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CRASH TEST AND EVALUATION OF RESTRAINED SAFETY-SHAPE CONCRETE BARRIERS ON CONCRETE BRIDGE DECK

ISO 17025 Laboratory
Testing Certificate # 2821.01

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

Test Report 9-1002-15-3

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
Federal Highway Administration and the
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16. Abstract

This research designed and tested a new portable concrete barrier that meets the performance of *MASH* TL-4 and can be used in temporary and permanent applications on bridge decks. Additionally, this new barrier system will minimize deflection, allowing placement of the barrier system as close to the edge of the deck system without compromising barrier performance for *MASH* TL-4. Additional, using the barrier system on a minimum deck thickness of 7.0 inches was also preferred. This report presents the design and testing results of the new successful barrier system developed for this project.

The purpose of the testing reported herein was to assess the performance of the restrained safety-shape concrete barrier on concrete bridge deck according to the safety-performance evaluation guidelines included in AASHTO *MASH* for Test Level 4 (TL-4). The crash test performed was in accordance with *MASH* test 3-11, which involves a 10000S vehicle impacting the restrained safety-shape concrete barrier at a target impact speed and impact angle of 56 mi/h and 15 degrees, respectively.

The safety-shape concrete barrier restrained on concrete deck contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 7.1 inches. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment or show undue hazard to others in the area. Maximum occupant compartment deformation was 6.0 inches in the left side floor pan adjacent to the left front door. The 10000S vehicle remained upright during and after the collision period. The restrained safety-shape concrete barrier on concrete deck performed acceptably for *MASH* Test 4-12.

The new restrained barrier section with the cross-bolt connection as described and tested herein using 1-inch diameter dowels anchored to a 7.0-inch thick deck is recommended for implementation on new or existing retrofit projects. This barrier system successfully met all the requirements of MASH TL-4. This barrier system as designed and tested herein is recommended for use on the National Highway System with deck thicknesses of 7.0 inches or greater.

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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.

This report is not intended for construction, bidding, or permit purposes. The researcher in charge of the project was William F. Williams, P.E., #71898.

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.

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 BACKGROUND

This project provides 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. Some obstacles that cannot be moved out of the clear zone (e.g., mailboxes, sign supports) are designed to break away. To maintain the desired level of safety for the motoring public, these safety devices must be designed to accommodate various site conditions and 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.

Historically, TxDOT standards have include several different barrier systems that can be classified as temporary/precast barriers. The low-profile barrier has been successfully tested and approved for Test Level 2 (TL-2) of National Cooperative Highway Research Program (NCHRP) *Report 350* (*1*), which permits its use on roadways with speeds up to 43.5 mi/h. This 20-inch tall barrier is intended for use in urban work zones where sight distance problems at intersections are common (*2*). The single slope barrier has been approved for TL-3, which makes it acceptable for general use on all roadways, including high-speed facilities on the national highway system (*3*). The Type 3 precast concrete traffic barrier is intended for use in work zones, primarily on bridge deck, where a temporary barrier is required to be placed less than 2 ft from the edge of a deck or drop-off. This system, which involves securing the barrier section to the deck using angled pins, was successfully tested to TL-3 conditions (*4*).

The Type 2 precast concrete traffic barrier (PCTB[1]-90) has two different joint types. Joint type A includes a male-female design option, which uses three 1-inch diameter tiebars and a slotted design option, which uses a prefabricated tiebar grid. During a full-scale crash test, this joint can fail, resulting in dynamic barrier deflection in excess of 9 ft (*5*). A retrofit for this barrier has been developed that limits the lateral deflection to 4 ft under design impact conditions. The retrofit involves attaching a steel plate or strap on the toe of each side of the barrier across the joint between two segments using epoxy or mechanical anchors. Joint type B incorporates a 12-inch overlap of the two barrier sections, which are then bolted together through the overlapping sections using a 1-inch diameter threaded rod. There are presently no plans to evaluate this barrier with additional crash testing due to its limited use throughout the state.

Connection of the portable and precast concrete barrier rail (CB[P&P]-87) involves bolting a 3 ft-6 inch steel angle section to the bottom of the barrier segments across each side of a joint. The Houston District uses a modified version of the design that utilizes a channel connector. This system has not been crash tested.

Several years ago, a new precast concrete traffic barrier was developed and successfully crash tested under Project 0-4162 (*6*). The barrier incorporated an innovative cross-bolt connection comprised of two ⅞-inch diameter high-strength threaded rods. This connection limited the barrier deflection to only 19 inches, which is the lowest deflection of any free-standing, portable concrete barrier approved to *NCHRP Report 350*. The barrier incorporated an F-shape profile rather than the New Jersey profile used on current TxDOT barriers. The F-shape is widely considered to provide improved impact performance over the New Jersey shape. Full-scale crash testing indicates that vehicles experience less climb and remain more stable during impacts with barriers having an F-shape profile compared to those with a New Jersey profile. This successfully crash tested connection design was used for this project.

These portable work zone barriers all serve a similar purpose of shielding motorists from hazards, and separating and protecting work crews from traffic. However, with the exception of the low-profile barrier, which is limited to low-speed applications, all of the above mentioned barriers use 30-ft long segments that weigh approximately 14,000 lb each. Thus, while these barriers typically serve their intended functions well once they are in place, many consider them to be only minimally portable because heavy equipment such as cranes are usually required to lift and place them on and off the trailers used to deliver them to a job site. Because maintenance sections do not typically have the heavy equipment capable of moving and setting these long, heavy rail sections, they must contract for these services. In emergency situations, such as damaged bridge railing, any delay between the time the need for the rail occurs and the time that it is eventually placed can leave traffic exposed to hazards.

In addition to addressing emergency situations, there are many routine maintenance and construction operations that would benefit from a truly portable rail system that TxDOT maintenance crews could transport and place with readily available equipment such as a front-end loader. Such a barrier system could reduce the expense and liability associated with moving and placing the standard 30-ft barrier segments.

There is a need to have a portable concrete barrier that can be used in temporary and permanent applications that meets the performance of American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) TL-4 with minimal deflection (*7*). The barrier designed and tested for this project will address these needs. The X-Bolt barrier designed and tested for Project 0-4162 provided excellent benefits for minimizing barrier deflections. Many of the features designed and tested for Project 0-4162 were incorporated into the new barrier for this project. Based on the results from the previous testing of the X-Bolt barrier, cost effective changes were incorporated into the new barrier for this project. Significant changes to the barrier reinforcement reducing costs and making the barrier units easier to construct were incorporated into the new barrier for this project. In addition, all these changes were incorporated into a barrier system meeting the requirements of *MASH* TL-4.

1.2 RESEARCH PROBLEM STATEMENT

TxDOT requested assistance with the development of a safety-shape concrete barrier system restrained to a concrete deck using vertical dowels that anchor into the deck and extend upward into the barrier system. The dowels in the barrier would extend in a longitudinal slot in the barrier. The dowels would serve to provide lateral resistance to the barrier against the transverse impact loading from the impacting vehicle. The intent of the dowels would be to minimize the lateral deflection of the barrier for vehicular impacts. A minimal deck thickness of 7.0 inches was selected for this project. Placement of the barrier near the edge of the deck was also selected. The barrier is intended to meet the evaluation criteria recommended in the AASHTO *MASH*. It was desired that the barrier designed and tested for this project meet the requirements of *MASH* TL-4.

1.3 OBJECTIVE/SCOPE OF RESEARCH

The objective of this research was to design and test a new portable concrete barrier that meets the performance of *MASH* TL-4 and can be used in temporary and permanent applications on bridge decks. Additionally, this new barrier system will minimize deflection, allowing placement of the barrier system as close to the edge of the deck system without compromising barrier performance for *MASH* TL-4. Additional, using the barrier system on a minimum deck thickness of 7.0 inches was also preferred. This report presents the design and testing results of the new successful barrier system developed for this project.

The purpose of the testing reported herein was to assess the performance of the restrained safety-shape concrete barrier on concrete bridge deck according to the safety-performance evaluation guidelines included in AASHTO *MASH* for Test Level 4 (TL-4). The crash test performed was in accordance with *MASH* test 4-12, which involves a 10000S vehicle impacting the restrained safety-shape concrete barrier at a target impact speed and impact angle of 56 mi/h and 15 degrees, respectively.

CHAPTER 2: DESIGN AND SIMULATION ANALYSIS*

2.1. DESIGN CONCEPT

There were several design requirements that guided the conceptual design of the new restrained barrier system. TxDOT required the profile of the barrier to be symmetrical single slope that can be used for both roadside and median applications. The height of the barrier was required to be 42 inches. Each barrier segment was required to be 30 ft long.

Adjacent barrier segments are connected using cross-bolt connections. A 13-inch long vertical slot is cast into the bottom of the barrier segments. This slot is continuous along the length of the barrier. To restrain the barrier, the segments are lowered onto vertical rebar that are cast into an underlying concrete deck or pavement.

A full-scale finite element model of the barrier system was developed and vehicle impact simulations were performed. Results of these simulations guided researchers in selecting the appropriate size and spacing of the restraining rebar to achieve an acceptable dynamic performance of the barrier system. Details of the simulation analyses are presented next.

2.2. FINITE ELEMENT MODEL

The objective of the simulation analysis was to determine the kinematic performance of the restrained barrier system and the influence of various design parameters. The simulations were performed using the finite element method. LS-DYNA, which is a commercially available general purpose finite element analysis software, was used for all simulations.

The 42-inch tall and 30 ft long single slope barrier segments were modeled using rigid material representation. A 13-inch vertical slot was modeled at the base of the barrier along its centerline. The overall system model was comprised of five (5) barrier segments to achieve a total barrier length of 150 ft. Adjacent barrier segments were connected using the cross-bolt connections. These connections were modeled with elastic-plastic material representation (connection details are presented in a later chapter). Vertical rebar that restrained the lateral movement of the barrier were also modeled with elastic-plastic material representation. The

* The simulations discussed in this section are outside the scope of TTI Proving Ground's A2LA Accreditation.

barriers segments were placed at the edge of a rigid ground that simulated the edge of a bridge deck. Bottom ends of the vertical rebar were constrained to the ground.

Figure 2.1 shows various details of the finite element model. The cross-section of the barrier system restrained on the vertical rebar is shown. Also shown are the views of the full system model and the impact vehicle. The simulations were performed for *MASH* Test 4-12 impact conditions, which involve a single unit truck impacting the barrier at 56 mi/h and 15 degrees. The vehicle model used in the simulations was originally developed by National Crash Analysis Center and Battelle under sponsorship from the Federal Highway Administration. However, this original model has subsequently been modified and improved for greater accuracy and robustness by Texas A&M Transportation Institute (TTI) over the course of many research projects involving simulation and testing with the singe unit truck.

Impact simulations of the 42-inch tall single slope barrier were performed with three different restraint designs. These included the barrier segments restrained with #6 rebar at a 6 ft spacing, #6 rebar at a 3 ft spacing, and #8 rebar at 6 ft spacing. The images shown in this chapter are of the model with #8 rebar at 6 ft spacing, which was eventually selected for crash testing.

2.3. SIMULATION RESULTS

Figure 2.2 shows the results of the simulation analysis. Results are shown for the case with single slope barrier restrained on #8 rebar with 6 ft spacing. Other than the lateral deflection of the barrier, the results of the different cases are very similar. The restrained barrier successfully contained and redirected the single unit truck for all three designs. Figure 2.3 shows differences in the lateral deflection of the top of the barrier. The design with #6 rebar at 6 ft spacing had a maximum dynamic lateral deflection of 10.4 ft. This deflection was reduced to 5.9 ft when the spacing was reduced to 3 ft between the #6 rebar. The design with #8 rebar and 6 ft spacing had a maximum dynamic deflection of 7.1 ft.

The maximum permanent lateral displacement of the barrier’s toe, beyond the edge of the deck, is shown in Figure 2.4. The design with #6 rebar and 3 ft spacing had the lowest displacement of 3.5 inches. However, when the rebar size was increase to #8, similar deflection of 3.8 inches could be achieved with double the spacing (i.e., 6 ft spacing).

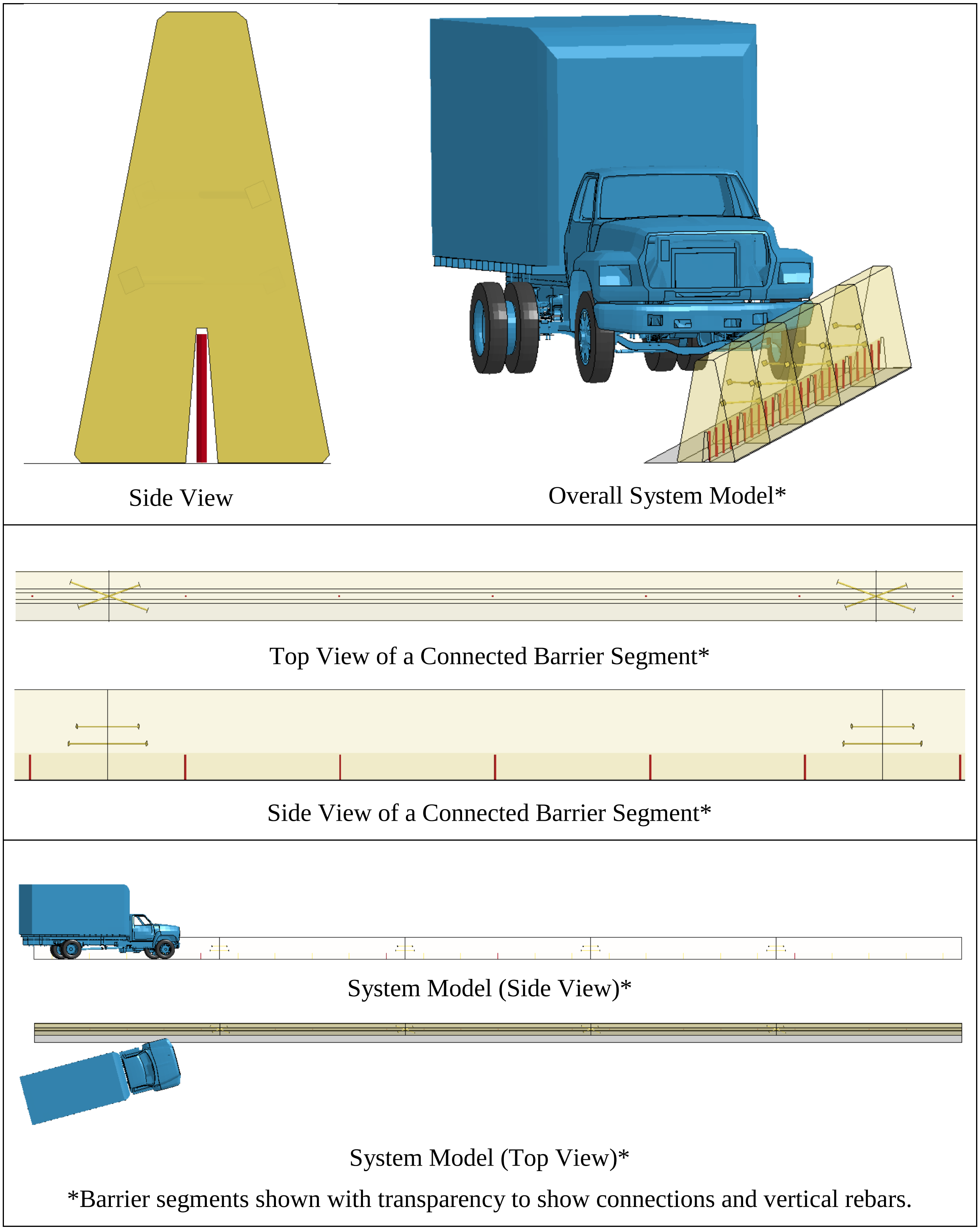


Figure 2.1. Simulation Model Details (Design Selected for Testing Shown).

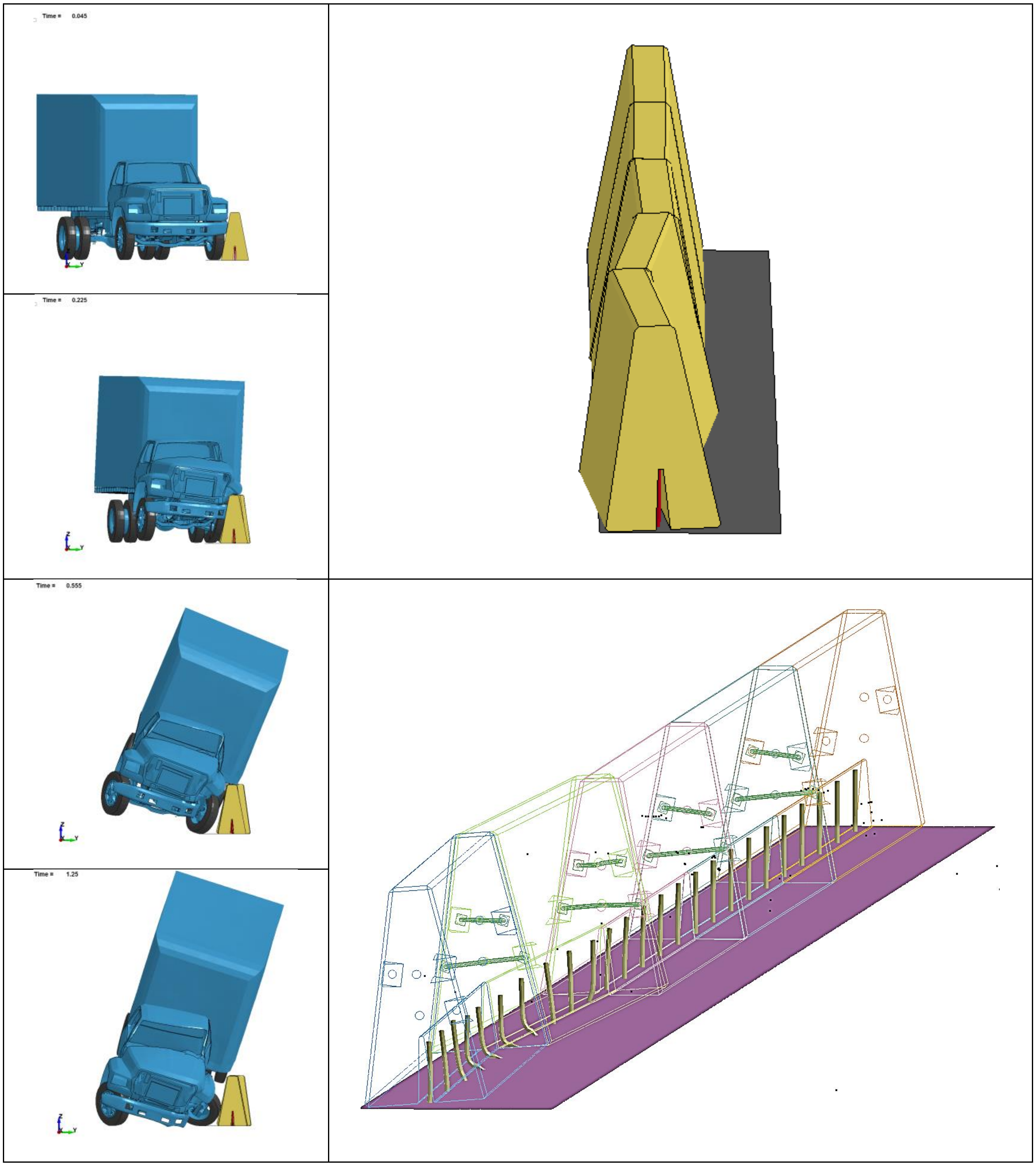


Figure 2.2. Finite Element Analysis Results (Design Selected for Testing Shown).

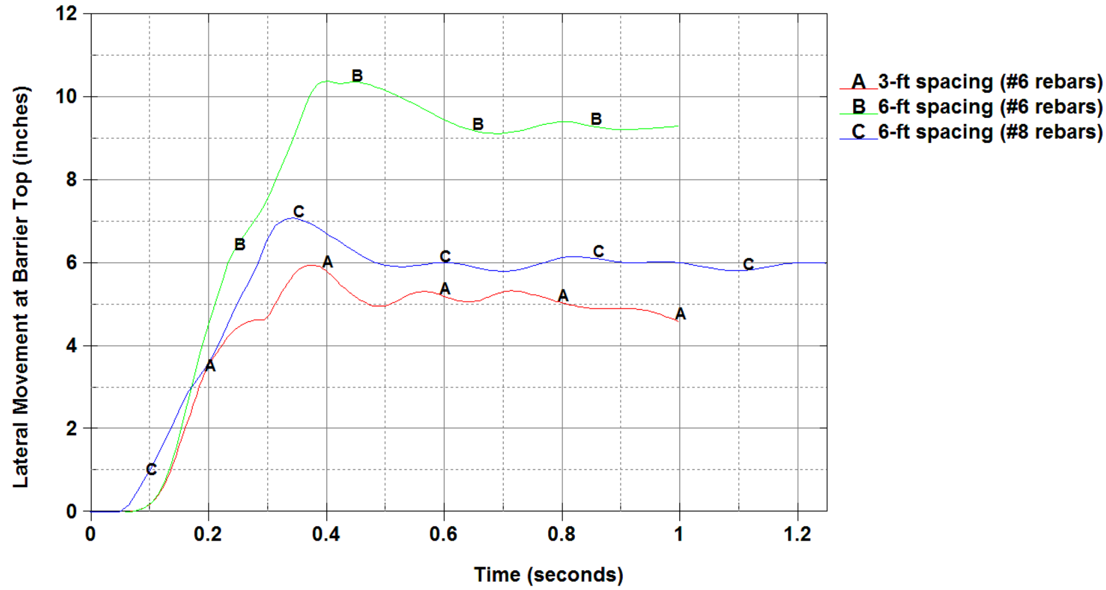


Figure 2.3. Lateral Deflection of the Barrier Top due to Vehicle Impact.

	Deflection Beyond Edge of Deck
3-ft spacing (#6 rebar)	3.5 inches
6-ft spacing (#6 rebar)	7.9 inches
6-ft spacing (#8 rebar)	3.8 inches

Figure 2.4. Deflection of the Bottom of the Barrier beyond the Edge of the Deck.

For comparison purposes, an additional simulation was performed with the single slope barrier in free-standing and unrestrained condition. The lateral deflection of the top of the barriers is compared in Figure 2.5 for the restrained and unrestrained cases. The unrestrained barrier resulted in a maximum lateral deflection of 56 inches.

2.4. SUMMARY AND CONCLUSIONS

The restraint design with #6 rebar at 3 ft spacing resulted in lowest lateral deflection of the barrier (3.5 inches from the edge of the deck). However, the design with #8 rebar at 6 ft spacing had a very comparable deflection (3.8 inches from the edge of the deck). It was considered desirable to have larger spacing between the rebar, so the restraint design with #8 rebar at 6 ft spacing was selected for further evaluation through full scale crash testing.

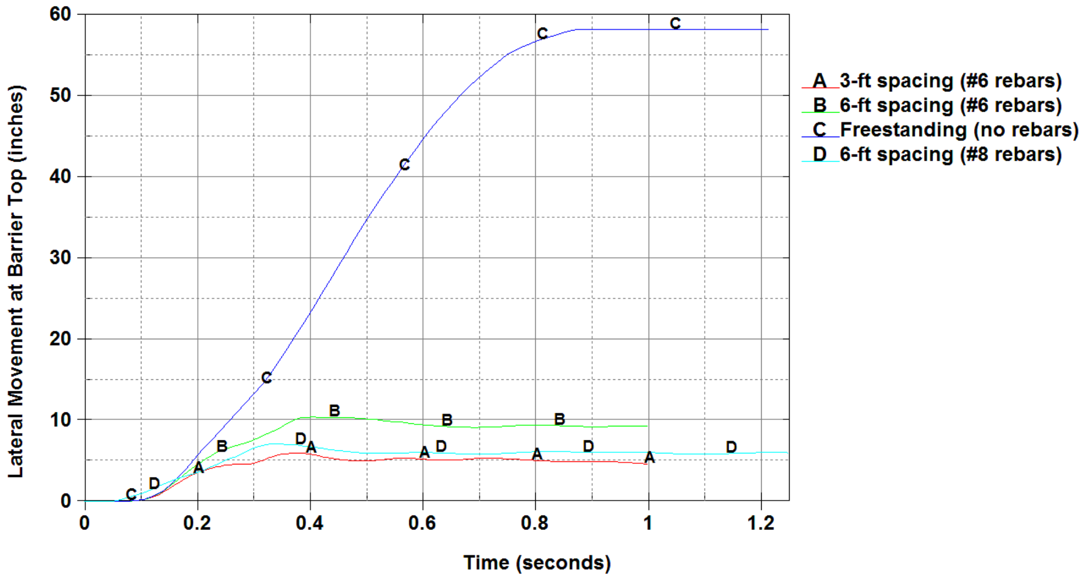


Figure 2.5. Lateral Deflection of the Barrier Top due to Vehicle Impact.

CHAPTER 3:
TEST ARTICLE DESIGN AND CONSTRUCTION

3.1 TEST ARTICLE AND INSTALLATION DETAILS

The test installation was comprised of five sections of 42-inch tall single slope concrete barrier (SSCB), each 30 ft long with 20-degree, horizontal "X" cross bolting at the joints, installed straddling vertical steel pins that were embedded in a bridge deck. The overall length of the test installation was 150 ft.

The SSCB was 24 inches wide at the base, and 8 inches wide at the top. The barrier had a nominal slope of 11-degrees (1H:5¼V, 10.8 degrees actual) on both the traffic side and the field side faces. The X cross bolting was located 17 inches and 26 inches above the base. A longitudinal, vertical, tapered tunnel measuring 3×2 inches wide × 13 inches deep was cast into the bottom of each barrier segment to accommodate steel retention pins that protruded from the bridge deck.

To emulate the overhang of a bridge deck, a 21¼-inch wide, 7-inch thick steel reinforced concrete cantilever was cast abutting an existing concrete vertical footer wall that measured approximately 12 inches thick × 3 ft deep and was integral to the concrete apron. Refer to Appendix A, Sheet 8 of 8 for details.

The X cross bolting consisted of ⅞-inch diameter threaded rods with Society of Automotive Engineers (SAE) hardened washers and heavy hex nuts. The upper rod was 32 inches long, and the lower rod was 42 inches long. A 4-inch square × ½-inch thick plate washer with a 1-inch diameter hole was installed on each end of the rods inboard of the ⅞-inch washer and nut to bear on the recessed wedge-shaped cavities that were cast into the barrier segments to accommodate the X cross bolting.

The barrier was secured on the bridge deck with 1-inch diameter × 17¼-inch long vertical reinforcing steel rods embedded in the deck 5¼ inches (for a 12-inch projection) and secured in drilled holes with Hilti RE-500 V3 epoxy per Hilti instructions. The rods were located 13 inches from the field side edge of the deck on 72-inch spacing for the length of the deck.

The barrier was reinforced using steel welded wire mesh comprised of D19.7 (0.501-inch diameter) WWR lateral stirrup bars generally spaced at 14-inch centers along the length of the barrier. The stirrup bars were bent to conform to the profile of the barrier and provide a minimum 1½-inch concrete cover. Longitudinal reinforcement of the SSCB was comprised of 12 D22.2 bars (0.532-inch diameter) positioned along the slope of each face and located inside the lateral stirrups. Similar WWR reinforcement straddled the longitudinal tunnel. Four horizontal ½-inch diameter U bars reinforced the X cross bolting area at the end of each barrier. Refer to Appendix B, Sheets 4-7 of 8 for reinforcing details.

The drawing and photos of the test installation are shown in Figures 3.1 and 3.2, respectively. Appendix B presents detailed drawings of the test installation.

Figure 3.1 presents overall information on the restrained safety-shape concrete barrier on concrete bridge deck, and Figures 3.2 through 3.4 provide photographs of the construction and installation. Appendix A provides further details of the restrained safety-shape concrete barrier on concrete bridge deck.

3.2 MATERIAL SPECIFICATIONS

The compressive strength of the concrete for the single slope barrier was specified as 4000 psi TxDOT Class S. The compressive strengths on the day of the test was 6040 psi for the bridge deck at 29 days of age (cast on July 10, 2017) and 4700 psi for the single slope barrier segments at 12 days of age (cast on July 27, 2017). Results of the tests performed to determine the compressive strength are shown in Appendix B.

Cross bolting rods met ASTM International (ASTM) A193 B7 specifications. Plate washers were of ASTM A36 material. The steel reinforcing welded wire mesh was grade 70 material. The vertical rebar pins and bridge deck reinforcement were grade 60 material.

Appendix B provides material certification documents for the materials used to install/construct the restrained safety-shape concrete barrier on concrete bridge deck.

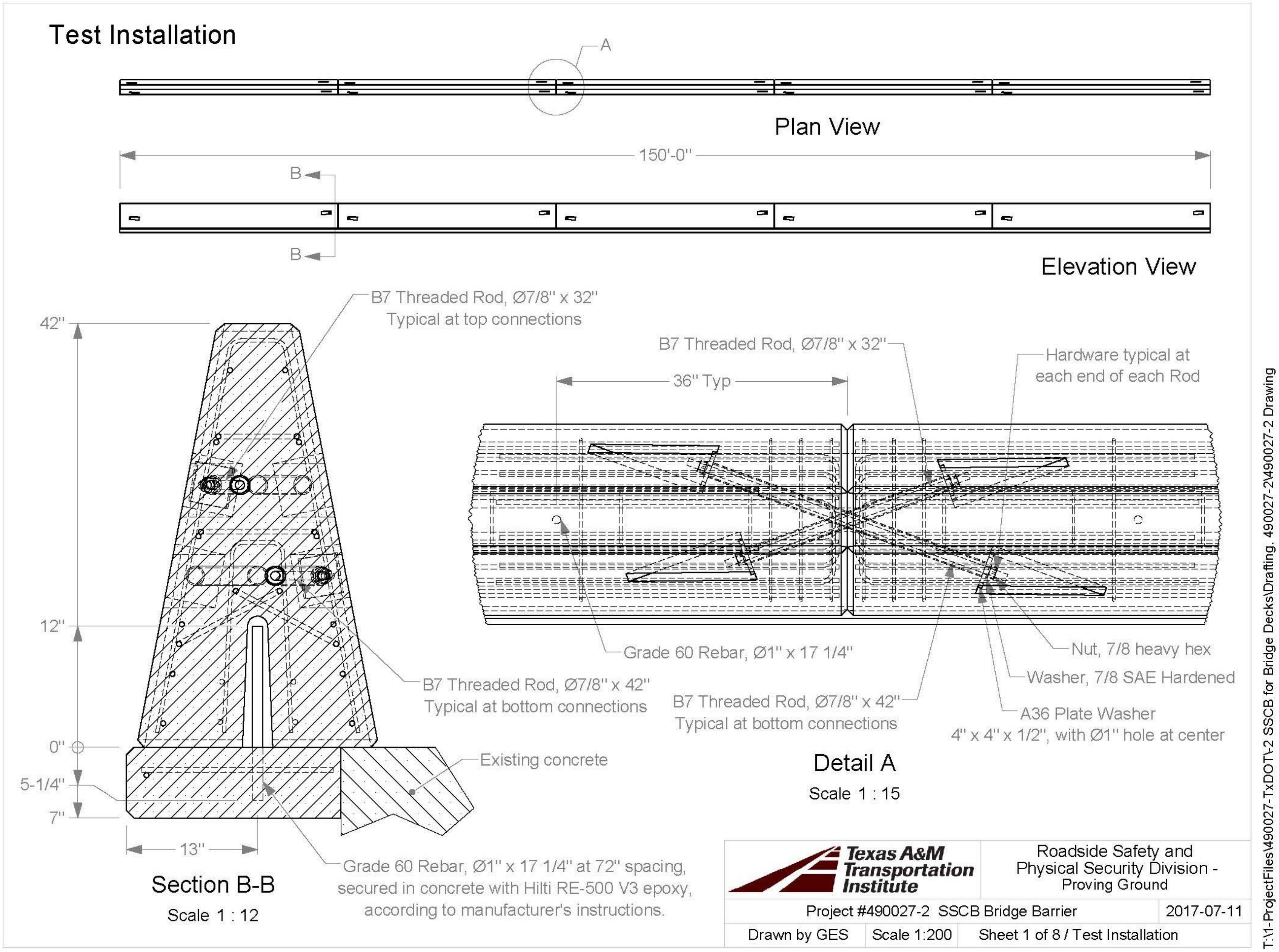


Figure 3.6. Overall Details of the Restrained Safety-Shape Concrete Barrier on Concrete Bridge Deck.

Figure 3.7. Restrained Safety-Shape Concrete Barrier under Construction.

Figure 3.8. Installation of Restrained Safety-Shape Concrete Barrier on Concrete Bridge Deck.

Figure 3.9. Restrained Safety-Shape Concrete Barrier on Concrete Bridge Deck prior to Testing.

CHAPTER 4:
TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1 CRASH TEST MATRIX

Table 4.1 shows the test conditions and evaluation criteria for *MASH* Test 4-12. *MASH* Test 4-12 involves a 10000S vehicle weighing 22,000 lb ±660 lb and impacting the critical impact point (CIP) of the restrained safety-shape concrete barrier on concrete bridge deck at an impact speed of 56 mi/h ±2.5 mi/h and an angle of 15 degrees ±1.5 degrees. The target CIP selected for the test was determined according to the information provided in *MASH* Sections 2.2.1 and 2.3.2.2, and Table 2-8, and was 5.0 ft upstream of the second barrier joint.

Table 4.1. Test Conditions and Evaluation Criteria Specified for *MASH* Test 4-12.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Longitudinal Barrier	4-12	10000S	56 mi/h	15	A, D, G

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

4.2 EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2A and 5-1A through 5-1C of *MASH* were used to evaluate the crash test reported herein. The test conditions and evaluation criteria required for *MASH* Test 4-12 are listed in Table 4.1, and the substance of the evaluation criteria in Table 4.2. An evaluation of the crash test results is presented in detail in the section Assessment of Test Results.

Table 4.2. Evaluation Criteria Required for *MASH* Test 4-12.

Evaluation Factors	Evaluation Criteria
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.*
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 undue hazard to other traffic, pedestrians, or personnel in a work zone.* *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.*
	G. It is preferable, although not essential, that the vehicle remain upright during and after the collision.

CHAPTER 5: TEST CONDITIONS

5.1 TEST FACILITY

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

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

5.2 VEHICLE TOW AND GUIDANCE SYSTEM

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 and ran unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site (no sooner than 2 s after impact), after which the brakes were activated, if needed, to bring the test vehicle to a safe and controlled stop.

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

Each of the TDAS Pro units is returned to the factory annually for complete recalibration and all instrumentation used in the vehicle conforms to all specifications outlined by SAE J211. All accelerometers are calibrated annually by means of an ENDEVCO® 2901, precision primary vibration standard. This standard and its support instruments are checked annually and receive a National Institute of Standards Technology (NIST) traceable calibration. The rate transducers used in the data acquisition system receive a calibration via a Genisco Rate-of-Turn table. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are also made any time data are suspect. Acceleration data are measured with an expanded uncertainty of ±1.7 percent at a confidence factor of 95 percent (k=2).

TRAP uses the data from the TDAS Pro to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-millisecond (ms) average ridedown acceleration. TRAP calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz low-pass digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals, then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact. Rate of rotation data is measured with an expanded uncertainty of ±0.7 percent at a confidence factor of 95 percent (k=2).

5.3.2 Anthropomorphic Dummy Instrumentation

According to *MASH*, use of a dummy in the 10000S vehicle is not required, and no dummy was used in the test.

5.3.3 Photographic Instrumentation and Data Processing

Photographic coverage of the test included three high-speed cameras:

- One overhead with a field of view perpendicular to the ground and directly over the impact point.
- One placed behind the installation at an angle.
- One placed to have a field of view parallel to and aligned with the installation at the downstream end.

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the restrained safety-shape concrete barrier. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.

CHAPTER 6:
MASH TEST 4-12 (CRASH TEST NO. 490027-2-1)

6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 4-12 involves a 10000S vehicle weighing 22,000 lb ±660 lb impacting the CIP of the restrained barrier at an impact speed of 56 mi/h ±2.5 mi/h and an angle of 15 degrees ±1.5 degrees. The CIP for *MASH* Test 4-12 restrained safety-shape concrete barrier was 5.0 ft ±1 ft upstream of the second joint.

The 2004 International 4300 single-unit box van truck used in the test weighed 22,370 lb, and the actual impact speed and angle were 58.3 mi/h and 15.6 degrees, respectively. The actual impact point was 4.7 ft upstream of the joint between barrier segments 2 and 3. Minimum target impact severity (IS) was 142 kip-ft, and actual IS was 184 kip-ft.

6.2 TEST VEHICLE

The 2004 International 4300 single-unit box van truck, shown in Figures 6.1 and 6.2, was used for the crash test. The vehicle's test inertia weight was 22,370 lb, and its gross static weight was 22,370 lb. The height to the lower edge of the vehicle bumper was 19.25 inches, and height to the upper edge of the bumper was 33.5 inches. The height to the center of gravity of the ballast was 64.0 inches. Tables C.1 in Appendix C.1 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 freewheeling and unrestrained just prior to impact.

Figure 6.1. Restrained Barrier/Test Vehicle Geometrics for Test No. 490027-2-1.

Figure 6.2. Test Vehicle before Test No. 490027-2-1.

6.3 WEATHER CONDITIONS

The test was performed on the morning of August 8, 2017. Weather conditions at the time of testing were as follows: wind speed: 3 mi/h; wind direction: 26 degrees (vehicle was traveling in a northwesterly direction); temperature: 81°F; relative humidity: 87 percent.

6.4 TEST DESCRIPTION

The test vehicle, traveling at an impact speed of 58.3 mi/h, contacted the restrained barriers 4.7 ft upstream of the joint between barrier segments 2 and 3 at an impact angle of 15.6 degrees. Table 6.1 lists times and significant events that occurred during Test No. 490027-2-1. Figures C.1 and C.2 in Appendix C.2 present sequential photographs during the test.

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 65.6 ft downstream from impact for heavy vehicle). The 10000S vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle came to rest 225 ft downstream of the impact and 10 ft toward the field side.

Table 6.1. Events during Test No. 490027-2-1.

TIME (s)	EVENT
-0.002	Left Front tire impacts barrier and leaves pavement
0.020	Barrier begins to displace to field side at 2-3 joint
0.021	Vehicle begins to redirect
0.050	Cab of vehicle pitches upward
0.076	Downstream end of segment #3 begins to displace to traffic side
0.076	Upstream field side of segment #2 (at #1) begins to spall near bottom
0.084	Right Front tire leaves pavement & toes inward
0.219	Right Rear tires leave pavement
0.236	Lower left of box near axle impacts barrier; concrete chips fly off
0.258	Lower left corner of box impacts barrier
0.278	Vehicle begins to travel parallel with the barrier
0.330	Max rotation of barrier to field side. 9.7 degrees from vertical
0.330	Traffic side toe inward approximately 2 inches
0.330	Max Deflection 7.1 inches to field at top of barrier
0.377	Left Front tire lands back on pavement
0.892	Right Front tire lands back on pavement
1.271	Right Front tire slides off of pavement and into ground
1.400	Vehicle loses contact with the barrier traveling at 55.3 mi/h and 0 degrees
2.200	Brakes applied

6.5 DAMAGE TO TEST INSTALLATION

Figure 6.3 shows the damage to the restrained barriers. Tire marks and gouging were evident along the traffic face of the barrier from the impact area to the end of the installation. Barrier segment 1 showed no apparent movement. The downstream end of barrier segment 2 was pushed toward the field side 1.5 inches. The upstream end of barrier segment 3 was pushed toward the field side 1.5 inches, and the downstream end was 1.5 inches toward the traffic lanes. Working width was 58.7 inches, and the height of maximum working width was 135.5 inches. Maximum dynamic deflection during the test was 7.1 inches, and maximum permanent deformation was 1.5 inches.

Figure 6.3. Restrained Safety Shape Concrete Barriers on Concrete Deck after Test No. 490027-2-1.

6.6 DAMAGE TO TEST VEHICLE

Figure 6.4 shows the damage that the vehicle had sustained. The front bumper, hood, grill, left front tire and rim, left frame rail, left front springs and U-bolts, left fuel tank and side steps, left lower corner of the box, and the left rear outer tire and rim were damaged. Maximum exterior crush to the vehicle was 12.0 inches in the side plane at the left front corner just behind the left front wheel below bumper height. Maximum occupant compartment deformation was 6.0 inches in the floor pan adjacent to the left front door. Figure 6.5 shows the interior of the vehicle.

Figure 6.4. Test Vehicle after Test No. 490027-2-1.

Before Test After Test

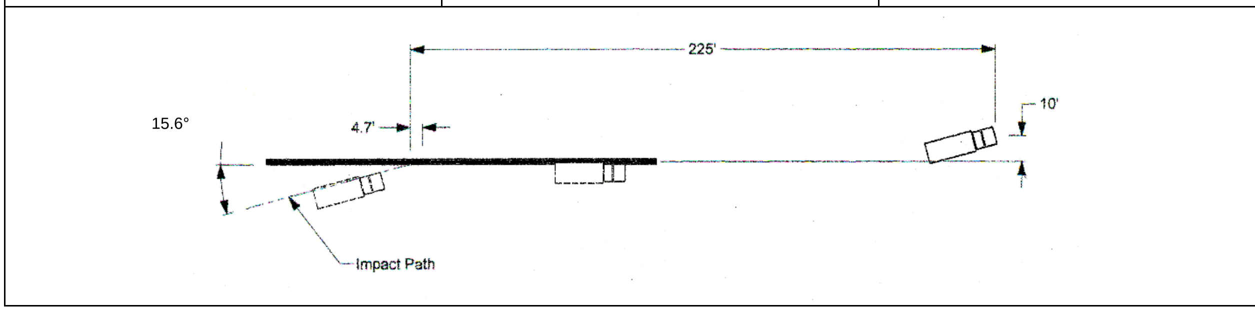
Figure 6.5. Interior of Test Vehicle for Test No. 490027-2-1.

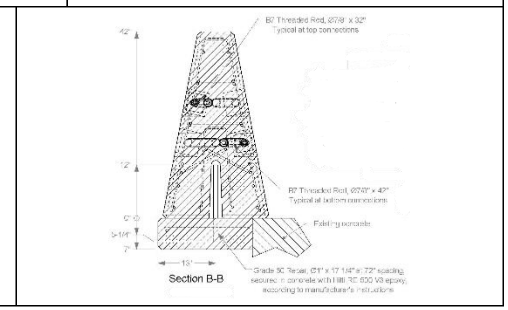
6.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and are shown in Table 6.2. Figure 6.6 summarizes these data and other pertinent information from the test. Figure C.3 in Appendix C.3 shows the vehicle angular displacements, and Figures C.4 through C.9 in Appendix C.4 show accelerations versus time traces.

Table 6.2. Occupant Risk Factors for Test No. 490027-2-1.

Occupant Risk Factor	Value	Time
Impact Velocity		
Longitudinal	**5.9 ft/s**	at 0.1952 s on left side of interior
Lateral	**11.5 ft/s**	
Ridedown Accelerations		
Longitudinal	**4.9 g**	0.2473–0.2573 s
Lateral	**10.9 g**	0.2401–0.2501 s
THIV	**14.7 km/h** **4.1 m/s**	at 0.1886 s on left side of interior
PHD	**11.6 g**	0.2403–0.2503 s
ASI	**0.64**	0.3195–0.3695 s
Maximum 50-ms Moving Average		
Longitudinal	**-1.9 g**	0.2070–0.2570 s
Lateral	**5.5 g**	0.2930–0.3430 s
Vertical	**-2.6 g**	1.2308–1.2808 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**19.4°**	1.4581 s
Pitch	**12.1°**	1.9250 s
Yaw	**21.1°**	0.4751 s





General Information
Test Agency...................... Texas A&M Transportation Institute (TTI)
Test Standard Test No. ...... MASH Test **Error! Reference source not found.**
TTI Test No. 490027-2-1
Test Date 2017-08-08

Test Article
Type .... Portable Concrete Barriers (Restrained)
Name................................ SSCB Restrained on Concrete Deck
Installation Length............. 150 ft
Material or Key Elements ... 42-inch tall single slope concrete barrier 30 ft long with 20-degree cross bolted at joints restrained on concrete deck with 1-inch diameter × 17¼-inch long vertical reinforcing steel rods on 72-inch spacing

Soil Type and Condition ..... Concrete Bridge Deck, Damp

Test Vehicle
Type/Designation 10000S
Make and Model .... 2004 International 4300
Curb.................................. 13,510 lb
Test Inertial .... 22,370 lb
Dummy .... No dummy
Gross Static .... 22,570 lb

Impact Conditions
Speed .... 58.3 mi/h
Angle .... 15.6 degrees
Location/Orientation .... 4.7 ft downstream of joint btw 2 and 3

Impact Severity.................. 184 kip-ft

Exit Conditions
Speed .... 55.3 mi/h
Angle .... 0.0 degree

Occupant Risk Values
Longitudinal OIV .... 5.9 ft/s
Lateral OIV........................ 11.5 ft/s
Longitudinal Ridedown .... 4.9 g
Lateral Ridedown .... 10.9 g
THIV .... 14.7 km/h
PHD .... 11.6 g
ASI.................................... 0.64
Max. 0.050-s Average
Longitudinal .... -1.9 g
Lateral.............................. 5.5 g
Vertical............................ -2.6 g

Post-Impact Trajectory
Stopping Distance .... 225 ft downstream
10 ft twd field side

Vehicle Stability
Maximum Yaw Angle .... 21 degrees
Maximum Pitch Angle .... 12 degrees
Maximum Roll Angle .... 19 degrees
Vehicle Snagging .... No
Vehicle Pocketing .... No

Test Article Deflections
Dynamic.................................. 7.1 inches
Permanent .... 1.5 inches
Working Width.......................... 58.7 inches
Height of Working Width .... 137.5 inches

Vehicle Damage
VDS .... NA
CDC... 11FLEW4
Max. Exterior Deformation......... 12.0 inches
OCDI.. LF0010000
Max. Occupant Compartment Deformation .... 6.0 inches

Figure 6.6. Summary of Results for *MASH* Test 4-12 on the Restrained Safety-Shape Concrete Barriers on Concrete Bridge Deck.

CHAPTER 7: SUMMARY AND CONCLUSIONS

7.1 SUMMARY OF RESULTS

Table 6.1 provides an assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 4-12.

7.2 CONCLUSIONS

The safety-shape concrete barrier restrained on concrete deck contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 7.1 inches. No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment or show undue hazard to others in the area. Maximum occupant compartment deformation was 6.0 inches in the left side floor pan adjacent to the left front door. The 10000S vehicle remained upright during and after the collision period.

The restrained safety-shape concrete barrier on concrete deck performed acceptably for *MASH* Test 4-12.

Table 7.1. Performance Evaluation Summary for *MASH* Test 4-12 on the Restrained Safety-Shape Concrete Barrier on Concrete Deck.

Test Agency: Texas A&M Transportation Institute | Test No.: 490027-2-1 | Test Date: 2017-08-08

***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 restrained safety-shape concrete barrier on concrete deck contained and redirected the 10000S vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 7.1 inches.	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 were present to penetrate or show potential for penetrating the occupant compartment or show undue 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.	Maximum occupant compartment deformation was 6.0 inches in the left side floor pan adjacent to the left front door.	
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 period.	Pass

CHAPTER 8: IMPLEMENTATION STATEMENT[*]

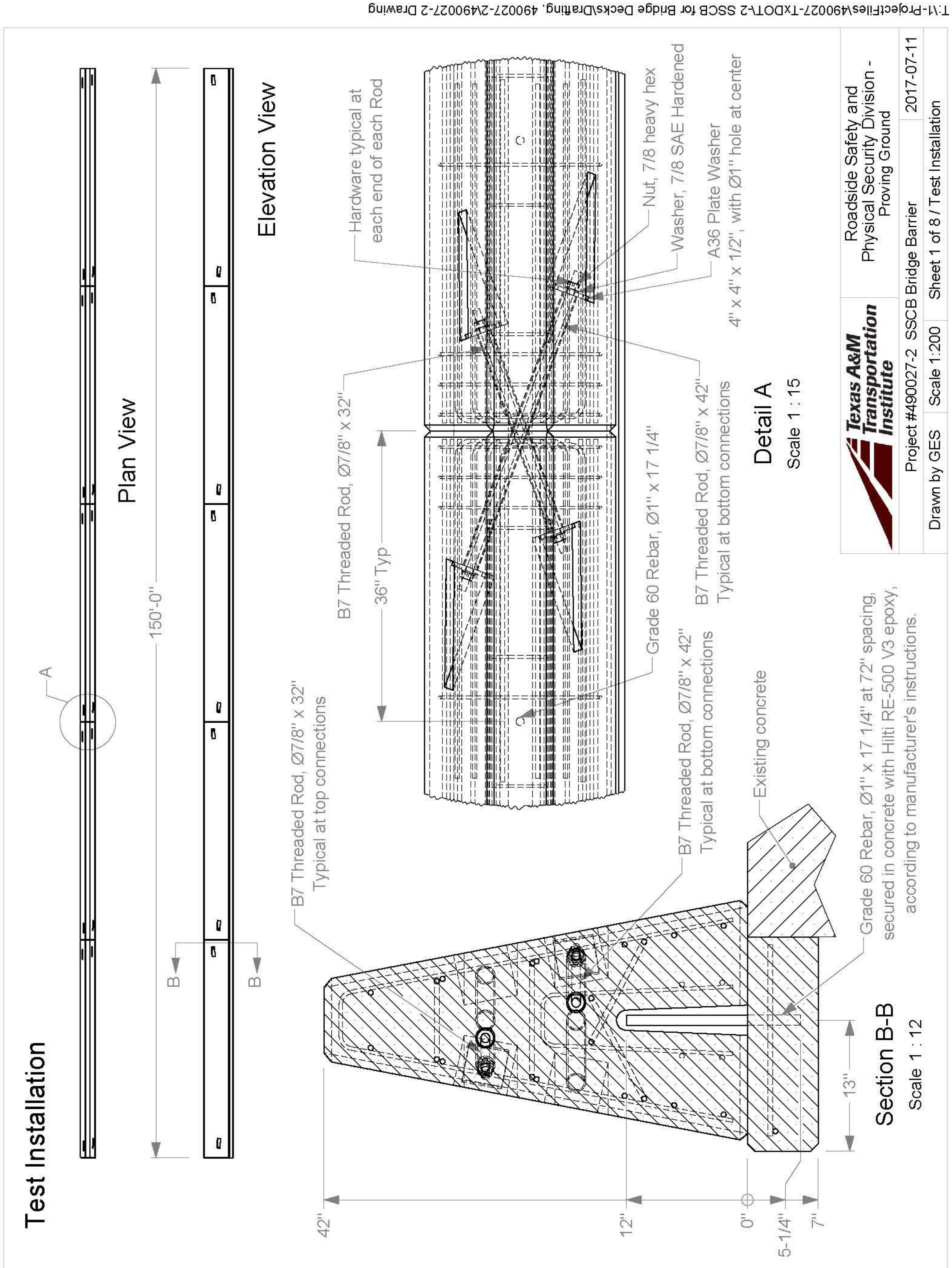
The new restrained barrier section with the cross-bolt connection as described and tested herein using 1-inch diameter dowels anchored to a 7.0-inch thick deck is recommended for implementation on new or existing retrofit projects. This barrier system successfully met all the requirements of *MASH* Test 4-12. This barrier system as designed and tested herein is recommended for use on the National Highway System with deck thicknesses of 7.0 inches or greater.

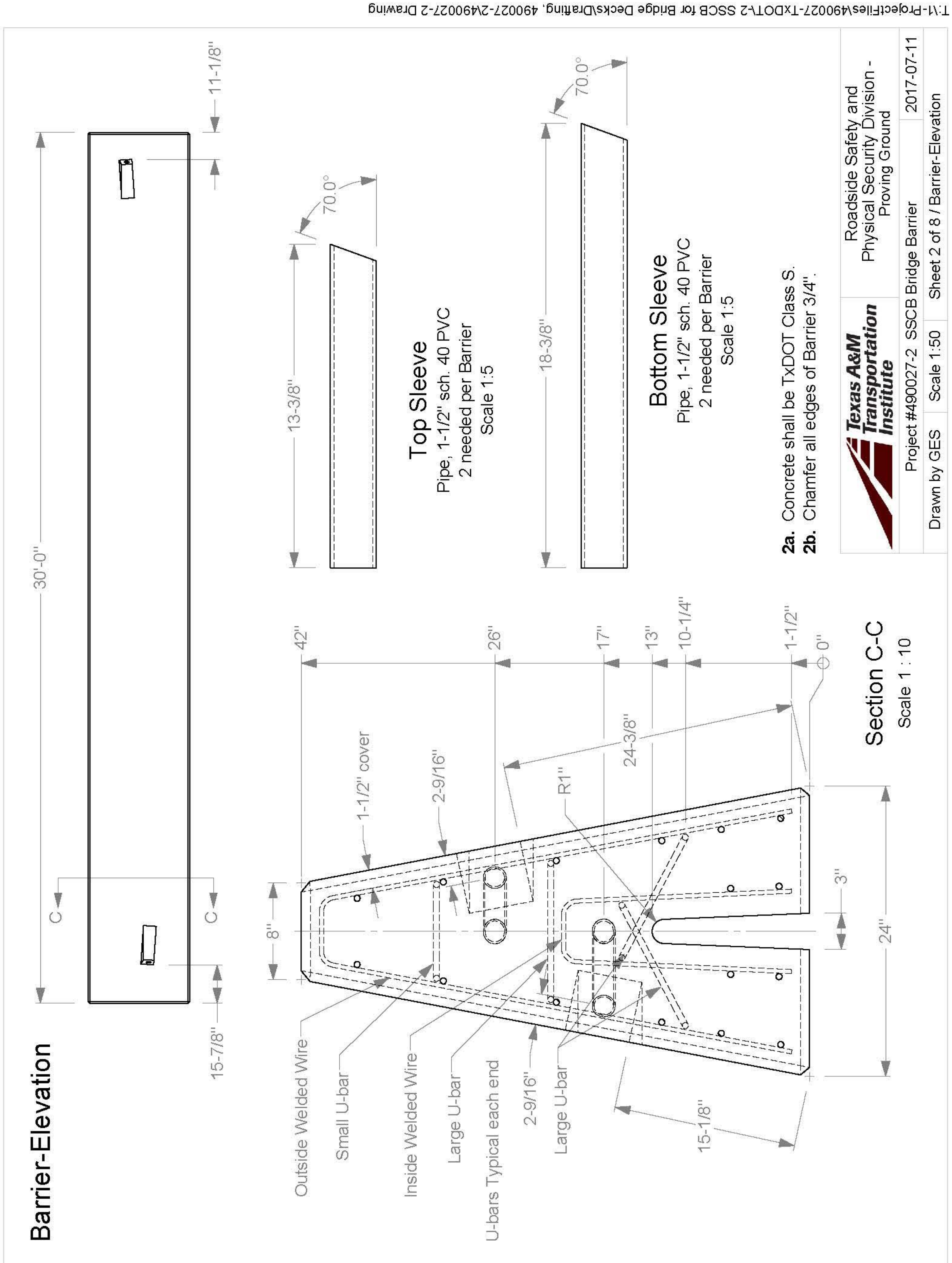
[*] The opinions/interpretations identified/expressed in this section are outside the scope of TTI Proving Ground's A2LA Accreditation.

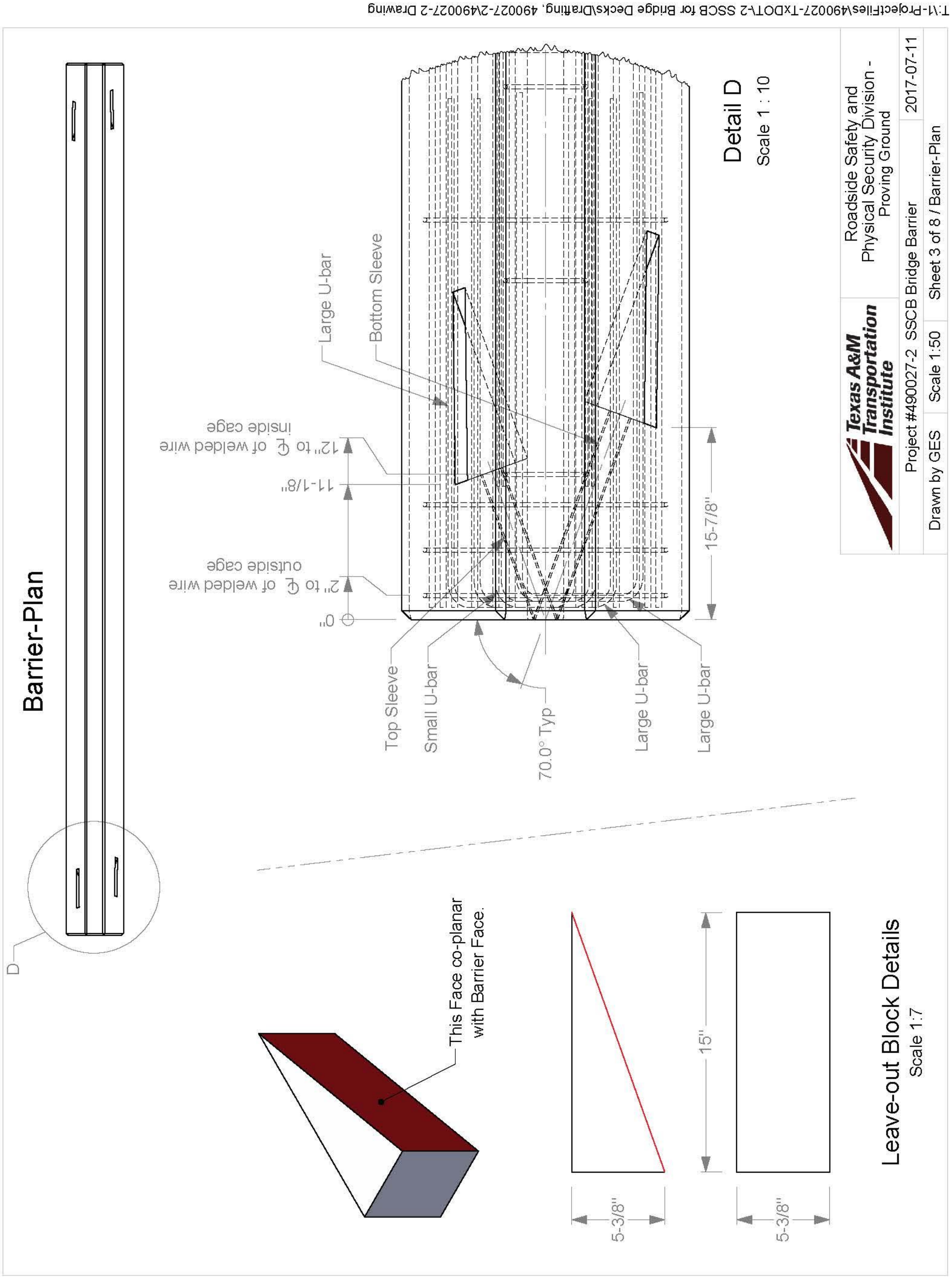
REFERENCES

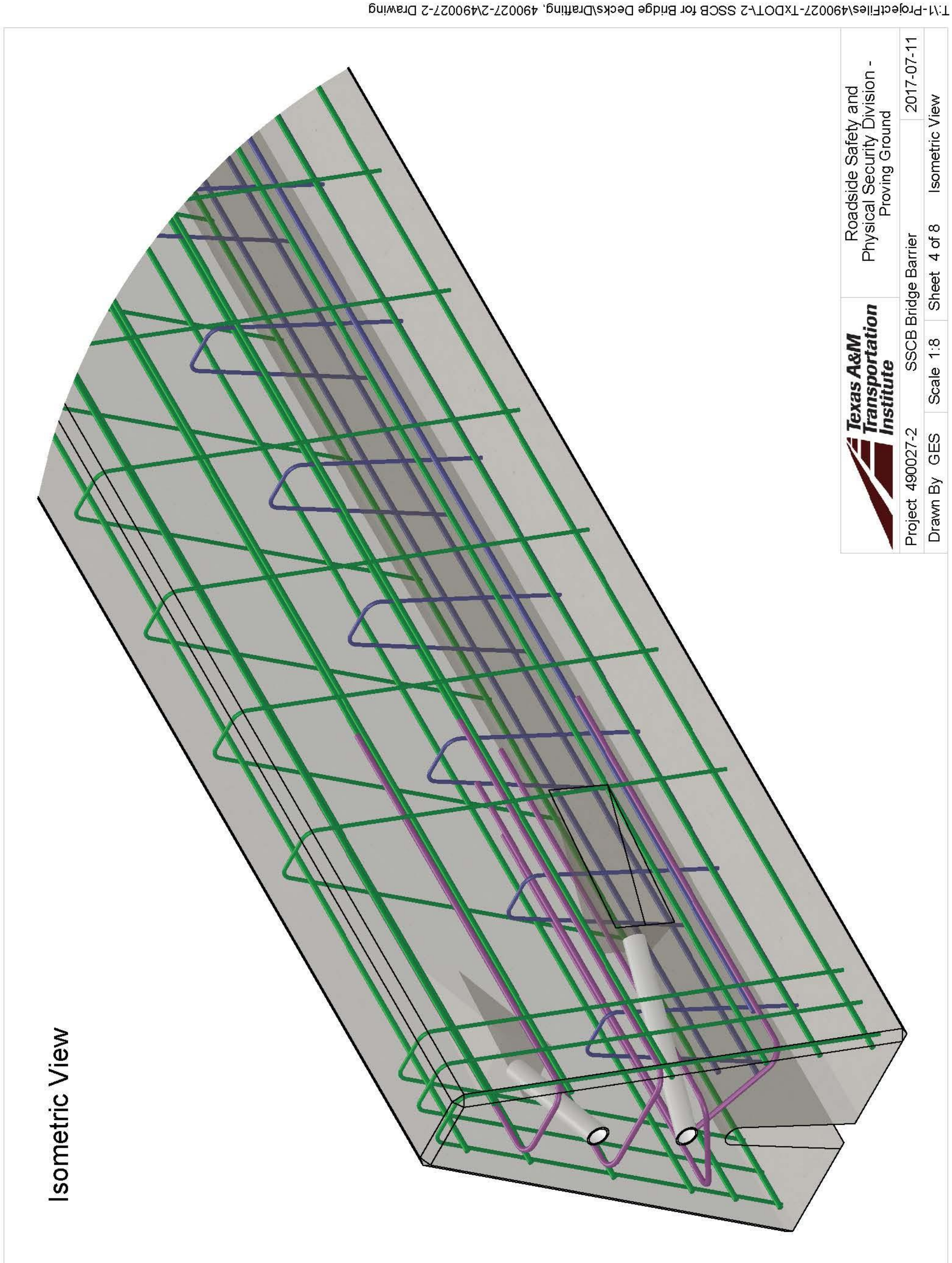
1. H. E. Ross, Jr., D. L. Sicking, R. A. Zimmer, and J. D. Michie. Recommended Procedures for the Safety Performance Evaluation of Highway Features, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.
2. T. R. Guidry and W. L. Beason. *Development of a Low-Profile Portable Concrete Barrier*. Research Report 990-4F, Texas Transportation Institute, College Station, TX, November 1991.
3. W. L. Beason, H. E. Ross, Jr., H. S. Perera, and W. L. Campise. *Development of a Single Slope Concrete Median Barrier*. Research Report 9429C-1, Texas Transportation Institute, College Station, TX, February 1989.
4. W. L. Beason and D. L. Bullard, Jr. *Development of a Limited Slip Portable Concrete Barrier Connection*. Research Report No. 1959-1, Texas Transportation Institute, College Station, TX, November 1993.
5. R. P. Bligh, D. L. Bullard, Jr., W. L. Menges, and B. G. Butler. *Evaluation of Texas Grid-Slot Portable Concrete Barrier System*. Report 0-4162-1, Texas Transportation Institute, College Station, TX, April 2002.
6. R. P. Bligh, N. M. Sheikh, W. L. Menges, and R. R. Haug. *Development of Low-Deflection Precast Concrete Barrier*. Report 0-4162-3. Texas Transportation Institute, College Station, TX, January 2005.
7. AASHTO. *Manual for Assessing Roadside Safety Hardware.* Second Edition, 2016, American Association of State Highway and Transportation Officials: Washington, D.C.

APPENDIX A. DETAILS OF THE SAFETY SHAPE CONCRETE BARRIERS PINNED ON CONCRETE DECK




T:\1-ProjectFiles\490027-TxDOT\-2 SSCB for Bridge Decks\Drafting, 490027-2\490027-2 Drawing
Barrier-Elevation
30'-0"
11-1/8"
15-7/8"
C
C
8"
42"
26"
17"
13"
10-1/4"
1-1/2"
0"
24-3/8"
1-1/2" cover
2-9/16"
R1"
3"
24"
15-1/8"
Outside Welded Wire
Small U-bar
Inside Welded Wire
Large U-bar
U-bars Typical each end
2-9/16"
Large U-bar
Section C-C
Scale 1 : 10
Top Sleeve
Pipe, 1-1/2" sch. 40 PVC
2 needed per Barrier
Scale 1:5
13-3/8"
70.0°
Bottom Sleeve
Pipe, 1-1/2" sch. 40 PVC
2 needed per Barrier
Scale 1:5
18-3/8"
70.0°
2a. Concrete shall be TxDOT Class S.
2b. Chamfer all edges of Barrier 3/4".
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #490027-2 SSCB Bridge Barrier
2017-07-11
Drawn by GES
Scale 1:50
Sheet 2 of 8 / Barrier-Elevation


T:\1-ProjectFiles\490027-TxDOT\-2 SSCB for Bridge Decks\Drafting, 490027-2\490027-2 Drawing
Barrier-Plan
D
Detail D
Scale 1 : 10
Large U-bar
Bottom Sleeve
12" to ℄ of welded wire
inside cage
11-1/8"
2" to ℄ of welded wire
outside cage
0"
15-7/8"
Top Sleeve
Small U-bar
70.0° Typ
Large U-bar
Large U-bar
This Face co-planar
with Barrier Face.
15"
5-3/8"
5-3/8"
Leave-out Block Details
Scale 1:7
Texas A&M Transportation Institute
Roadside Safety and
Physical Security Division -
Proving Ground
Project #490027-2 SSCB Bridge Barrier
2017-07-11
Drawn by GES
Scale 1:50
Sheet 3 of 8 / Barrier-Plan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Isometric View
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project 490027-2
SSCB Bridge Barrier
2017-07-11
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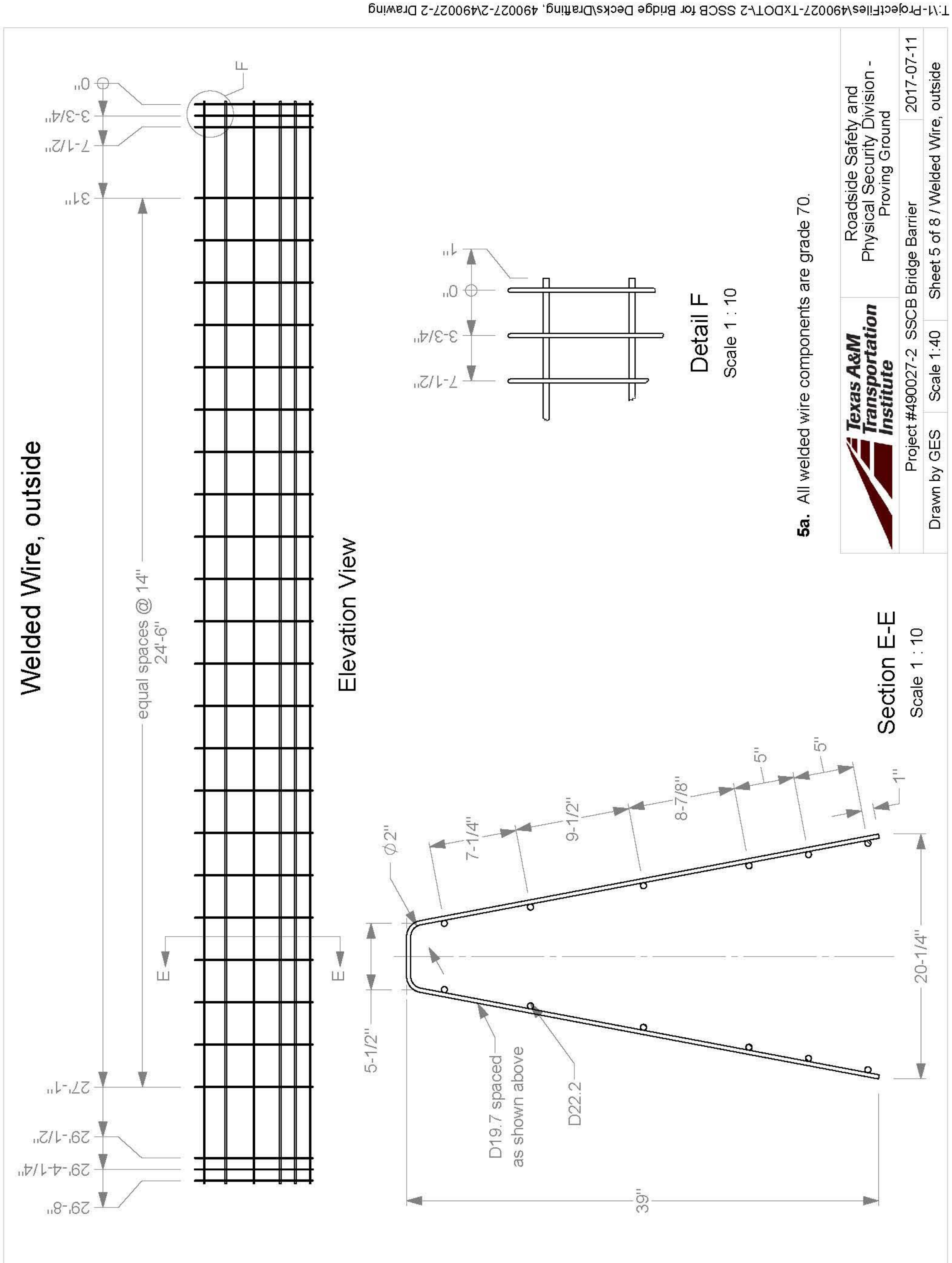
Scale 1:8
Sheet 4 of 8
Isometric View



Welded Wire, outside
Elevation View
equal spaces @ 14"
24'-6"
0"
3-3/4"
7-1/2"
31"
27'-1"
29'-1/2"
29'-4-1/4"
29'-8"
F
E
Detail F
Scale 1 : 10
1"
Section E-E
Scale 1 : 10
Ø2"
7-1/4"
9-1/2"
8-7/8"
5"
5"
1"
5-1/2"
20-1/4"
39"
D19.7 spaced
as shown above
D22.2
5a. All welded wire components are grade 70.
Texas A&M Transportation Institute
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Project #490027-2 SSCB Bridge Barrier
2017-07-11
Drawn by GES
Scale 1:40
Sheet 5 of 8 / Welded Wire, outside
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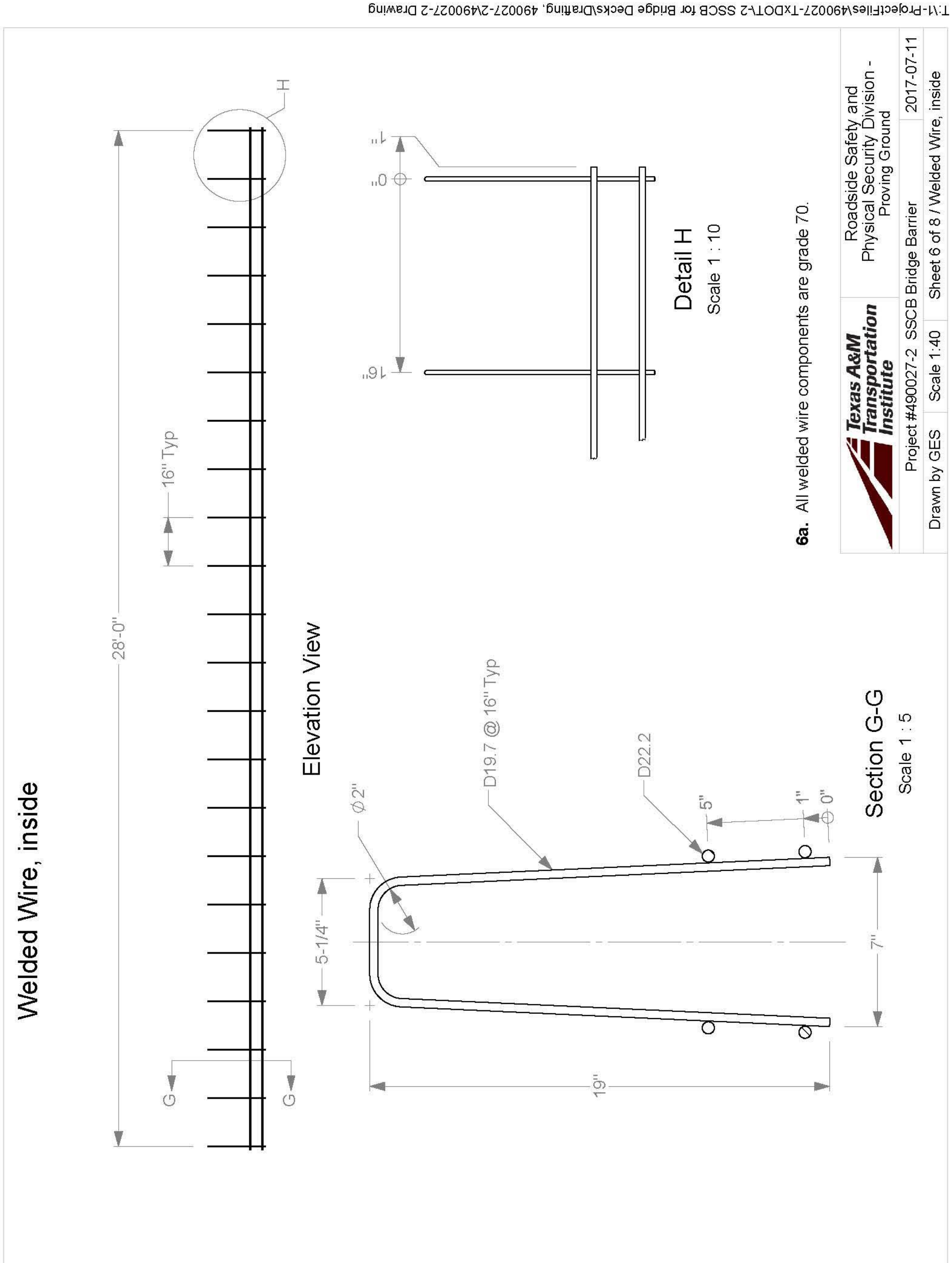
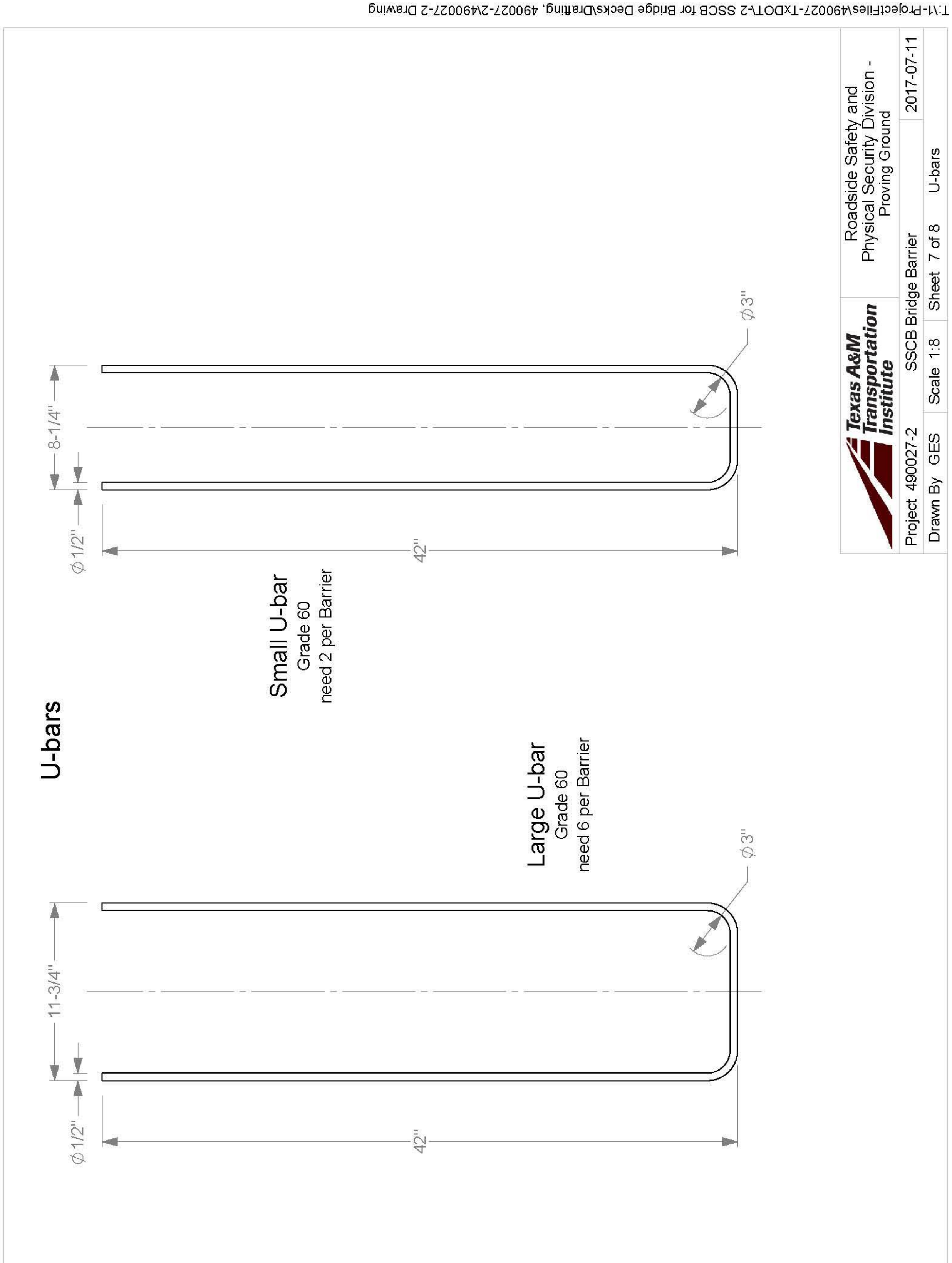

T:\1-ProjectFiles\490027-TxDOT\-2 SSCB for Bridge Decks\Drafting, 490027-2\490027-2 Drawing
Welded Wire, inside
28'-0"
16" Typ
H
G
G
Elevation View
ø2"
D19.7 @ 16" Typ
D22.2
5-1/4"
5"
1"
0"
7"
19"
Section G-G
Scale 1 : 5
1"
0"
16"
Detail H
Scale 1 : 10
6a. All welded wire components are grade 70.
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #490027-2
SSCB Bridge Barrier
2017-07-11
Drawn by GES
Scale 1:40
Sheet 6 of 8 / Welded Wire, inside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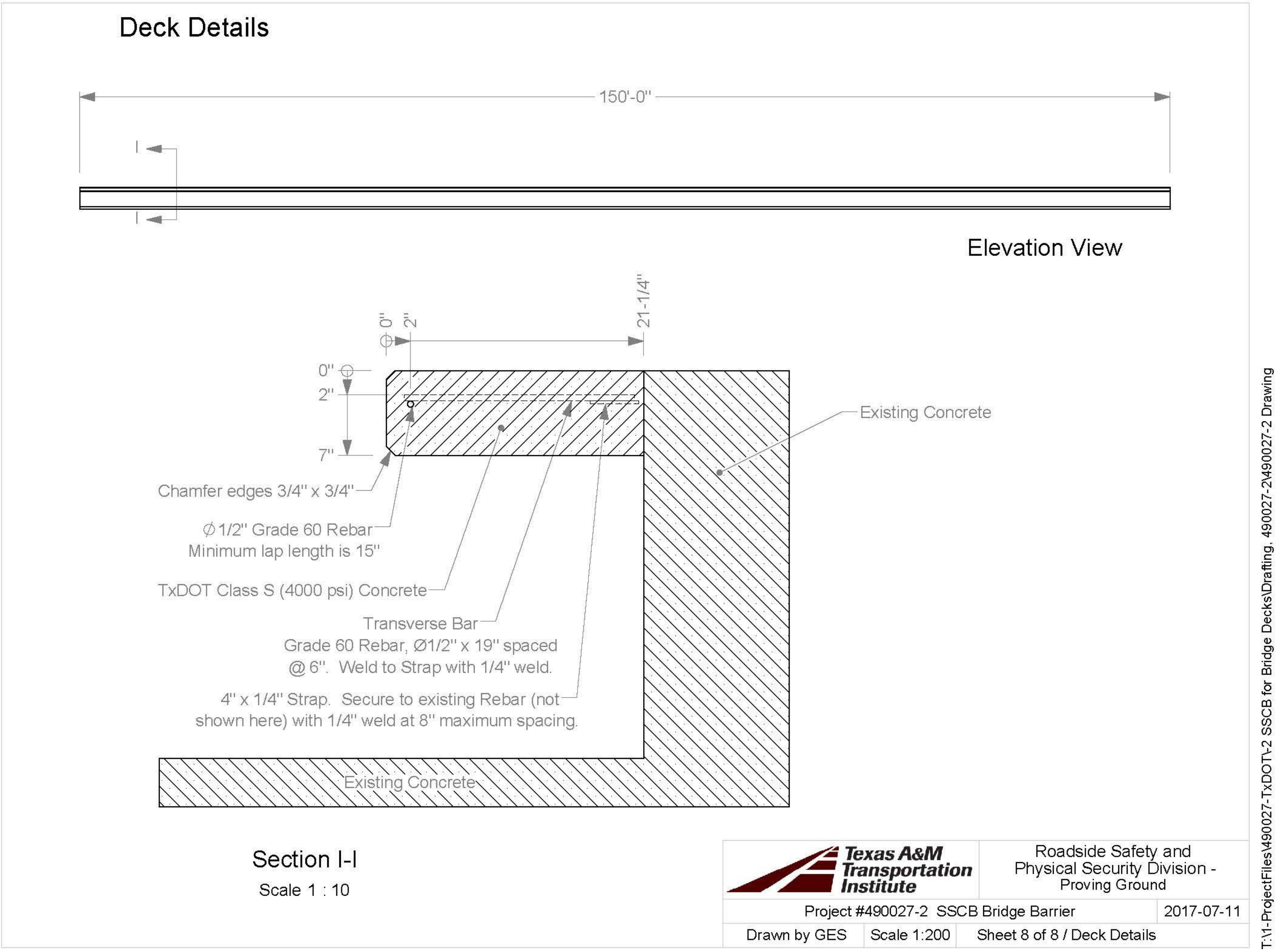
U-bars
Small U-bar
Grade 60
need 2 per Barrier
Large U-bar
Grade 60
need 6 per Barrier
8-1/4"
11-3/4"
ϕ1/2"
ϕ3"
42"
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project 490027-2
SSCB Bridge Barrier
2017-07-11
Drawn By GES
Scale 1:8
Sheet 7 of 8
U-bars


Deck Details
150'-0"
I
I
Elevation View
0"
2"
21-1/4"
0"
2"
7"
Existing Concrete
Chamfer edges 3/4" x 3/4"
ϕ 1/2" Grade 60 Rebar
Minimum lap length is 15"
TxDOT Class S (4000 psi) Concrete
Transverse Bar
Grade 60 Rebar, Ø1/2" x 19" spaced
@ 6". Weld to Strap with 1/4" weld.
4" x 1/4" Strap. Secure to existing Rebar (not
shown here) with 1/4" weld at 8" maximum spacing.
Existing Concrete
Section I-I
Scale 1 : 10
Texas A&M Transportation Institute
Roadside Safety and
Physical Security Division -
Proving Ground
Project #490027-2 SSCB Bridge Barrier
2017-07-11
Drawn by GES
Scale 1:200
Sheet 8 of 8 / Deck Details
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APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

Texas A&M Transportation Institute Proving Ground, 3100 SH 47, Bldg 7091, Bryan, TX 77807 Texas A&M University, College Station, TX 77843 Phone 979-845-6375	5.7.2 Concrete Break	Doc. No. QPF 5.7.2	Revision Date: 2012-09-17
Quality Policy Form	Revised by: G. E. Schroeder Approved by: C. E. But	Revision: 5	Page: 1 of 1

Project No.: 490027-2-1

Placement: DECK

Casting Date: 2017-7-10

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

Printed name of Technician taking sample: GREG FRITZ

Signature of Technician taking sample:

Printed name of Technician breaking sample: GREG FRITZ

Signature of Technician breaking sample:

Truck No.	Batch Ticket	Yards
1		

Break Date	Cylinder Age	Truck No.	Total Load (Pounds)	PSI Break	Average
2017-8-6	29 Days	1	161000	5700	
2017-8-8	29 DAYS	1	175000	6190	6040
2017-8-8	29 DAYS	1	176000	6225	

Texas A&M Transportation Institute Proving Ground, 3100 SH 47, Bldg 7091, Bryan, TX 77807 Texas A&M University, College Station, TX 77843, Phone 979-845-6375	5.7.2 Concrete Break	Doc. No. QPF 5.7.2	Revision Date: 2012-09-17
Quality Policy Form	Revised by: G. E. Schroeder Approved by: C. E. But	Revision: 5	Page: 1 of 1

Project No.: 490027-2-1 **Casting Date:** 2017-7-19

Placement: SINGLE SLOPE **Mix Design P.S.I.:** 4000

Truck No.	Batch Ticket	Yards
1		
2		

Printed name of Technician taking sample: GREG FRITZ

Signature of Technician taking sample: [signature]

Printed name of Technician breaking sample: GREG FRITZ

Signature of Technician breaking sample: [signature]

Break Date	Cylinder Age	Truck No.	Total Load (Pounds)	PSI Break	Average
2017-8-8	29 DAYS	1	122500	4330	4620 TRUCK 1
2017-8-8	29 DAYS	2	145000	5130	5090 TRUCK 2
2017-8-11	32 DAYS	1	135500	4790	
2017-8-11	32 DAYS	1	134000	4740	
2017-8-11	32 DAYS	2	140000	4950	
2017-8-11	32 DAYS	2	147000	5200	

Texas A&M Transportation Institute Proving Ground, 3100 SH 47, Bldg 7091, Bryan, TX 77807 Texas A&M University, College Station, TX 77843, Phone 979-845-6375	5.7.2 Concrete Break	Doc. No. QPF 5.7.2	Revision Date: 2012-09-17
Quality Policy Form	Revised by: G. E. Schroeder Approved by: C. E. But	Revision: 5	Page: 1 of 1

Project No.: 490027-2-1 **Casting Date:** 2017-7-27

Placement: SINGLE SLOPE **Mix Design P.S.I.:** CLASS C

Truck No.	Batch Ticket	Yards
1		8
2		4

Printed name of Technician taking sample: GREG FRITZ

Signature of Technician taking sample:

Printed name of Technician breaking sample: GREG FRITZ,

Signature of Technician breaking sample:

Break Date	Cylinder Age	Truck No.	Total Load (Pounds)	PSI Break	Average
2017-8-8	12 days	1	124500	4400	4550 TRUCK 1
2017-8-8	12 DAYS	2	135000	4775	4845 TRUCK 2
2017-8-11	15 DAYS	1	133500	4720	
2017-8-11	15 DAYS	1	128000	4530	
2017-8-11	15 DAYS	2	134500	4760	
2017-8-11	15 DAYS	2	141500	5005	

CUSTOMER COPY

INSTEEL WIRE PRODUCTS

INSTEEL WIRE PRODUCTS COMPANY
UNIFORM STRAIGHT BILL OF LADING
ORIGINAL - NOT NEGOTIABLE

Bill of Lading No. **00226029-7144137**
Date: 16-MAY-17
Stop 1 of 1
Page 1 of 1

SHIP FROM	CARRIER
Name: INSTEEL WIRE PRODUCTS COMPANY Address: 500 KLEMP ROAD DAYTON, TX 77535	CUSTOMER TRUCK

SHIP TO DESTINATION (CONSIGNEE)	FREIGHT PAYMENT METHOD
Name: TEXAS TRANSPORTATION INSTITUTE Address: SAFETY & STRUCTURAL SYSTEMS DIV. 3100 SH 47 BLDG 7091 BRYAN TX 77807	■ Prepaid ■ Customer Truck

SPECIAL INSTRUCTIONS/COMMENTS

Customer Truck

CARGO

NOTE: Wire carriers, if used, remain Insteel's property.
To return, please call 1-336-719-9000

Hazardous Material	Units	Package Type	Sales Order No.	Unit Weight	Weight	Commodity Description, Special Marks, Exceptions
	17 EA	SHEETS	460662	394	6690	53D-229768 VAR X 8 D19.7/D9.4 (.501/.346) DR 82.7" (+1.375",+1.375") X 31' 1" (17",4") 42" SSCB (1) or (1F) 539-270680-Epoxy 53D-229768-Bent 536-229767-Flat

Total Weight: 6,690 LBS

RECEIVED, subject exclusively to the Terms and Conditions stated herein to the exclusion of any rates, classifications, or tariffs established or maintained by the Carrier. The Carrier has received from the Shipper, the property described above in actual good order and condition, except as noted, at the location noted in the "SHIP FROM" Box above and will properly and carefully load, handle, carry, keep, care for, and deliver it to the destination noted in the "SHIP TO" Box above, in exchange for certain freight charges, the adequacy of which is hereby acknowledged by the Carrier. Notwithstanding the fact that Shipper may provide recommendations and personnel to assist in loading the Cargo on Carrier's vehicles, Carrier and its agents and employees remain solely responsible for proper arrangement of the Cargo on Carrier's vehicles. It is mutually agreed by and between the Shipper and Carrier that every service to be performed hereunder is subject to the Terms and Conditions hereof. The Carrier hereby certifies that it is familiar with all of those Terms and Conditions and that it irrevocably agrees to them for itself and its assigns.

NOTE QUANTITY & QUALITY EXCEPTIONS AT DESTINATION HERE

NOTE: Failure to specify exceptions at destination here does not affect the Shipper's rights against the Carrier.

Carrier Signature / Pick Up Date

5/16/17

Carrier acknowledges receipt of the property described above in actual good order and condition, except as noted. By signing this form, the driver accepts the Shipper's Terms and Conditions as provided. A Driver copy of the Terms and Conditions page may be requested from the Shipper, if desired.

Shipper Signature / Date

5-16-17

Shipper certifies that the property described above is properly packaged, marked, and labeled and in proper condition for transportation according to the applicable regulations of the DOT.

Customer Signature / Delivery Date

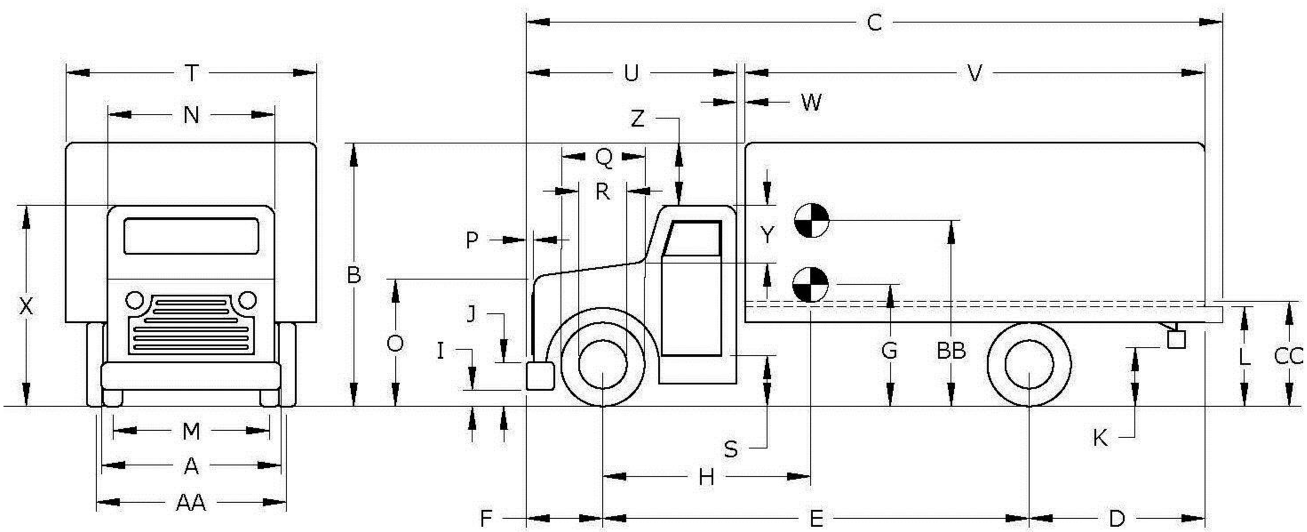
Customer acknowledges receipt of the property described above in actual good order and condition, except as noted.

APPENDIX C. CRASH TEST NO. 490027-2-1 (*MASH* TEST 4-12)

C.1 VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 490027-2-1.

Date:	2017-08-08	Test No.:	490027-2-1	VIN No.:	1HTMMAAL34H594534
Year:	2004	Make:	International	Model:	4300
Odometer:	NA	Tire Size Front:	295/75R22.5	Tire Size Rear:	295/75R22.5



Vehicle Geometry: inches

A	Front Bumper Width:	95.00	K	Rear Bumper Bottom:	-----	U	Cab Length:	106.00
B	Overall Height:	133.00	L	Rear Frame Top:	39.50	V	Trailer/Box Length:	216.50
C	Overall Length:	322.50	M	Front Track Width:	80.00	W	Gap Width:	3.00
D	Rear Overhang:	85.50	N	Roof Width:	71.00	X	Overall Front Height:	98.50
E	Wheel Base:	201.00	O	Hood Height:	59.00	Y	Roof-Hood Distance:	30.00
F	Front Overhang:	36.00	P	Bumper Extension:	1.00	Z	Roof-Box Height Difference:	46.00
G	C.G. Height:	-----	Q	Front Tire Width:	39.00	AA	Rear Track Width:	73.00
H	C.G. Horizontal Dist. w/Ballast:	131.00	R	Front Wheel Width:	23.50	BB	Ballast Center of Mass:	64.00
I	Front Bumper Bottom:	19.25	S	Bottom Door Height:	39.00	CC	Cargo Bed Height:	40.00
J	Front Bumper Top:	33.50	T	Overall Width:	101.75			-----

Wheel Center Height Front	19.00	Wheel Well Clearance (Front)	13.50	Bottom Frame Height (Front)	46.00
Wheel Center Height Rear	19.00	Wheel Well Clearance (Rear)	8.00	Bottom Frame Height (Rear)	29.75

Table C.1. Vehicle Properties for Test No. 490027-2-1 (Continued).

Date:	2017-08-08	Test No.:	490027-2-1	VIN No.:	1HTMMAAL34H594534
Year:	2004	Make:	International	Model:	4300

WEIGHTS (lb)	**CURB**	**TEST INERTIAL**
$W_{front\ axle}$	6710	7790
$W_{rear\ axle}$	6800	14580
W_{TOTAL}	13510	22370

Ballast: 8700 (lb)

Mass Distribution
(lb): **LF:** 3780 **RF:** 4010 **LR:** 7430 **RR:** 7150

Engine Type: DT

Engine Size: 466

Transmission Type:

x Auto or ____ Manual

____ FWD x RWD ____ 4WD

Accelerometer Locations (inches or mm)

	x[3]	**y**	**z**[4]
Front:	--	--	--
Center:	131.00	0	50.25
Rear:	225.50	0	50.25

Describe any damage to the vehicle prior to test: None

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

Block (Height 30 inches/Width 60 inches/Length 30 inches)

Block (Height 24 inches/Width 60 inches/Length 31 inches) on 3-inch tube

Centered in middle of bed

64 inches to center of block to ground level

Four 5/16-inch cables per block

[3] Referenced to the front axle
[4] Above ground

C.2 SEQUENTIAL PHOTOGRAPHS

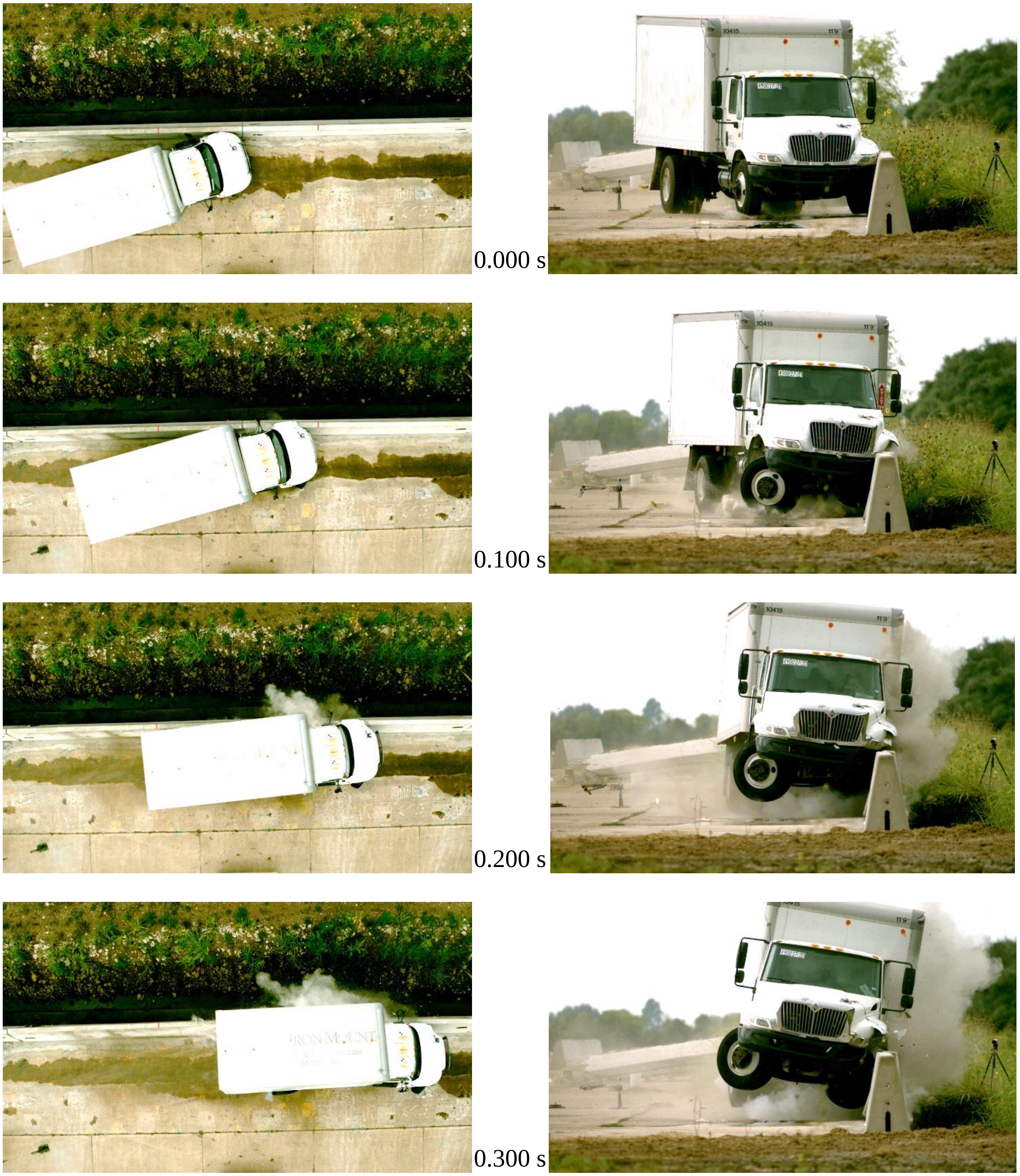


Figure C.1. Sequential Photographs for Test No. 490027-2-1 (Overhead and Frontal Views).

0.500 s

0.700 s

Out of View

0.950 s

Out of View

1.400 s

Figure C.1. Sequential Photographs for Test No. 490027-2-1 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s

0.200 s

0.300 s

0.500 s

0.700 s

0.950 s

1.400 s

Figure C.2. Sequential Photographs for Test No. 490027-2-1 (Rear View).

C.3 VEHICLE ANGULAR DISPLACEMENT

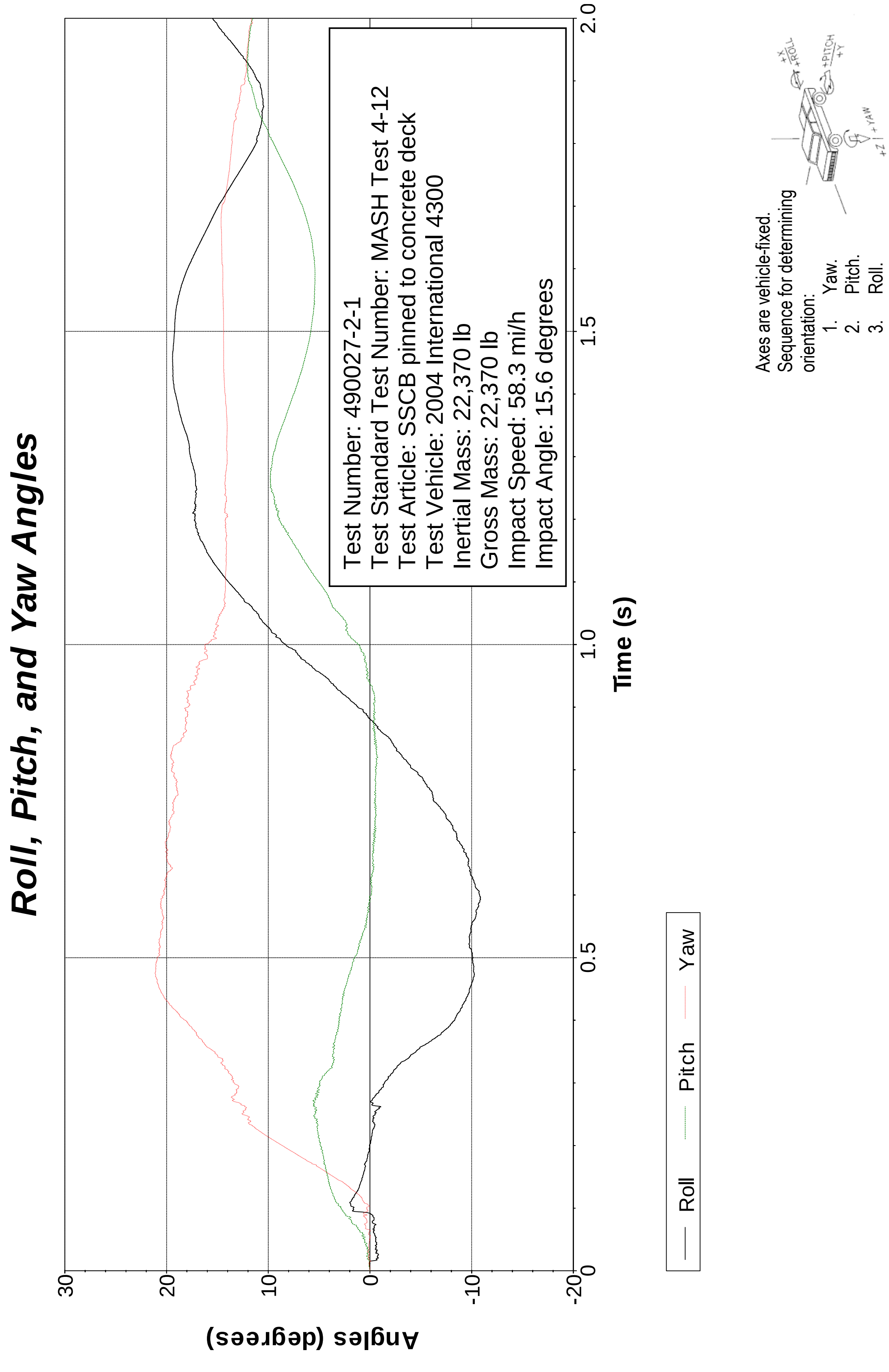


Figure C.3. Vehicle Angular Displacements for Test No. 490027-2-1.

C.4 VEHICLE ACCELERATIONS

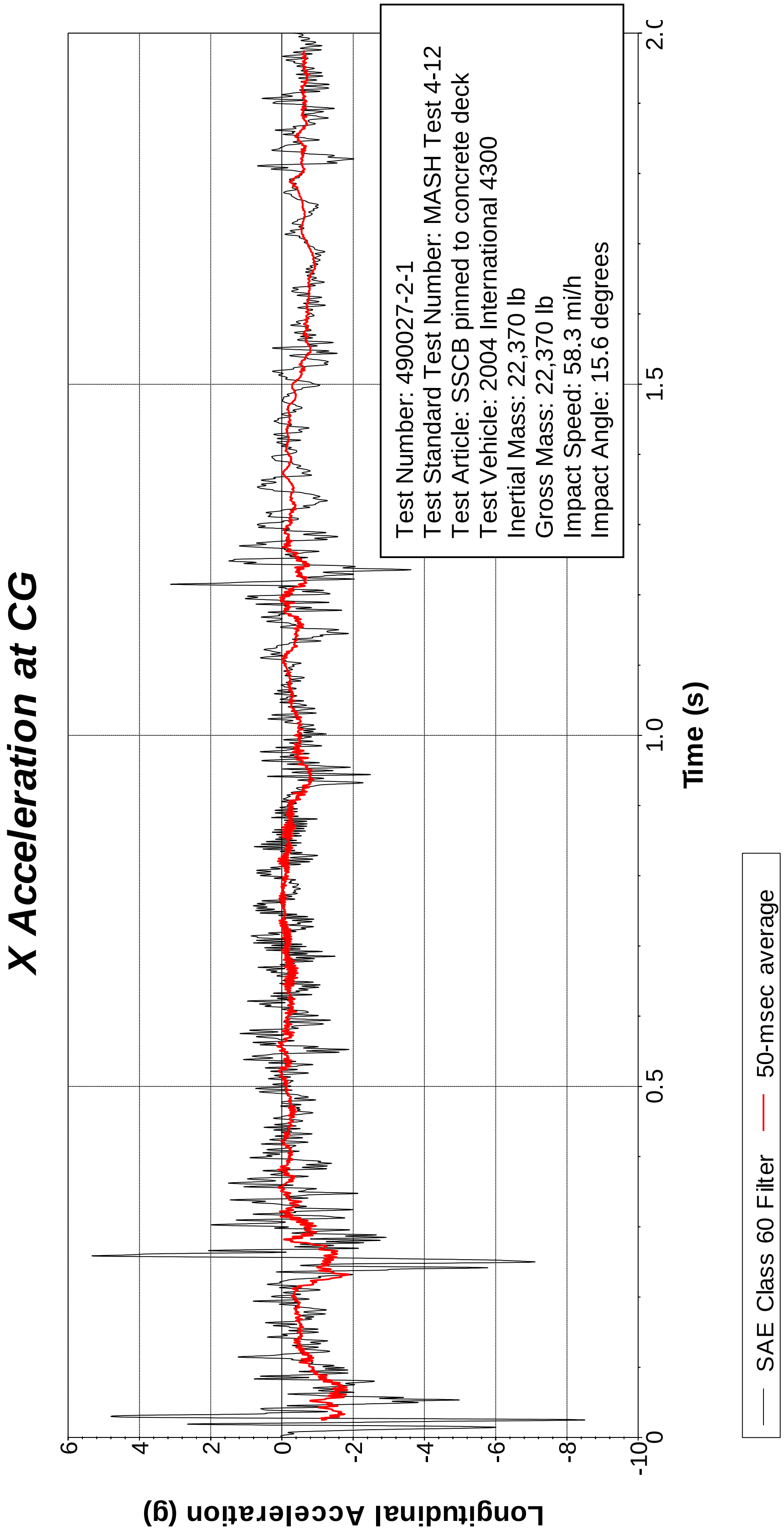


Figure C.4. Vehicle Longitudinal Accelerometer Trace for Test No. 490027-2-1 (Accelerometer Located at Center of Gravity).

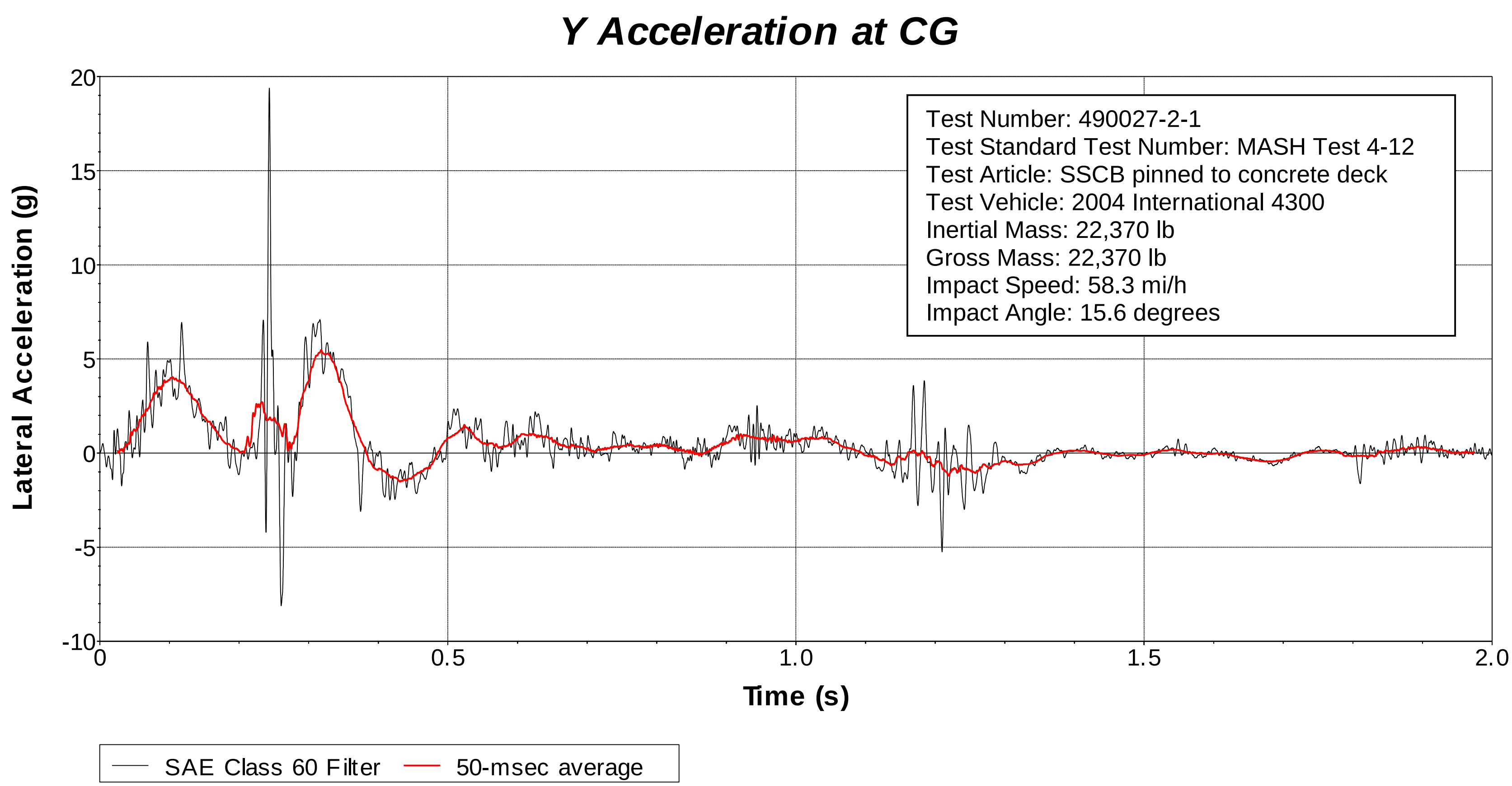


Figure C.5. Vehicle Lateral Accelerometer Trace for Test No. 490027-2-1 (Accelerometer Located at Center of Gravity).

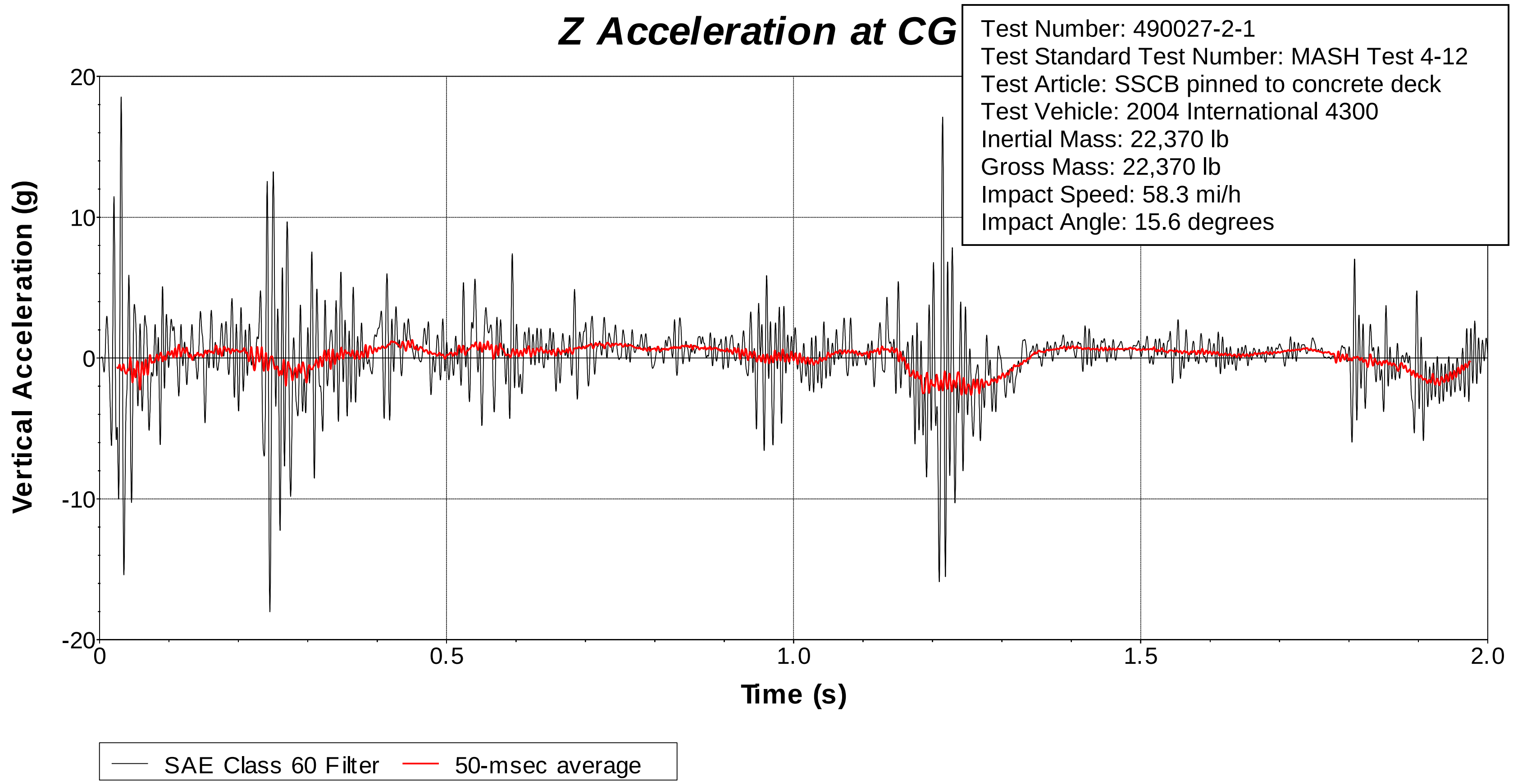


Figure C.6. Vehicle Vertical Accelerometer Trace for Test No. 490027-2-1 (Accelerometer Located at Center of Gravity).

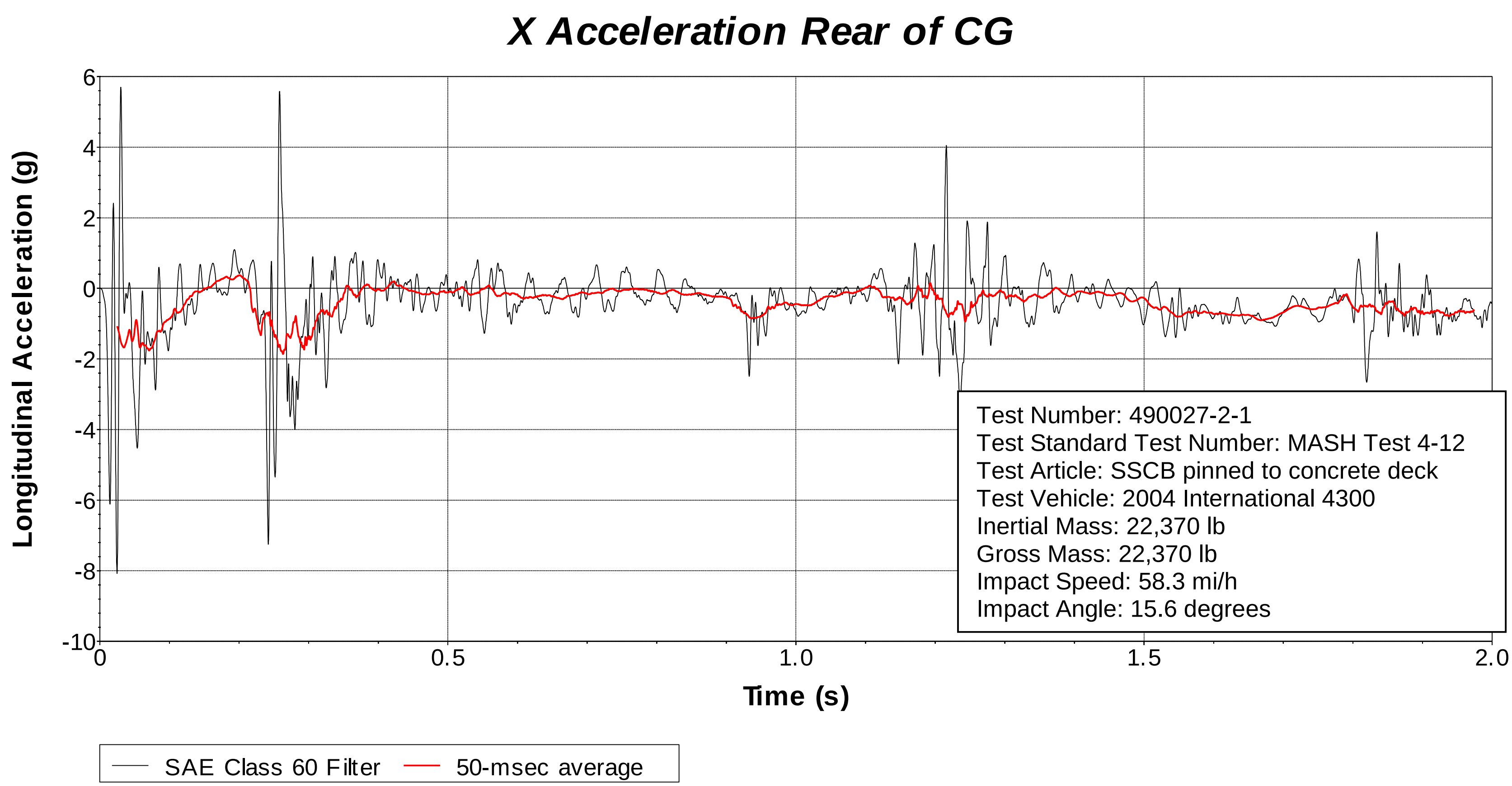


Figure C.7. Vehicle Longitudinal Accelerometer Trace for Test No. 490027-2-1 (Accelerometer Located Rear of Center of Gravity).

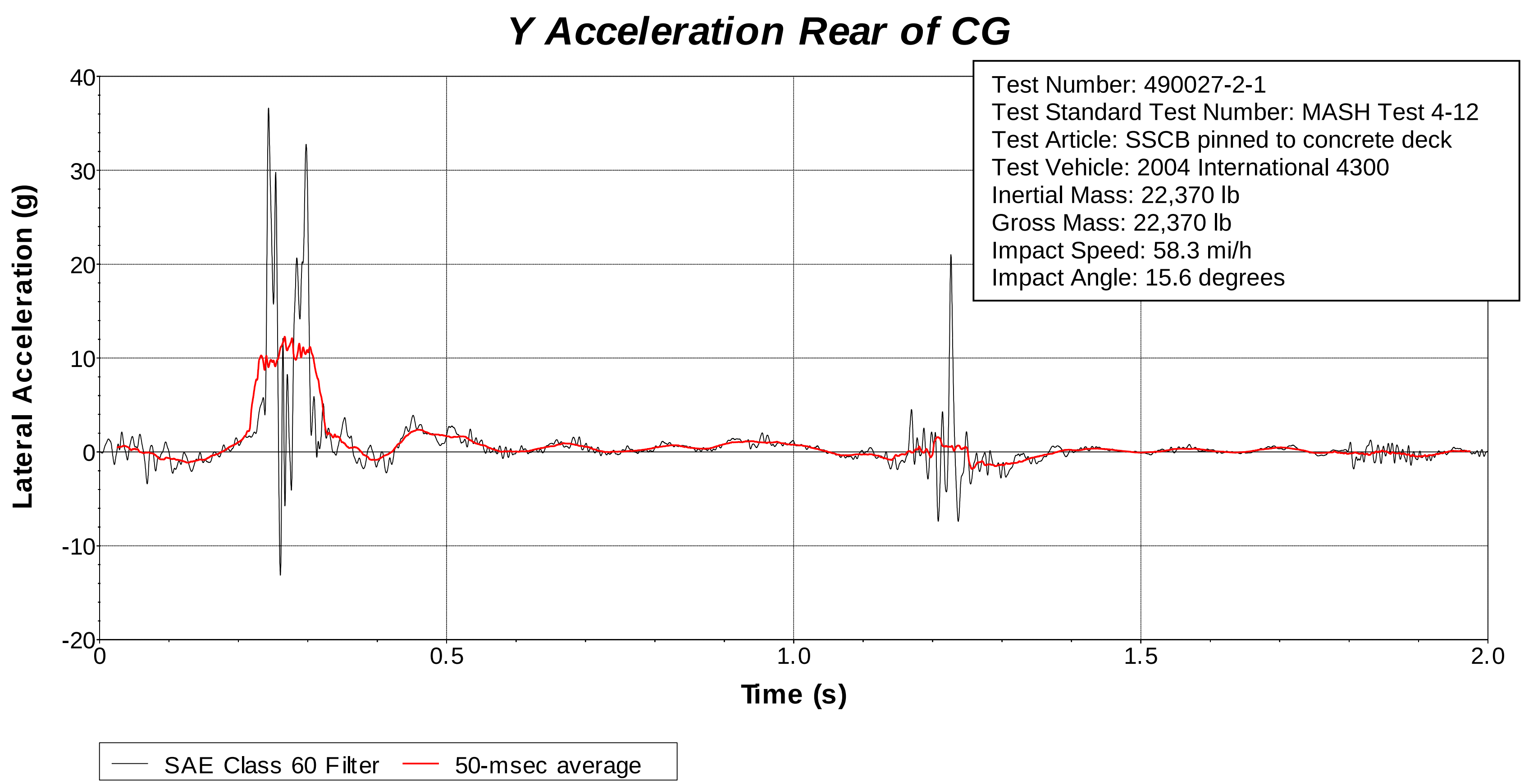


Figure C.8. Vehicle Lateral Accelerometer Trace for Test No. 490027-2-1 (Accelerometer Located Rear of Center of Gravity).

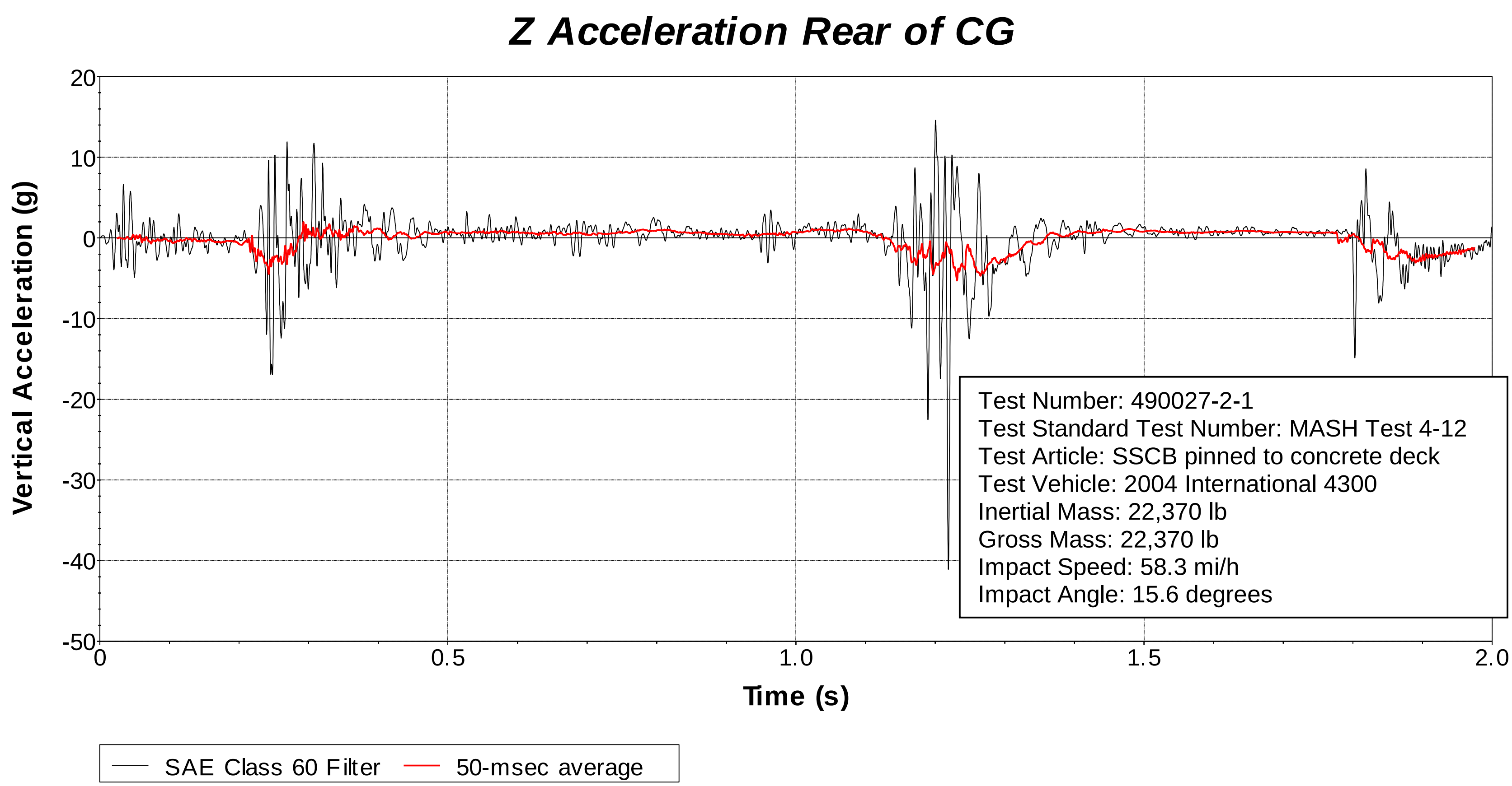


Figure C.9. Vehicle Vertical Accelerometer Trace for Test No. 490027-2-1 (Accelerometer Located Rear of Center of Gravity).