previous testing with the 32-inch NJ barrier under *MASH* TL-4 conditions did not reveal any significant climb attributable to the safety profile of the barrier (*4*). Therefore, although the simulation analyses and crash test performed in this research used the single slope barrier profile, the minimum rail height and design impact load recommendations are considered applicable to all other barrier profiles.

In this research, only *MASH* test 4-12 was performed on the 36-inch SSTR to verify simulation results in establishing the minimum rail height for TL-4 bridge rails. The matrix for *MASH* test level 4 also includes test 4-10 with a small passenger car and test 4-11 with a pickup truck. While these tests were not performed under this research, the results of other tests can be used to infer that the 36-inch tall SSTR should perform acceptably for both the small car and pickup truck vehicles.

In 2010, TTI performed *MASH* test 4-11 on a 36-inch TxDOT SSTR cast on a pan-formed bridge deck (*8*). The TxDOT SSTR performed acceptably in this test.

In 2006, the Midwest Roadside Safety Facility (MwRSF) conducted test 4-10 on a rigid 32-inch tall New Jersey profile concrete barrier (*9*). Although significant climb was observed, the vehicle was successfully contained and redirected. It is expected the vehicle will undergo less climb with the TxDOT 36-inch SSTR due to its single slope profile and increased rail height. The reduced vehicle climb is expected to result in greater damage to the vehicle and an increase in the impact force and occupant risk indices compared to the MwRSF test. More recently in 2010, TTI performed a crash test with an 1100C *MASH* vehicle impacting the end of a vertical face median gate at a nominal speed and angle of 62.2 mi/h and 25 degrees, respectively (*10*). The face of the median gate was 24-inches in height with an 11-inch clearance underneath providing an overall height of 35 inches. The impact took place 49 inches upstream of the end of a vertical concrete parapet that supported the median gate. The median gate and concrete parapet acted nearly rigid to the impacting vehicle with no measurable permanent or dynamic deflection. Under these nearly rigid impact conditions, which are similar to impact conditions of test 4-10 required for *MASH* TL-4 barriers, the small car performed acceptably with regard to occupant compartment deformation and occupant risk.

The small car tests with the 32-inch NJ barrier and the nearly rigid vertical-faced median gate lead the researchers to believe that the 36-inch TxDOT SSTR should perform acceptably for test 4-10 with a small passenger car.

Table 7.1. Performance Evaluation Summary for *MASH* Test 4-12 on the TxDOT Single Slope Traffic Railing (SSTR).

Test Agency: Texas Transportation Institute — Test No.: 420020-9b — Test Date: 2011-03-10

***MASH* Test 4-12 Evaluation Criteria**	***Test Results***	***Assessment***
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*	The TxDOT Single Slope Traffic Railing (SSTR) contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the SSTR installation. No measureable deflection of the SSTR occurred.	Pass
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.*	No detached elements, fragments, or other debris from the SSTR were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
Deformations of, or intrusions into the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No measureable occupant compartment deformation occurred.	Pass
G. *It is preferable, although not essential, that the vehicle remain upright during and after collision.*	The 10000S vehicle remained upright during and after the collision event.	Pass

CHAPTER 8. IMPLEMENTATION STATEMENT

Based on the finite element analysis and crash testing presented in this report, the minimum rail height for *MASH* test level 4 bridge rails was determined to be 36 inches. The impact load for designing *MASH* TL-4 bridge rails using the *AASHTO LRFD* yield line strength analysis was determined to be 80 kips.

A crash test was performed on a 36-inch tall TxDOT Single Slope Traffic Rail (SSTR). The impact capacity of the TxDOT SSTR was determined to be 80 kips, which meets the recommended 80-kip design strength requirement. The rail performed acceptably under *MASH* test 4-12 impact conditions (i.e., 22,046-lb single unit truck impacting at a speed of 56 mi/h and an angle of 15 degrees). In previous testing, the TxDOT SSTR performed acceptably for *MASH* test 4-11 with a 5000-lb pickup truck. While no direct tests have been performed with the small passenger car (i.e., test 4-10), previous testing with other barriers leads the researchers to believe that the TxDOT SSTR will perform acceptably for this test.

The 36-inch tall TxDOT SSTR is, therefore, considered suitable for immediate implementation on Texas highways wherever *MASH* test level 4 protection is desired. Statewide implementation can be achieved by revising the standard detail sheet of the TxDOT SSTR to indicate that it can be used as a *MASH* test level 4 bridge rail.

REFERENCES

1. American Association of State Highway and Transportation Officials. *Manual for Assessing Safety Hardware*, AASHTO Subcommittee on Bridges and Structures, Washington, D.C., 2009.
2. H. E. Ross, D. L. Sicking, R. A. Zimmer, and J. D. Michie. *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.
3. American Society of State Highway and Transportation Officials. *AASHTO LRFD Bridge Design Specifications*. Third Edition. Washington, D.C., 2004.
4. D. L. Bullard, R. P. Bligh, and W. L. Menges. *Appendix A: MASH-08 TL-4 Testing and Evaluation of the New Jersey Safety Shape Bridge Rail.* NCHRP Project 22-14, College Station, Texas, 2008.
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7. *Methodology for Validation and Documentation of Vehicle Finite Element Crash Models for Roadside Hardware Applications*, National Transportation Research Center, Inc., http://single-unit-truck.model.ntrci.org/description/ .
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9. D. L. Sicking and K. K. Mak. *Improvement of Procedures for the Safety-Performance Evaluation of Roadside Features, Draft Final Report*, National Cooperative Highway Research Program Project No. 22-14(02), National Research Council, Washington, D.C., 2007.
10. R.P. Bligh, D.R. Arrington, C. Silvestri, W.L. Menges. *Development of a MASH TL-3 Median Barrier Gate*. Report No. 9-1002-2. Texas Transportation Institute, College Station, Texas, 2011.

APPENDIX A. CONCRETE STRENGTH TESTING

CONCRETE CORE TEST REPORT

Report Number: A1111007.0002
Service Date: 01/13/11
Report Date: 01/21/11
Task: PO#420020-9a

Terracon
6198 Imperial Loop
College Station, TX 77845
979-846-3767 Reg No: F-3272

Client

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

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1111007

Material Information

Specified Strength: 4000 psi @ 28 days

Specified Length: 3.23 Min
Mix ID:
Nominal Maximum Size Aggregate: 1"

Sample Information

Placement Date: August 2010
Date Tested: 01/18/11 **Time:** 0000
Sampled By: Hill, Joseph
Drill Directions: Vertical
Date Core Obtained: 01/11/11 **Time:** 0900
Date Ends Trimmed: 01/18/11 **Time:** 0000
Moisture Conditioning History: According to ASTM C-42

Laboratory Test Data

Core ID	Location	Cored Length (in)	Trim Length (in)	Capped Length (in)	Diam. (in)	Area (sq in)	Length / Diam. Ratio	Max Load (lbs)	Corr. Factor	Comp. Strength (psi)	Fracture Type	Density (pcf)
1	Single slope wall	7.3	6.6	6.7	3.23	8.19	2.07	47560	1.000	5800	4	
2	Single slope wall	7.8	6.4	6.6	3.23	8.19	2.04	45900	1.000	5600	4	
3	Single slope wall	8.0	6.5	6.7	3.23	8.19	2.07	45560	1.000	5560	4	
4	Single slope deck	7.8	6.4	6.5	3.23	8.19	2.01	41910	1.000	5110	4	
5	Single slope deck	8.2	6.5	6.6	3.23	8.19	2.04	40960	1.000	5000	4	
6	Single slope deck	8.0	6.5	6.7	3.23	8.19	2.07	44150	1.000	5390	4	

Comments:

CONCRETE CORE TEST REPORT

Report Number: A1111007.0002
Service Date: 01/13/11
Report Date: 01/21/11
Task: PO#420020-9a

Terracon
6198 Imperial Loop
College Station, TX 77845
979-846-3767 Reg No: F-3272

Client

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

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1111007

Services: Secure cores from insitu concrete and test cores for compressive strength in accordance with ASTM C41.
Terracon Rep.: Cut-N-Shoot Drilling
Reported To:
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Emailed

Started: 0730
Finished: 1030
Lunch/NC:
Reviewed By:
Mark E.Dornak, E.I.T.
Project Manager

Test Methods: ASTM C42

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.

CR0004, 4-28-10, Rev.3

APPENDIX B. STEEL CERTIFICATION DOCUMENTATION

MATERIAL USED

TEST NUMBER	420020-9	Single Slope Parapet
DATE		

DATE RECEIVED	ITEM NUMBER	DESCRIPTION	SUPPLIER	HEAT #
2010-08-12	Rebar 04-20	1/2" x 20' gr 60 SLV	CMC-Sheplers	3017081
2010-08-12	Rebar 05-13	5/8" x 20' gr 60 SLV	CMC-Sheplers	3016372
2010-08-03	Welded Wire-2	Welded Wire for Parapet	Insteel	TO92121

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

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

Daniel J. Schacht
Quality Assurance Manager

HEAT NO.:3017081 SECTION: REBAR 13MM (#4) 20'0" 420/60 GRADE: ASTM A615-09b Gr 420/60 ROLL DATE: 06/05/2010 MELT DATE: 06/01/2010	SOLD TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	SHIP TO	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 80338951 BOL#: 70114631 CUST PO#: 4576UU CUST P/N: DLVRY LBS / HEAT: 46011.000 LB DLVRY PCS / HEAT: 3444 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.40%				
Mn	0.79%				
P	0.015%				
S	0.043%				
Si	0.18%				
Cu	0.81%				
Cr	0.16%				
Ni	0.34%				
Mo	0.059%				
V	0.003%				
Cb	0.001%				
Sn	0.024%				
Al	0.002%				
Yield Strength test 1	67.1ksi				
Tensile Strength test 1	104.5ksi				
Elongation test 1	14%				
Elongation Gage Lgth test 1	8IN				
Bend Test Diameter	1.750IN				
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 :

07/16/2010 23:20:12
Page 1 OF 1

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT

For additional copies call
830-372-8771

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

Daniel J. Schacht
Quality Assurance Manager

HEAT NO.:3016372 SECTION: REBAR 16MM (#5) 20'0" 420/60 GRADE: ASTM A615-09b Gr 420/60 ROLL DATE: 05/02/2010 MELT DATE: 04/30/2010	S O L D T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	S H I P T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 80320707 BOL#: 70108882 CUST PO#: 45767T CUST P/N: DLVRY LBS / HEAT: 45990.000 LB DLVRY PCS / HEAT: 2205 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.39%				
Mn	0.95%				
P	0.017%				
S	0.032%				
Si	0.20%				
Cu	0.33%				
Cr	0.28%				
Ni	0.21%				
Mo	0.069%				
V	0.002%				
Cb	0.002%				
Sn	0.013%				
Al	0.002%				
Yield Strength test 1	69.3ksi				
Tensile Strength test 1	106.2ksi				
Elongation test 1	13%				
Elongation Gage Lgth 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 :

06/15/2010 20:42:39
Page 1 OF 1

Insteel Wire Products
500 Klemp Road
Dayton, TX 77535
Metals Tensile

Job Number:	330005-01	Heat Number (XW): TO91834
Item Number:	533-153483-(2)	
Product Style:	VARX6D10.7/D13.4	
Prod. Style Cont.:	68"(.8125+.875)X31'	
Rod Size & Origin (LW):	W11716	
Heat Number (LW):	TO92121	
Rod Size & Origin (XW):	W1112	

Oper. #	Sample #	Diameter in	CS Area in^2	Ultimate lbf	Ultimate ksi	Red Area %	Bend Test OK
4667/7230	1	0.369	0.1069	10420	97.5	0	YES
4667/7230	2	0.369	0.1069	10730	100.4	0	YES
4667/7230	1	0.413	0.134	13200	98.6	0	YES
4667/7230	2	0.413	0.134	13220	98.7	0	YES
Avg.		0.391	0.1205		98.8		
SD		0.0254	0.0156		1.196		
Min.				10420			
Max.				13220			

The use of this product conforms with Buy America Requirements set forth in 23 CFR Subpart D, Section 635.410, Buy America Requirements and Title 49 - Transportation, Chapter VI - Federal Transit Administration, Department of Transportation Part 661 - Buy America Requirements - Surface Transportation Assistance Act of 1982, As Amended

This is to certify that the material listed above conforms to the following specifications.:

ASTM: A 496-07/ A 497-0 Test Requirements.

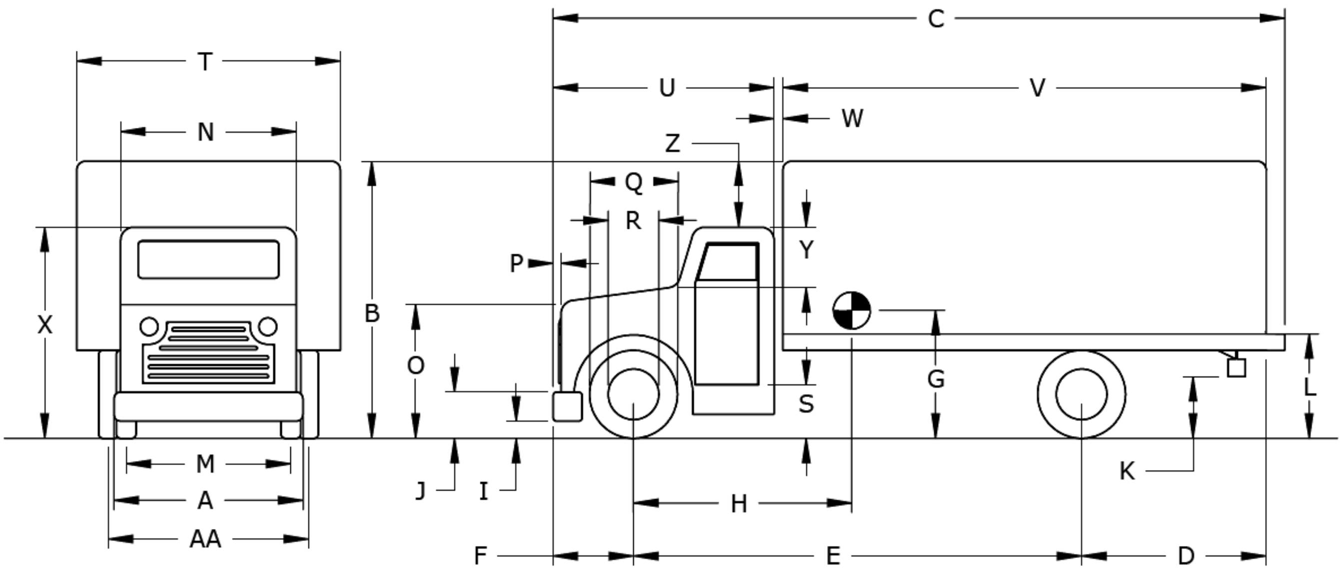
Signature: EHaley Date: 8 / 2 / 2009

APPENDIX C. TEST VEHICLE PROPERTIES AND INFORMATION

Table C1. Vehicle Properties for Test No. 420020-9b.

Vehicle Inventory Number: 909

Date:	2011-03-10	Test No.:	420020-9b	VIN No.:	1HTSCNEN2MH351312
Year:	1991	Make:	International	Model:	4700
Odometer:	67607	Tire Size Front:	275/75R22.5	Tire Size Rear:	275/80R22.5



Vehicle Geometry: inches

A	Front Bumper Width:	95.25	J	Front Bumper Top:	30.50	S	Bottom Door Height:	39.25
B	Overall Height:	133.00	K	Rear Bumper Bottom:	27.50	T	Overall Width:	95.00
C	Overall Length:	274.00	L	Rear Frame Top:	48.00	U	Cab Length:	97.00
D	Rear Overhang:	56.00	M	Front Track Width:	80.50	V	Trailer/Box Length:	173.50
E	Wheel Base:	187.50	N	Roof Width:	73.00	W	Gap Width:	1.00
F	Front Overhang:	30.50	O	Hood Height:	61.50	X	Overall Front Height:	96.00
G	C.G. Height:		P	Bumper Extension:	2.00	Y	Roof-Hood Distance:	26.50
H	C.G. Horizontal Distance:.	103.87	Q	Front Tire Width:	39.50	Z	Roof-Box Height Difference:	33.50
I	Front Bumper Bottom:	19.00	R	Front Wheel Width:	23.50	AA	Rear Track Width:	80.50

Allowable Range: C = 394 inches max.; E = 240 inches max.; L = 51 ±2 inches; Ballast Center of Mass Ht = 63 ±2 inches above ground;

Wheel Center Height Front	19.00	Wheel Well Clearance (Front)	12.50	Frame Height (Front)	25.00
Wheel Center Height Rear	19.75	Wheel Well Clearance (Rear)	5.25	Frame Height (Rear)	28.75

Table C1. Vehicle Properties for Test No. 420020-9b (continued).

Vehicle Inventory Number: 909

Date:	2011-03-10	Test No.:	420020-9b	VIN No.:	1HTSCNEN2MH351312
Year:	1991	Make:	International	Model:	4700

WEIGHTS
(lb)

	CURB		**TEST INERTIAL**		**GROSS STATIC**
$W_{front\ axle}$	6430		9880		
$W_{rear\ axle}$	5970	Allowable Range	12270	Allowable Range	
W_{TOTAL}	12400	13,200 ±2200 lb	22150	22,046 ±660 lb	

Ballast: 5290 + 4530 (as-needed)
(See *MASH* Section 4.2.1.2 for recommended ballasting)

Mass Distribution
(lb): **LF:** 4940 **RF:** 4940 **LR:** 6260 **RR:** 6010

Engine Type: 6 cylinder

Engine Size: DAT 360

Transmission Type:

___ Auto or x Manual

___ FWD x RWD ___ 4WD

Accelerometer Locations (inches)

	x	**y**	**z**
f			
c	109.00	0	42.00
r	192.00	0	44.00

Describe any damage to the vehicle prior to test:

Other notes:

APPENDIX D. SEQUENTIAL PHOTOGRAPHS

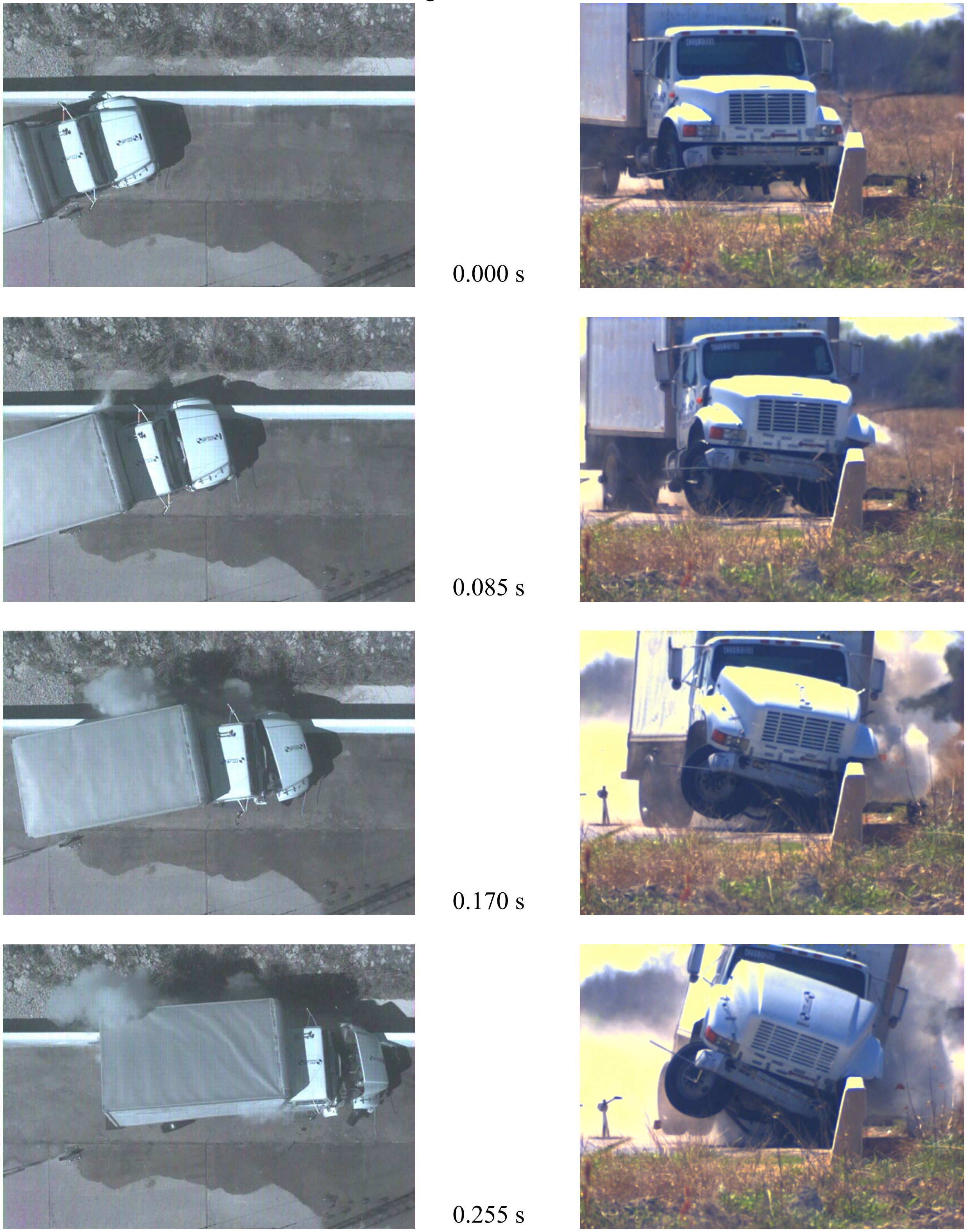


Figure D1. Sequential Photographs for Test No. 420020-9b (Overhead and Frontal Views).

0.340s

0.425 s

0.510 s

0.595 s

Figure D1. Sequential Photographs for Test No. 420020-9b (Overhead and Frontal Views) (continued).

0.000 s

0.085 s

0.170 s

0.255 s

0.340 s

0.425 s

0.510 s

0.595 s

Figure D2. Sequential Photographs for Test No. 420020-9b (Rear View).

APPENDIX E. VEHICLE ACCELERATIONS

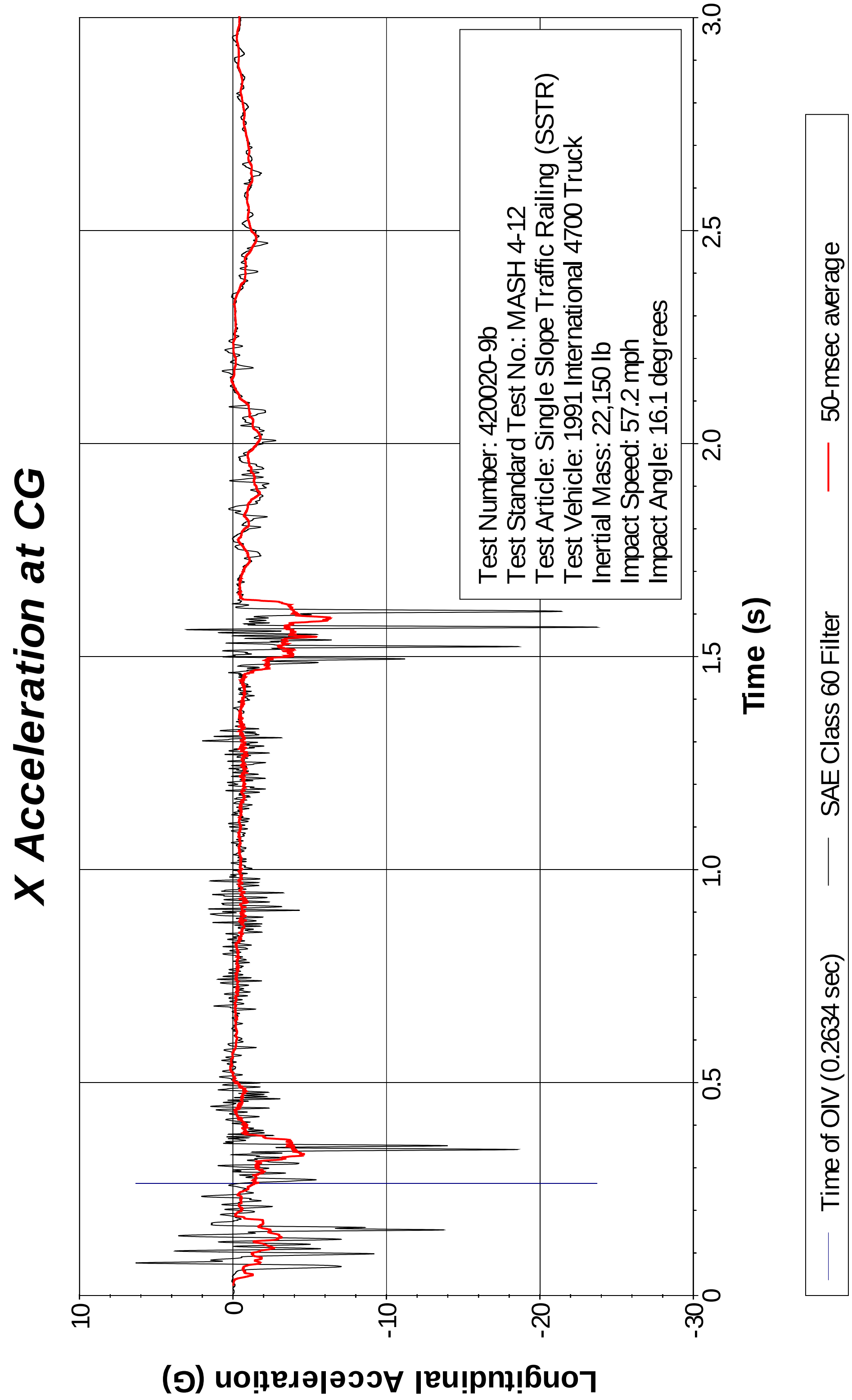


Figure E1. Vehicle Longitudinal Accelerometer Trace for Test No. 420020-9b (Accelerometer Located at Center of Gravity).

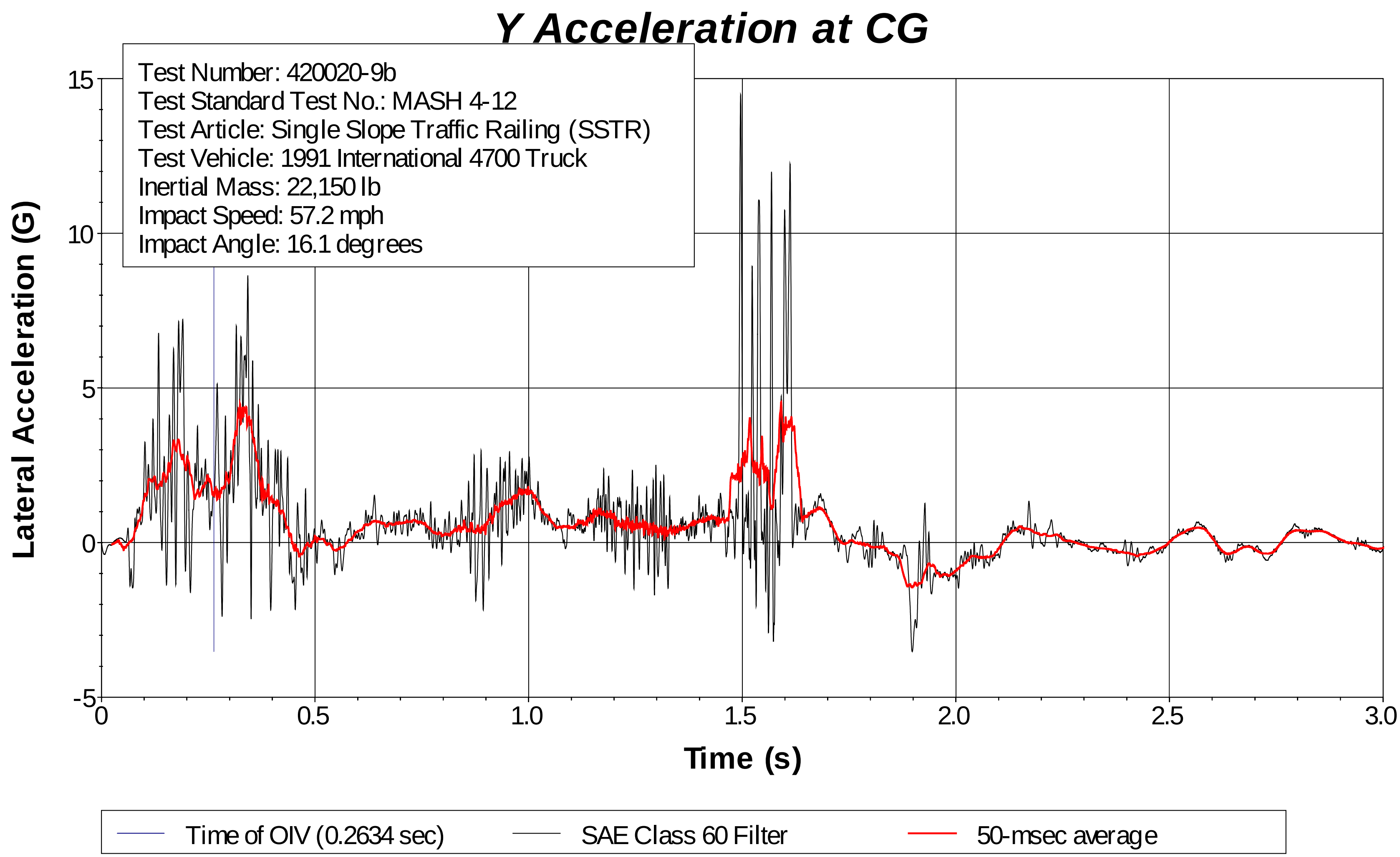


Figure E2. Vehicle Lateral Accelerometer Trace for Test No. 420020-9b (Accelerometer Located at Center of Gravity).

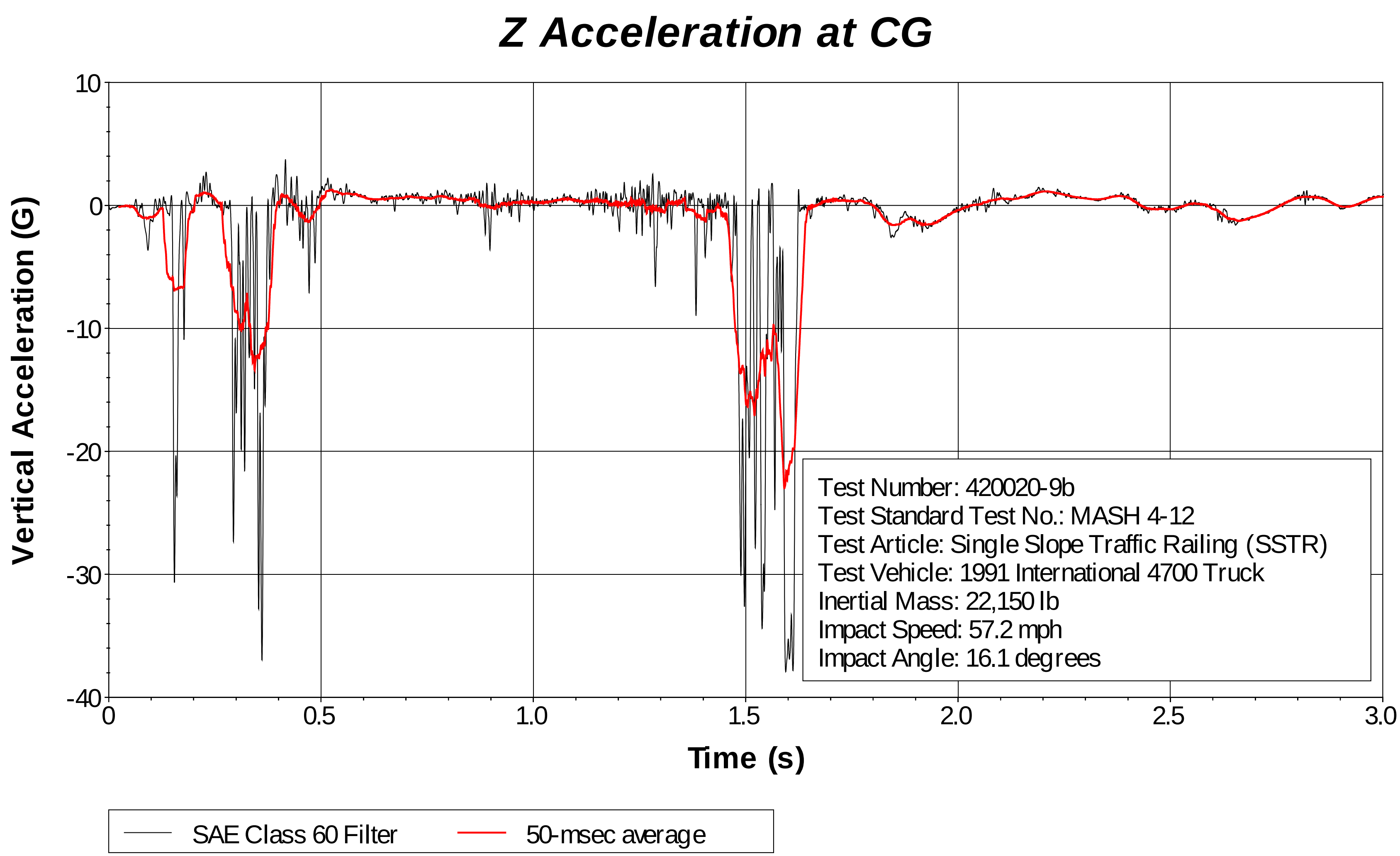


Figure E3. Vehicle Vertical Accelerometer Trace for Test No. 420020-9b (Accelerometer Located at Center of Gravity).

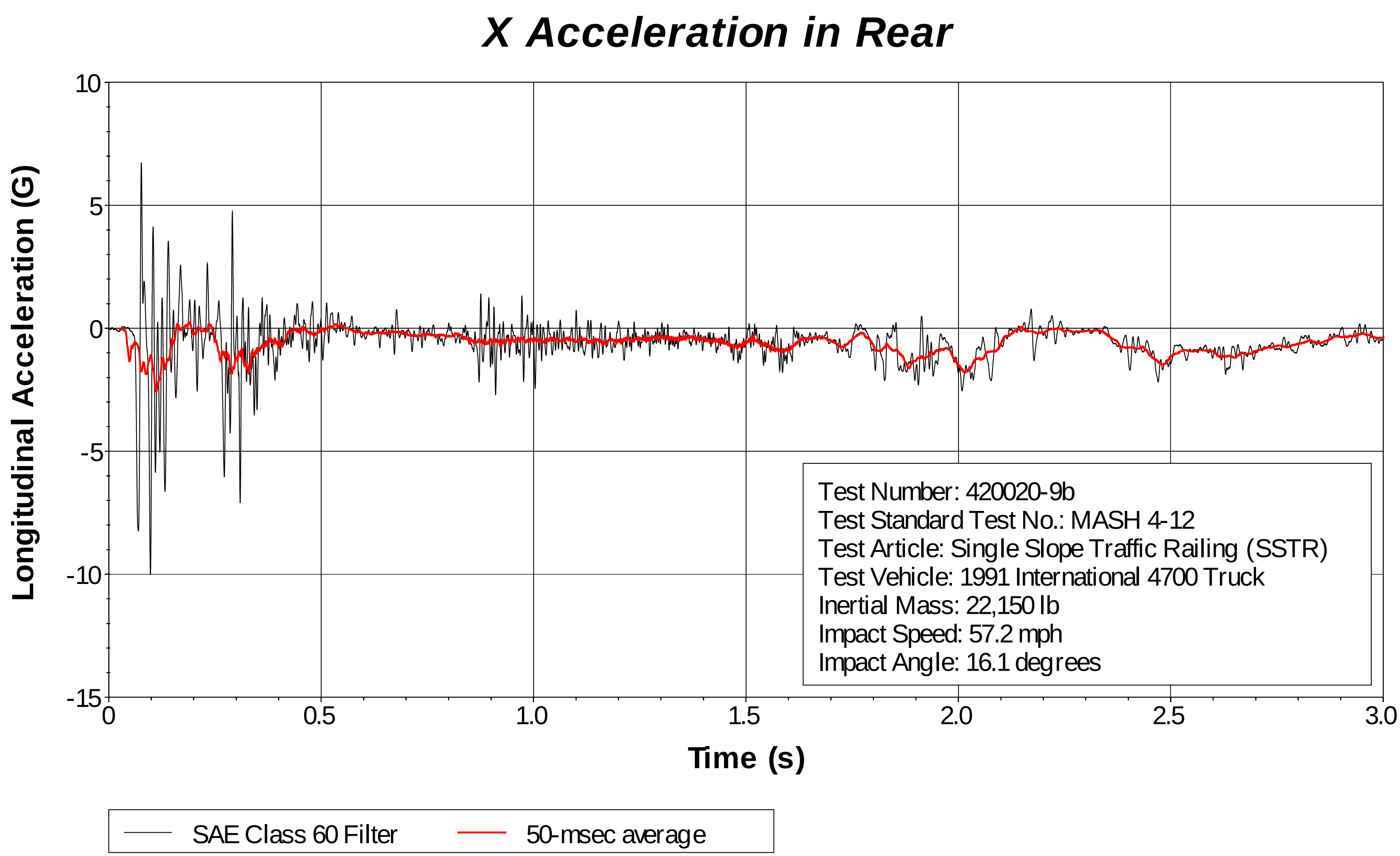


Figure E4. Vehicle Longitudinal Accelerometer Trace for Test No. 420020-9b (Accelerometer Located over Rear Axle).

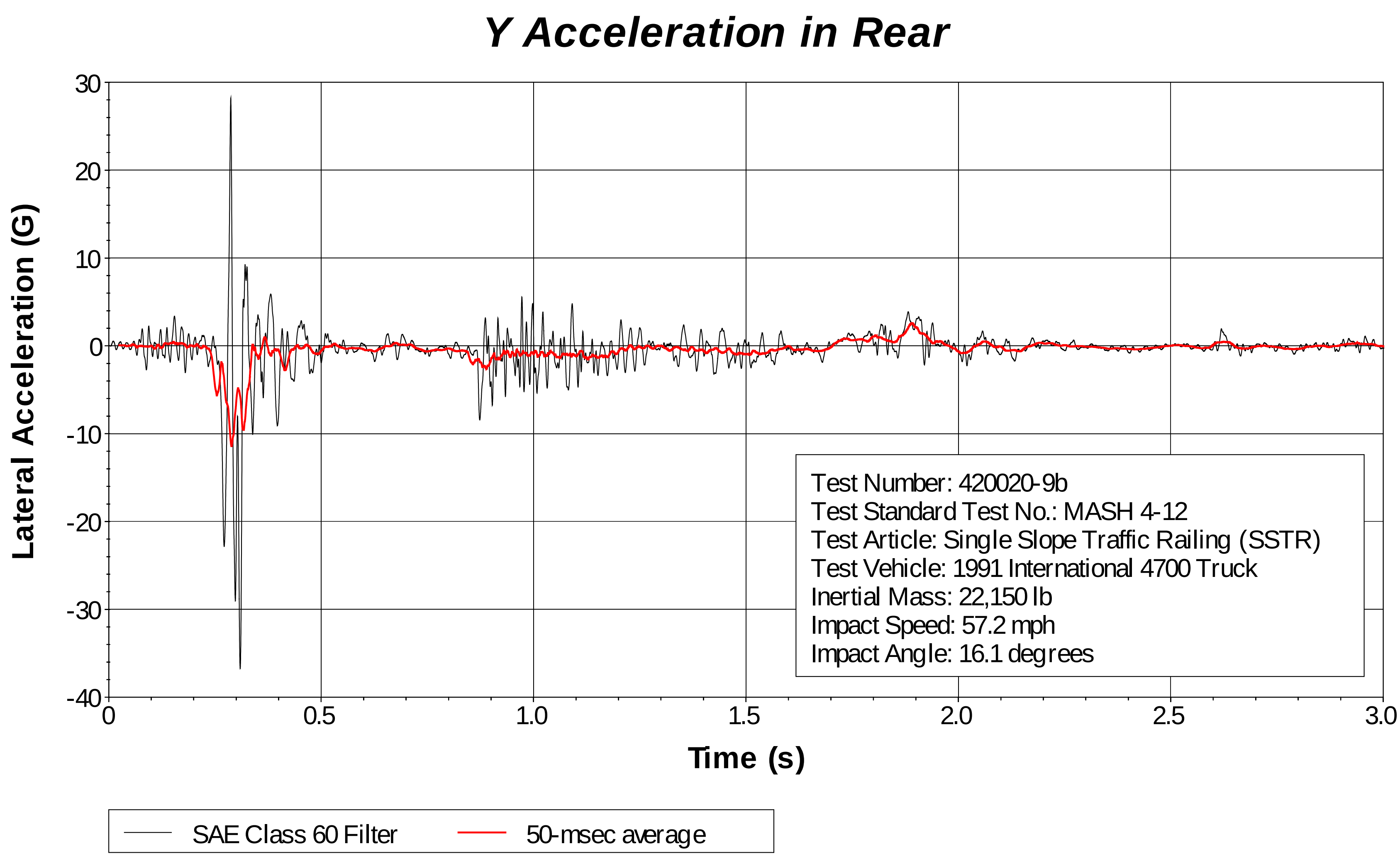


Figure E5. Vehicle Lateral Accelerometer Trace for Test No. 420020-9b (Accelerometer Located over Rear Axle).

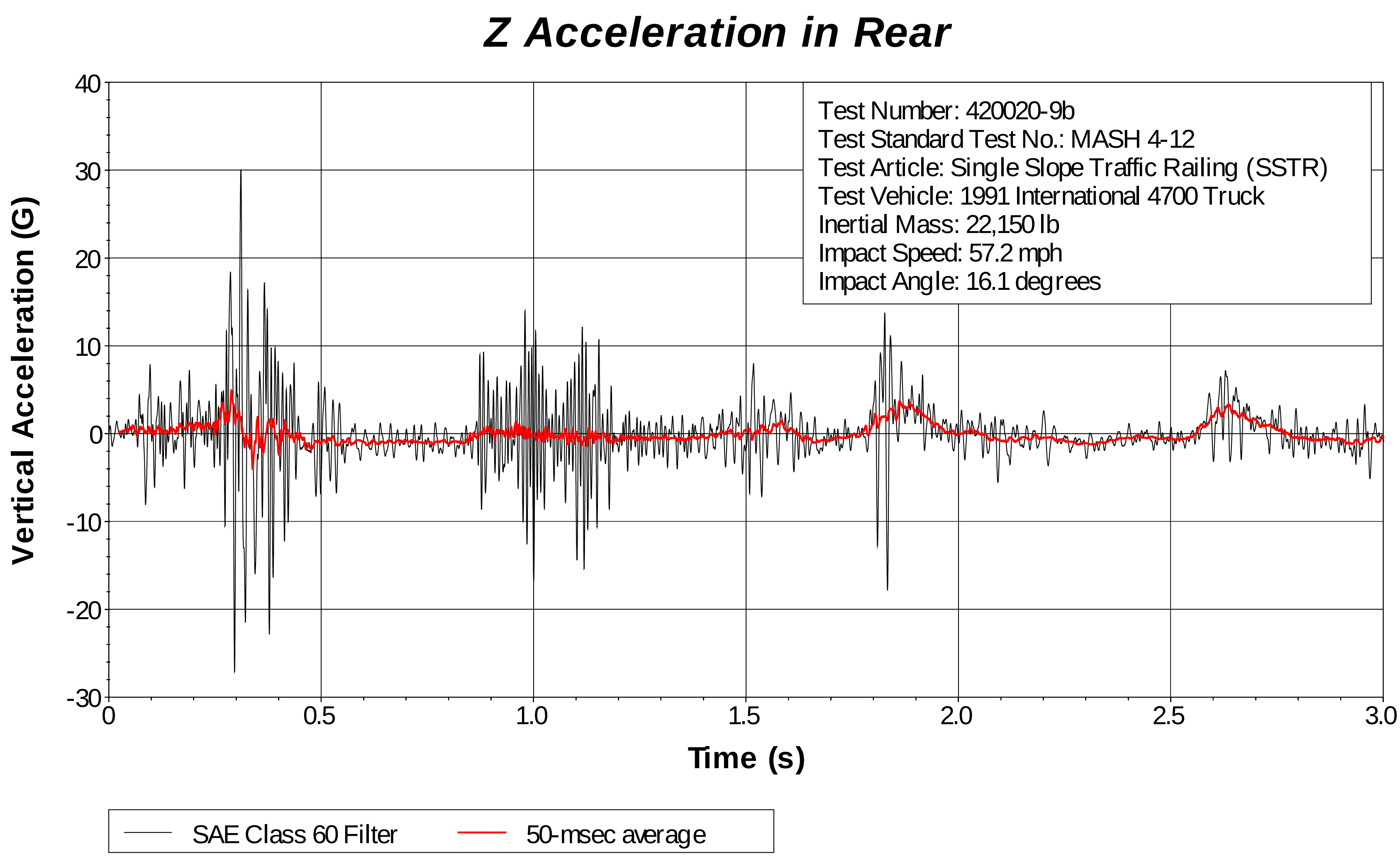


Figure E6. Vehicle Vertical Accelerometer Trace for Test No. 420020-9b (Accelerometer Located over Rear Axle).