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Signs on Concrete Median Barriers

Test Report 0-6646-1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

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16. Abstract

Concrete median barriers have been used throughout the state as permanent and temporary barriers for providing separation of traffic. Typically, these barriers are tested and considered crashworthy through crash testing according to National Cooperative Highway Research Program *Report 350* or American Association of State Highway and Transportation Officials *Manual for Assessment of Safety Hardware*. Due to space restrictions, a sign or a light pole is placed on top of such barriers. However, when signs or light poles are mounted on top of barriers, the crashworthiness of the system is not necessarily guaranteed. There is very limited research on how a combination of device and barrier would perform if impacted by an errant vehicle. Moreover, no full-scale crash tests have been performed to accurately identify the influence of attachments on vehicular deceleration. Therefore, there is a need to identify existing practices of placing hardware on top of median barriers, as well as defining the crashworthiness of such combinations.

In this project, a survey of the practice of mounting hardware on top of barriers was performed. Analytical, computer simulation, and testing tasks were conducted to define crashworthy hardware and placement guidelines. This research developed a design guideline and a standard that could be incorporated into TxDOT standards and specifications.

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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 objective of this report. The engineer in charge of the project was Roger P. Bligh, P.E. (Texas, #78550).

TTI PROVING GROUND DISCLAIMER

The full-scale crash tests reported herein were performed at TTI Proving Ground. TTI Proving Ground is an ISO 17025 accredited laboratory with A2LA Mechanical Testing certificate 2821.01. This certificate does not include simulation analysis. The results of the crash testing reported herein apply only to the articles being tested.

ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01

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CHAPTER 1. INTRODUCTION

1.1 INTRODUCTION

Concrete median barriers have been used throughout the state as permanent and temporary barriers for providing separation of traffic. Typically, these barriers are tested and considered crashworthy through crash testing according to National Cooperative Highway Research Program (NCHRP) *Report 350* or American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessment of Safety Hardware* (*MASH*) (*1,2*). Due to space restrictions, a sign or a light pole is placed on top of such barriers. However, when signs or light poles are mounted on top of barriers, the crashworthiness of the system is not necessarily guaranteed. There is very limited research on how a combination of device and barrier would perform if impacted by an errant vehicle. Moreover, no full-scale crash tests have been performed to accurately identify the influence of attachments on vehicular deceleration. Therefore, there is a need to identify existing practices of placing hardware on top of median barriers, as well as defining the crashworthiness of such combinations.

The following sections present the methodologies performed to develop a design guideline and a standard that could be incorporated into Texas Department of Transportation (TxDOT) standards and specifications.

1.2 WORK PLAN

1.2.1 Task 1 – Literature Review and Survey of Current Practices

The Texas A&M Transportation Institute (TTI) research team performed a thorough literature review of available research performed in the area of signs and poles mounted on permanent concrete median barriers. Inquiries were made to the large TxDOT districts to obtain their current practices in using such construction methods. The research team obtained drawings of sign and/or pole construction on top of the concrete median barriers. Information gathered from the literature review was evaluated and reported in Chapter 2.

1.2.2 Task 2 – Engineering Review and Development of Construction Concepts

The research team performed an engineering review of the available construction details to identify potential performance issues as well as to define possible corrective changes. Concepts for new construction details were developed during this task and were presented to TxDOT for consideration. A set of construction concepts was recommended for further evaluation by nonlinear finite element analysis. These concepts are presented in Chapter 3.

1.2.3 Task 3 – Numerical Simulation and Development of Preliminary Guidelines

In this task, the research team conducted finite element analyses of the recommended concepts from Task 2. The finite element analyses were conducted to simulate *MASH* test 3-11. Details of the median barrier and the selected sign/pole connection were modeled in order to obtain high reliability in the simulation. The simulation represented an actual construction practice obtained in Task 1. This provided a benchmark case for the remainder of the simulation cases. The simulations served to provide performance evaluations for each construction detail or concept. Consequently, a preliminary guideline was developed to define parameter variation (e.g., ramp rate on top the barrier for a given barrier height). Recommendations of designs for full-scale crash testing were conveyed to TxDOT for approval and selection of four candidates. Chapter 4 presents the results of the finite element analyses and the recommended design/concepts for testing.

1.2.4 Task 4 – Full-Scale Crash Testing of Selected Mount Design

TTI researchers installed a 75-ft long F-shape concrete barrier in accordance with the barrier specifications from TxDOT standards. The barrier was anchored to the runway at the TTI Proving Ground testing facility. Four crash tests were performed to impact the sign connection areas on top of the barrier. The impact points were selected to maximize vehicle interaction with the sign support. These tests followed *MASH* test 3-11.

MASH test 3-11 involves a 5000-lb quad-cab pickup truck impacting the critical impact point to maximize the vehicle interaction with the mounted sign support at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. Each crash test was evaluated according to *MASH* specifications. These crash tests are reported in Chapter 6.

1.2.5 Finalize Guidelines and Document Findings

After the crash tests were performed, the TTI research team finalized the guidelines and provided TxDOT with specific mounting standards for the cases tested in Task 4. This report documents the work performed, methods used, and results achieved, including standards for rigidly mounting signs and light poles on top of permanent concrete barriers.

1.3 OBJECTIVES/SCOPE OF RESEARCH

In this project, a survey of the practice of mounting hardware on top of barriers was performed. Analytical, computer simulation, and testing tasks were conducted to define crashworthy hardware and placement guidelines. This research developed a design guideline and a standard that could be incorporated into TxDOT standards and specifications.

CHAPTER 2. LITERATURE REVIEW

2.1 INTRODUCTION

This literate review presents an overall view of what has been accomplished in the area of signs and poles mounted on permanent concrete median barriers. The literature review is divided into four key parts. The first part (sections 2.2, 2.3 and 2.4) includes a review of existing guidelines for the attachments and classification of attachment types used nationwide. The second part (sections 2.5 and 2.6) includes the review of crash tests performed on concrete median barriers and the barriers with signs and poles mounted on top. An overview of nonlinear finite element techniques (section 2.7) used in the past to evaluate concrete barriers is presented in the next part. The final part (section 2.8) of this chapter discusses the current TXDOT standards for constructing concrete barriers and sign support systems.

2.2 EXISTING GUIDELINES FOR THE ATTACHMENTS

Researchers at Midwest Roadside Safety Facility (MwRSF) developed the concept of Zone of Intrusions (ZOIs) as a guideline for the placement of attachments on top of or behind a barrier (*3*). They conducted a comprehensive review of full scale crash testing of bridge rail and median barriers to establish ZOIs for traffic barriers. A wide variety of traffic barrier classes including sloped-faced and vertical-faced concrete barriers were reviewed. ZOIs were identified for different *NCHRP Report 350* test levels (*1*). Extent that a pick-up or single truck intrudes over the top of barrier during an impact was the basis for establishing the ZOI. The maximum intrusions of any portion of a test vehicle beyond the top-front corner of the barrier were first considered as the definition of intrusion. However, it was found that the maximum intrusion was sometimes controlled by vehicle's exterior mirror and snagging of mirror on a barrier attachment was not considered to represent significant risk for occupant injury. Hence, it was necessary to identify the structural portion of test vehicle that should be considered when defining the ZOI. Table 2.1 shows some of the crash test data reviewed by Keller et al. (*3*). As can be seen from the table, researchers identified the maximum significant intrusion of the vehicle components considered as threat for occupant injury.

For TL-3, barrier classes were combined into three groups based on the size of intrusion extent: (1) sloped face concrete barrier and steel tube rail on 6-inch curb or greater; (2) vertical face concrete barrier, combination of concrete and steel rail, all timber rail; and (3) steel tube rails not on a curb or on less than a 6-inch curb. ZOIs for TL-3 identified by Keller et al. are shown in Figure 2.1. As can be seen, the intrusion zones for TL-3 sloped face concrete barriers with 30 inches to 32 inches in height consisted of an area above the barrier that is 18 inches wide and extends above the barrier to a height of 78 inches above the roadway surface. A 6-inch wide ZOI was recommended for the vertical face concrete barrier with 29 inches to 32 inches in height.

Table 2.1. Portion of the Intrusion Extent Results from Crash Review (*3*).

Barrier Class	Barrier Name	Barrier Height (inches)	Test Level	Vehicle	Maximum Intrusion (inches)	Vehicle Component
Concrete with sloped face	New Jersey Safety Shape Bridge rail	30	TL-4	Small Car	6	Hood/Fender
				Pickup	8	Hood/Fender
		32	TL-4	Pickup	9	Hood/Fender
		32	TL-3	Pickup	18	Hood/Fender
	Single Slope	32	TL-4	Pickup	12	Hood/Fender
	F-Shape	32	TL-4	Small Car	2	Hood/Fender
				Pickup	8	Hood/Fender
Concrete with vertical face	Nebraska Open Conc.	29	TL-4	Pickup	16	Hood/Fender
				Pickup	14	Hood/Fender
	Vertical Wall	32	TL-4	Small Car	8	Hood
				Pickup	15	Hood/Fender
	Texas Type T411	32	TL-3	Pickup	24	Hood/Fender

Since, TL-4 barriers have little height variations, all of them exhibited similar intrusion number (*3*). Hence, only one ZOI was defined for TL-4 barriers. As shown in Figure 2.2, ZOI for TL-4 barriers with heights in the range of 28 inches to 42 inches was much wider at the top where the cargo box extended significantly beyond the front face of the barrier. Near the top of the barrier, ZOI for single unit trucks was similar to that of the pickup truck in TL-3 analysis. The truck cab ZOI extends 34 inches back from the front face of the barrier from top of the barrier to 8 ft above roadway surface. For cargo box, bottom of the intrusion zone was placed 9 inches below the barrier top and top of intrusion zone was placed 10 ft above the road surface.

Keller et al. recommended the placements of attachments outside the ZOI identified for each barrier class. The authors recommended that the impact performance of an attachment and its placement that does not follow these suggested criteria can only be verified through the use of full-scale crash testing.

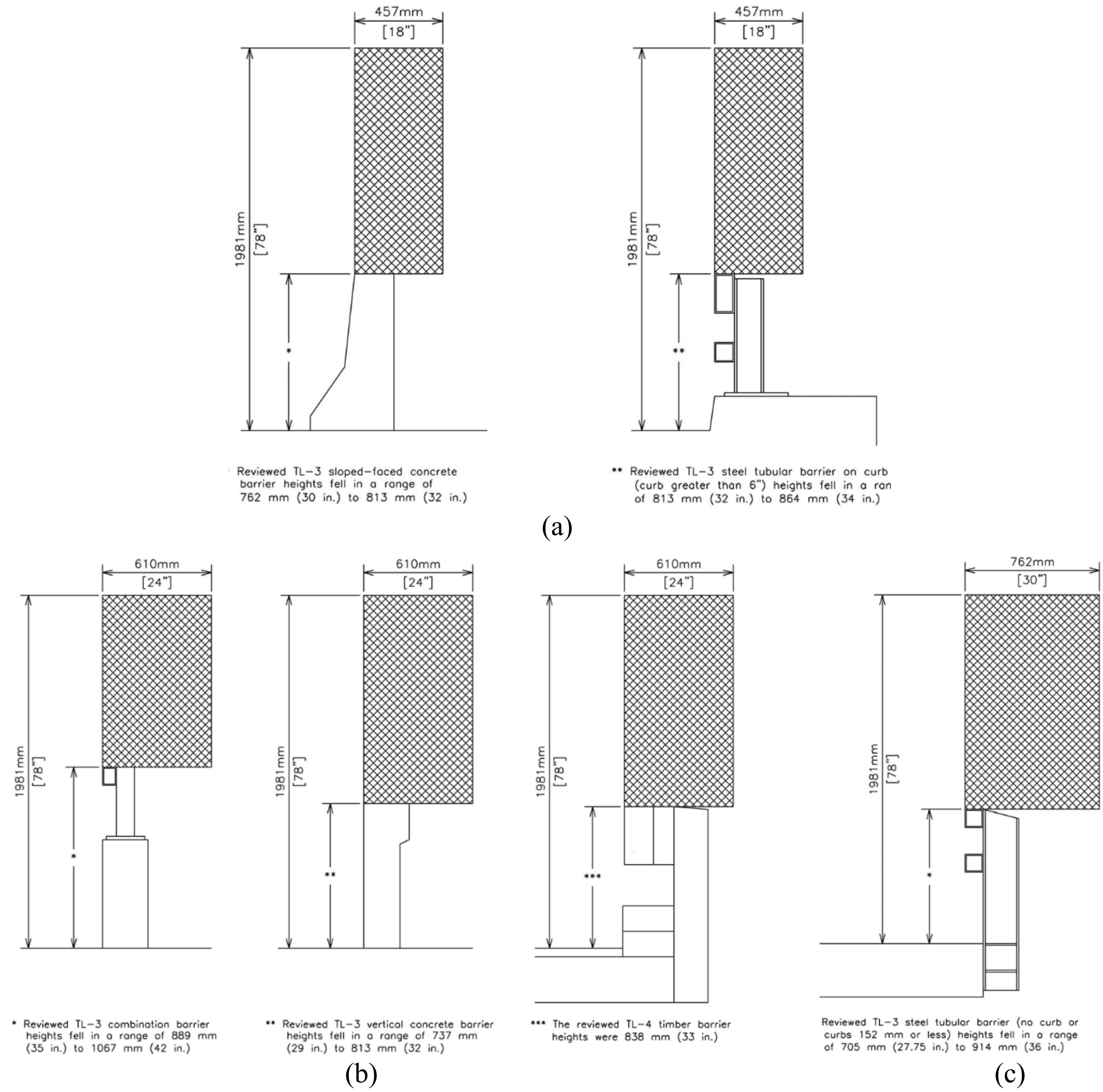


Figure 2.1. TL-3 Zone of Intrusions for
(a) Sloped Face Concrete Barrier and Steel Tube Rail on Curbs > 6 inches;
(b) Vertical Face Concrete Barrier and Combination Concrete and Steel Rail;
and (c) Steel Tube Rail on Curbs > 6 inches (*3*).

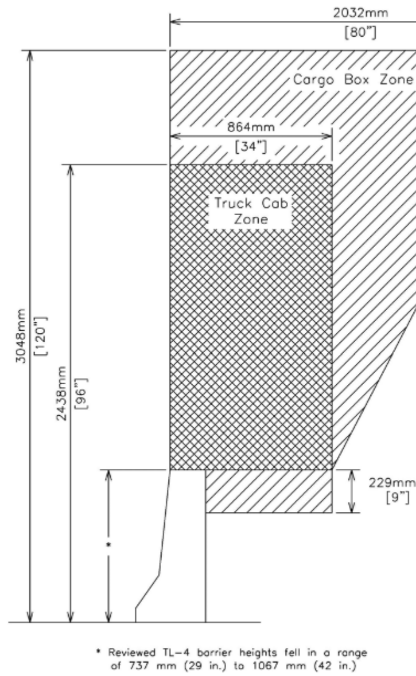


Figure 2.2. Zone of Intrusions for TL-4 Barriers (*3*).

2.3 ATTACHMENT TYPES

Figure 2.3 shows lists of barrier attachments used in the national highway. Keller et al. identified more than 125 traffic barrier attachments. Based on the size and method of connections to the barrier these were grouped as follows (*3*):

- Luminaire supports mounted on top of traffic barrier.
- Luminaire supports mounted behind the barrier.
- Signs on traffic on grade-separated intersecting roadways.
- Large single support signs and overhead sign support structures.
- Medium to small signs.
- Fences and screens.
- Pedestrian/bicycle railings.
- Miscellaneous attachments or fixed objects adjacent to parapets.

Based on the geometry and potential to cause safety hazard, these attachments were further classified as discrete and continuous. Discrete attachments (e.g., luminaire support, sign support poles) are single, individual entity, and continuous attachments (e.g., bicycle railing, noise wall, and fences) that span the entire length of traffic barrier. Based on geometry, structure, and connection to barrier, Keller et al. subdivided the discrete attachments as rigid, breakaway, and non-rigid barriers.

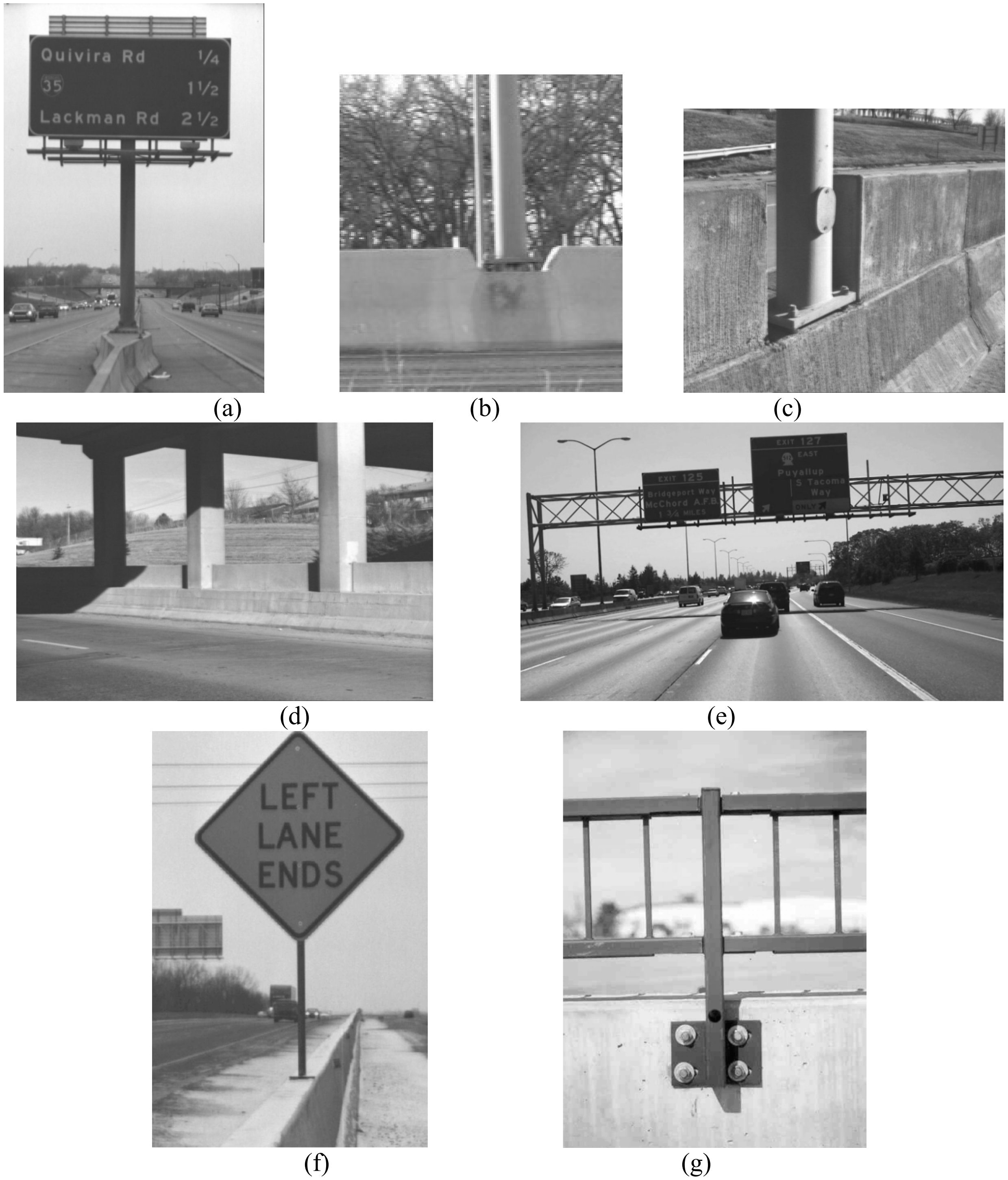


Figure 2.3. (a) Large Overhead Sign on Expanded Barrier (*4*); (b) Luminaire Pole on Lowered Barrier Top; (c) Luminaire Pole within Rigid Glare (*4*); (d) Bridge Pier on Top of Median Barrier (*4*); (e) Sign Bridges (*5*); (f) Medium Signs (*3*); (g) Minnesota Bridge Rail Breakaway Posts (*3*).

Rigid attachments are large, structurally stiff, and rigidly connected devices. These devices are expected to impart significant deceleration force to the vehicle impact occurs within the ZOI region and have potential to cause severe vehicle snagging and occupant compartment deformation. Keller et al. recommended avoiding the use of rigid discrete attachments in ZOI regions until such time as the risks can be adequately assessed through crash testing. The researchers will investigate safety and integrity of these types of attachments when mounted on median barriers within the ZOI.

Breakaway discrete attachments utilize the mechanisms to weaken the connection to the barrier. These breakaway mechanisms are generally designed to activate during frontal collision (*3*). Hence impact by hood or fender of the truck may require significant deformation to activate the mechanism. Therefore, vehicle snagging can be a potentially serious problem. If the breakaway mechanism is activated, these devices also have potential to create debris problem.

Non-rigid discrete attachments (e.g., light-gauge steel and aluminum posts and reflectors) contain minimal connection to the barriers, and hence have great potential to create debris problem when impacted by the vehicles. Performance of continuous attachments placed within ZOI, as shown in Figure 2.3(g) depends on post location and stiffness, geometry, continuity, and tensile capacity of longitudinal elements, transition at the attachment ends, and proximity to the pedestrian or vehicles that may be affected by debris (*3*).

2.4 GUIDELINES FOR THE PERFORMANCE EVALUATION OF ROADSIDE SAFETY HARDWARE

Subsequent to its publication in 1993, the impact performance of longitudinal barriers (e.g., median barriers, guardrails) was evaluated following guidelines set forth in *NCHRP Report 350*. Six test levels were defined for longitudinal barriers that place an increasing level of demand on the structural capacity of a barrier system. The basic test level was Test Level 3 (TL-3). The structural adequacy test for this test level consisted of a 2000 kg pickup truck (2000P) impacting a barrier at 62 mi/h and 25 degrees. The severity test consists of an 1800-lb passenger car (820C) impacting the barrier at 62 mi/h and 20 degrees. At a minimum, all barriers on high-speed roadways on the National Highway System (NHS) are required to meet TL-3 requirements. Some state departments of transportation require that their bridge railings and/or median barriers meet TL-4, which requires accommodation of a 17,640 lb single unit truck (8000S) impacting a barrier at 50 mi/h and 15 degrees.

NCHRP Project 22-14(2), "Improvement of Procedures for the Safety-Performance Evaluation of Roadside Features," was initiated to take the next step in the continued advancement and evolution of roadside safety testing and evaluation. The final product of Project 22-14(2) was published by the AASHTO in October 2009 and is known as the *Manual for Assessment of Safety Hardware (MASH)*. This document supersedes *NCHRP Report 350* as guidance for the impact performance evaluation of roadside safety devices.

Major revisions incorporated into the new guidelines include new design test vehicles, revised test matrices and impact conditions, changes to the evaluation criteria, inclusion of tests for additional features, and increased emphasis on in-service performance evaluation. Table 2.2 presents the revised test matrix and impact conditions. As can be seen from the table the large design test vehicle has been changed from a standard cab, ¾-ton pickup truck with a center of gravity (C.G.) height of approximately 27-inches to a ½-ton, four-door, quad-cab pickup truck with a minimum C.G. height of 28-inches. The weight of the test vehicle increased approximately 13 percent from 4400 lb to 5000 lb. The weight of the small car test vehicle increased 35 percent from 1800 lb to 2425 lb. The impact angle for all TL-3 level redirection tests was fixed to 25 degrees. Considering both the increase in weight and impact angle, the impact severities of the small car redirection test (Test 3-10) increased by 106 percent. The weight of the TL-4 single-unit truck increased 25 percent from 17,640 lb to 22,050 lb, and the impact speed increased 12 percent from 50 mi/h to 56 mi/h. The resulting increase in impact severity is 57 percent. This change will affect the status of some barriers currently classified as TL-4 barriers under *NCHRP Report 350*.

Table 2.2. Test Matrix for TL 3 and TL -4 Specified in *NCHRP Report 350* and *MASH*.

Test Level	Test Designation	*NCHRP Report 350* (*1*)			*MASH* (*2*)		
		Test Vehicle	Impact Speed	Impact Angle	Test Vehicle	Impact Speed	Impact Angle
TL-3	3-10	820C 1800-lb Passenger car	62 mi/h	20 deg	1100C 2425-lb Passenger car	62 mi/h	25 deg
	3-11	2000P 4400 lb Pickup truck	62 mi/h	25 deg	2270P 5000-lb Pickup truck	62 mi/h	25 deg
TL-4	4-12	8000S 17,640 lb Single-unit truck	50 mi/h	15 deg	10000S 22,050 lb Single-unit truck	56 mi/h	15 deg

MASH warrants three categories of safety evaluation criteria for full scale crash testing: (1) structural adequacy, (2) post-impact vehicle trajectory, and (3) occupant risk factor. To pass the structural adequacy criteria, the test vehicle should be contained and redirected by the test article and the vehicle should not penetrate, underride, or override the test installation. The vehicle trajectory after impact is an indicator of the potential of post-impact trajectory to cause subsequent multi vehicle collisions, or secondary collisions with fixed objects. The vehicle trajectory and final stopping position should intrude a minimum distance, if at all, into adjacent or opposing traffic lanes (*1,6*).

The occupant risk evaluates the degree of hazard to the occupant in the impacting vehicle. In 1981, Michie developed the flail space model to evaluate occupant risks in roadside safety hardware crash tests (*7*). The model assumes that the occupant injury severity is related to the velocity at which occupant impacts the interior and the subsequent acceleration experienced by the occupant. As shown in Figure 2.4, the occupant is allowed to flail 2 ft in longitudinal direction (parallel to the typical vehicle travel direction) and 1 ft in lateral direction before impacting the vehicle interior. Difference in velocity between the occupant and vehicle interior at the instant the occupant reach either 2 ft longitudinally or 1 ft laterally is computed using measured vehicle kinematics (*8*). The largest difference in velocity, at the instant of occupant impact, is termed as occupant impact velocity (OIV). OIV in lateral and longitudinal directions are calculated independently. Once the occupant impacts the vehicle interior, the occupant is assumed to remain in contact with the interior and experience subsequent vehicular accelerations. The maximum 10-millisecond (ms) average of the acceleration (lateral and longitudinal directions are calculated independently) subsequent to the occupant impact is termed as ridedown acceleration. *MASH* prescribes threshold values, shown in Table 2.3, for both occupant impact velocity and occupant ridedown acceleration to minimize the risk of occupant injury. To pass the occupant risk criteria, occupant impact velocities and ridedown accelerations in both longitudinal and lateral directions obtained from a crash test must not exceed the maximum values specified. These maximum values correspond to serious but not life-threatening occupant injury (*9*).

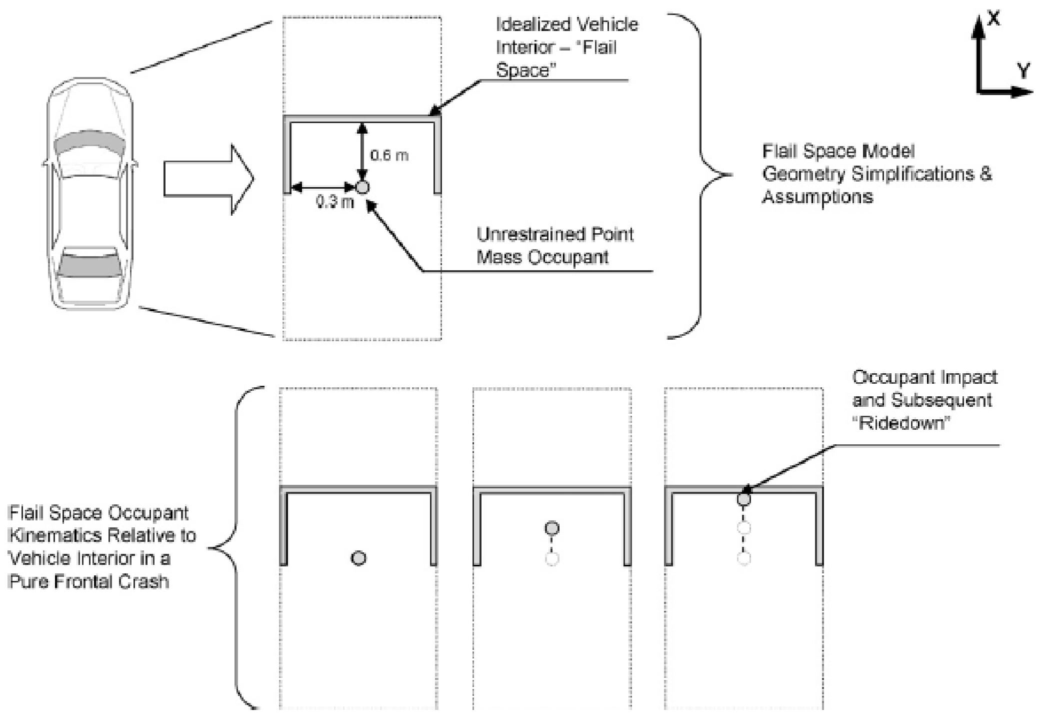


Figure 2.4. Flail Space Model Assumption and Simplifications as Described by Michie (*8,9*).

Table 2.3. *MASH* Specified Flail Space Model Threshold Values Used for Occupant Risk Evaluation Criteria (*6*).

Occupant Risk Factors in Longitudinal and Lateral Direction	Preferred Value	Maximum Value
Occupant Impact Velocity (OIV)	30 ft/s	40 ft/s
Occupant Ridedown Acceleration	15 Gs	20 Gs

2.5 CRASH TESTS PERFORMED ON CONCRETE BARRIER

Several crash tests have been performed on various concrete barriers following *NCHRP Report 350* guideline. Table 2.4 presents a list of crash tests performed on sloped face and vertical face concrete barriers following *NCHRP Report 350* test conditions.

In 2010, a number of full scale crash tests were performed at TTI to understand and evaluate the consequences of adopting recommended changes in the new *MASH* guideline on existing roadside hardware. One of these tests involved a 2270P pickup truck impacting the 32-inch tall New Jersey safety shape concrete barrier at a speed and angle of 62.6 mi/h and 25.2 degrees, respectively (*10*). The vehicle was successfully contained and redirected by the barrier. Figure 2.5 shows sequential photographs of the test. As can be seen, the right front tire began climbing the barrier face at 0.066 s. The left tire became airborne at the same time. The vehicle became parallel to the barrier at 0.199 s. The left rear tire began to rise at 0.277 s and the right front tire contacted the ground surface at 0.282 s. The vehicle lost contact with barrier at 0.471 s. The maximum exterior crash to the barrier was 14 inches in the right front corner of the side panel at bumper height. Maximum occupant compartment deformation was 2 inches in the lateral area across that cab at right kickpanel (*10*). Table 2.4 summarizes the occupant risk factors obtained from the test. The New Jersey safety shape barrier performed acceptably in accordance to the safety evaluation criteria set forth in *MASH* 3-11.

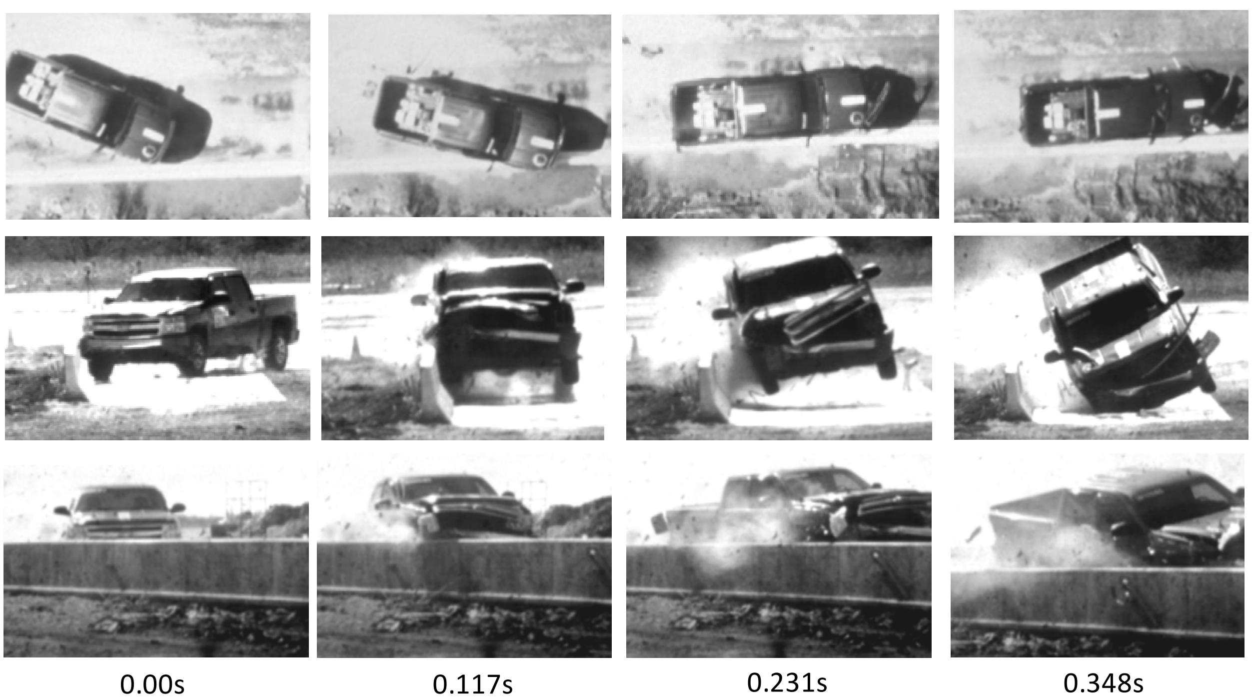


Figure 2.5. Sequential Photograph of Test Performed on New Jersey Safety Shape Barrier Following *MASH* Guidelines (*10*).

Table 2.4. Summary of the Crash Test Performed on New Jersey Safety Shape Following *MASH* Guidelines.

Testing Org.	Test Article Description	Test Cond.	Vehicle	Impact Condition Speed; Angle	OIV (ft/s)		RDA (Gs)		Vehi-cle remain upright
					Long.	Lat.	Long.	Lat.	
TTI (*10*)	New Jersey Safety Shape Concrete Barrier	*MASH* 3-11	5000 lb Pickup	62.7 mi/h; 25.2 deg.	14.1	30.2	5.6	9.6	Yes

2.6 CRASH TESTS PERFORMED ON BARRIER MOUNTED HARDWARE

Several crash tests have been performed to evaluate the performance of barrier mounted hardware systems. Table 2.5 summarizes results of the crash tests performed on various types of barrier mounted hardware. As can be seen from the table, only one crash test was performed following the new *MASH* guidelines. Vehicle in some of these tests failed to remain upright after the impact. Brief descriptions of these tests are presented below.

Researchers at TTI recently investigated the performance of a temporary concrete barrier with sign attachments mounted on top (*11*). The objective of the research was to develop a TxDOT standard for mounting traffic control signs and devices on concrete barrier in construction work zones. A crash test was performed on a TxDOT Type 2 portable concrete traffic barrier (PCTB) with a sign support assembly as per *MASH* test 3-11 (*6*). A crash test performed in 2001 on the modified TxDOT Type 2 PCTB with grid-slot connection and steel straps bolted to the base satisfactorily passed the evaluation criteria set forth in *NCHRP Report 350*. However, the connector strap was ruptured during the test. Hence researchers at TTI increased the strap thickness to 1/4 inch to improve the performance of the barrier. Sign support and sign mount connection was anchored on top of this modified concrete barrier in conjunction with the steel strap connections to three barrier joints as shown in Figure 2.6. A 2270P (5000 lb) Dodge Ram 1500 pickup impacted the test article at a speed and angle of 63.4 mi/h and 24.6 degrees, respectively. The test successfully passed the safety evaluation criteria set forth in *MASH* test 3-11.

Figure 2.7 shows the sequential photographs of the crash test. The vehicle contacted the base of the PCTB mounted sign support at 0.082 s and as the vehicle continued forward, the left front exterior fender panel of the vehicle caught on the sign support and pulled away from the vehicle. Figure 2.8 shows the sign support connection after the test.

Table 2.5. Summary of Crash Tests Performed on Barrier Mounted Hardware.

Testing Org.	Test Article Description	Test Cond.	Vehicle	Impact Condition Speed; Angle	OIV (ft/s) Long.; Lat.	RDA (Gs) Long.; Lat.	Max Dyn Defl (ft)	Vehicle remained upright
TTI (*11*)	Sign post mounted on PCTB	*MASH* 3-11	5004 lb Pickup	63.4 mi/h; 24.6 deg.	13.8; 21.3	10.3 9.8	4.3	Yes
MwRSF (*12*)	Luminaire pole mounted on single slope barrier	*Report 350* 4-12	17,604 lb Single-unit Truck	50.3 mi/h; 15.6 deg.	8.4; 6.7	4.14 6.54	NA	No
		Report 350 4-11	4409 lb Pickup	61.7 mi/h; 23.4 deg.	19.4; 28.2	5.9 12.5	NA	Yes
	Luminaire pole mounted behind single slope barrier	*Report 350* 4-12	17,637 lb Single-unit Truck	50.2 mi/h; 16.4 deg.	8.5; 7.3	3.13 6.43	NA	Yes
MwRSF (*13*)	Noise Wall Attachment to Single Slope Concrete barrier	*Report 350* 4-12	17,840 lb Single-unit Truck	51.2 mi/h 17.7 deg.	10.8; 14.7	6.00 7.86	NA	Yes
		Report 350 4-11	4409 lb Pickup	61.5 mi/h; 25 deg.	17.7; 28.0	9.01 15.6	0.15	Yes
MwRSF (*14*)	Bicycle rail (3-rails) on single slope barrier	*Report 350* 4-11	4409 lb Pickup	62.8 mi/h; 25.6 deg.	17.6; 27.7	6.23 12.8	0.21	No
	Bicycle rail (4-rails) on single slope barrier	*Report 350* 4-11	4409 lb Pickup	63.8 mi/h 25.6 deg.	20.3; 27.6	5.11 14.2	0.01	No
TTI (*15*)	Vandal Protection fence on New Jersey safety shape bridge railing	*AASHTO* PL2	5600 lb Pickup	62.8 mi/h 20.2 deg.	16.4; 9.2	5.6 7.6	0.46	Yes

Table 2.5. Summary of Crash Tests Performed on Barrier Mounted Hardware (continued).

Testing Org.	Test Article Description	Test Cond.	Vehicle	Impact Condition Speed; Angle	OIV (ft/s) Long.; Lat.	RDA (Gs) Long.; Lat.	Max Dyn Defl (ft)	Vehicle remained upright
Ohio TRC (16)	Light pole in the deflection zone of Ohio Type 5 barrier							
	At point of max rail deflection AT-X base	*Report 350* 3-11	4409 lb Pickup	59.0 mi/h; 24.6 deg.	--	--	3.35	Yes
	Close to impact point AT-X base	*Report 350* 3-11	4409 lb Pickup	60.0 mi/h; 27.6 deg.	--	--	4.00	Yes
	Close to impact point AT-A base	*Report 350* 3-11	4409 lb Pickup	58.0 mi/h; 26.7 deg.	19.7; 14.1	7.5 8.8	4.49	Yes
	Close to impact point AT-X base	*Report 350* 3-10	1808 lb Small car	64.9 mi/h 21.4 deg.	12.8; 20.7	14.5 8.5	0.92	Yes
Cal- Trans Dynamic Testing Facility (17)	Concrete Median Barrier Retrofitted with slip formed concrete glare screen (CGS)	*Report 230*	5395 lb Pickup	55.3 mi/h; 20 deg.	9.8; 20.7	1.4 20	0.03	Yes
			4363 lb Station Wagon	55.9 mi/h; 25 deg.	21.9; 21.2	5.5 16.3	0.003	Yes
TTI (18)	Concrete Safety Shape with metal rail on top	*Report 230* S20	80,000 lb Truck	48.4 mi/h; 14.5 deg.	6.6; 15.5	2.34 5.6	0.10	Yes

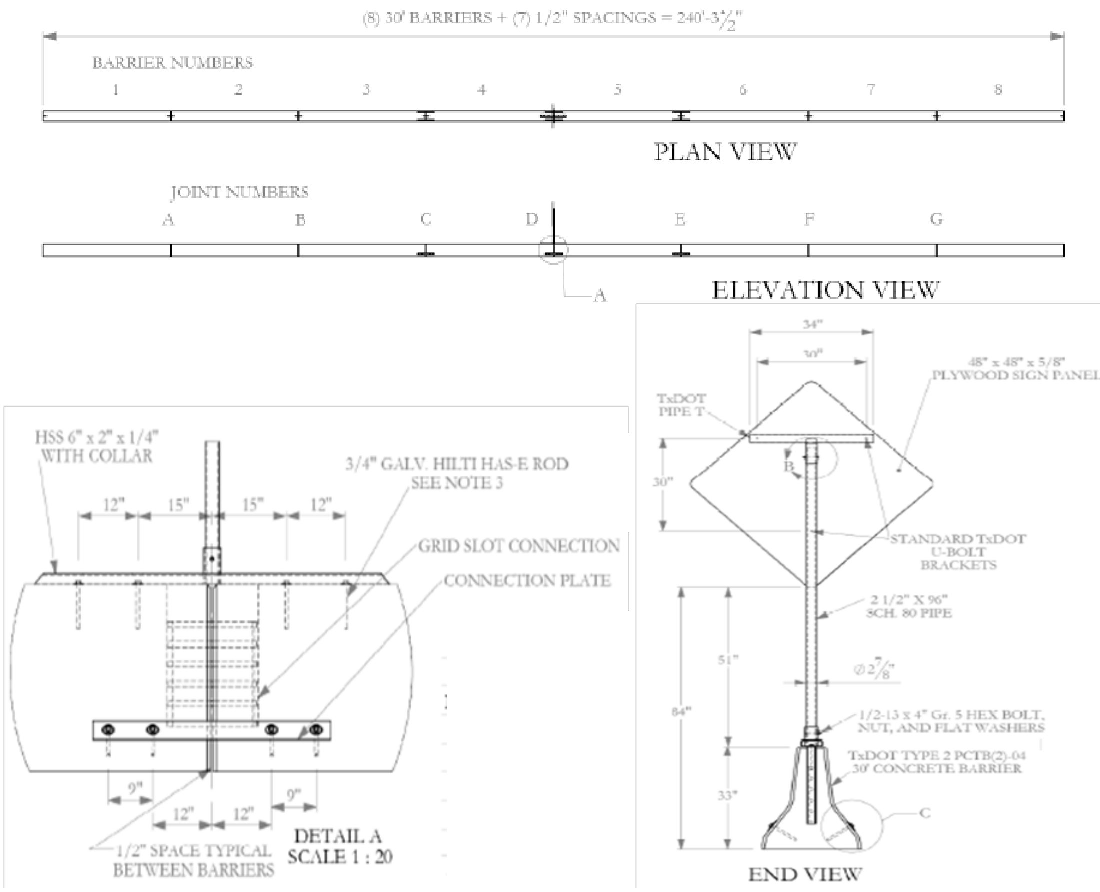


Figure 2.6. Details of PCTB Mounted Sign Support Assembly Used for TTI Test 466431 (*11*).

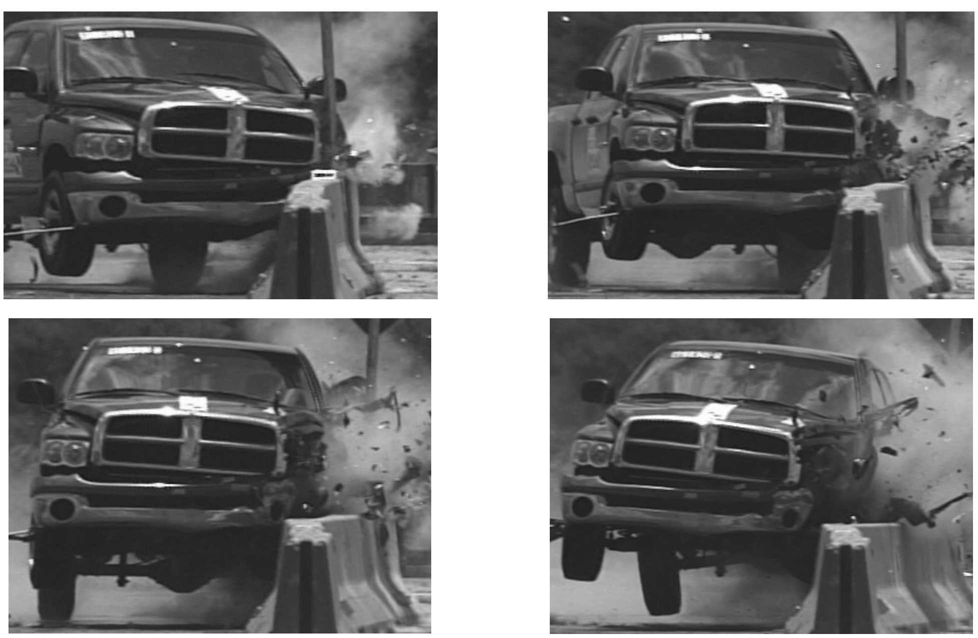


Figure 2.7. Sequential Photographs of TTI Test 466431 (*11*).

Figure 2.8. Sign Support Connection after the Crash Test (*11*).

The steel straps added to the barrier connection at sign mount connection and joints upstream and downstream of the sign mount connection minimized the intrusion of the vehicle over the barrier. This reduced the snagging of the vehicle on sign support and sign mount connection (*11*). The sign support connection developed and tested during this project was recommended for implementation and inclusion into the TxDOT standard specifications for sign supports used in construction zone.

To evaluate the current practices for the placement of luminaire pole both on top and behind the concrete barrier, researchers at MwRSF performed several crash tests following *NCHRP Report 350* guidelines (*12*). For the first two tests, the test article consisted of a 37.5 ft long steel luminaire pole attached on top of an 32-inch tall single slope concrete barrier. As shown in Figure 2.9, a pedestal extended (6.6 inches backward) on backside of the barrier was built at the attachment location to fit the 10-inch wide luminaire pole base on 9.5-inch wide barrier top. In the first test (ZOI-1), a 17,605 lb single unit truck impacted a single slope concrete barrier with a luminaire pole mounted on top at a speed and angle of 50.4 mi/h and 15.6 degrees, respectively (*12*). Figure 2.10 shows the sequential images obtained from the crash test. It can be seen that the luminaire pole disengaged from the barrier and rotated downward to the truck as the front of the truck impacted the pole at 0.83 s. The dislodged pole landed directly behind the barrier and parallel to it. Researchers asserted that these results would not pose significant concerns for the median barrier applications as the pole would likely be within the shoulder and edge of the lane regions. The truck finally rolled to a 40 degree angle and left front corner of the truck contacted the ground at 1.984 s. The crash test, however, was determined to be acceptable according to the evaluation criteria of test designation 4-12 found in *NCHRP Report 350*. The second test (ZOI-2), performed according to test designation 4-11, involved a 4430-lb pickup truck impacting the single slope concrete barrier with luminaire pole attached on top at a speed and angle of 61.7 mi/h and 23.4 degrees, respectively (*12*). Test article successfully contained and redirected the 2000P vehicle. Figure 2.11 shows sequential photographs from the test. As can be seen, the vehicle did not penetrate or override the barrier and remained upright during and after the collision. The impact did not create any detached element or fragment that could show potential hazard to the occupant or other traffic. Occupant risk factors obtained from the test, as shown in Table 2.5, were within the acceptable values. Thus, the test was determined to be acceptable according to the safety evaluation criteria set forth in *NCHRP Report 350*. However, the test did not use any non-instrumented dummy positioned in the impact side of the occupant compartment, which could demonstrate whether or not a belted passenger would partially be ejected outside of the occupant compartment, thereby allowing the head to contact the pole attached to the barrier. Researchers suggested the use of dummies in future crash testing and evaluation of barrier mounted hardware to observe the potential of occupant head ejection and contact with the attachments.

Figure 2.9. Luminaire Pole Attached to Single Slope Barrier for MwRSF Tests: ZOI-1 and ZOI-2 (*12*).

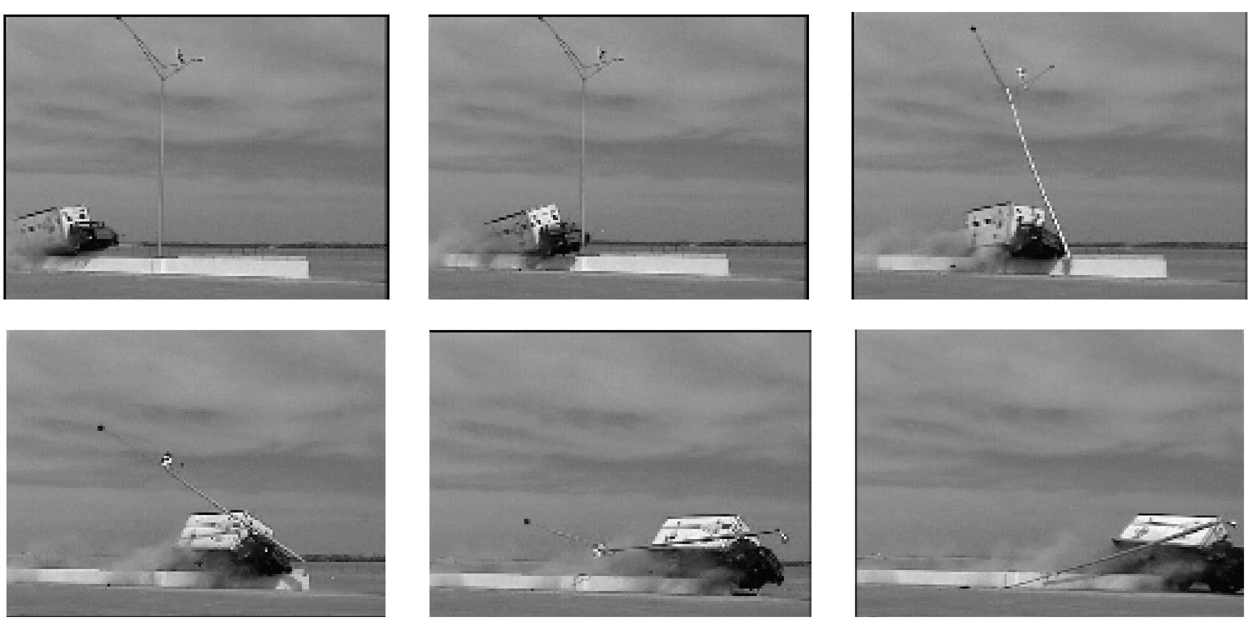


Figure 2.10. Sequential Photographs from MwRSF Test ZOI-1 (*12*).

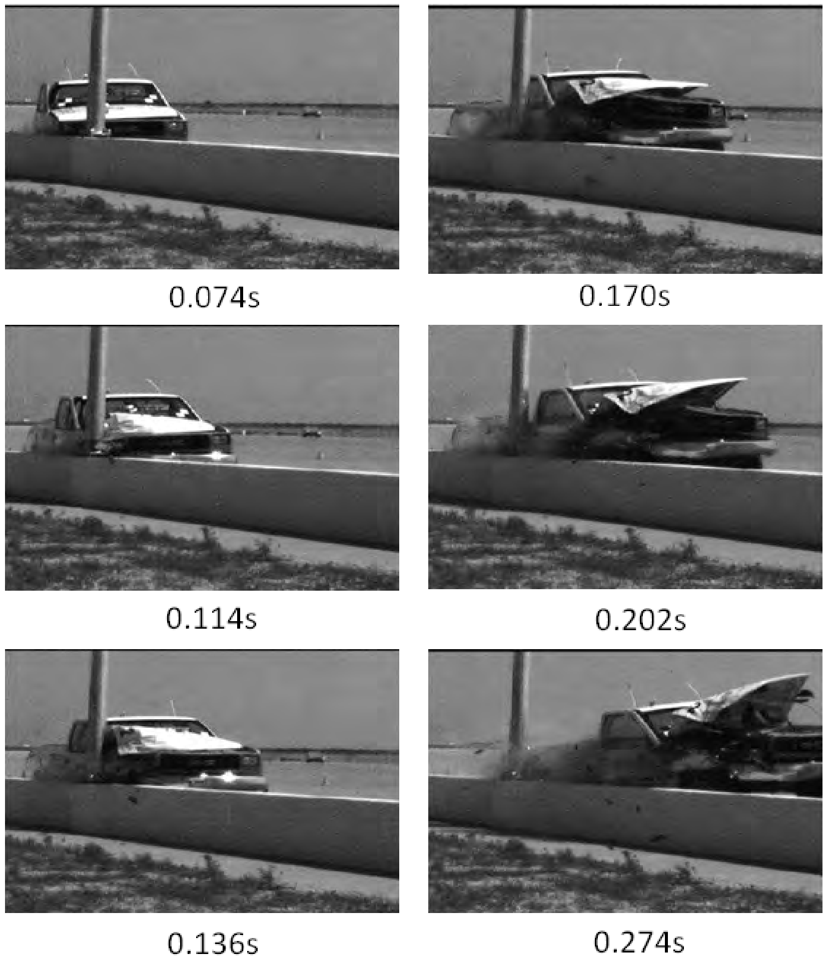


Figure 2.11. Sequential Photographs from MwRSF Test ZOI-2 (*12*).

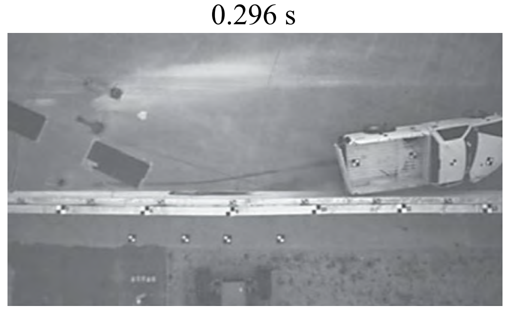
To develop a noise barrier system for use on 32-inch tall single slope concrete barrier, researchers at MwRSF performed two full scale crash tests in accordance with requirements specified in *NCHRP Report 350* Test Level 4 (*13*). An 8000S single-unit truck and 2000P pickup truck were used in these tests. Both tests passed the safety evaluation criteria set forth in *NCHRP Report 350* test designation 4-12 and 4-11, respectively. The test article, as shown in Figure 2.12, consisted of 18 support posts spaced 6.5 ft on center anchored to the back-side vertical face of the concrete barrier. Two paraglass Soundstop GS CC panels occupied the span between each pair of posts. In the first test (CYRO-1), a 17,840-lb single unit truck impacted the noise wall barrier system at a speed and angle of 51.2 mi/h and 17.7 degrees, respectively (*13*). The vehicle was successfully contained and redirected by the system. Damage to the noise barrier wall was minimal. Exterior vehicle damage was moderate and occupant compartment deformation (OCD) to the right side and center of the floorboard was judged insufficient to cause serious occupant injury. In the second test (CYRO-2), a 4416-lb C2500 pickup impacted the test article at a speed and angle of 61.5 mi/h and 25 degrees, respectively. The barrier system successfully contained and redirected the pickup truck. Vehicle reached its maximum roll angle 24.8 degrees at 0.65 s before beginning to roll back and become stable. Figure 2.13 shows sequential photographs captured during the test. During the test the right front corner of the vehicle hood snagged on the up-stream flange of steel post causing minor hood penetration through lower right corner of the windshield (*13*). However, the engine hood remained attached to the truck at both hinge locations and did not pose any significant threat to the occupant (*13*). Occupant risk factors, as shown in Table 2.5, were within acceptable limit. Due to the windshield damage, the test performed on the noise barrier system was considered marginally acceptable according to test designation 4-11 safety evaluation criteria. However, to reduce or eliminate snag locations and provide better safety for a system already determined to be acceptable according to existing safety standards, researchers recommended use of smooth, gauge resistant, wedge-shaped fittings or hardware.

Figure 2.12. Noise Wall Barrier System Used in MwRSF Test (*13*).

0.09 s

0.296 s

0.196 s



0.440 s

Figure 2.13. Sequential Photographs of Crash Test Performed on Noise Barrier Wall System (*13*).

Researchers at MwRSF designed and tested two open traffic/bicycle bridge railing systems for use on a rigid, single-slope concrete barrier (*14*). One full scale crash test was performed for each system in accordance to test designation 4-11 set forth in *NCHRP Report 350*. The bicycle rail used in the first and second tests consisted of three and four longitudinal rails, respectively, mounted on steel posts as shown in Figure 2.14. In both systems, the bicycle rail was mounted to the back of the single slope barrier. In the first test (MOBR-1), a 4442-lb pickup truck impacted the system with three longitudinal rails at a speed and angle of 63.1 mi/h and 25.6 degrees, respectively (*14*). In the second test (MOBR-2), a 4493-lb pickup impacted the system with four longitudinal rails at a speed and angle of 63.8 mi/h and 25.6 degrees, respectively (*14*). In both tests, the open railing on top of the single-slope concrete barrier prevented the test vehicle from climbing the barrier allowing the vehicle roll during exit. Figure 2.15 show sequential photographs obtained from these tests. As shown in the figure, both systems failed to redirect the vehicle safely as it rolled over during the exit.

Figure 2.14. Setup for Crash Tests (MOBR1 and MOBR2) Performed on Two Combination Traffic/Bicycle Bridge Railing Systems Designed at MwRSF (*14*).

(a) (b)

Figure 2.15. Sequential Photographs of Cash Test Performed on Combination Traffic/Bicycle Railing Systems (a) MOBR1 and (b) MOBR2 (*14*).

In 1995, a full scale crash test, as shown in Figure 2.16(a), was performed at TTI on 31-inch tall New Jersey safety shape concrete barrier with vandal protection fence mounted on top following the AASHTO performance level 2 impact conditions (*15*). The thicknesses of the New Jersey shape barrier at the base and top are 15 inches and 6 inches, respectively. The vandal protection fence was mounted on 7.25-ft long × 2.875-inch OD (schedule 40 pipe) straight posts mounted to the back of the barrier. A 5600-lb pickup impacted the test article at a speed and angle of 62.9 mi/h and 20.2 degrees. Contact with fence occurred at 0.032 s. As shown in Figure 2.16(b), the middle horizontal line rail pulled out of the connection at upstream side of post 5 at 0.089 s. Maximum deflection of the fence of 5.6 inches occurred at 0.11 s. The vehicle exited the system at 0.274 s and remained upright during and after the collision. Occupant risk factors obtained from the test, as shown in Table 2.5, were within acceptable values. Hence, the impact performance of the vandal protection fence on New Jersey safety shape bridge railing was considered satisfactory according to the guideline set forth in AASHTO (*16*).

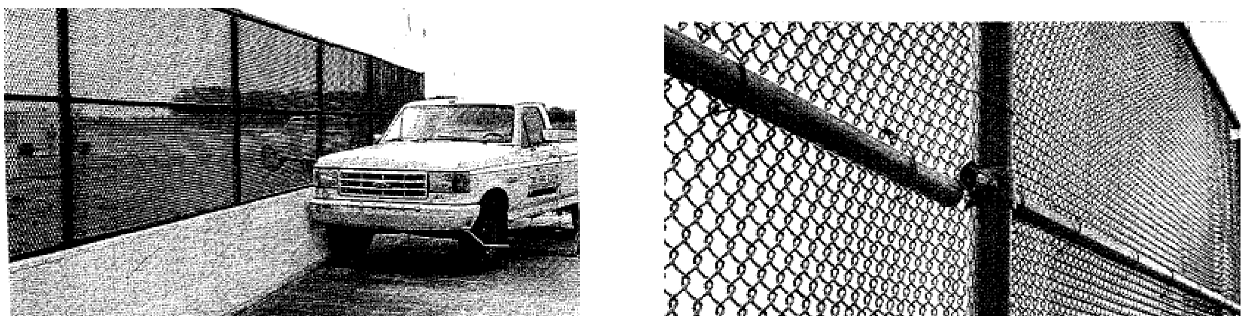


Figure 2.16. (a) Test Setup for New Jersey Shape Concrete Barrier with Vandal Protection Fence Mounted on Top (b) Longitudinal Rail Detached from Post 5 after the Impact (*15*).

In the mid-1990s, a study was performed at Ohio Transportation Research Center (TRC) to determine the effect of light post on the redirecting performance of a roadside guardrail when installed within its deflection zone (*17*). Six crash tests involving two light pole base design (AT-A, and AT-X) and a typical Ohio Type 5 (W-beam) guardrail were performed following *NCHRP Report 350* TL-3 conditions. Basic difference in two aluminum bases was the dimension. While AT-X was almost constant in width and height, the wider AT-A was tapered with height. Figure 2.17 shows the crash test setup for two of these tests. Test 1 and 5 were performed to establish baseline performance of the guardrail and involved a 2000P truck and an 820C small car impacting the guardrail with no light pole. The guardrail performed satisfactorily as per *NCHRP Report 350* requirements. In test 2, a 2000P truck impacted a guardrail with a light pole installed on AT-X base at an approximate point of maximum guardrail deflection as determined in Test 1. This test was performed to provide worst case scenario for the vehicle to snag the pole. The vehicle, however, did not snag the pole and the pole did not breakaway. In the third and fourth tests, the 2000P vehicle impacted the guardrail with a light pole installed close to the impact point using AT-X and AT-A bases, respectively. The pole with a wider AT-A base was located farther from the back of the guardrail compared to the pole with AT-X base. For both tests the light pole did not cause vehicle snagging, but the pole did breakaway. The damage to the vehicle front end was more severe in test 4 compared to test 3, possibly due to the location of the pole farther back from guardrail. Due to the greater distance available, the vehicle in test 4 pitched downward before impacting the pole involving more of the hood and engine area. In the sixth test, 820C small car impacted the guardrail with light pole on AT-X base installed close to the impact point. The vehicle did not snag during the impact and light pole did not breakaway. All the four tests involving the light pole mounted behind the Type 5 guardrail passed the safety evaluation criteria set forth in *NCHRP Report 350*. Table 2.5 present the summary of these tests.

Figure 2.17. Setups for Two Crash Tests Performed at Ohio Transportation Research Center (*17*).

In the early 1990s, two crash tests were performed at Caltrans Dynamic Test Facility on a retrofitted concrete glare screen (CGS) slip formed on top of a 32-inch tall New Jersey safety shape concrete barrier (*18*). Table 2.5 summarizes these tests. Figure 2.18 shows detailed cross section of the test article. In the first test, a 5390-lb pickup truck impacted the test article at a speed and angle of 55.3 mi/h and 20 degrees, respectively. Lengths of the vehicle contact with the barrier and glare screen were 18.4 ft and 10.8 ft, respectively. The maximum height of the truck marks on the test article was 3.1 ft. The pickup did not show any tendency to snag or pocket and was upright throughout and after the collision. It was successfully redirected at an exit speed and angle of 45.7 mi/h and 6 degrees, respectively. There was no evidence of any structural distress of the CGS. The only damage to the barrier was a few scrapes and tire marks. In the second test, a 4363-lb heavy passenger car impacted the test article at a speed and angle of 56.2 mi/h and 25 degrees, respectively. The maximum height of the truck mark on the system was 2.6 ft. The vehicle was successfully contained and redirected without exhibiting any tendency to snag or pocket. However, the vehicle was severely damaged. Both the crash tests successfully passed the safety evaluation criteria set forth in *NCHRP Report 230* (*19*,*20*). Since an errant vehicle might be somewhat less likely to climb over a CGS-equipped barrier, researchers concluded that the additional height and strength of the CGS may cause some safety enhancements.

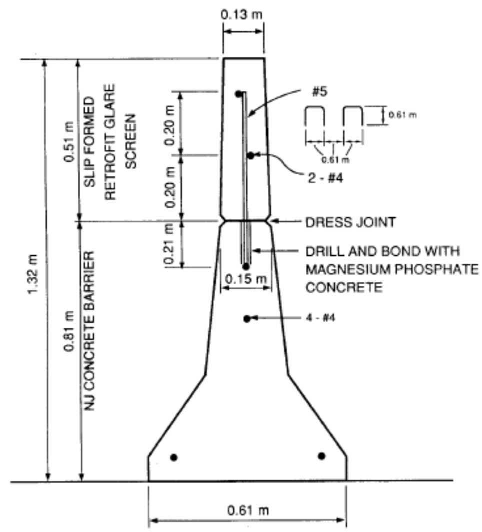


Figure 2.18. Cross Section of Concrete Median Barrier Retrofitted with Slipformed Concrete Glare Screen (*17*).

In the early 1980s, a crash test, as shown in Figure 2.19, was performed at TTI where an 80,000 lb van-type tractor-trailer impacted an 810 mm concrete safety shape with metal rail mounted on top (*21*). This study modified a 32-inch concrete safety shape to make an effective truck traffic rail. The combination rail selected for the test was a modification of the 32-inch tall Texas Type T5 traffic rail with an 18-inch tall modified Texas Type C4 metal rail mounted on top. The truck impacted the bridge rail 2.16 ft downstream of post 5 of the metal rail at a speed and angle of 48.4 mi/h and 14.5 degrees, respectively. Although the truck was contained and redirected, its tandem axles and trailer rolled 90 degrees and the truck came to rest on its side. The concrete parapet was not significantly damaged but the rail experienced damage between post 5 and 8. The threads were stripped from the anchor nuts of post 5 and 6. The maximum dynamic deflection of the metal rail was 11 inches. Table 2.5 summarizes the test. Although the truck rollover was not desirable, the bridge rail did meet the S20 criteria of *NCHRP Report 230*.

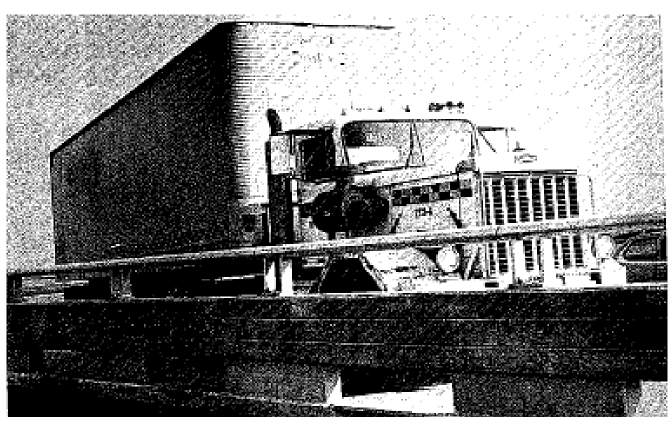


Figure 2.19. Crash Test Setup for 80,000 lb Van-Type Tractor-Trailer Impacting Concrete Safety Shape with Metal Rail on Top (*21*).

In the early 1970s, full scale crash tests were performed at TTI to evaluate the performance of sloped face concrete median barrier with continuous steel fence and luminaire pole mounted on top (*22*). Table 2.6 summarizes these tests. In the first test a 4000-lb passenger car impacted the barrier at the center of luminaire support at a speed and angle of 62.4 mi/h and 25 degrees, respectively. The vehicle rode partially up the side of the barrier and lightly scrapped the attached fence and luminaire pole. Although vehicle did not snag the pole, left front quarter and wheel of the vehicle were severely damaged. The vehicle, however, was successfully contained and redirected by the system. The second test involved a 4000 lb passenger vehicle impacting the concrete median barrier (CMB) with continuous steel fence at a speed and angle of 55.7 mi/h and 25 degrees, respectively. The vehicle to barrier interaction was similar to that of the first test. However due to the 6-mi/h lower impact speed and the fact that the vehicle did not impact a luminaire pole, slightly lower vehicle damage and lateral vehicle deceleration was observed in this test. Third and fourth tests involved a 4000-lb passenger car impacting a 150-ft unanchored CMB with steel fence under in-service type collisions with lower impact angles. For both tests, the average lateral deceleration of the vehicle was low compared to the previous two tests. Also, damages to the vehicle were less severe as expected.

Table 2.6. Crash Tests Performed at TTI in Early 1970s on Light Pole and Continuous Steel Fence on Top of Concrete Barrier.

Testing Org.	Test year	Test Article Description	Vehicle	Impact Condition		Avg. deceleration		Vehi-cle remain stable
				Speed (km/h)	Angle (deg.)	Longit udinal	Transv erse	
TTI (*22*)	1972	Light pole on top of CMB with steel fence	1963 Plymouth 4004 lb	62.5	25	3.2 Gs	4.4 Gs	Yes
		Unanchored section of CMB with continuous steel fence	1964 Chevrolet 4233 lb	55.8	25	1.8 Gs	2.8 Gs	Yes
			1964 Chevrolet 4213 lb	61.0	7	0.5 Gs	1.8 Gs	Yes
				60.8	15	1.4 Gs	3.0 Gs	Yes

2.7 FINITE ELEMENT ANALYSIS [*]

In addition to full scale crash tests, finite element (FE) techniques are widely used to evaluate the performance of roadside safety devices. Due to the availability of powerful computers, roadside safety researchers are overwhelmingly using LS-DYNA (*23,24*), a commercially available finite element software package, to simulate vehicular impacts with roadside safety features. LS-DYNA incorporates explicit and implicit algorithms for the integration of the equation of motion in the time domain. It incorporates state-of-the-art contact algorithms that can be used to model vehicular collisions with roadside objects. Moreover, tire interactions with the ground can be simulated in a more realistic manner using the contact library

[*] TTI Proving Ground is an ISO 17025 accredited laboratory with A2LA Mechanical Testing certificate 2821.01. This certificate does not include finite element analysis.

in LS-DYNA rather than using other assumed behavior models incorporated into some of the other codes. As shown in Figure 2.20, public domain finite element models of 2270P test vehicle, specified in the *MASH*, is already available in LS-DYNA. This vehicle model, developed by the National Crash Analysis Center (NCAC), will be used in this study to perform LS-DYNA simulations on barrier mounted hardware following the specifications set forth in the *MASH* test designation 3-11.

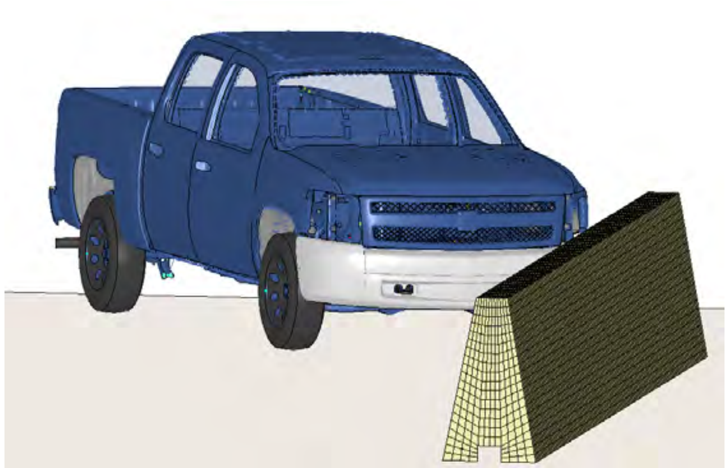


Figure 2.20. 5004 lb *MASH* Test Vehicle Impacting a Single Slope Concrete Barrier.

Researchers at TTI performed several FE simulations to evaluate the performance of single slope concrete barrier under high speed impact conditions (*25*). FE simulations were performed with *NCHRP Report 350* specified 2000P pickup truck impacting the single-slope barrier, modeled using rigid material representation, at a speed of 62 mi/h and 85 mi/h. Figure 2.21 shows the sequential images obtained from the simulation where the 2000P pickup model impacted the single slope barrier at a speed of 62 mi/h and an angle of 25 degrees. As can be seen from the figure, the vehicle experienced substantial climb and instability. The intrusion zone for the vehicle hood and fender extended beyond two times the width of barrier top. In longitudinal direction, OIV and ridedown acceleration (RDA) obtained from the simulation were 21.3 ft/s and 8.4 Gs, respectively. In lateral direction, these values were 26.2 ft/s and 10.8 Gs, respectively. The vehicle, in the simulation, successfully passed the safety evaluation criteria set forth in *NCHRP Report 350*.

Researchers at TTI recently performed a full scale vehicle impact simulation on a New Jersey safety shape bridge rail using *MASH* TL-4 impact conditions (*26*). The single unit truck (SUT) model developed by NCAC was modified by the researchers to reflect the *MASH* 10000S test vehicle specification. For the TL-4 in *MASH*, the mass of the SUT increased from 17,637 lb to 22,000 lb and the impact speed increased from 50 mi/h to 56 mi/h (*26*). The ballast height of *MASH* TL-4 SUT is changed to 63 inches from 67 inches in *NCHRP Report 350* (*26*). The full scale simulation performed using the modified SUT model was validated against the results obtained from a previously conducted crash test.

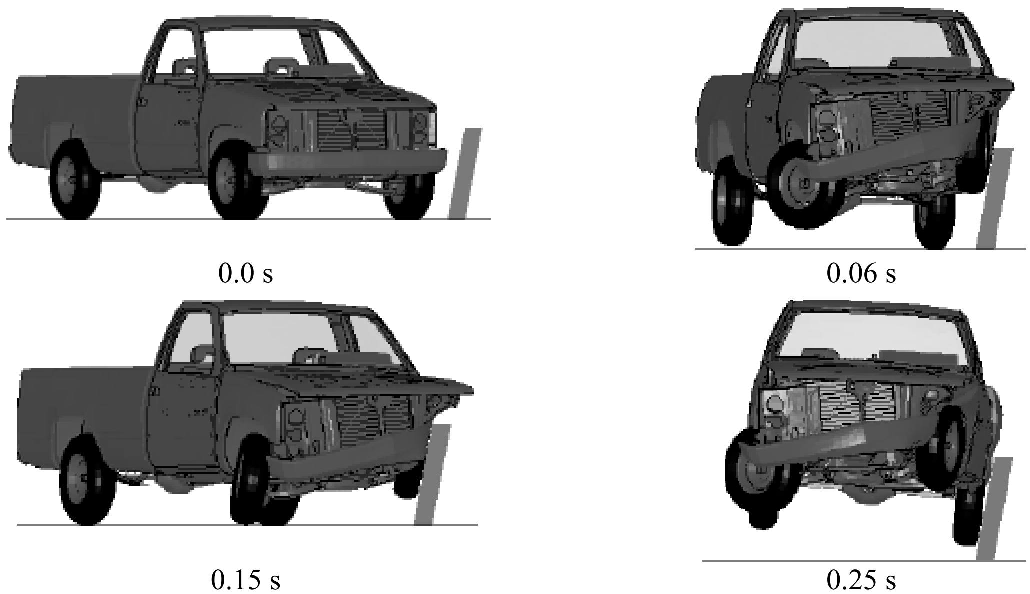


Figure 2.21. Sequential Images of the Simulation Performed on Single Slope Concrete Barrier Following *NCHRP Report 350* TL 3-11 (*25*).

The crash test used for this investigation was conducted at TTI using *MASH* TL-4 impact conditions (*27*). A 32-inch New Jersey safety shape bridge rail was used in this test. The test vehicle was traveling at an impact speed of 57.4 mi/h and impacted the safety shape bridge rail 20 ft from the upstream end at an impact angle of 14.4 degrees. The full scale impact simulation was performed following the same impact conditions. Sequential photographs of the test and simulation were compared as shown in Figure 2.22. The vehicle in the crash test ended up rolling on top of the bridge rail. The simulation captured that dynamics from the beginning of rolling until 0.7 s (*26*). Occupant risk factors, vehicle yaw, pitch, and roll angles of both test and simulation were calculated using the Test Risk Assessment Program (TRAP) (*28*) developed by TTI. Figure 2.23(a) shows vehicle yaw, pitch, and roll angles obtained from the test and simulation. Figure 2.23(b) shows the longitudinal acceleration data obtained at vehicle C.G. for both test and simulation. The acceleration and angular rate data obtained from the test and simulation were compared using the Roadside Safety Verification and Validation (RSVVP) program developed by Mongiardin and Ray (*29*). A phenomena importance ranking table (PIRT), similar to the evaluation tables in *NCHRP Report 350* and *MASH,* was also developed to compare two cases. Both the qualitative and quantitative comparisons between results obtained from test and simulation showed good correlation and the modified SUT model was considered sufficiently validated to proceed with the impact simulations on various crash walls.

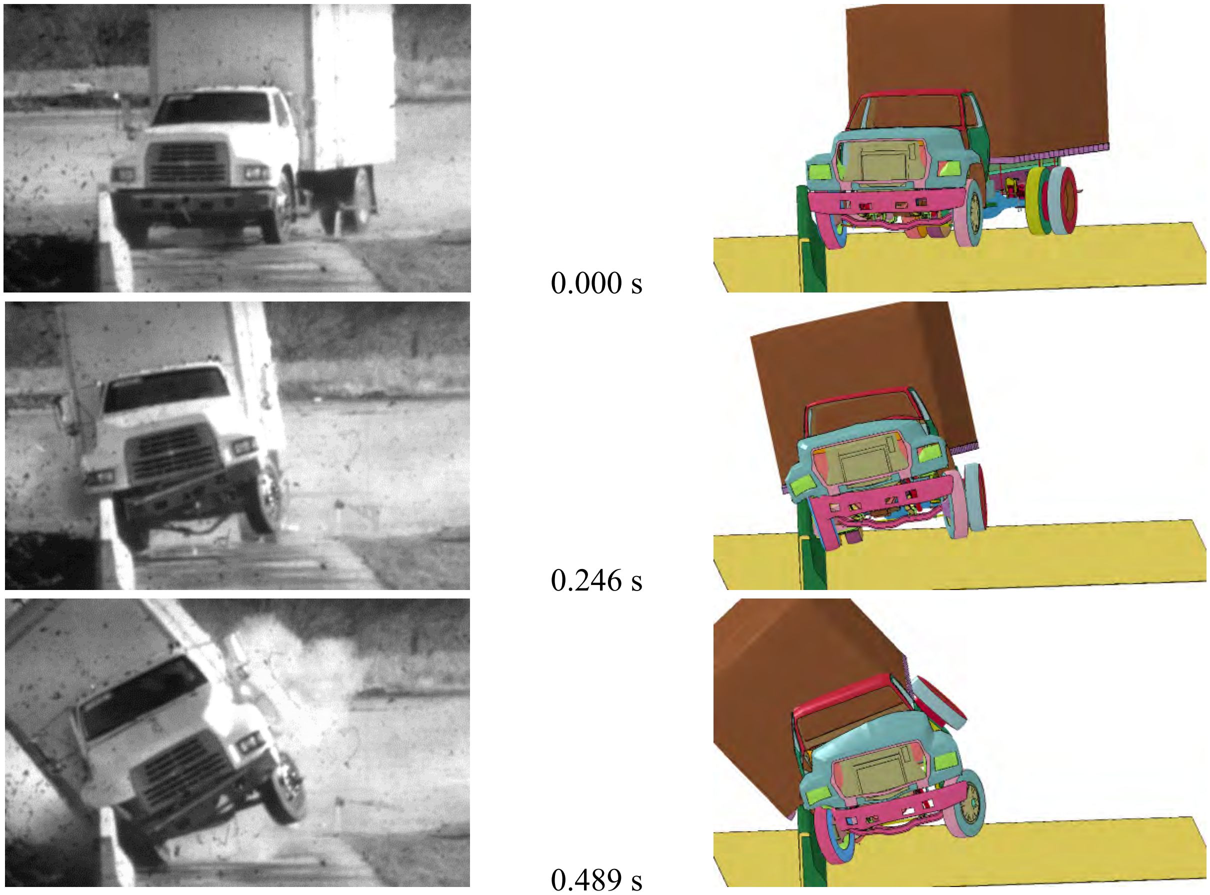


Figure 2.22. Comparison Front View Sequential Photographs for TTI Test 476460-1b (*27*) and Simulation (*26*).

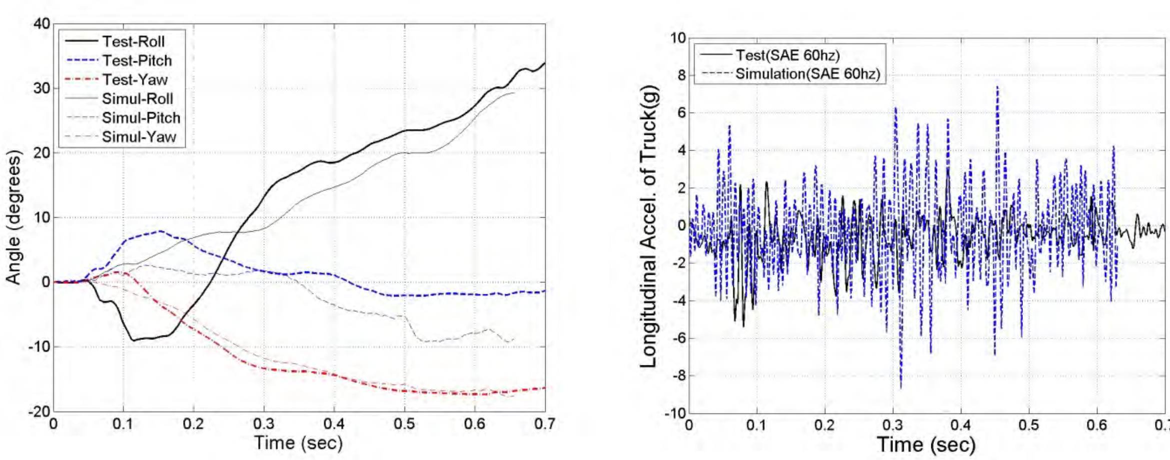


Figure 2.23. Comparisons of (a) Angular Displacements; and (b) Longitudinal Acceleration for Test and Simulation (*26*).

In this study, FE simulation results will be compared with previous crash test results to validate the vehicle and concrete barrier models. The vehicle response and attitude signals, photographic documentations, occupant risk factors, and maximum dynamic deflection of the barrier during and after the impact obtained from simulation and crash test will be compared. Methodologies for making quality assessments on an FE model by comparison with physical test data taken as the object have recently been presented by Ray et al. (*30*) and Schwer (*31*).

Ray et al. recently developed the RSVVP program that can calculate comparison metrics between simulation and crash test signals that are helpful in quantitatively validating a roadside hardware model. The program compares the vehicle response and attitude signals obtained from simulation and crash tests to calculate two comparison metrics: (a) Sprague and Geer metrics and (b) Analysis of variance (ANOVA) of the signals. Sprague and Gears metrics represent integral comparison where time integrals of the response wave forms are combined in the metrics (*31*). The magnitude (M_{SG}) and phase (P_{SG}) components of the metrics are calculated using Equations 2.1 and 2.2:

$$M_{SG} = \sqrt{\frac{c_i^2}{m_i^2}} - 1 \tag{2.1}$$

$$P_{SG} = \frac{1}{\pi}\cos^{-1}\frac{\sum c_i m_i}{\sqrt{\sum c_i^2 \sum m_i^2}} \tag{2.2}$$

The ANOVA metrics are based on the residual between the measured and computed curves. Ray (*32*) proposed a method shown in Equations 2.3 and 2.4 to determine the average residual error and its standard deviation:

$$\bar{e}^r = \frac{\sum (c_i - m_i)/m_{max}}{n} < 0.05 \cdot m_{max} \tag{2.3}$$

$$\sigma^r = \sqrt{\frac{\sum (e^r - \bar{e}^r)^2}{n-1}} < 0.35 \cdot m_{max} \tag{2.4}$$

Here, m_i and c_i are the measured and computed values, respectively. The average residual error ($\bar{e}^r$) and its standard deviation (σ^r) for the ANOVA metrics are normalized with respect to the peak value of the measured curve (m_{max}). The acceptance criteria for both metrics, suggested by Mongiardin and Ray (*33*), are shown in Table 2.7. Ray et al. (*30*) also recommended developing a PIRT in order to verify and validate roadside hardware model. Occupant risk factors, maximum dynamic deflection of the barrier, and data obtained from photographic documentations are compared in PIRT. The relative difference between the simulation and test results presented in PIRT should not exceed 20 percent. Both the RSVVP and PIRT will be used in this research to improve and validate the numerical models of *MASH* TL-3 vehicle and concrete barriers.

Table 2.7. Acceptance Criteria Used in RSVVP Program (*33*).

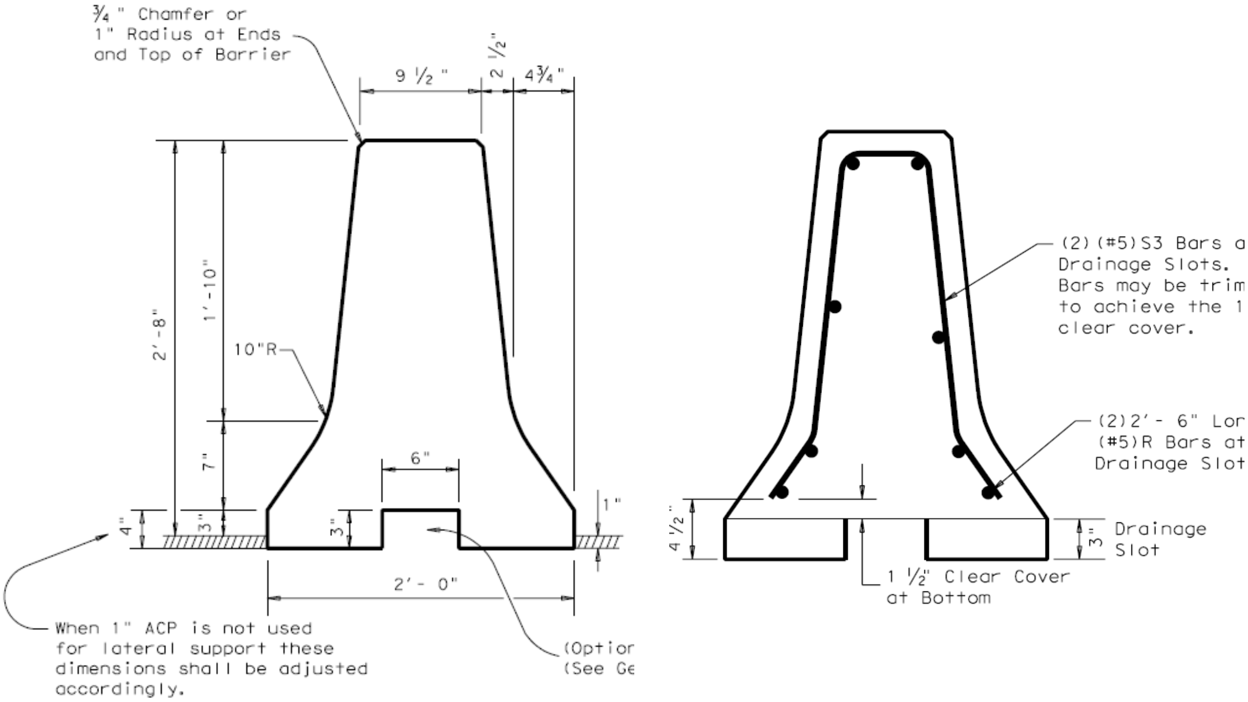
Sprague and Gear Metrics		ANOVA metrics	
M_{SG}	≤ 40	Mean	≤ 0.05
P_{SG}	≤ 40	Standard deviation	≤ 0.35

2.8 EXISTING TXDOT STANDARDS

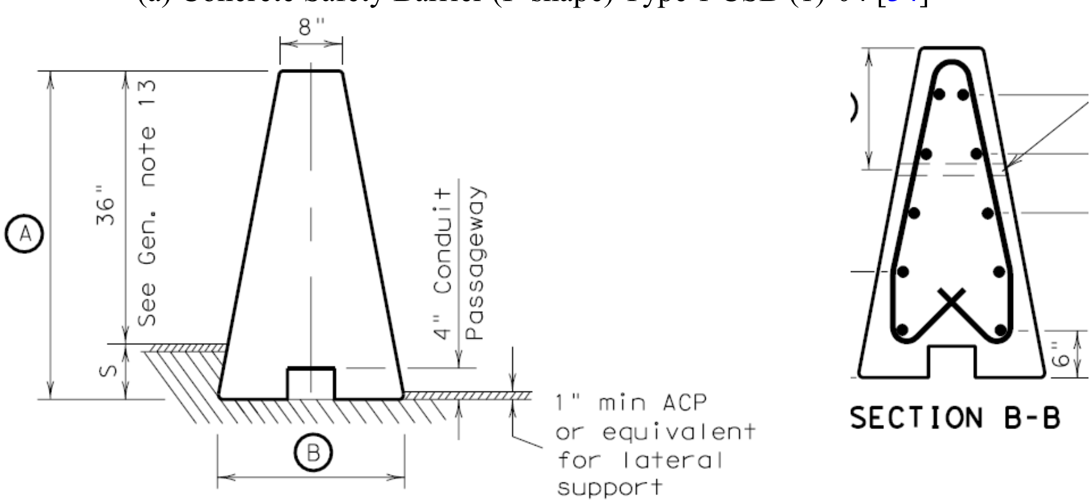
F-shape and single slope concrete barriers are the most commonly used permanent concrete barriers on Texas highways. Figure 2.24 shows the TxDOT standard drawings for a Type 1 concrete safety barrier (F-shape) and Type 2 single slope concrete barrier. Although the 42 inches single slope barriers are taller compared to the 32-inch F-shape barriers, a 1.5-inch wider barrier top can make the F-shape barrier better candidate for the attachments mounted on top. Hence, researchers in this study will investigate the methods and feasibilities to construct and mount a sign on top of both of these barriers.

Figure 2.25 shows sign support descriptive codes used in TxDOT standards. These codes indicate the types of anchors and types and number of posts used to construct sign support systems on state highways. Three types of anchors are generally used to mount the sign posts on top of a concrete base: triangular silpbase system, universal anchor system, and wedge anchor system. The slip base system, as shown in Figure 2.26, is considered unfit for barrier mounted hardware. This type of breakaway anchor allows the posts to detach from the base during a crash event. When used on median barriers, this breakaway mechanism, if activated, can cause potential debris hazard to the adjacent traffics. Both universal anchor system, shown in Figure 2.27, and wedge anchor systems, shown in Figure 2.28, are rigid type connections and can be used to mount a sign post on permanent concrete barriers. Researchers investigated the performance of using these anchor types to mount sign support systems on top of F-shape and single slope concrete barriers.

The small signs used in Texas highways are generally supported by 10 gauge tubing or Schedule 80 pipe with 2.875 inches outside diameter, thin-walled tubing (TWT) with 2.375-inch outside diameter, and fiber reinforced plastic (FRP) pipe with 3-inch outer diameter. The 10 BWG tubing and Schedule 80 pipe are generally mounted on concrete base using slip base anchor systems. TWT posts that conform to 13 BWG tubing posts with 2.375-inch outside diameters are generally mounted using the universal anchor system and wedge anchor system. FRP pipes with 3-inch outer diameter are mounted using universal anchor systems.



(a) Concrete Safety Barrier (F-shape) Type 1 CSB (1)-04 [34]



(b) Single slope concrete barrier Type 2: SSCB (2)-00A [34]

Figure 2.24. TxDOT Standards for the Commonly Used Permanent Concrete Median Barriers (*34*).

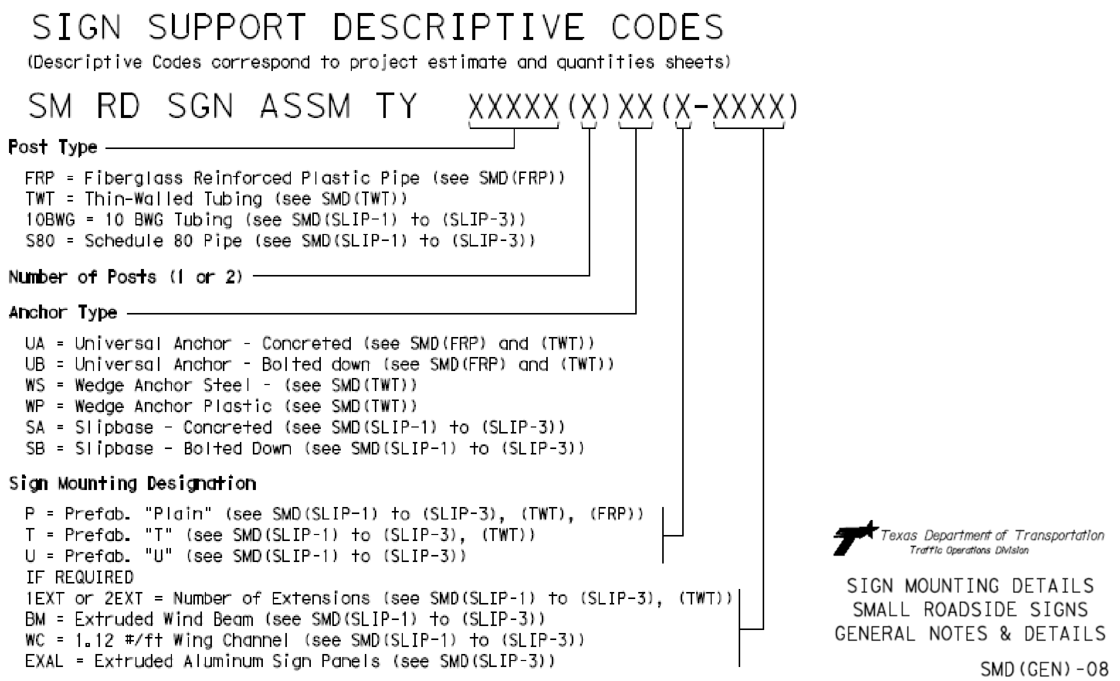


Figure 2.25. Sign Support Descriptive Codes Used by TxDOT to Define Number and Types of Posts and Types of Anchors Used for Sign Support Systems.

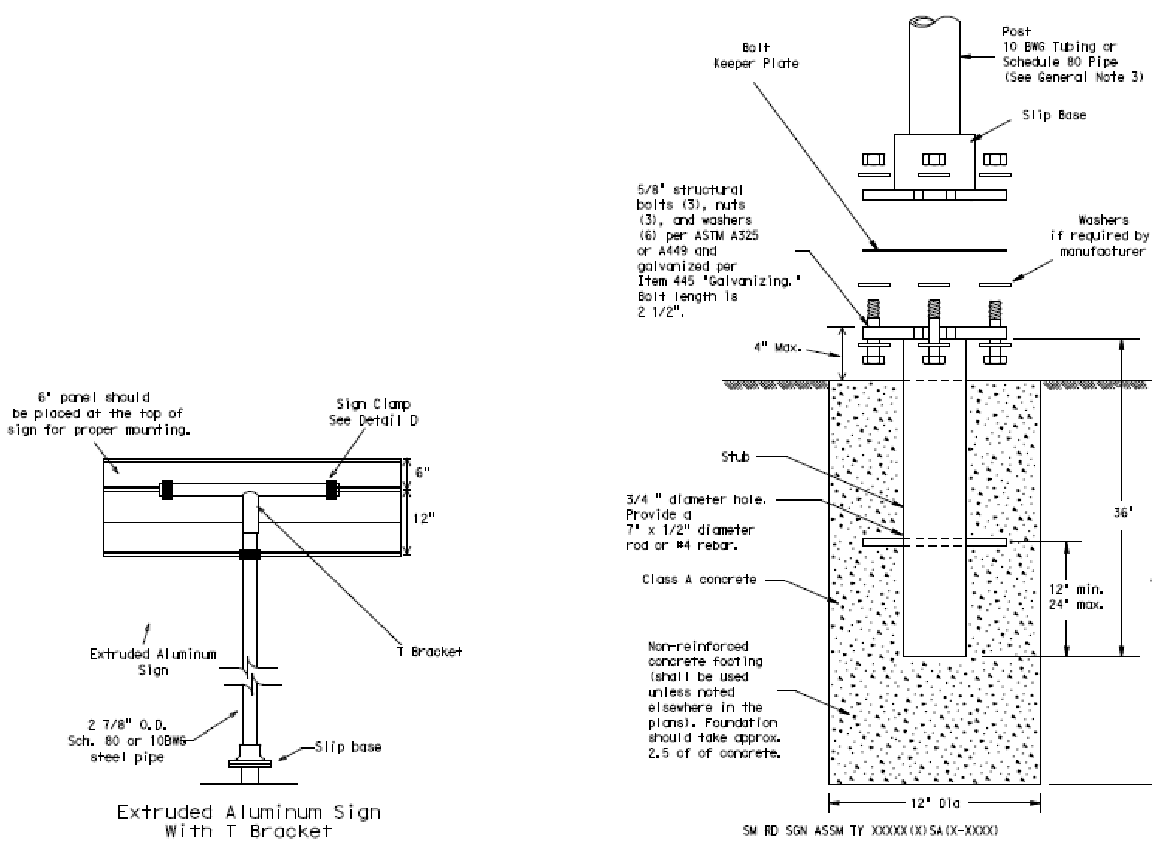


Figure 2.26. Sign Mounting Details Using Triangular Slipbase Anchor System: SMD (SLIP 1-3) (*35*).

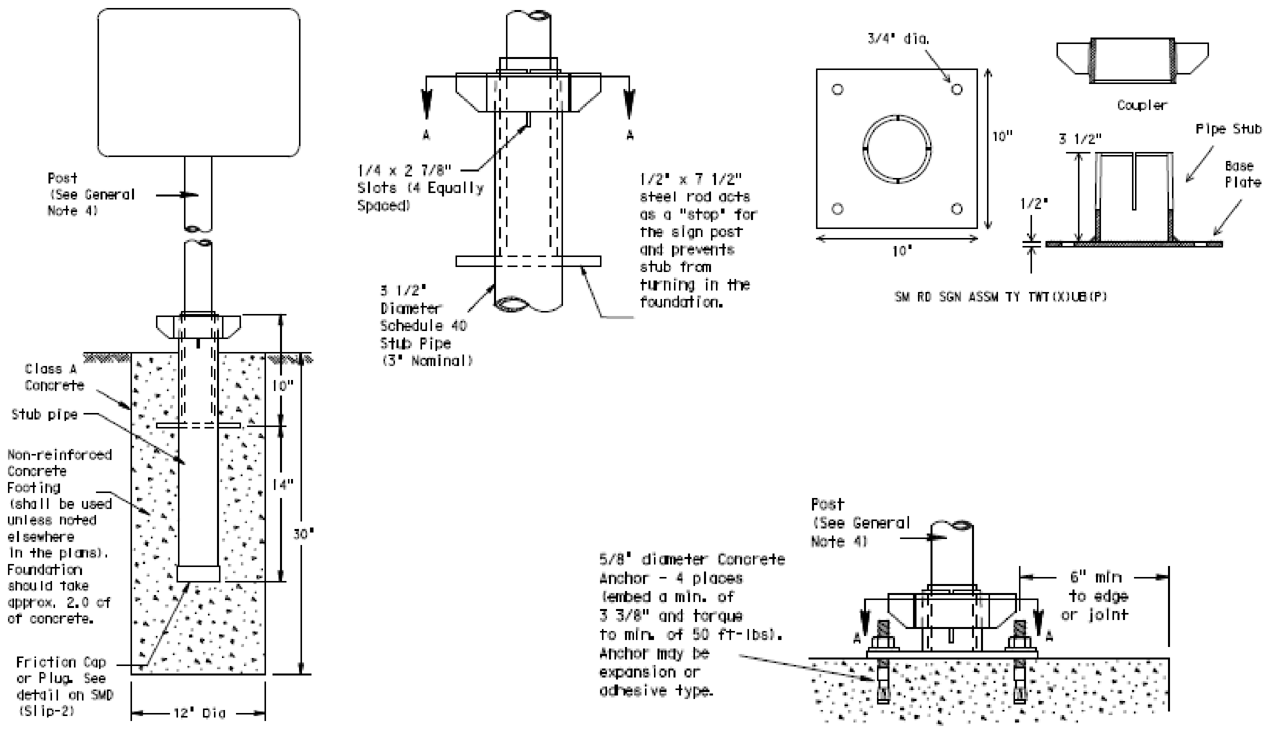


Figure 2.27. Sign Mounting Details Using Universal Anchor System SMD (TWT) (*35*).

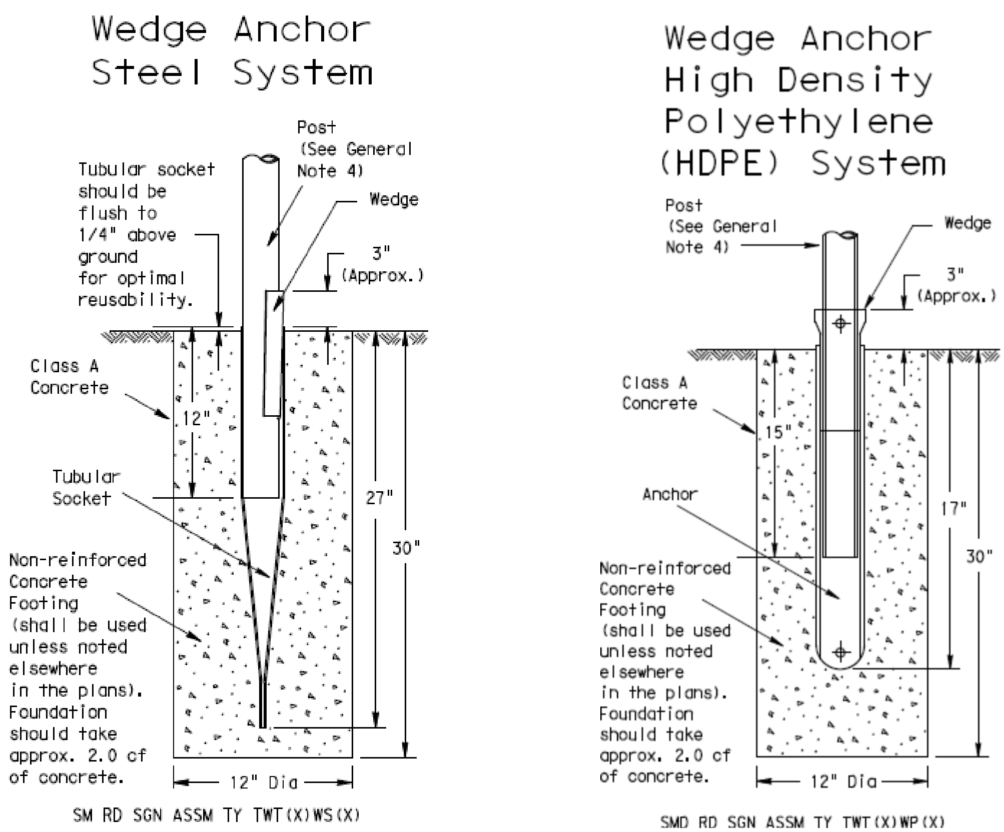


Figure 2.28. Sign Mounting Details Using Wedge Anchor System SMD (TWT) (*35*).

CHAPTER 3. ENGINEERING REVIEW AND DEVELOPMENT OF CONSTRUCTION CONCEPTS*

3.1 INTRODUCTION

This chapter presents various concepts developed for the mounting of sign posts on concrete barriers. The engineering review of available details is also presented. Maximum forces acting on a barrier mounted sign post due to the vehicular impact and wind load were calculated to determine the required connection capacity. Results obtained from a crash test and a finite element simulation of a barrier mounted sign post under impact were analyzed to determine maximum impact force acting on the sign post. Wind load on a typical sign panel was calculated following the current AASHTO guidelines (*36*). Engineering analyses of the available construction details were performed to determine the capacity of the connection used. Potential performance issue of the existing connection was identified to define possible corrective changes.

3.2 CONCEPT DEVELOPMENT

Several concepts were developed for mounting sign posts on median barriers. Figure 3.1 shows a concept where a sign post is mounted on a guiding channel attached to the top of the barrier. The post base is attached to the channel through clamped friction. The translation of the post base in longitudinal direction is further prevented by the stoppers at both ends of the channel. Figure 3.2 shows a concept where hinge and spring assembly is used to mount the sign post on top of a median barrier. The post is connected to the barrier using a hinge that allows the post to rotate about the lateral axis of the barrier. The springs connected on either side of the post would counter this rotation elastically by virtue of their stiffness. The objective is to allow the post to rotate toward the barrier top when impacted by a significant force along the longitudinal direction of a crash event. This would reduce the potential of post to vehicle snagging and allow a safer performance during a crash event. In the concept shown in Figure 3.3, the post is attached to the barrier using a bracket. The cable with shackle connecting the post and bracket is used to prevent the breakaway of the post if detached. A loose post flying free during a crash event may cause severe occupant injury. The shape of the bracket used on top of the barrier should match the shape of the barrier top. Hence same bracket cannot be used for all types of concrete barriers. Thus, this concept requires different mounting details for different barrier types. The concept shown in Figure 3.4 uses the same approach of using a bracket to mount the post on top of a barrier. The post here is attached to the two vertical steel plates welded on top of the bracket using a hinge and a sacrificial pin. The sacrificial pin is designed to fail during a crash event allowing the post to rotate toward the longitudinal barrier. This would reduce the post-to-vehicle engagements and allow safer performance during a crash event.

* TTI Proving Ground is an ISO 17025 accredited laboratory with A2LA Mechanical Testing certificate 2821.01. This certificate does not include simulation/engineering analysis.

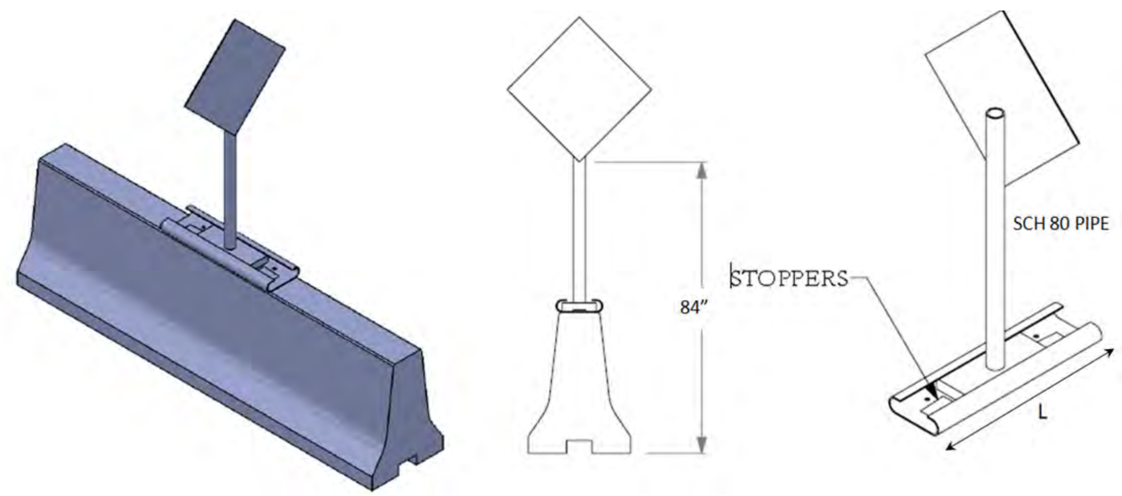


Figure 3.1. Concept 1: Chute Channel.

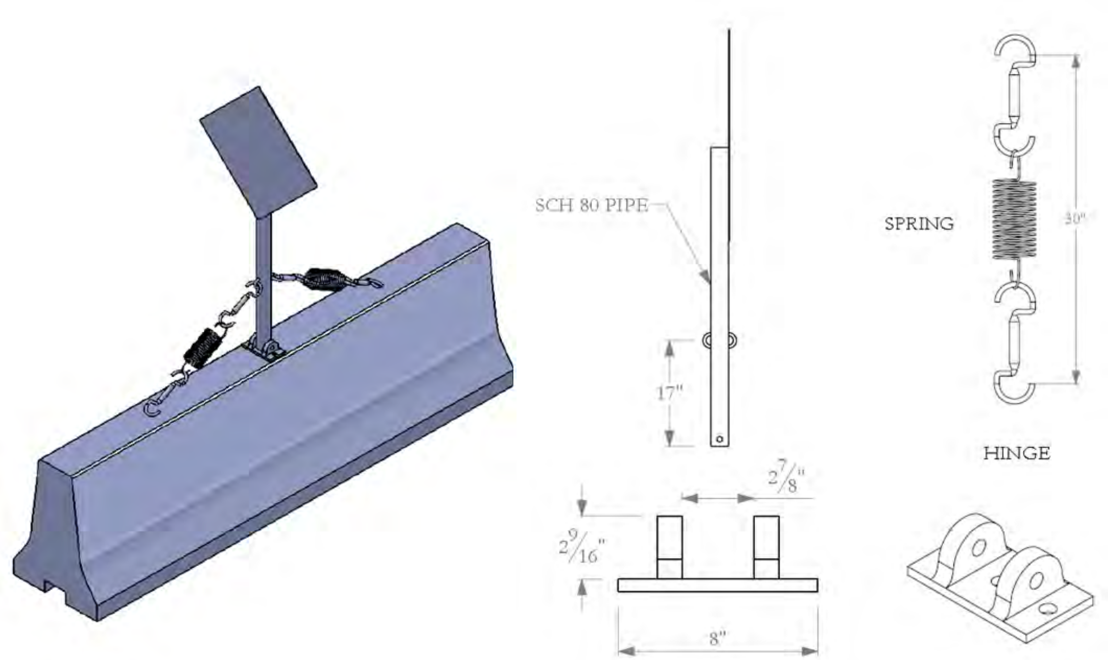


Figure 3.2. Concept 2: Hinge and Spring Assembly.

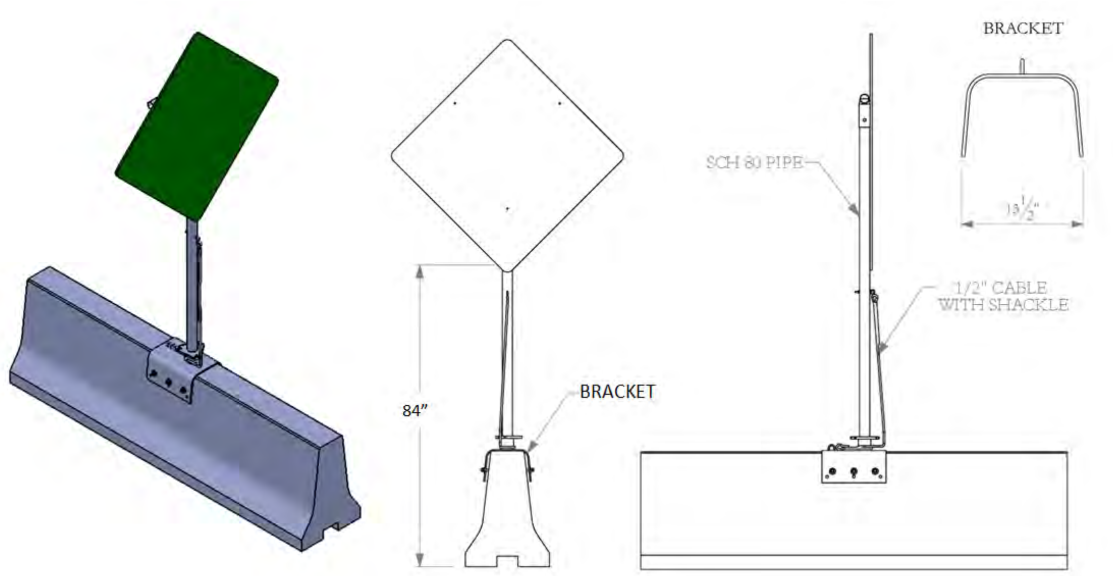


Figure 3.3. Concept 3: Bracket and Cable with Shackle Assembly.

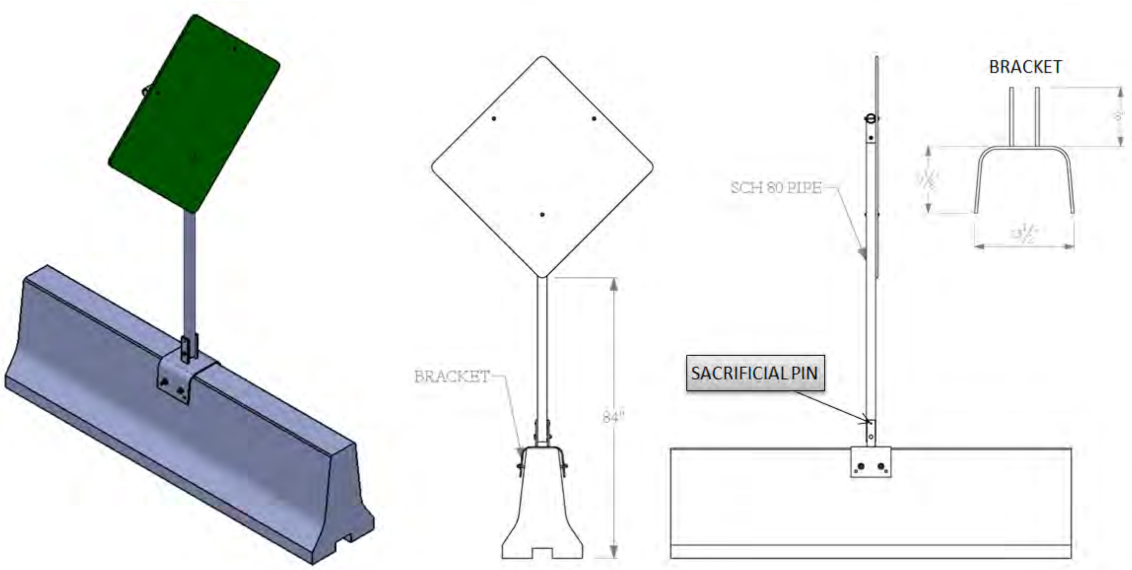


Figure 3.4. Concept 4: Bracket and Sacrificial Pin Assembly.

Figure 3.5 shows a concept where triangular side plates are used to shield the post from an impacting vehicle. The intention is to reduce the potential of post-vehicle snagging. The top of the plate should be high enough to effectively capture the fender of the airborne vehicle. Concept shown in Figure 3.6 uses a spread tube to mount the post on the barrier. One of the problems associated with mounting a post on top of a barrier using bolts is the limited space available for the connection in the direction of the width of the barrier (i.e., lateral direction). This can cause an insufficient moment capacity for the connection in lateral direction. Spread tube, as shown in Figure 3.6, can be used to increase the stiffness of the connection in lateral direction and provide adequate bolting space along longitudinal direction.

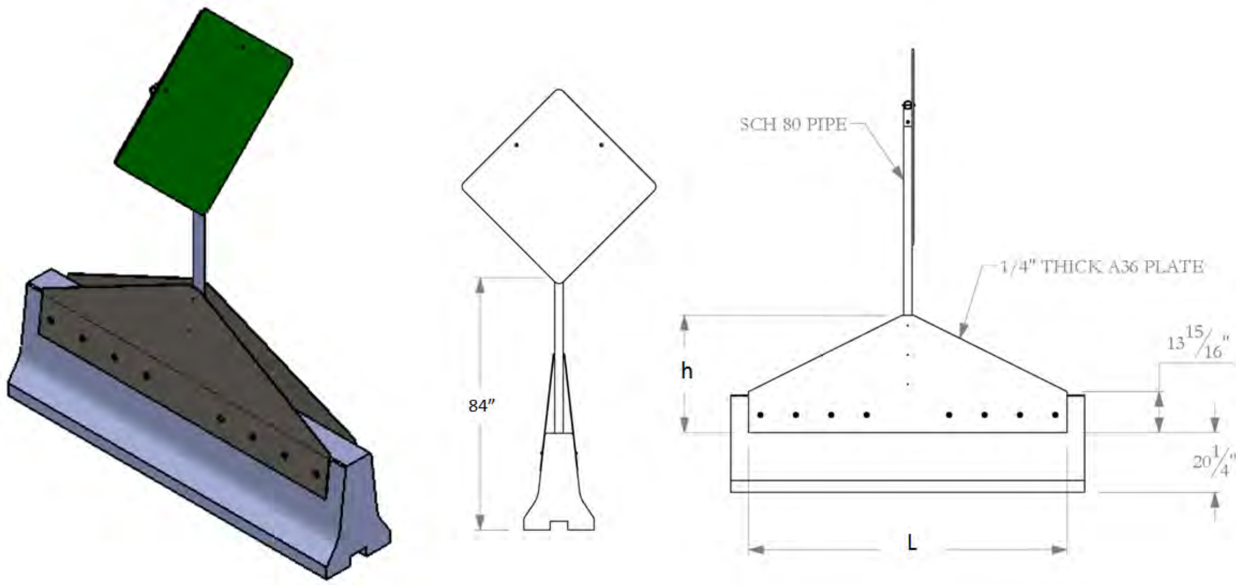


Figure 3.5. Concept 5: Triangular Plate to Shield Pole.

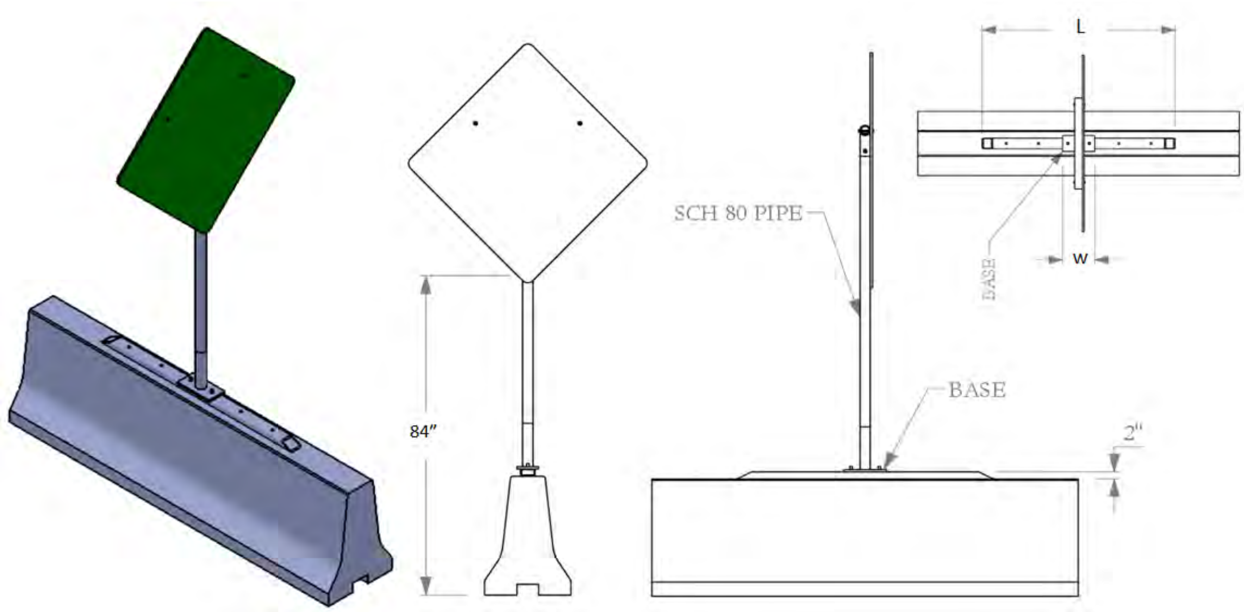


Figure 3.6. Concept 6: Spread Tube System.

3.3 EXISTING CONSTRUCTION DETAILS

Figure 3.7 presents the details of a typical construction practice for mounting sign post on concrete barrier. As shown in the figure, the Schedule 10 sign pipe (2-1/2-inch outer diameter) was mounted on a 7/16-inch-thick base plate attached on top of the barrier. Two 3/4-inch bolts with 6-inch embedment lengths were used to attach the base plate on top of the concrete barrier. Performance issues of this connection must be identified for vehicle impact conditions specified in *MASH* test *3-11*. For this task, the impact loads on a typical barrier mounted sign post was identified from an existing crash test data. The wind load on a typical 4-ft × 4-ft sign panel was also determined following AASHTO guidelines (*36*). Currently the engineering analyses are being performed to determine whether the connection shown in Figure 3.7 can withstand both the impact and wind loads.

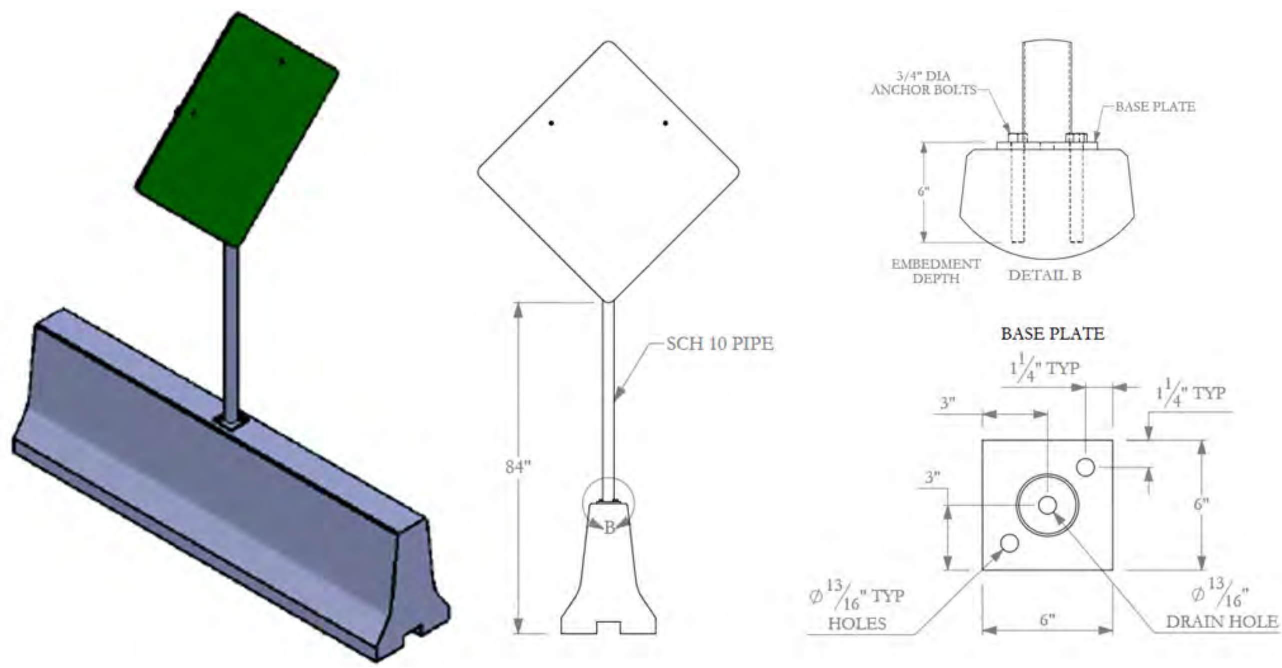


Figure 3.7. TXDOT Type H4 (Dallas IH 35E) Sign Mount Details (*37*).

3.4 ENGINEERING REVIEW

3.4.1 Evaluation of Impact Load

3.4.1.1 Using Crash Test Data

Researchers at TTI recently investigated the performance of a temporary concrete barrier with sign attachments mounted on top (*38*). Objective of the research was to develop a TxDOT standard for mounting traffic control signs and devices on portable concrete barrier in construction work zones. Crash test was performed on a TXDOT Type 2 PCTB with sign support assembly as per *MASH* test 3-11. Results obtained from this test were used to estimate the impact force on a barrier mounted sign post. However, this test kinematics are different than those observed in rigid barrier tests.

A film analysis was performed to identify the sequential positions of the vehicle with respect to the barrier and the sign post during the crash test. Figure 3.8 shows the results obtained from the film analysis of TTI test 461430. As can be seen from the figure, the vehicle impacted the post at 0.081 s and lost contact with the post after 0.121 s.

Video 1C (Frame 520) OH view

Vehicle contacts barrier in Frame 520 (Video 1C). t=0 s

Video 1C (Frame 579) OH view

Vehicle Impacts the base tube in Frame 579 (Video 1C). t=(579-520)/1000=0.059 s

Figure 3.8. Film Analysis Results: *MASH* Test on TXDOT PCTB Sign Support Assembly (*38*).

Video 1C (Frame 601) OH view

Vehicle Impacts the pole in Frame 601. t=(601-520)/1000=**0.081 s**

Video 1C (Frame 640) OH view

Vehicle fender snags into the pole in Frame 641. t=(640-520)/1000=**0.121 s**

Figure 3.8. Film Analysis Results (continued).

Video 1C (Frame 665) OH view

The pole impacts the vehicle side view mirror in Frame 665. t=(665-520)/1000=0.145 s

Video 1B (Frame 190) OH View

Rear of the vehicle contacts the barrier in Frame 190(Video 1B). t=(190-67)/500= 0.24 s

Front of the vehicle slap onto the barrier from Top in Frame 321 (Video 1A). t=0.523 s

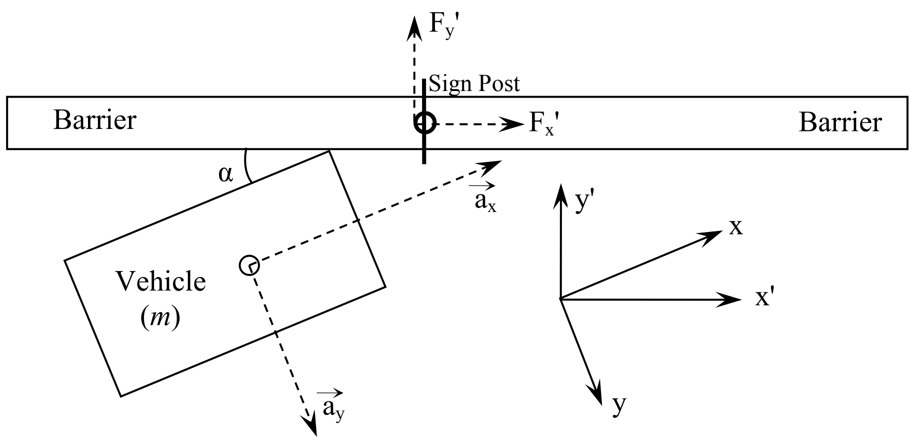
Figure 3.8. Film Analysis Results (continued).

The impact forces on the barrier and the sign post during the crash test were estimated using vehicle accelerometer data. The vehicle and the barrier co-ordinate systems used for the test are schematically shown in Figure 3.9(a). As can be seen from the figure, the driver side of the vehicle impacted the sign mounted barrier during this test. Hence, Equations 3.1 and 3.2 were used to determine the impact forces in the barrier co-ordinate system.

$$Fx'(t) = m\overrightarrow{a_x}(t) \times cos \propto (t) + m\overrightarrow{a_y}(t) \times sin \propto (t)) \tag{3.1}$$

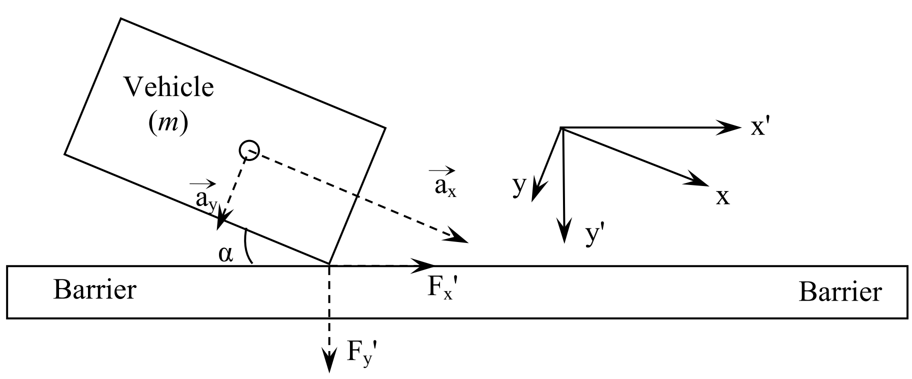
$$Fy'(t) = m\overrightarrow{a_x}(t) \times sin \propto (t) - m\overrightarrow{a_y}(t) \times cos \propto (t)) \tag{3.2}$$

where, $F_x'(t)$ and $F_y'(t)$ are the impact forces on the barrier and the sign post in longitudinal and lateral directions, respectively, using the barrier coordinate system. $m\overrightarrow{a_x}(t)$ and $m\overrightarrow{a_y}(t)$ are the longitudinal and lateral component of the vehicle impact force on the vehicle coordinate system. *α(t)* is the vehicle yaw angle with respect to the barrier. *m* is the mass of the vehicle. In this test, the test inertia weight of the pickup was 5000 lb (*38*). Equations 3.1 and 3.2 assume the truck as single rigid body for the purpose of calculating the impact forces.



$$Fx'(t) = m\overrightarrow{a_x}(t) \times cos \propto (t) + m\overrightarrow{a_y}(t) \times sin \propto (t))$$
$$Fy'(t) = m\overrightarrow{a_x}(t) \times sin \propto (t) - m\overrightarrow{a_y}(t) \times cos \propto (t)$$

(a) Driver side of the vehicle impacting the barrier



$$Fx'(t) = m\overrightarrow{a_x}(t) \times cos \propto (t) - m\overrightarrow{a_y}(t) \times sin \propto (t))$$
$$Fy'(t) = m\overrightarrow{a_x}(t) \times sin \propto (t) + m\overrightarrow{a_y}(t) \times cos \propto (t)$$

(b) Passenger side of the vehicle impacting the barrier

Figure 3.9. Coordinate Systems Used for the Vehicle and Sign Post/Barrier.

Data obtained from the vehicle mounted accelerometer were analyzed to determine the maximum impact forces during the times vehicle was in contact with the sign post, i.e., from 0.081 sec to 0.121 sec. Figure 3.10 shows the change in yaw angle with respect to the time. The longitudinal and lateral acceleration data at the C.G. of the vehicle are presented in Figure 3.11 (a) and (b), respectively. Using Equations 3.1 and 3.2, the acceleration-time histories shown in Figure 3.11, and yaw angles-time history shown in Figure 3.10, the impact force components in the barrier co-ordinate system were computed as a function of time as shown in Figure 3.12. The figure shows a sudden rise of longitudinal impact force at the time the vehicle impacts the post. From Figure 3.12(b), the maximum 50-ms average impact forces during the vehicle-to-post contact period were obtained as 16.6 kips and 39 kips in the longitudinal and lateral directions, respectively. The negative values in Figure 3.12(b) indicate the forces acting on the vehicle in a direction opposite to those acting on the post and the barrier. During the period vehicle was in contact with the post, some portion of the vehicle was in contact with the barrier. Thus, the impact forces shown in Figure 3.12 comprise the forces resisted by both the barrier and the post. In order to separate the contribution from the barrier, similar analyses were performed using results obtained from two other crash tests where the vehicle impacted a barrier with no attachment. The impact height was calculated from the image shown in Figure 3.13. Top of the PCTB barrier used in the TTI 461430 test was 33 inches above the ground. Using the ratio between the height of the highest contact point on the sign post and the barrier height observed in Figure 3.13, the maximum vehicle-to-post contact height was calculated as 19.3 inches above post base. This height can be conservatively used as the vehicle impact height for the engineering analyses of post mounting connections.

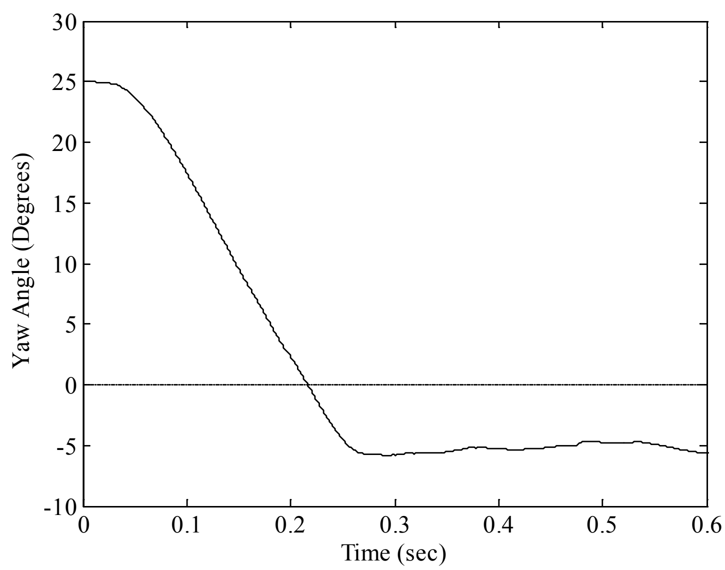


Figure 3.10. Vehicle Yaw Angle with Respect to the Barrier (TTI Test 461430) (*4*).

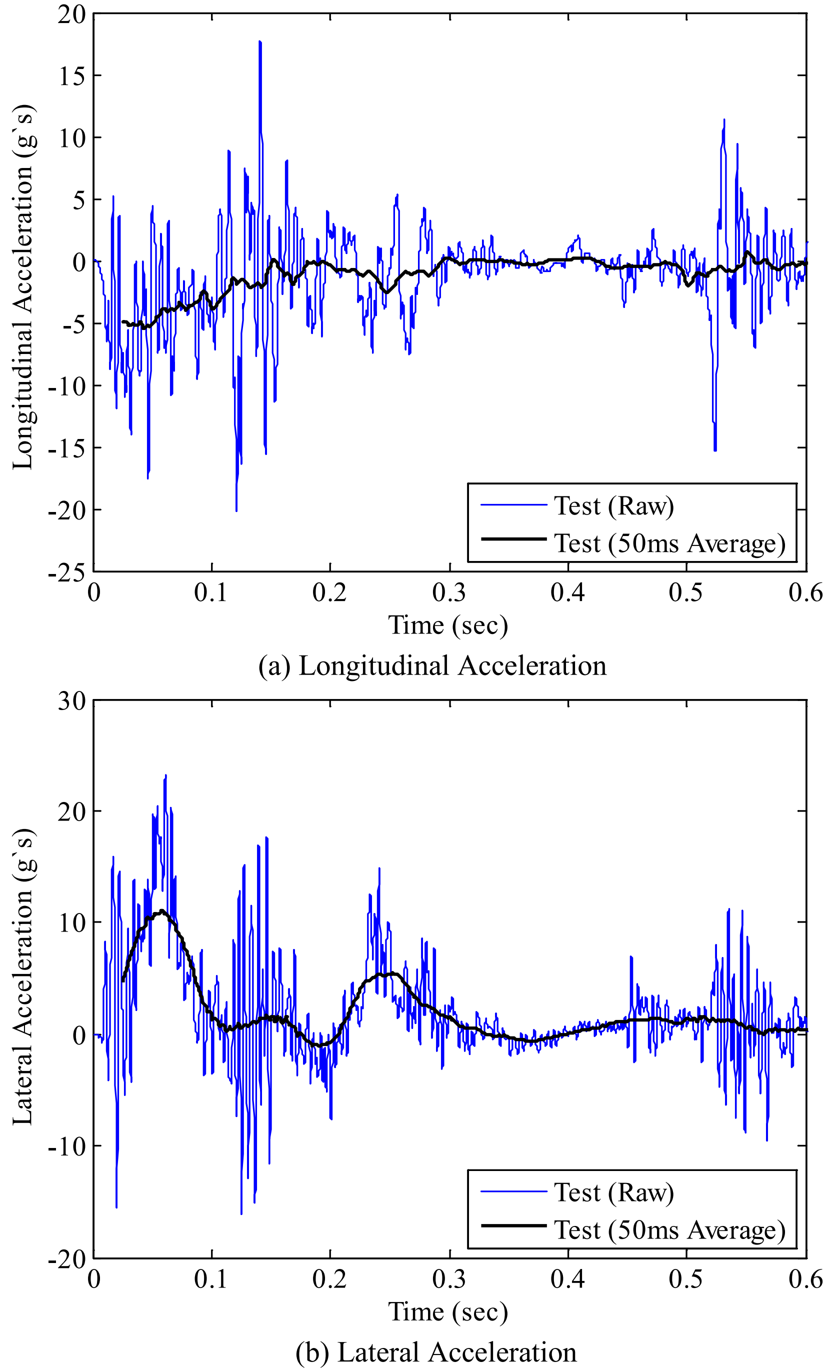
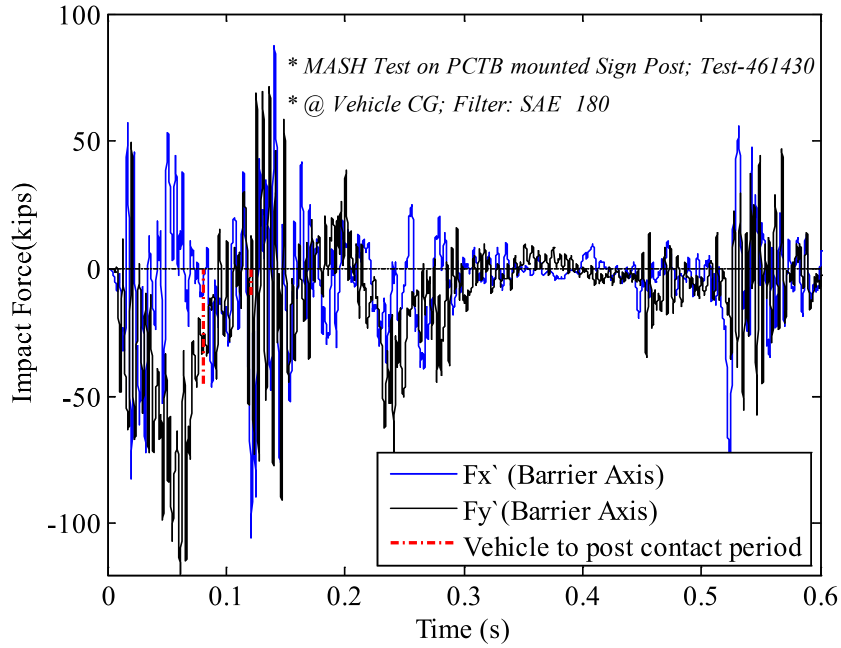
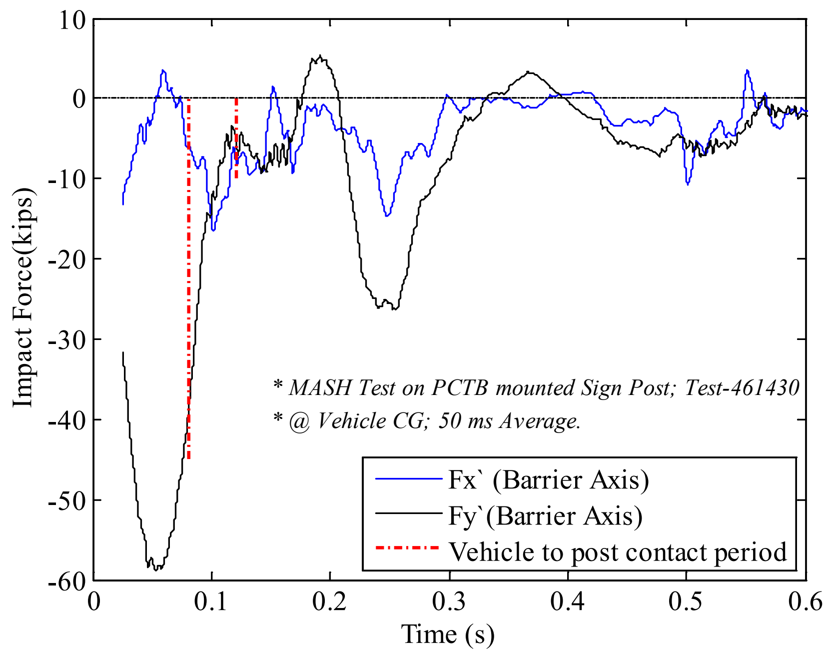


Figure 3.11. Accelerations of the Vehicle (TTI Test 461430) (*4*).



(a)



(b)

Figure 3.12. Impact Force Components Acting on PCTB Mounted Sign Post (*MASH* Test 461430).

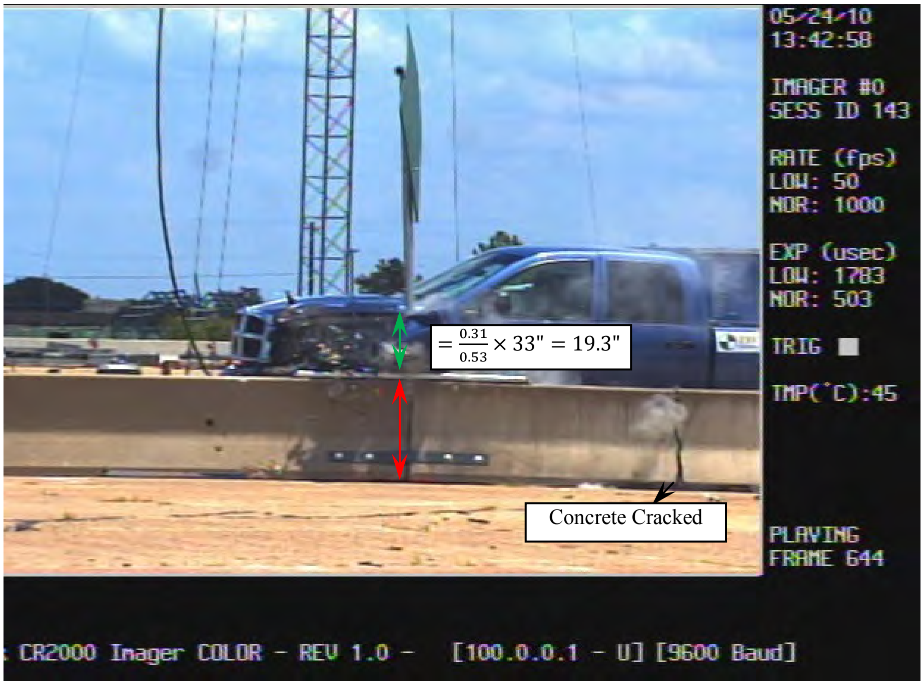
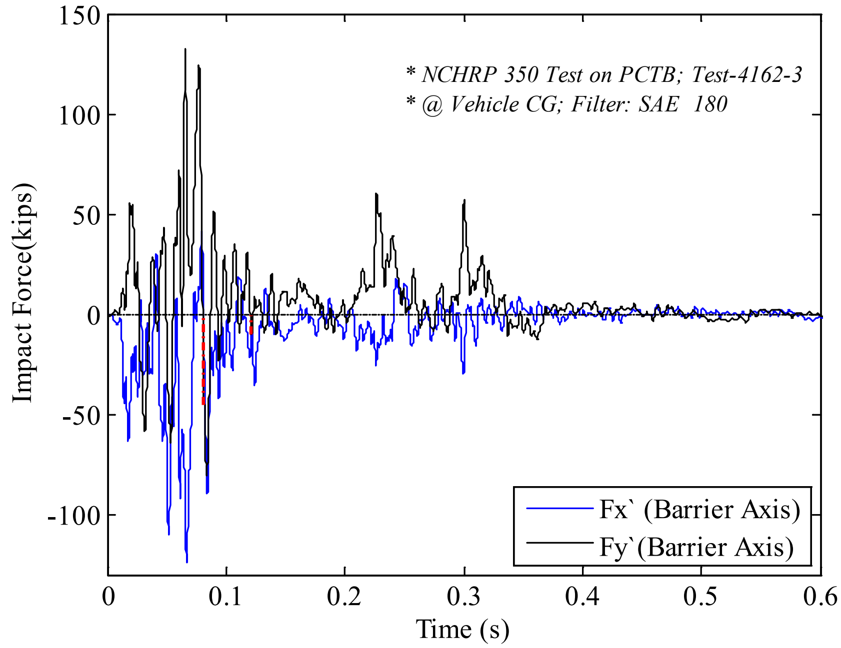


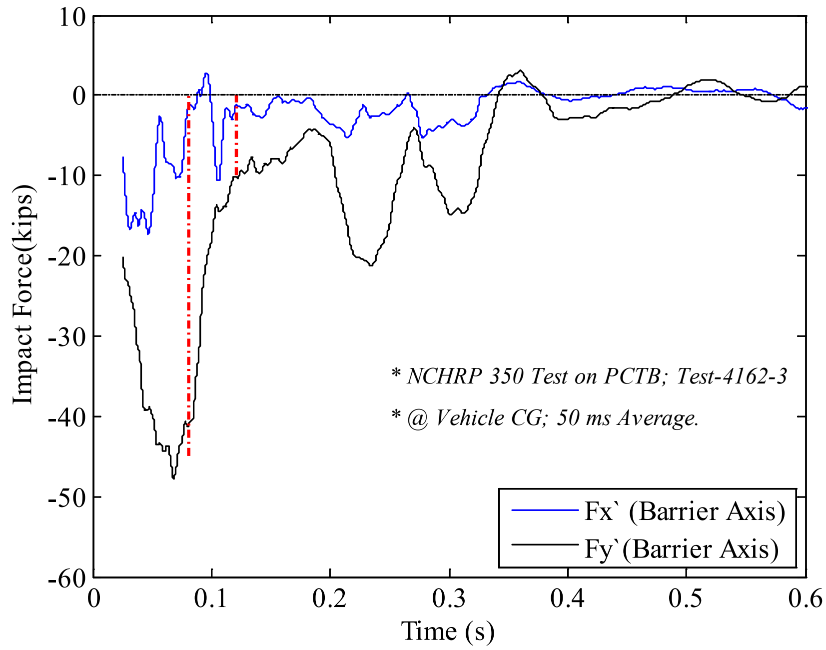
Figure 3.13. Impact Height from Post Base.

At the time the vehicle impacted the post, the impact forces, as shown in Figure 3.12, were resisted by both the barrier and the post. Thus, the forces acting on the post can be obtained by determining the forces resisted by the barrier. Although the Texas grid-slot PCTB used in the test 461430 has not been evaluated following *MASH* test 3-11, a crash test was performed on this barrier as per *NCHRP Report 350* test 3-11 (*39*). The 4496 lb pickup truck used in this test was 10 percent lighter compared to the 5040 lb truck used in the *MASH* test. Researchers at TTI also performed a crash test as per *MASH* test 3-11 to evaluate the performance of New Jersey barrier (*10*). The impact forces resisted by the barrier at the time the vehicle impacted the post in the test performed on PCTB mounted sign post can be qualitatively assessed using the data obtained from these two tests.

In the TTI test 44162-3 (*39*), the driver side of the Chevrolet 2500 pickup truck impacted the Texas grid-slot PCTB at a speed and angle of 62.5 mi/h and 25 degrees, respectively. Hence, as shown in Figure 3.9(a), the Equations 3.1 and 3.2 can be used to map the impact force components in barrier co-ordinate system. Using these equations, and the acceleration time histories and yaw angle data obtained at vehicle C.G. from the test, the impact force components in the barrier co-ordinate system were computed as a function of time as shown in Figure 3.14. As can be seen from the figure, the maximum 50-ms average impact forces acting on the barrier between times 0.082 s to 0.122 s (the vehicle-to-post contact period in TTI test 461430) were 10 kips and 40 kips in the longitudinal and lateral directions, respectively.



(a)



(b)

Figure 3.14. Impact Force Components Acting on the Texas Grid-Slot Portable Concrete Barrier (*NCHRP Report 350* Test 441621-3) (*39*).

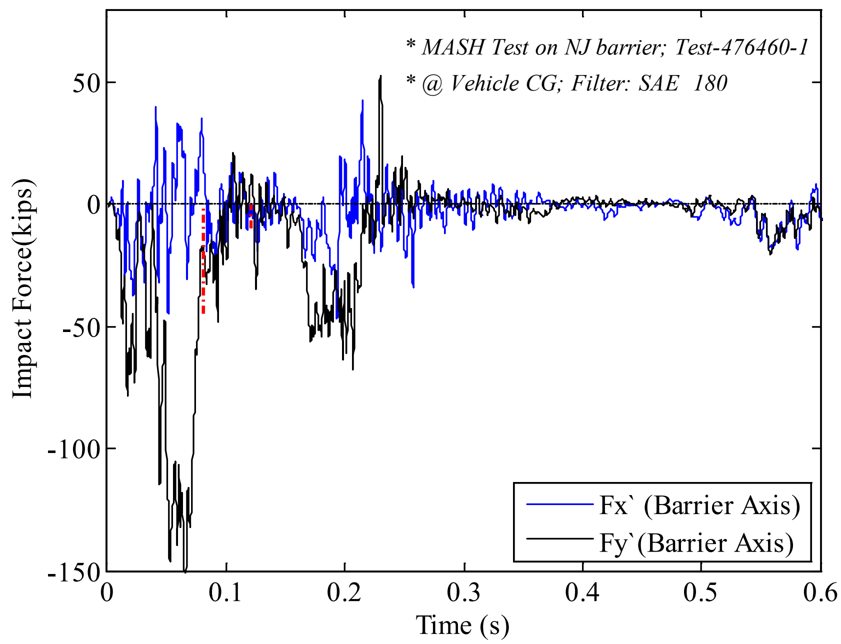
In the TTI test 476460-1 (*10*), the passenger side of the 5049 lb Chevrolet Silverado impacted a New Jersey concrete barrier at a speed and angle of 62.6 mi/h and 25.2 degrees, respectively. Hence, as shown in Figure 3.9 (b), the Equations 3.3 and 3.4 can be used to map the impact force components in the barrier co-ordinate system:

$$Fx'(t) = m\overrightarrow{a_x}(t) \times cos \propto (t) - m\overrightarrow{a_y}(t) \times sin \propto (t)) \quad (3.3)$$

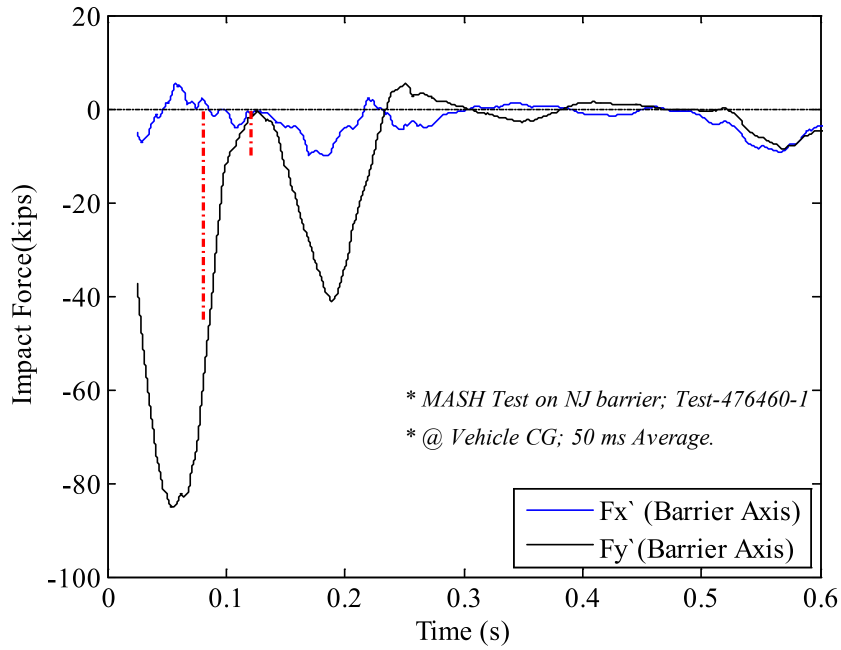
$$Fy'(t) = m\overrightarrow{a_x}(t) \times sin \propto (t) + m\overrightarrow{a_y}(t) \times cos \propto (t) \quad (3.4)$$

Using these equations, and the acceleration time histories and yaw angle data obtained at vehicle C.G. from the test, the impact force components in the barrier co-ordinate system were computed as a function of time as shown in Figure 3.15. As can be seen from the figure, the maximum 50-ms average impact forces acting on the barrier between times 0.082 s to 0.122 s (the vehicle-to-post contact period in TTI test 461430) were 3 kips and 50 kips in the longitudinal and lateral directions, respectively.

Thus, both Figure 3.14 and Figure 3.15 show that the impact force component in the lateral direction (F_y') during the vehicle to post contact period shown in Figure 3.12 was acting almost entirely on the barrier. However, a significant portion of the impact force component in the longitudinal direction (F_x') during the vehicle to post contact period shown in Figure 3.12 was resisted by the post. The permanent concrete median barriers selected for this study and used in TTI test 476460-1 are rigid compared to the PCTB used in TTI test 461430 and 44162-3, and do not undergo large lateral deformation during a crash event. Thus the lateral forces acting on these barriers are larger compared to those acting on a PCTB. Due to the higher lateral deflections of the PCTB barrier, the impact forces on the post observed in Figure 3.12 (Test 461430) can be slightly different compared to the case where the post is mounted on a permanent concrete barrier. Hence, numerical analysis was performed to determine a more reliable value for the impact load on a sign post mounted on a rigid barrier.



(a)



(b)

Figure 3.15. Impact Force Components Acting on the New Jersey Barrier (TTI Test 476460-1) (*6*).

3.4.1.2 Using Numerical Analysis

Numerical simulation was used to evaluate the impact load acting on the sign post mounted on a permanent concrete median barrier. Finite element analyses were performed to simulate *MASH* 3-11 test conditions. A 251,241 elements Silverado pickup model developed by NCAC was used for these simulations. To assess the model fidelity, an impact analysis, as shown in Figure 3.16, was performed to simulate the *MASH* 3-11 test of the New Jersey barrier (*10*). The vehicle to barrier impact forces at the C.G. of the vehicle on the barrier coordinate systems were calculated using Equations 3.3 and 3.4 and the acceleration time histories and yaw angle data obtained at the C.G. of the vehicle from the simulation. Figure 3.17 compares the impact force components in the longitudinal and lateral direction obtained from the simulation and the test. As can be seen from the figures, the 50-ms average impact force obtained from the simulation closely matched the test result in the longitudinal direction. The impact force in the lateral direction obtained from the simulation, however, followed the forces obtained from the test until 0.15 s. In both the test and the simulation, the rear of the vehicle impacted the barrier at 0.15 s. The vehicle impacting a sign post, mounted on the barrier near the critical impact point, should lose contact with the post by the time the rear of the vehicle reaches the barrier. Thus impact forces after 0.15 s are resisted entirely by the barrier and are not important for the evaluation of the integrity of the post mounting connections based on this test/simulation analysis case.

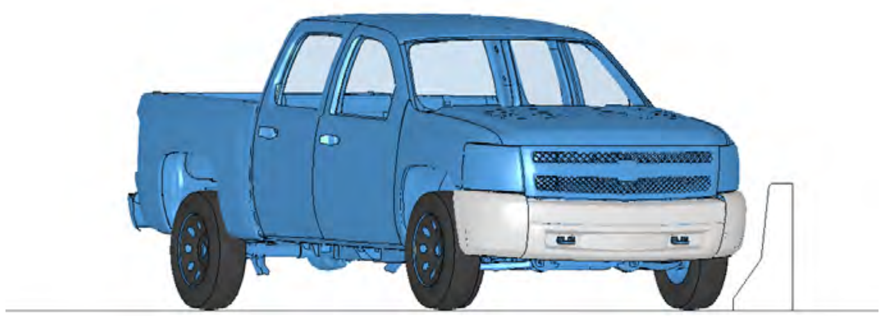
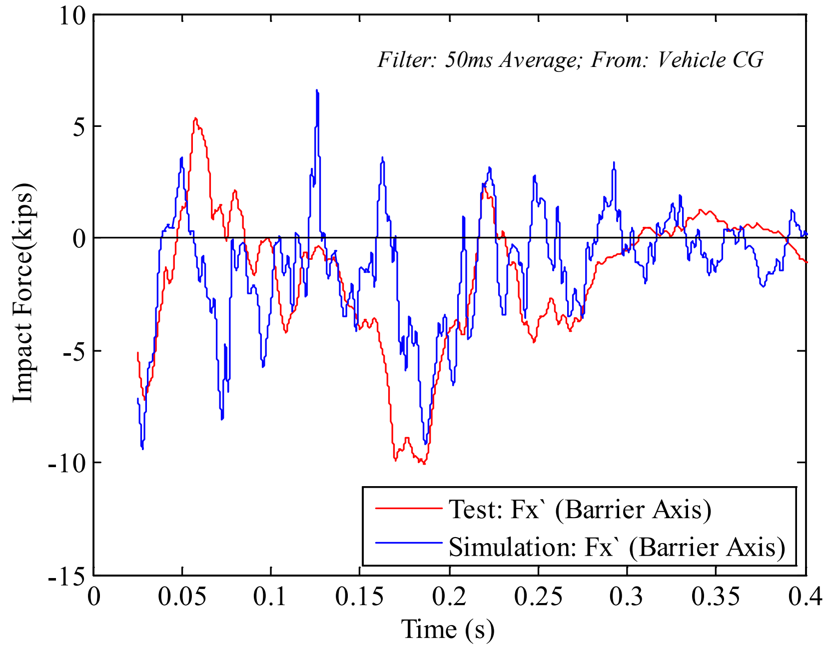
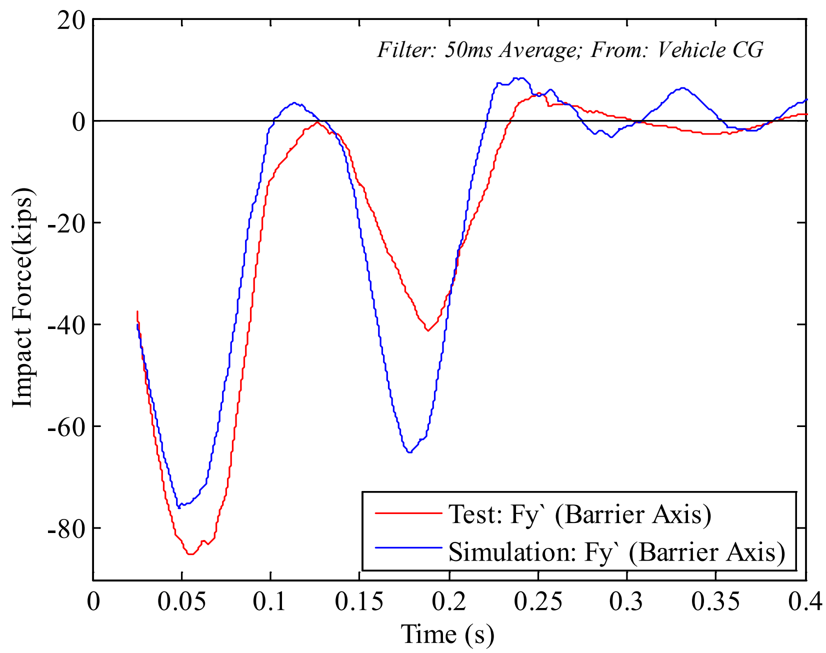


Figure 3.16. Simulation Setup for the *MASH* Test Performed on New Jersey Barrier.

Finite element model of a sign post mounted on top of a rigid barrier was developed in this study to evaluate the impact load. The FE model, as shown in Figure 3.18, consisted of a Schedule 80 pipe mounted on top of a rigid F-shape barrier. The material properties of the Schedule 80 pipe used in the simulation correspond to American Society for Testing Materials (ASTM) 500 grade C as specified in TXDOT Standards (*35*). Table 3.1 shows the section and material properties of the Schedule 80 pipe used in the FE model. The pipe in the model was mounted on an 8-inch × 8-inch elastic steel base plate connected to the rigid barrier using four bolts modeled using stiff elastic beams.



(a) Longitudinal direction



(b) Lateral direction

Figure 3.17. Impact Force Comparison between Simulation and Test 476460-1 (*10*).

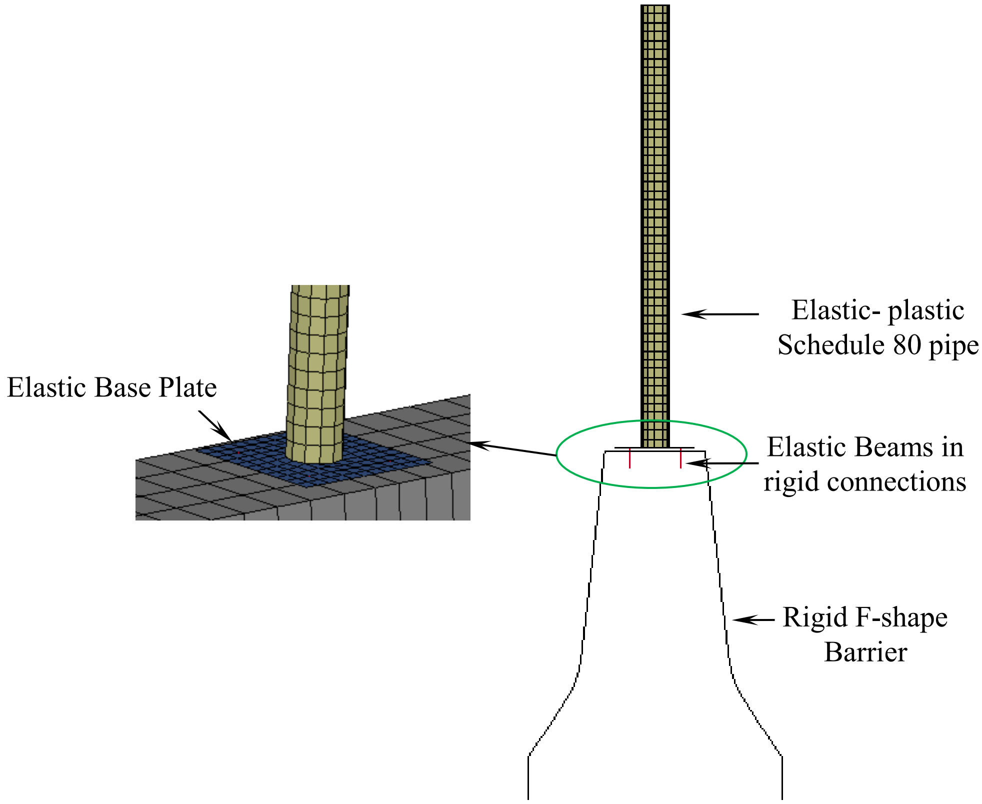


Figure 3.18. FE Model for the Schedule 80 Sign Post Mounted on Top of F-Shape Barrier.

Table 3.1. Material and Section Properties Used for the Schedule 80 Sign Post Used in the Simulation.

Section Properties			Material Properties for ASTM A500 Grade C			
Outer Diameter	Thickness	Plasticity Modulus Z_x	Yield Strength	Ultimate Strength	Percent Elongation in 2"	True Tangent Modulus, ETan
2.875"	0.276"	1.87"	46 ksi	62 ksi	21%	153 ksi

To evaluate the impact load, LS-DYNA simulation was performed using this barrier mounted sign post model and the Silverado pickup model as per *MASH* test 3-11. The sequential photographs obtained from the simulation are shown in Figure 3.19 and Figure 3.20. As can be seen from the figures, the Schedule 80 post yielded 2 inches above its base and was bent toward the barrier due to impact. The impact forces in the barrier coordinate system were calculated as shown in Figure 3.21 using Equations 2.1 and 2.2 and acceleration time histories and yaw angle data obtained from the accelerometer located at vehicle C.G. As can be seen from the figure, the maximum 50-ms average longitudinal and lateral impact forces obtained from the simulation during the vehicle to post contact period was 19 kips and 81 kips, respectively. Similar to that observed from the crash test results discussed earlier, the barrier resisted the entire lateral impact forces during the vehicle-post contact period. Significant portion of the longitudinal force, however, acted on the post causing it to bend toward the barrier top face. Figure 3.22(a) shows the LS-DYNA generated contact forces obtained at vehicle-to-barrier and vehicle-to-post contact regions in the direction parallel to the barrier. As can be seen from the figure, the critical impact time for the post was 0.065 s when the maximum 50-ms average force acting on post was 7.2 kips. Longitudinal force acting on the barrier at that time was 11 kips. To determine the average impact height for the post, forces at various impact heights above the post base at critical impact time were plotted in Figure 3.22(b). It can be seen that the height of the maximum 50-ms average force acting on the post was 12.5 inches above post base. This height can be considered as the impact height for the total 7.2 kips force acting on the post in the direction parallel to the barrier. Thus the maximum 50-ms average moment acting at the base of the post due to the *MASH* 3-11 vehicle impact was:

$$M_{bp|impact} = 7.2 \text{ kips} \times 12.5 \text{ inches} = 90 \text{ k-in} = 7.5 \text{ k-ft} \quad (3.5)$$

This impact moment exceeds the plastic moment capacity (F_yZ_x= 1.87 inches × 46 ksi = 86 k-inch = 7.1 k-ft) of the Schedule 80 pipe used in the simulation. This caused the post to collapse and bend toward the barrier after the impact during the simulation. The contact forces acting on the barrier and the post in the lateral direction are shown in Figure 3.23. As can be seen from the figure, the entire lateral force was resisted by the barrier and the force acting on the post in this direction was insignificant.

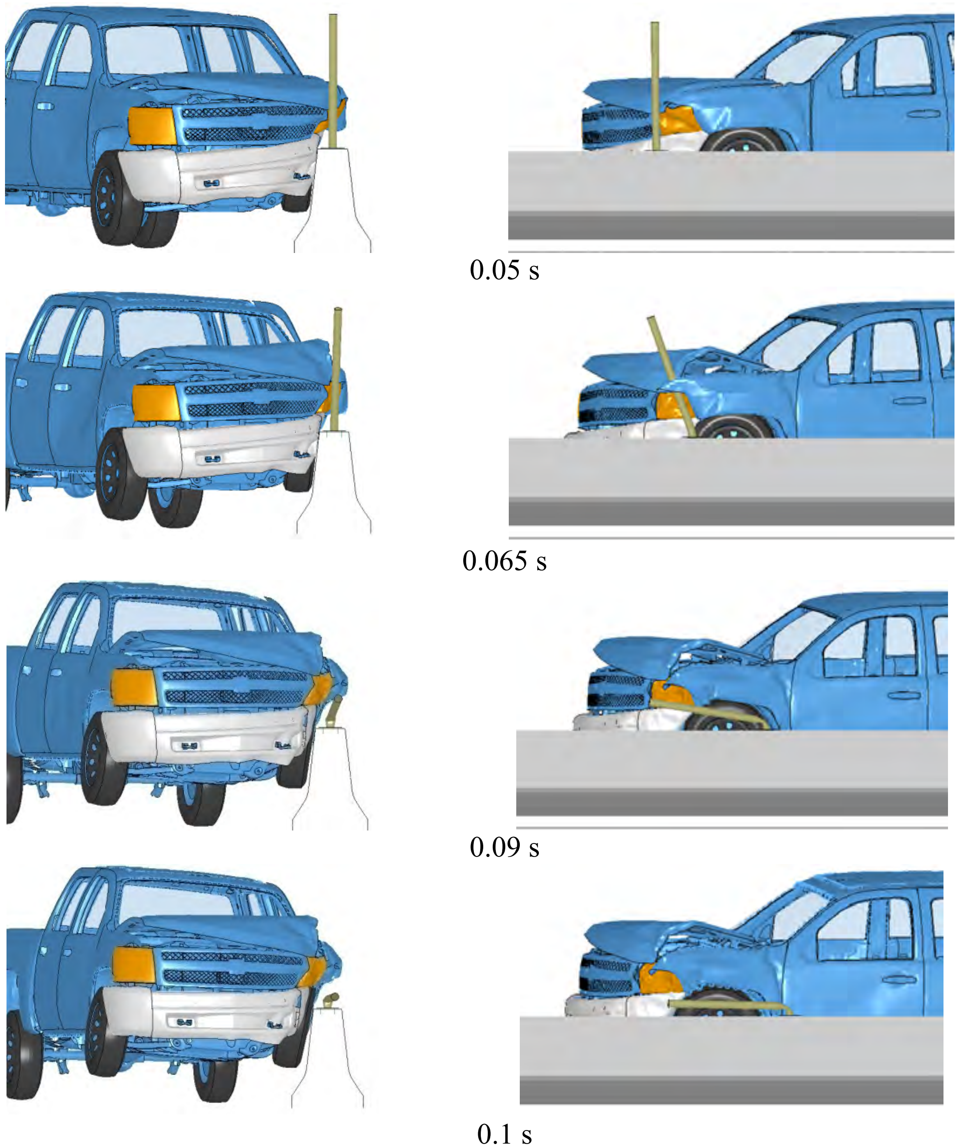


Figure 3.19. Sequential Photographs Obtained from the Simulation.

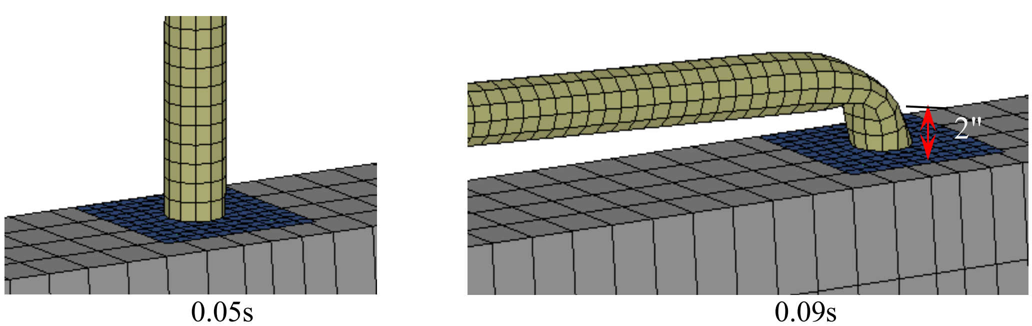
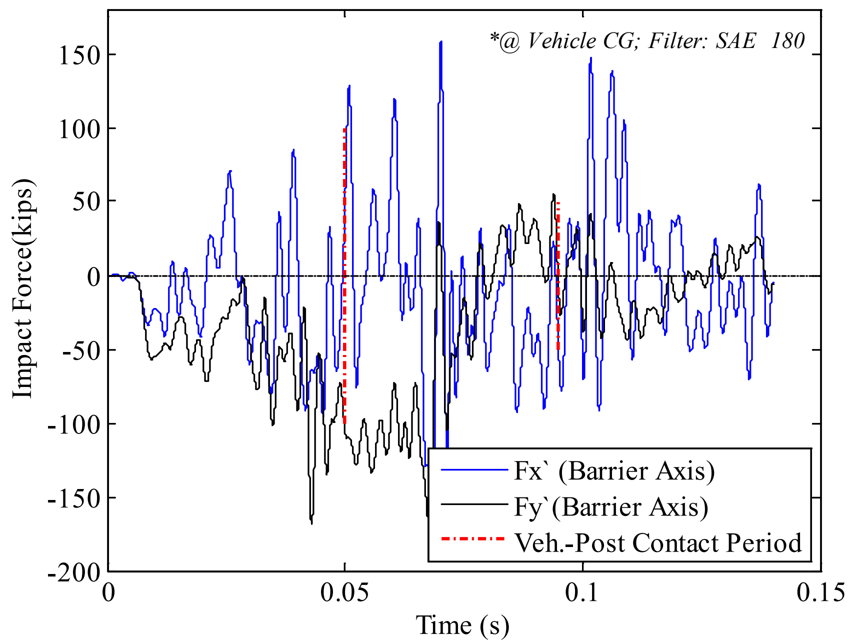
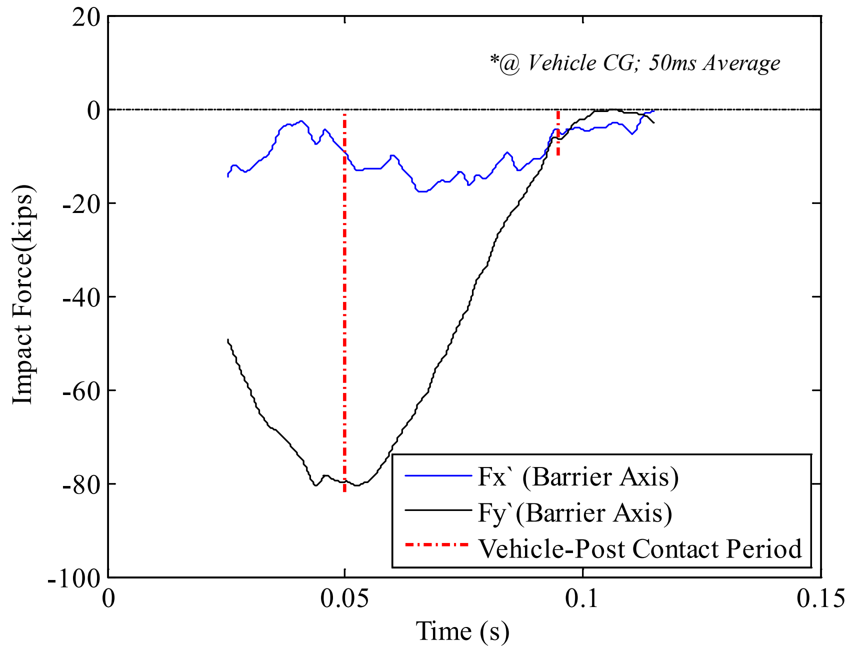


Figure 3.20. Yielding of the Schedule 80 Post Due to Impact in the Simulation.

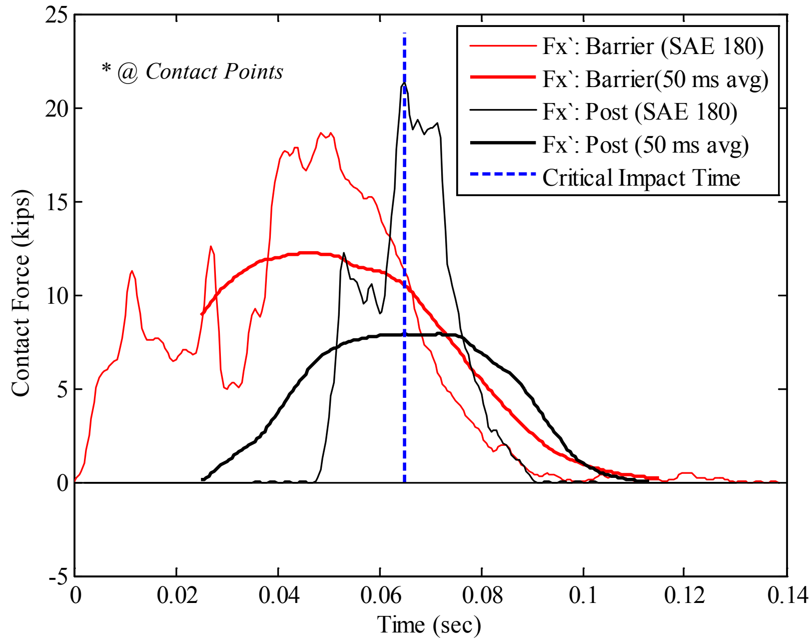


(a)

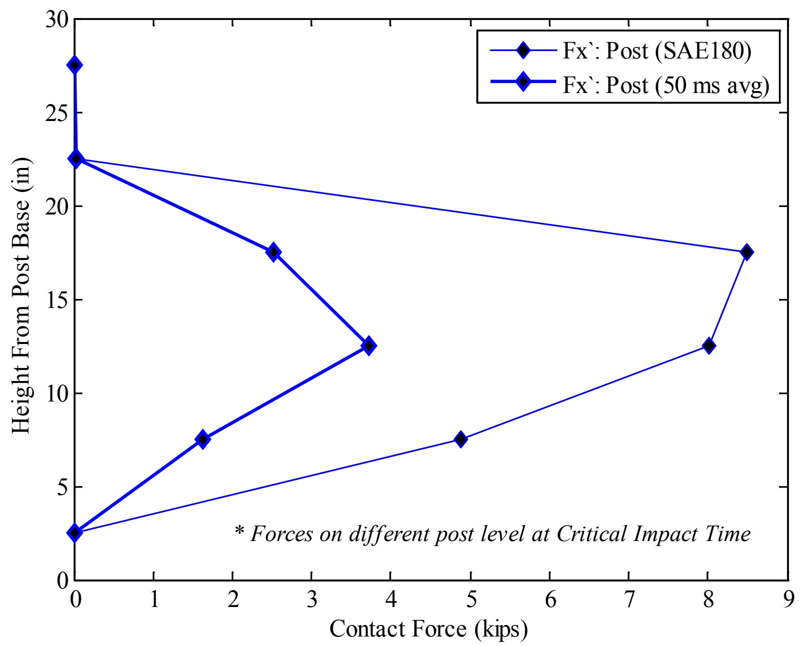


(b)

Figure 3.21. Impact Forces Obtained at Vehicle CG (*MASH* Simulation Performed on Schedule 80 Post Mounted on Rigid Barrier).



(a)



(b)

Figure 3.22. Longitudinal Contact Forces on Barrier Coordinate System (*MASH* Simulation Performed on Schedule 80 Post Mounted on Rigid Barrier).

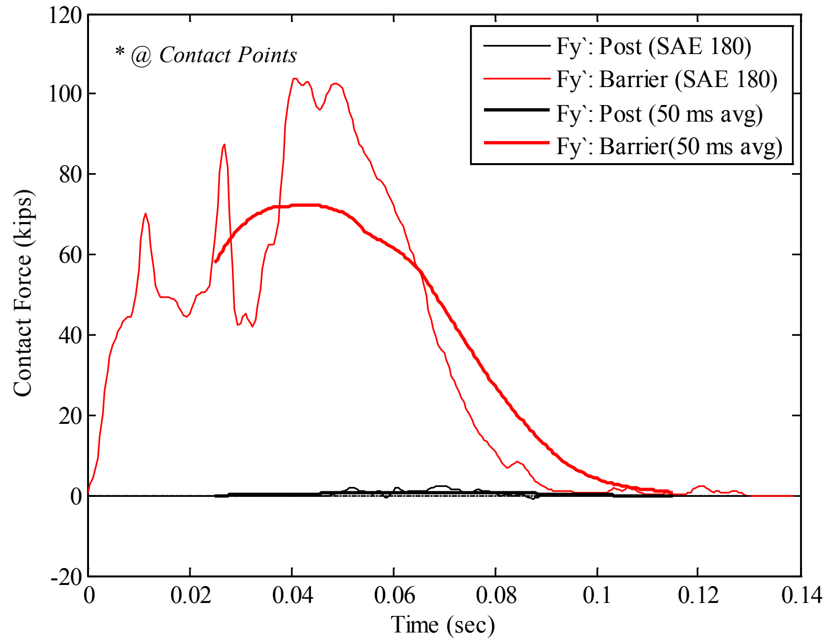


Figure 3.23. Lateral Contact Forces on Barrier Coordinate System (*MASH* Simulation Performed on Schedule 80 Post Mounted on Rigid Barrier).

3.4.2 Evaluation of Wind Load

Wind load on a 4-ft × 4-ft sign panel mounted on the permanent concrete barriers selected for this study was calculated following AASHTO guidelines (Source: AASHTO Standard, 4th Edition) (*36*). The calculation approach used to determine the force and moments acting on the sign mounting connection due to wind load is presented below:

Wind Pressure, $P_Z = 0.00256 K_Z G V^2 I_r C_d$ (psf) *(Eqn 3-1 , page 3-5)* (*36*)

Basic Wind Speed (3 sec-gust):

Houston: V= 120 mi/h (54 m/s)

San Antonio V=100 mi/h (45 m/s)

Wind Importance factor I_r (for recurrence interval=10 yrs): *(Table 3-2, Page 3-10)*

I_r= 0.54 (for V=120 mi/h)

I_r= 0.71 (for V=100 mi/h)

Height and Exposure factor K_z: K_z=0.87 (for height < 16.4 ft) *(Table 3-5, Page 3-11)*

Gust effect factor, G: G(min)=1.14. (*Page 3-12*)

Drag Coefficients, C_d=1.12 (for 4 ft × 4 ft sign panel with ratio L/W=1.0) *(Table 3-6, Page 3-17)*

$$P_Z = 0.00256 \times 0.87 \times 1.14 \times (120)^2 \times 0.54 \times 1.12 = 22.11 psf \quad \text{(for V=120 mi/h)}$$

$$P_Z = 0.00256 \times 0.87 \times 1.14 \times (100)^2 \times 0.71 \times 1.12 = 20.19 psf \quad \text{(for V=100 mi/h)}$$

For 4 ft × 4 ft sign panel:

Horizontal Wind Load: W_p= 22.11×16= 353 lb

Moment arm: For F-shape barrier: d =(7-33/12)'+2.83' =7.08'

For single slope barrier: d =(7-42/12)'+2.83' =6.33'

Bending Moment: On F-shape barrier: M_{Fs} =2.5 kips-ft

On Single Slope Barrier: M_{Ss} =2.235 kips-ft

Torque on vertical support: T =W_p×e =W_p×(0.15b) =W_p× (0.15*5.66) =0.3 kips-ft.

3.4.3 Engineering Analyses of Existing Construction Details

Engineering analyses were performed as shown in Figure 3.24 to determine the capacity of the bolts and the base plate used in the TXDOT Type H4 sign mount connection shown in Figure 3.7. It can be seen that the moment capacity of the connection based on bolt strength is 2.381 kip-ft. Also, bending capacity of the base plate used in the connection is 1.615 k-ft. This indicates that some bending of the base plate is likely to occur prior to the failure of the bolt at 2.38 k-ft moment.

As discussed in the previous sections, the maximum moments acting on a typical sign mounting connection due to the vehicular impact and wind load are 7.5 k-ft and 2.5 k-ft, respectively. Thus the bolts used in TxDOT type H4 connection shown in Figure 3.7 should fail at vehicular impact or severe wind load. In the next task of this study, conceptual sign mounting connections will be analyzed and recommended based on the results obtained from the analyses to be performed and TxDOT input.

$HIT_{ultimatebond} := 25395lbf$ for 3000 psi concrete for Hilti HIT 150 Adhesive Anchoring System (see page 204 2008 Product Technical Guide)

$f_{RN} := 0.30$ Reduction factor for limited edge cover (approximated from extrapolated value for minimum listed fpr 3 5/16" edge w/ 0.6 reduction (2 inches approximate), see page 213

$$\phi HIT_{ultimatebond} := HIT_{ultimatebond} \cdot f_{RN}$$

$$\phi HIT_{ultimatebond} = 7.618 \cdot kip$$

$$M_{bpbolt} := (6in - 1.25in - 1in) \cdot \phi HIT_{ultimatebond}$$

$\boxed{M_{bpbolt} = 2.381 \cdot kip \cdot ft}$ Based on bolt strength .... probably controls

Check baseplate bending

$$t_p := \frac{7}{16} in \qquad w_p := 6in$$

$$Z_{bp} := \frac{w_p \cdot t_p^2}{4}$$

$$Z_{bp} = 0.287 \cdot in^3$$

$$M_{bp} := Z_{bp} \cdot 36ksi$$

$$M_{bp} = 0.861 \cdot kip \cdot ft$$

$F_{bp} := \frac{M_{bp}}{2in}$ $F_{bp} = 5.168 \cdot kip$ limiting...

$M_{BP} := F_{bp} \cdot (6in - 1.25in - 1in)$ $M_{BP} = 1.615 \cdot kip \cdot ft$ based on baseplate bending .... some bending likely to occur prior to bolt failure

Figure 3.24. Engineering Analysis of Existing Construction Details.

CHAPTER 4. NUMERICAL SIMULATION AND DEVELOPMENT OF PRELIMINARY GUIDELINE

4.1 INTRODUCTION

Finite element simulations were performed to evaluate and compare performances of various concepts of mounting sign panel on a permanent concrete median barrier. Public domain FE model of 2270P *MASH* test vehicle was used to conduct these simulations. The impact performance of the vehicle model was validated against an existing crash test. Several modifications were made to the existing vehicle model to match the impact performance of the vehicle used in *MASH* TL-3 Crash Tests. Static tests were performed to verify the stiffness of the sign posts used in the FE model of each concepts. A brief description of the vehicle model used for the simulations is provided in this chapter. Component level static tests and material properties used for various components of the sign mount systems are also discussed. This chapter also presents the results obtained from the simulations performed on each concept to determine the two best possible options for mounting sign system on a median barrier. Engineering analyses were performed to develop detailed post to barrier connection for the selected concepts.

4.2 VALIDATING THE FINITE ELEMENT VEHICLE MODEL*

NCAC developed the finite element model of a 5004-lb Silverado pickup (*40*), as shown in Figure 4.1, which matches the *MASH* specifications for TL-3 2270P test vehicle. Researchers increased the fidelity of the *MASH* TL-3 2270P vehicle model by modifying certain components meshes and material definitions. The team made these modifications to the NCAC developed *MASH* 2270P truck model (reduced version) to ensure reliable results. Material properties for the tire and rim was modified to match the detailed version of the NCAC developed Silverado model. The researchers re-meshed (re-fined) the rear suspension bushing to avoid excessive deformation of the coarse rubber elements after the backslap event.

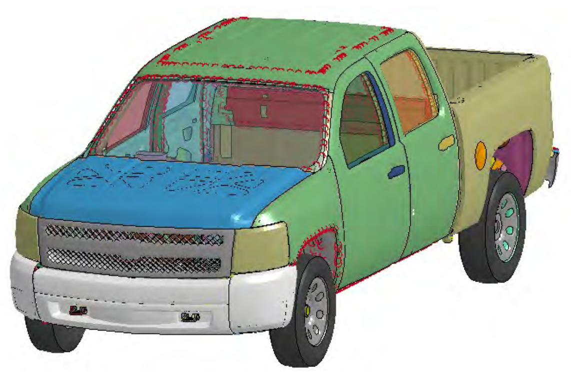
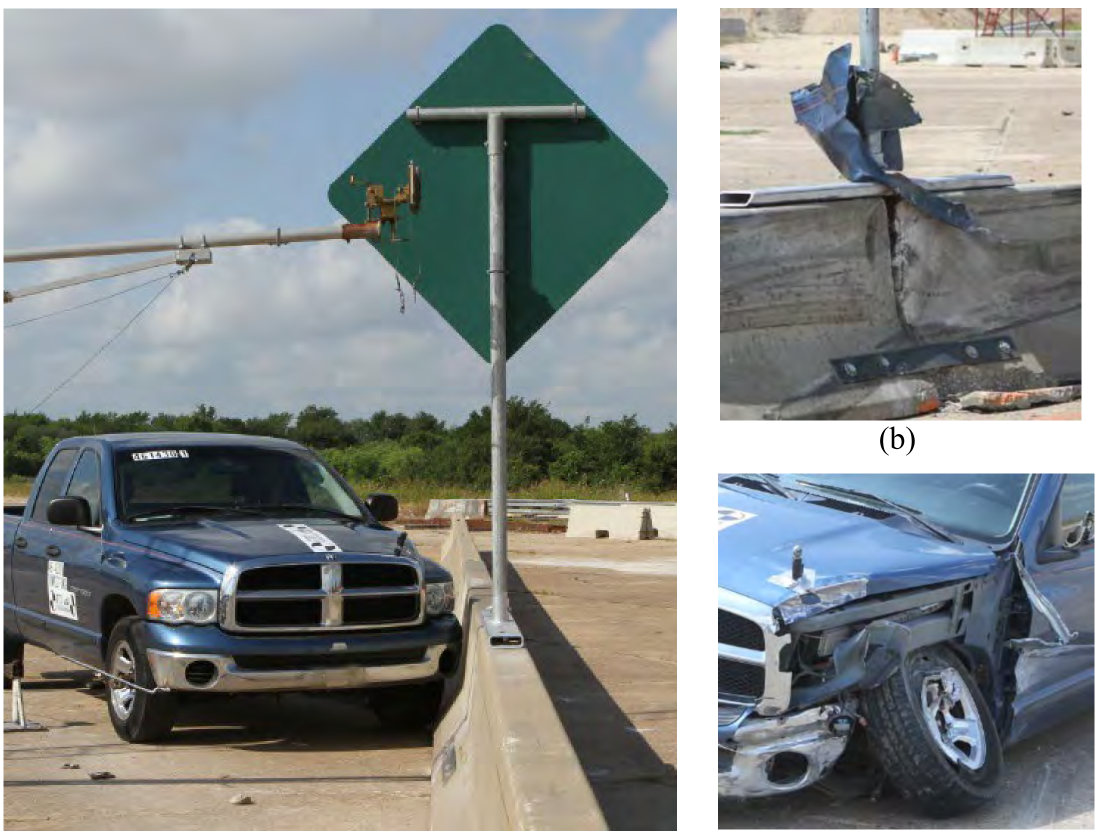


Figure 4.1. Silverado Pickup 253,225 Element Model (Reduced Version).

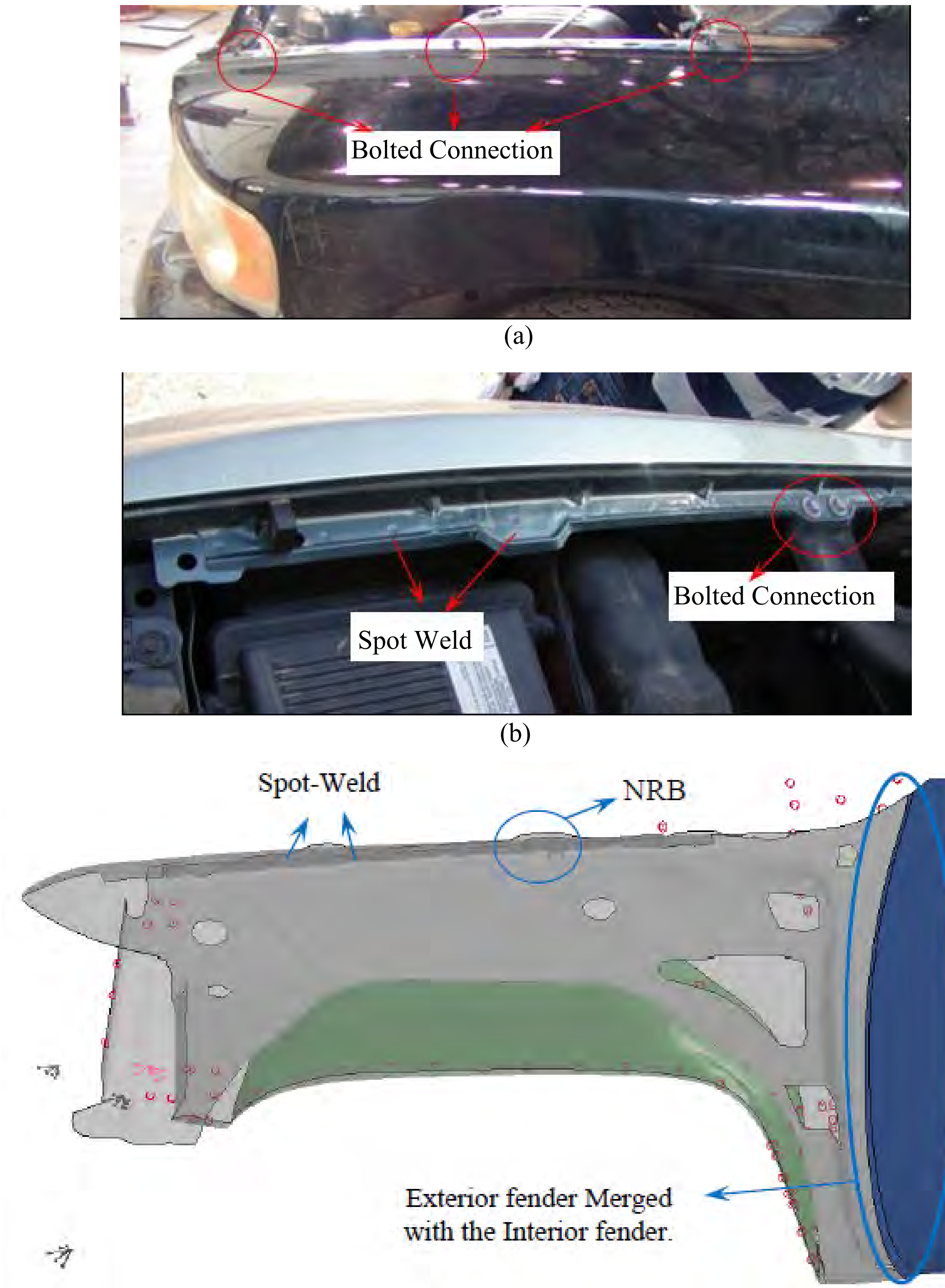
* TTI Proving Ground is an ISO 17025 accredited laboratory with A2LA Mechanical Testing certificate 2821.01. This certificate does not include finite element analysis.

Researchers at TTI recently investigated the performance of a temporary concrete barrier with sign attachments mounted on top (*38*). A crash test of this barrier-sign configuration was performed using a 2005 Dodge Ram 1500 pickup truck. During the test, the exterior fender of the truck snagged into the Schedule 80 sign post and was detached from the vehicle as shown in Figure 4.2. An initial LS-DYNA simulation of the original (unmodified) Silverado model impacting the barrier mounted sign post showed that the vehicle model does not have any failure mechanism for the exterior fender connection. A subsequent investigation showed that there are distinct differences in the fender connection for a Dodge Ram and Silverado pick up. As shown in Figure 4.3, the exterior fender of a Dodge Ram is attached to the interior parts using bolts. In a Silverado pickup, on the other hand, the exterior fender is attached to the interior parts using both spot-welds and bolts. As shown in Figure 4.3(c), in the original Silverado model, the bolts were modeled using nodal rigid body (NRB) connections and no failure criteria was assign to the spot- weld connections. The fender elements near the edge of the door were merged/attached to the surrounding elements. Thus the exterior fender in the existing pickup model does not detach from the vehicle and can impart excessive force on the sign post once snagged during a side impact.



(a) (b) (c)

Figure 4.2. (a) Setup for *MASH* Test Performed on Temporary Concrete Barrier with Sign Post Mounted on Top; (b) Schedule 80 Sign Post after Test; (c) Exterior Fender Detached from Vehicle after Impact.



(a) (b) (c)

Figure 4.3. Exterior Fender Connection of (a) Dodge Ram 1500 Pickup; (b) Silverado Pickup; and (c) Silverado Pickup Truck Model.

Dodge Ram pickup truck is generally used to perform *MASH* TL-3 tests at TTI and at other test labs. Hence, the research team modified the fender connection in the NCAC developed model to incorporate failure mechanism and match the fender connection in a Dodge Ram. As shown in Figure 4.4, the team removed the NRB connections and unmerged the exterior fender elements from interior parts at the edge near the door. Spot-weld representation was used to define the bolted connections. The research team used an effective failure strain of 0.3 to define the failure criteria for the spot-welds. Figure 4.5 shows the effect of these modifications on an impact simulation performed on a barrier mounted sign system. Figure 4.5(a) shows the result obtained from the simulation using the existing vehicle model. As can be seen in the figure, the spot welds near the fender region did not fail and the fender attached to the vehicle continued to impart high forces on the sign post producing excessive deformation of the Schedule 80 post. Exterior fender in the modified version of the vehicle model, as shown in Figure 4.5(b), on the other hand was detached from the vehicle imparting lower force on the post. Thus sign post in this simulation did not undergo large deformation due to this impact.

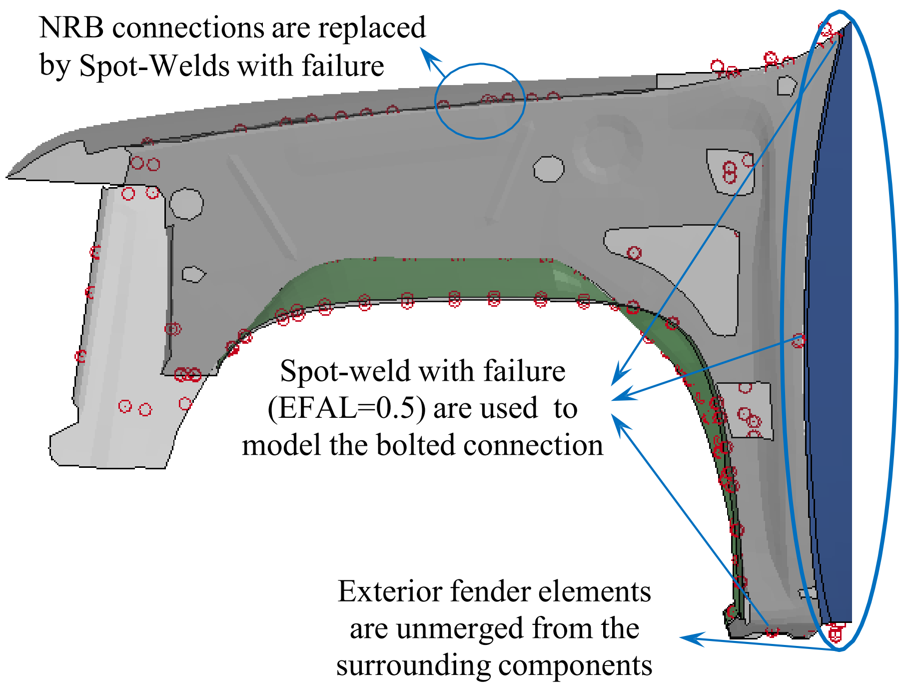
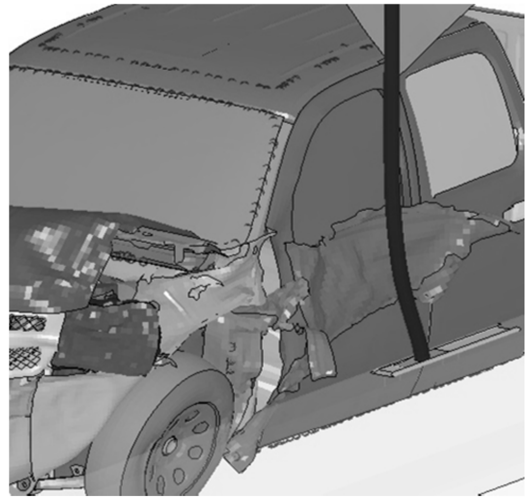


Figure 4.4. Modifications to Fender Connection of Existing Vehicle Model.

(a) Simulation using original version of the Silverado Model



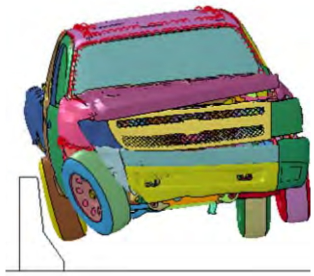
(b) Simulation using modified version of the Silverado Model

Figure 4.5. Effect of Fender Connection Modifications of Vehicle Model on Simulation of Impact on Barrier Mounted Sign System.

To validate the modified vehicle model the research team performed a full-scale impact simulation identical to a previously performed crash test. The *MASH* test selected for the validation was a 32-inch tall New Jersey safety shape barrier (TTI Test 476460-1-4) (*3*). Both in test and simulation, a 2270P vehicle impacted the rigid New Jersey safety shape barrier at a speed and angle of 62.6 mi/h and 25.2 degrees, respectively. The researchers used both qualitative and quantitative comparison approaches to validate the results obtained from simulation against those obtained from the test. RSVVP was used to calculate and evaluate the comparison matrices for time history curves. Sequential photographs, acceleration, and angular rate data were compared. The simulation results showed very good correlation with the crash test data. A detailed comparison of the simulation and test results is presented below.

4.2.1.1 Event Time-Sequence Comparison

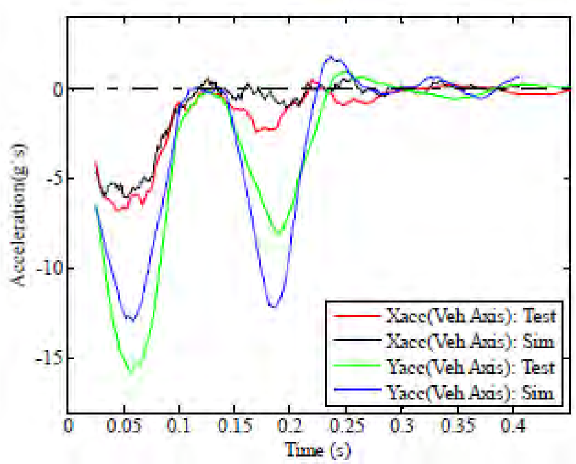
Figure 4.6 compares the sequential photographs of simulation and test results. As can be seen, the vehicle in the simulation closely followed the trend observed in the crash test. Comparisons of longitudinal accelerations and lateral accelerations obtained at vehicle C.G. during crash tests and simulations are presented in Figure 4.7 (a). Vehicle's yaw, roll, and pitch angles are also compared in Figure 4.7 (b). A reasonable overall correlation between the test and simulation results was observed from these figures. As can be seen from Figure 4.7 (a), lateral accelerations (i.e., impact force) obtained from the simulation was slightly lower during the initial impact and higher during backslap compared to that obtained during the crash test. The accelerations in longitudinal direction closely matched the test results. The vehicle's yaw, roll, and pitch angles obtained from the simulation closely followed the test results.



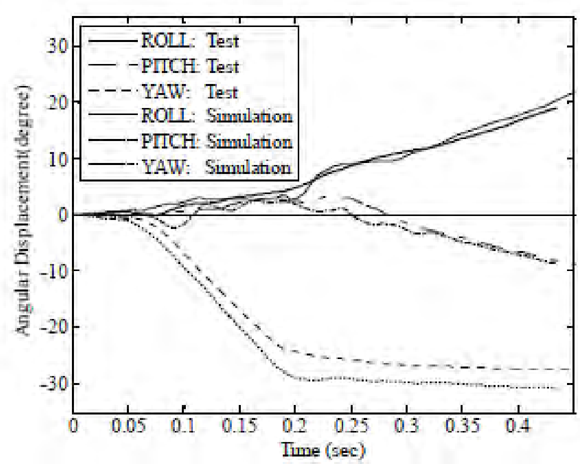
0.23 s

0.46 s

Figure 4.6. Comparison of Sequential Photographs.



(a)



(b)

Figure 4.7. Comparisons of (a) Longitudinal and Lateral Accelerations (50 ms Avg.) and (b) Angular Displacements.

4.2.1.2 *Quantitative Validation*

Mongiardini and Ray (*29*) recently developed the RSVVP program that can calculate comparison metrics between simulation and crash test signals that are helpful in quantitatively validating a roadside hardware model. These metrics are mathematical measures of the agreement between two curves. The Sprague and Geers metrics and ANOVA metrics were computed for the three acceleration channels and three angular rate channels obtained from the LS-DYNA simulation and TTI crash test (*10*) using the RSVVP computer program. According to the procedure, if one or more channels do not directly satisfy the criteria, a multi-channel weighting option may be used. For vehicle to barrier impact tests, the barrier redirects the vehicle by keeping its asset horizontal during all the crash events. Hence for these cases, acceleration collected along the vehicle vertical axis and roll and pitch motions of the vehicle can be considered insignificant compared to other two vehicle acceleration components and vehicle yaw motion. The default multi-channel weighting option in RSVVP calculates weighting factors based on area under the curve with equal distribution of weights between acceleration and rotational rate group. As shown in Table 4.1, the distribution of weights calculated following this approach reflects the actual importance of the channels. Therefore, in the acceleration group, X- and Y-acceleration channels received the higher weights and Z-acceleration channel received the lowest. Similarly, in rotational rate group, yaw rate channel received the highest weight compared to roll and pitch motions. Time history comparison metrics between the crash test and simulation performed on New Jersey safety shape barrier, as shown in Table 4.1, satisfied the criteria for the multiple channel weighting option.

Table 4.1. Time History Evaluation Table for *MASH* Simulation on New Jersey Barrier.

Compare Test 476460-1-4(*3*) (Filter Type: C180) and Simulation (Filter Type: SAE180, source: TRAP) (No Filter in RSVVP)

Channel Type	Weighting factor: (Area II)	Sprague-Geers Metrics		ANOVA Metrics		Pass ?
		M ≤ 40	P ≤ 40	Mean Residual ≤ 0.05	Std. Deviation ≤ 0.35	
X acceleration	0.145	31.8	36.7	0.02	0.26	Y
Y acceleration	0.329	0.5	18.8	0.008	0.14	Y
Z acceleration	0.026	53.2	42	−0.01	0.39	N
Roll rate	0.173	28	28.5	0.01	0.18	Y
Pitch rate	0.066	106	39	−0.02	0.77	N
Yaw rate	0.26	12.6	7.2	−0.03	0.12	Y
Multiple Channel	1.0	21.3	22	0.0	0.21	Y

Ray et al. (*30*) recommended developing a PIRT as another means of comparing the test and simulation. The relative difference between the simulation and test results presented in PIRT should not be greater than 20 percent. As shown in Table 4.2, simulation results satisfied all but one of these PIRT evaluation criteria. The ridedown acceleration in lateral direction was found higher in the simulation due to the higher impact force generated during backslap. In current project the simulations will be performed to evaluate the structural integrity of the sign mount device. The vehicle is expected to lose contact with the sign post before it reaches the point of backslap. Hence the researchers concluded that the differences in lateral ridedown acceleration between the test and simulation will not have a significant effect on the outcome of the future simulations performed for the project.

Table 4.2. Phenomenon Importance Ranking Table for *MASH* Simulation on New Jersey Barrier.

Evaluation Criteria	TTI Test (*3*)	Simulation	Relative Difference < 20%	Pass?
Maximum Roll (deg.)	20	19.1	>	N
Maximum Pitch (deg.)	−8.1	−8.7	<	Y
Maximum Yaw (deg.)	−27.5	−30.8	<	Y
Longitudinal direction: Occupant Impact Velocity < 40 ft/s (12m/s); Ridedown Acceleration <20Gs	14.1 ft/s @ 0.086 s; −5.6Gs	14.1 ft/s @ 0.098 s; −5.4 Gs (0.11-1.2 s)	< <	Y Y
Lateral direction: Occupant Impact Velocity < 40 ft/s (12m/s); Ridedown Acceleration <20Gs	30.2 ft/s @ 0.086s; −9.6Gs	26.6 ft/s @ 0.096s; −17.8 Gs (0.182-0.19 s)	< >	Y N

4.3 STATIC TEST

The small signs used on Texas highways are generally supported by 10 gauge tubing or Schedule 80 pipes with 2.875-inch nominal outside diameter. To determine crashworthiness of barrier mounted hardware using numerical simulations, accurate finite element representation of the sign post is needed. Table 4.3 shows the material properties obtained from the Material Test Reports (MTR) for Schedule 80 and 10 British Wire Gauge (BWG) pipes used in the previous crash tests performed at TTI (*41*). Table 4.3 also presents the minimum strength requirements for each pipe as specified in TxDOT standard (*35*). Researchers used bi-linear elasto-plastic material properties to model the sign posts used in FE model for the barrier mounted hardware. The true yield strength and true tangent modulus (Etan) used in the DYNA card were calculated from the data shown in MTR.

Table 4.3. Material and Section Properties for Schedule 80 and 10 BWG Pipes.

Pipe Type	TXDOT Minimum Requirements(*8*)				Static Test Specimen	Material Type	MTR report(*7*)			Measured	
	Thickn-ess (in)	Fy (ksi)		Elongat-ion(%)			Fy (ksi)	Fu (ksi)	Elongat-ion(%)	OD (in)	Thickn-ess(in)
SCH 80	0.276"	42	ASTM A500 Gr. Type B(*7*)	21	S1, S2, S3	ASTM A500 Gr. Type B(*7*)	63.1	67.7	23	2.9"	0.276"
10 BWG	0.134"	55	ASTM A653 Gr. 50 G-10(*7*)	20	S4	ASTM A653 Gr. 50 G-10(*7*)	60.29	70.5	28	2.9"	0.146"
					S5, S6		65.37	72.63	30	2.89"	0.146"

To ensure accurate bending behavior of the post due to the vehicular impact during FE crash simulations, the research team performed six component level static tests on Schedule 80 and 10 BWG pipes. Results obtained from these tests were compared against those obtained from identical simulations on two FE post models. Three tests were performed for each pipe types. Figure 4.8 and Figure 4.9(a) illustrate the setup for the static load test of Schedule 80 and 10 BWG pipes. A 2-ft long 3-inch diameter Schedule 40 pipe was anchored in between a load frame and 6-inch × 6-inch × 5/8-inch tubing using bolted compression. One end of the test pipe was inserted inside the Schedule 40 pipe. The two pipes were attached using a bolted connection 4.5 inches away from the pipe edge. The Schedule 40 pipe was used to protect the test pipe from local buckling due to the presence of rigid flat support. An eye bolt was attached to the test pipe at a distance 4 ft away from the support. The lab crew applied an upward vertical load on the eye bolt attached to the post using a hydraulic cylinder. An in-line load cell was used to measure the applied load. A string pot was connected to the bottom end of the eye bolt to measure vertical post displacement. The lab crew stopped the loading once the string pot displacement reading reached 22 inches for the Schedule 80 pipe and 16 inches for the 10 BWG pipe.

The research team performed finite element simulations of these static loading tests to validate the sign post model. The simulation setup is shown in Figure 4.9(b). Fully integrated shell elements were used to model each pipe. Rigid material with constrained six degrees of freedom was used to model the Schedule 40 pipe. The Schedule 80 and 10 BWG pipes were modeled using LS-DYNA MAT24 (elasto-plastic). The material properties were defined using the MTR data shown in Table 4.3. Two mesh sizes were used to analyze the mesh sensitivity.

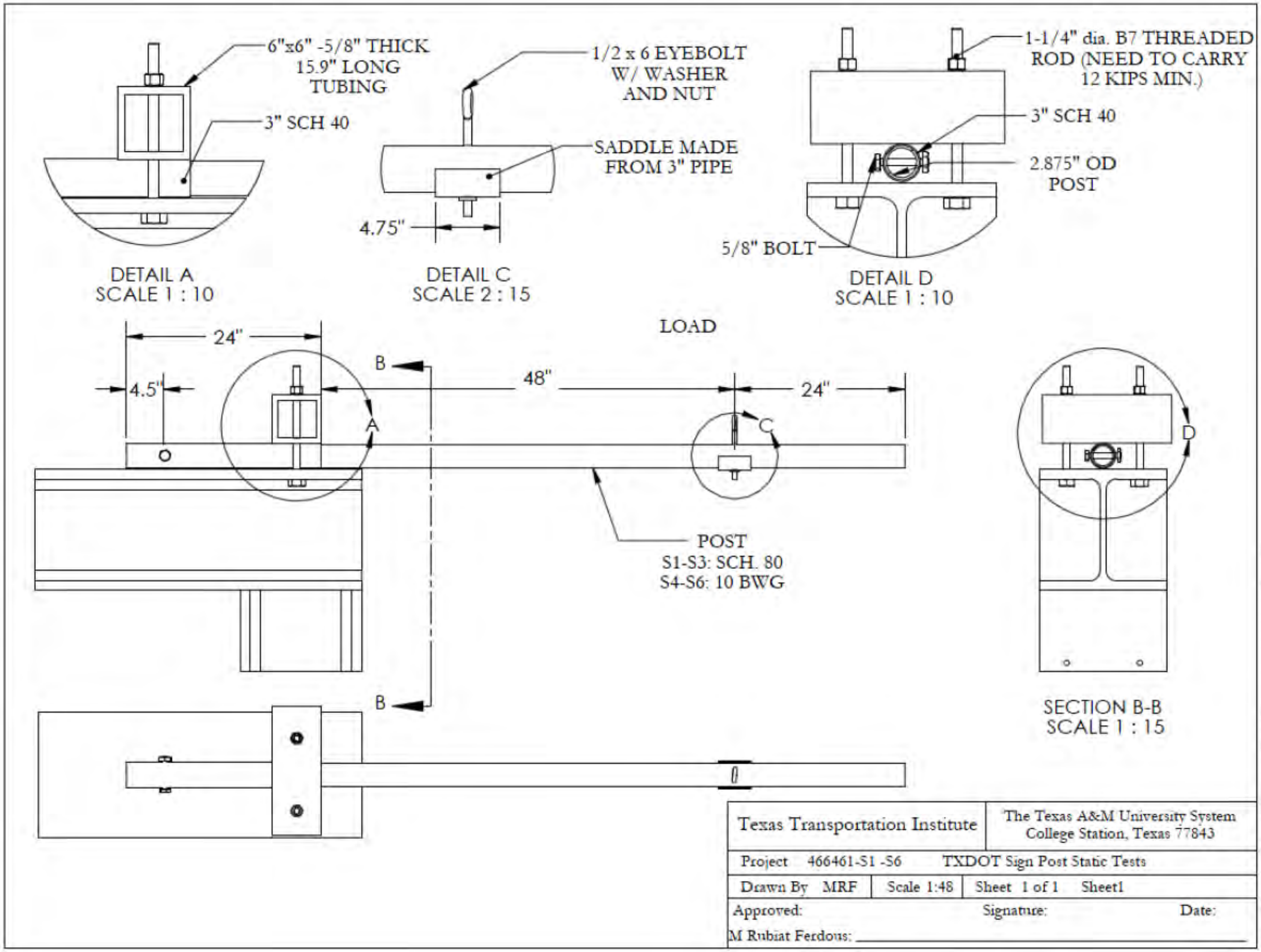


Figure 4.8. Static Load Test Setup for TxDOT Sign Posts.

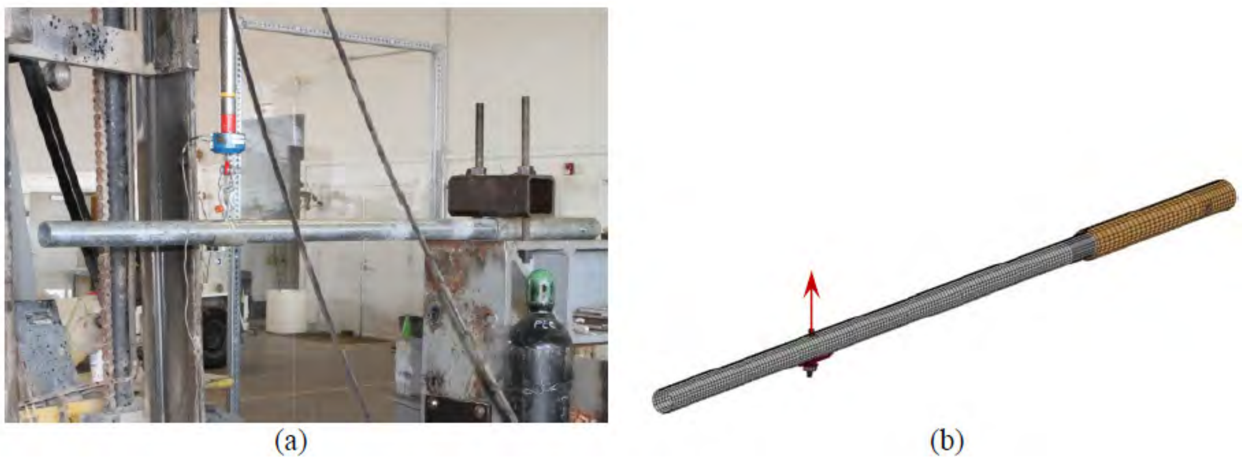
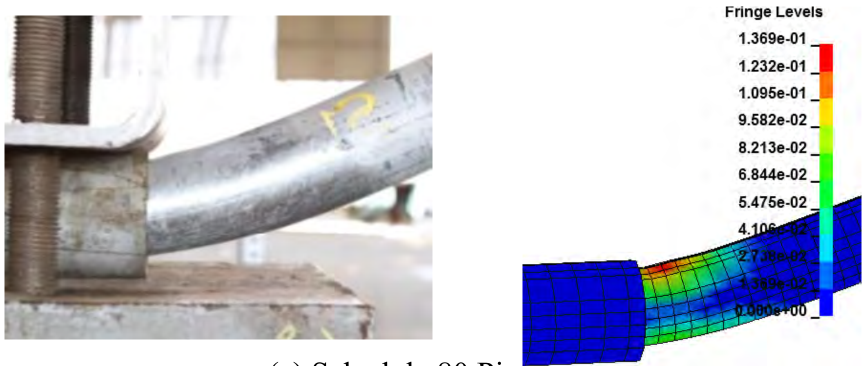


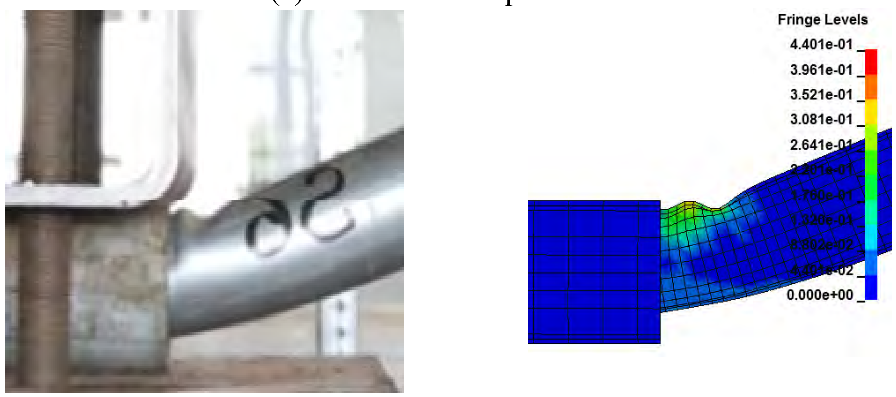
Figure 4.9. (a) Test and (b) Simulation Setup for Static Load Tests Performed on TxDOT Sign Posts.

The deformation of the Schedule 80 and 10 BWG pipe near support after the test and the simulation are compared in Figure 4.10. It can be seen that the thinner 10 BWG pipe experienced local buckling near support at the end of the test. The simulation also showed the local buckling of 10 BWG pipe. The load-deflection curves generated from the tests and the simulation are shown in Figure 4.11 and Figure 4.12. Figure 4.11 presents the load-deflection curves obtained from the three tests performed on Schedule 80 pipes. MTR data for each pipe specimen are shown in Table 4.3. As can be seen, all three Schedule 80 pipe had the same material property and therefore behaved in a similar fashion during the static load test. Each pipe yielded at a moment of (2.5×4=) 10 k-ft and continued to undergo linear strain hardening. Load-deflection curves obtained from the simulations, as shown in Figure 4.11, closely followed the test results for Schedule 80 pipe. The change in mesh size did not have significant effect on the post behavior.

Figure 4.12 presents the data obtained from the tests and the simulations performed on the 10 BWG pipe. In each test, the 10 BWG pipe showed a nonlinear strain hardening followed by a nonlinear strain softening after the reaching yield point. One of the test specimens (S4), as presented in Figure 4.12, showed slightly lower load capacity. This specimen had slightly lower yield strength compared to the other 10 BWG pipes tested as reported in MTR shown in Table 3.3. In the simulation research team used the properties of the pipes used in test S5 and S6. As shown in Figure 4.12, load-deflection curves obtained from the simulations deviated from the test results after reaching the yield point. Slopes of the curves obtained from the simulations in the hardening and softening region were milder compare to those observed in the test. Hence, maximum load capacity of the pipe obtained from the simulation was lower than that observed in tests S5 and S6. The test specimens had slightly higher wall thickness compared to the nominal thickness for a 10 BWG pipe. Using wall thickness of the test pipe slightly increased the maximum capacity obtained from the simulation. However, the value was still slightly lower compared to that obtained from the test.



(a) Schedule 80 Pipe



(b) 10 BWG Pipe

Figure 4.10. Bending of Pipe near Support Observed in Static Test and Simulation.

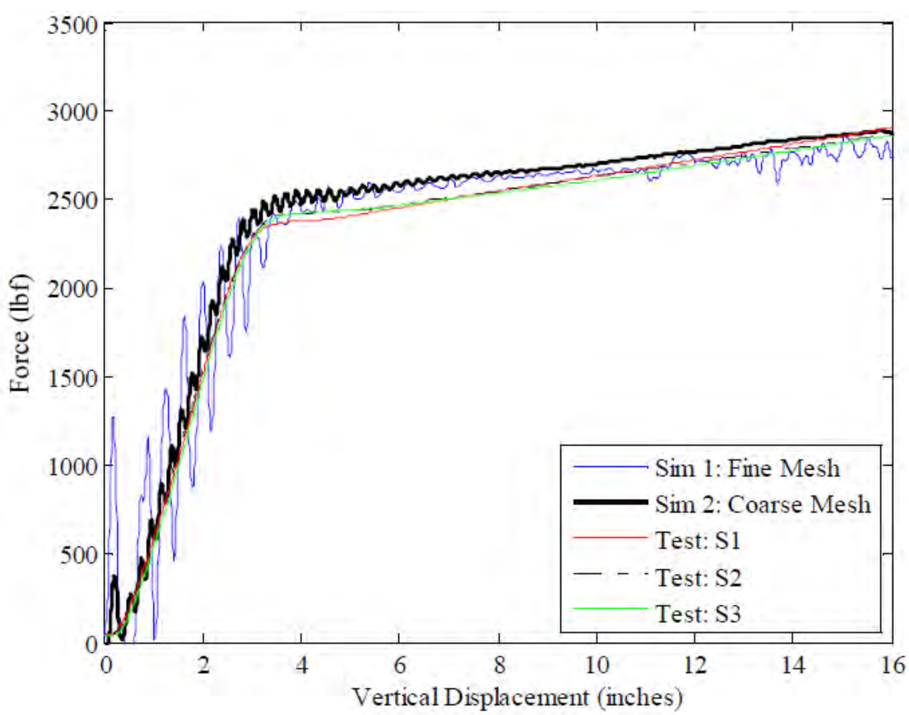


Figure 4.11. Load-Deflection Curves Obtained from Tests and Simulation Performed on Schedule 80 Pipe.

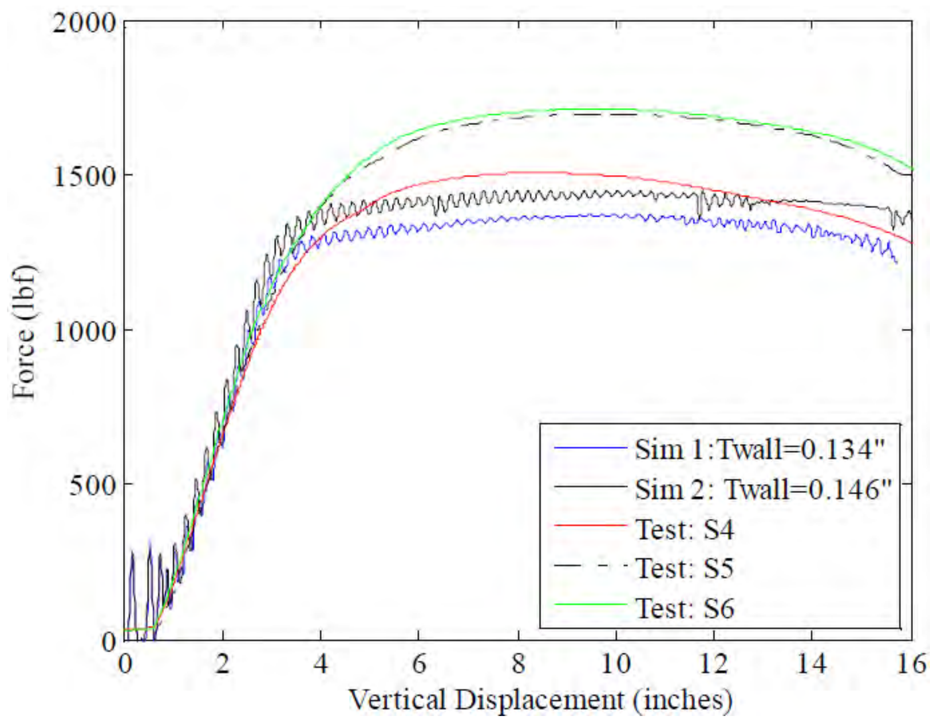


Figure 4.12. Load-Deflection Curves Obtained from Tests and Simulation Performed on 10 BWG Pipe.

4.4 NUMERICAL SIMULATIONS[§]

At the end of the previous task, the research team submitted six construction concepts and an existing construction detail of sign mount systems for TxDOT to review. Based on the feedback obtained from TxDOT (shown in Table 4.4), these concepts were prioritized in the following order:

(1) Concept 3: Bracket and Cable with Shackle

(2) Concept 4: Bracket and Sacrificial Pin

(3) Concept 1: Chute Channel

(4) Concept 6: Spread Tube System

(5) Existing Practice: TXDOT Type H4

(6) Concept 2: Hinge and Spring Assembly

(7) Concept 5: Triangular Plate

[§] TTI Proving Ground is an ISO 17025 accredited laboratory with A2LA Mechanical Testing certificate 2821.01. This certificate does not include numerical simulations.

Table 4.4. TXDOT Ranking of Sign Mount Concepts.

CONCEPTS		Ranking				
		A	B	C	D	Avg. Rank
Concept 1	Chute Channel	2	5	3	3	3
Concept 2	Hinge and Spring Assembly	4	6	4	7	6
Concept 3	Bracket and Cable with Shackle	1	1	1	5	1
Concept 4	Bracket and Sacrificial	3	2	2	1	1
Concept 5	Triangular Plate	7	7	7	6	7
Concept 6	Spread Tube System	5	3	5	2	4
Concept 7	TXDOT Type H4	6	4	6	4	5

The team selected four top ranked concepts for further evaluations using nonlinear finite element analysis. Finite element models were developed for the four concepts of mounting sign panel on a rigid median barrier. Still used old New Jersey safety shape barrier, as shown in Figure 4.13, was selected for the initial evaluation of the sign mounting concepts. This barrier, although crashworthy, has the lowest performance among other barrier profiles in terms of vehicular stability. Researchers used rigid materials to model the barrier in the initial evaluation stage. As discussed in the previous section, the team validated the FE model for the two sign post (Schedule 80 and 10 BWG) used in the analyses using static load tests. Material properties (see Table 4.5) used to model sign mount system components were obtained from the Mechanical Test Report of previous crash test (*41*).

Maximum panel size allowed to mount on a 10 BWG and a Schedule 80 pipe are 16 SF and 32 SF, respectively (*35*). To represent the 16SF panel a 4 ft × 4 ft-0.125-inch-thick diamond shape Aluminum Type A sign panel were selected. A 6-ft × 5.33-ft-0.125-inch-rectangular panel was selected to represent the 32 SF panel. A panel wider than 6-ft was considered unacceptable for placement on a median barrier. T-bracket was used to mount the 4 ft × 4 ft panel on a 10 BWG or a Schedule 80 pipe and U-bracket was used to mount the 32 SF panel on a Schedule 80 pipe. Effects of both sign panel sizes were investigated for each mounting concept. Piecewise linearly plastic material model with properties shown in Table 3.5 were used to develop FE models for sign panel, T-bracket, and U-bracket components.

Research team performed *MASH* TL-3 impact simulations on the FE models developed for four sign mounting concepts using the modified version of the NCAC developed 2270P test vehicle model. Results obtained from the simulations were used to evaluate the performance of each concept.

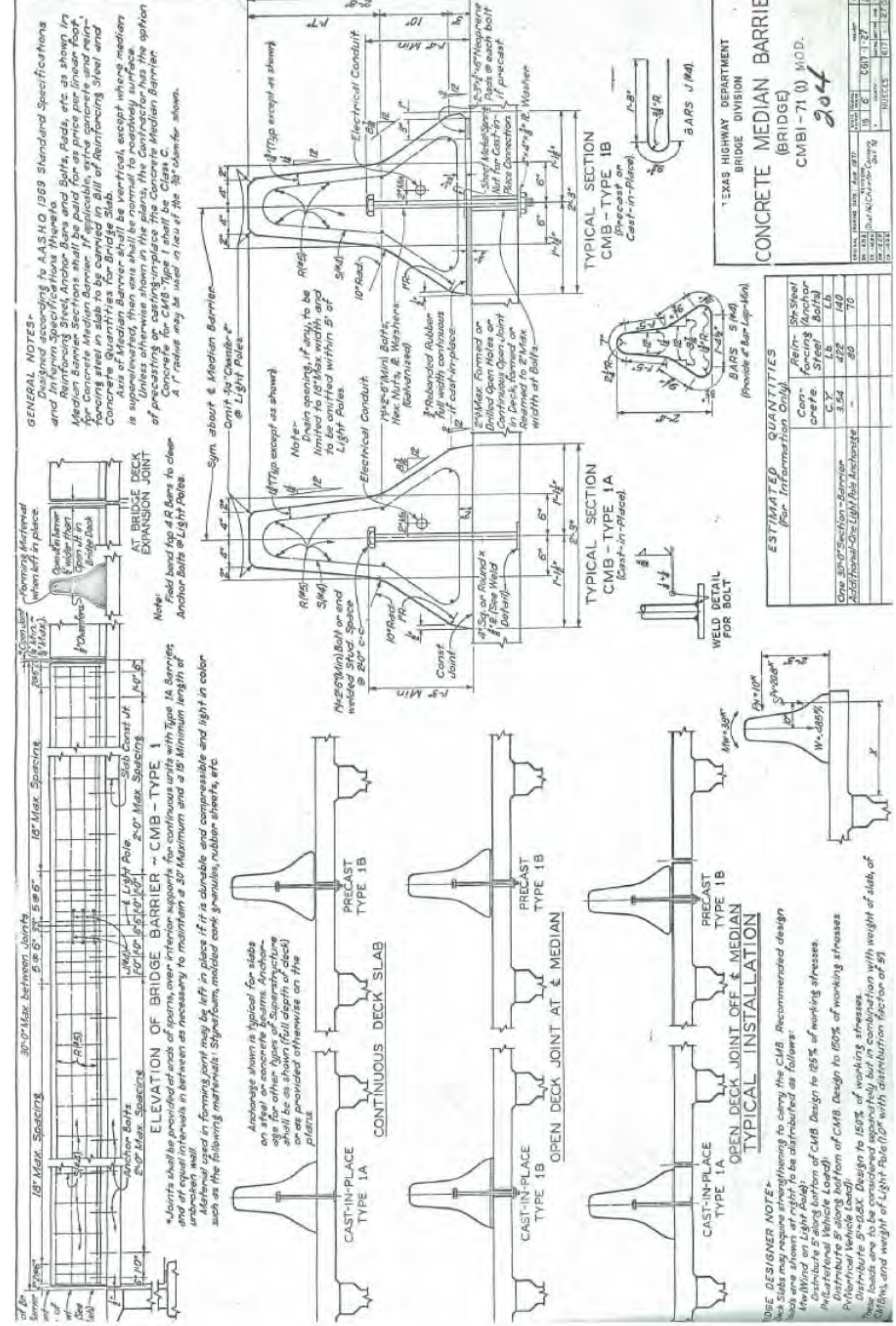


Figure 4.13. Old New Jersey Safety Shape Barrier Still Used on Texas Highways.

Table 4.5. Material Properties (*41*) of Sign Mount System Components Used in Finite Element Analyses.

Component	Material	Thickness	Pipe OD	Yield strength, σ_y ksi	Ultimate Strength, σ_y ksi	% Elon-gation	True Tangent Modulus, ksi	*nu*
4'×4' Sign Panel	Al, Alloys 6061-T6	0.125" (*38*)	N/A	40.07	45	12	92.43	0.36
Post, SCH 80	Steel, ASTM A500 Gr Type B	0.276" (*41*)	2.875"	63.24	67.7	23	97.8	0.29
Post, 10 BWG	Steel, ASTM A653 Gr 50	0.134"	2.875"	65.51	72.6	28	111.1	0.29
Horz. T-bracket, 13 BWG	Steel, ASTM A1011, Gr. Type B	0.095"	2.375"	63.66	85.6	24.7	197.3	0.29
Vert. Nipple for T-bracket, 11 BWG	Steel, ASTM A513, Gr 1020	0.109"	2.66"	67.9	80.1	29.4	139.7	0.29
U-bracket	ASTM A1011	0.134"	2.375"	63.5	85.6	24.7	197.3	0.29
Vert. Nipple for U-bracket,	Steel, Gr. 70MY	0.12"	3.25"	90.1	96.8	36.4	136.5	0.29

4.4.1 Concept 3: Bracket and Cable with Shackle

In Concept 3, the shape of the bracket/saddle needs to match the shape of the barrier top. Thus, the saddle concept required different mounting details for different barrier types. Also, the bolts used to attach the saddle on the side of the barrier can potentially snag into the vehicle impact side. To avoid these inconveniences, researchers considered replacing the bracket used in Concept 3 with a rectangular base plate attached on top of the barrier. As shown in Figure 4.14 the FE model developed for this concept included the sign post mounted on top of an old New Jersey safety shape barrier using a base plate and a cable with shackle assembly. As shown in the figure, one end of the cable with some slack was attached to the post at a height 2-ft above the barrier top. The other end of the cable was attached to the base plate. The researchers used finely meshed beam elements with piecewise linearly plastic material to model the cable. Figure 4.15 shows the effective stress vs. strain curve (*42*) used to define cable material. Spot weld connection was used to define slip-base connection to allow the post to detach from its base once impacted by the vehicle. This case assumed that the breakaway mechanism of the slip-base connection will activate as soon as the vehicle impacts the post. The case where breakaway mechanism of the connection does not activate is expected to behave similar to Concept 6 and therefore was not studied here. With breakaway mechanism activated, the post, in this concept, is expected to undergo small deformation and a lighter sign mount system is expected to produce better performance. Hence, the researchers, for this case, selected the thinner 10 BWG pipe to mount a 4-ft × 4-ft-0.125-inch-thick diamond shape sign panel. In determining the critical impact point, the research team, from a previous simulation, found that the pickup impacting a New Jersey Safety shape barrier intruded the maximum extent above top of the barrier at a distance 3.94 ft downstream from the impact point. Hence, in the simulation the 2270P vehicle model was set up to impact the barrier 3.94 ft upstream from the sign mount system.

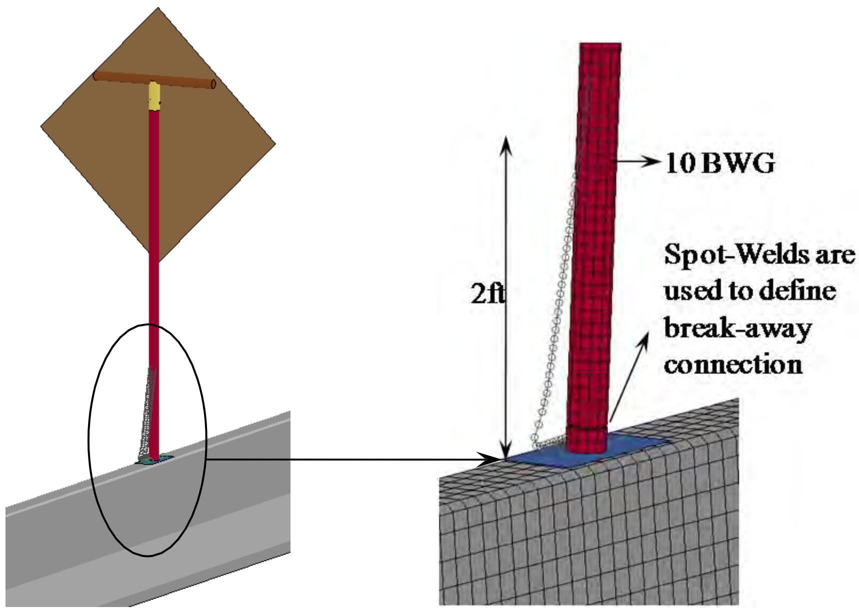


Figure 4.14. FE Model of Sign Mount Concept 3: Cable with Shackle Assembly.

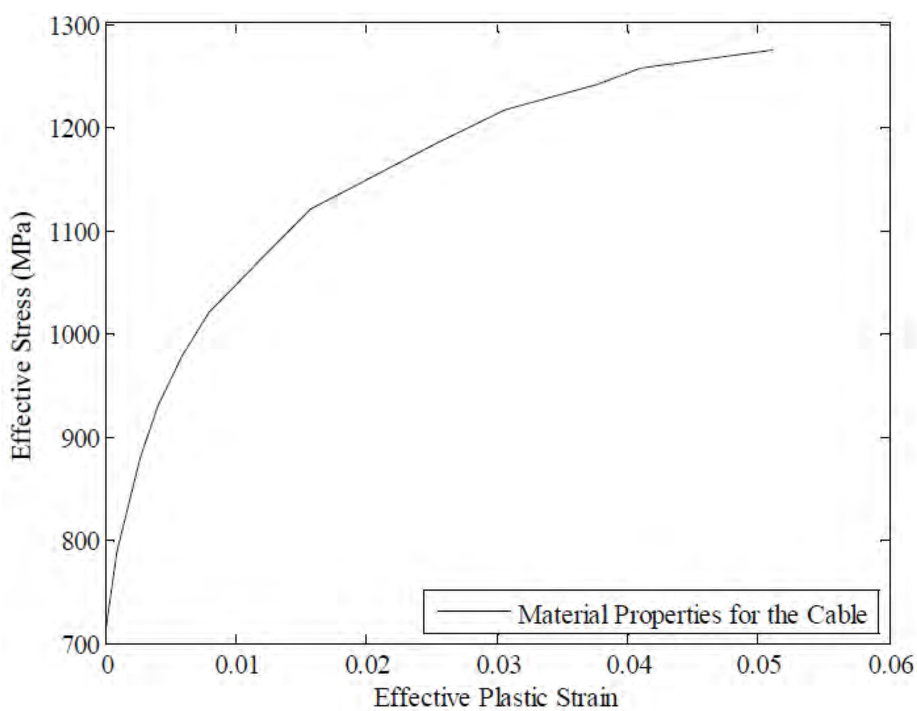


Figure 4.15. Material Properties (42) of Cable Used in FE Model of Sign Mount Concept 3.

The sequential images obtained from the simulation are shown in Figure 4.16. It can be seen from the figure that the sign mount system, detached after the impact, traveled toward the opposing traffic lane producing a potential debris problem. The extent to which the sign system travels toward the oncoming traffic lane depends on the length of the attached cable and maximum length of the unsupported sign system. The top of a 4 ft × 4 ft sign panel extends 10-ft high above the barrier top. Based on the velocity of the detached sign post at 0.5 s, research team decided that the sign system can extend its fullest length into the opposing traffic lane at a later stage in this crash event. As can be seen in Figure 4.17, the impact forces on the post were insignificant. Axial force in the cable reached up to 4 kips when it stretched to its fullest length at 0.09 s.

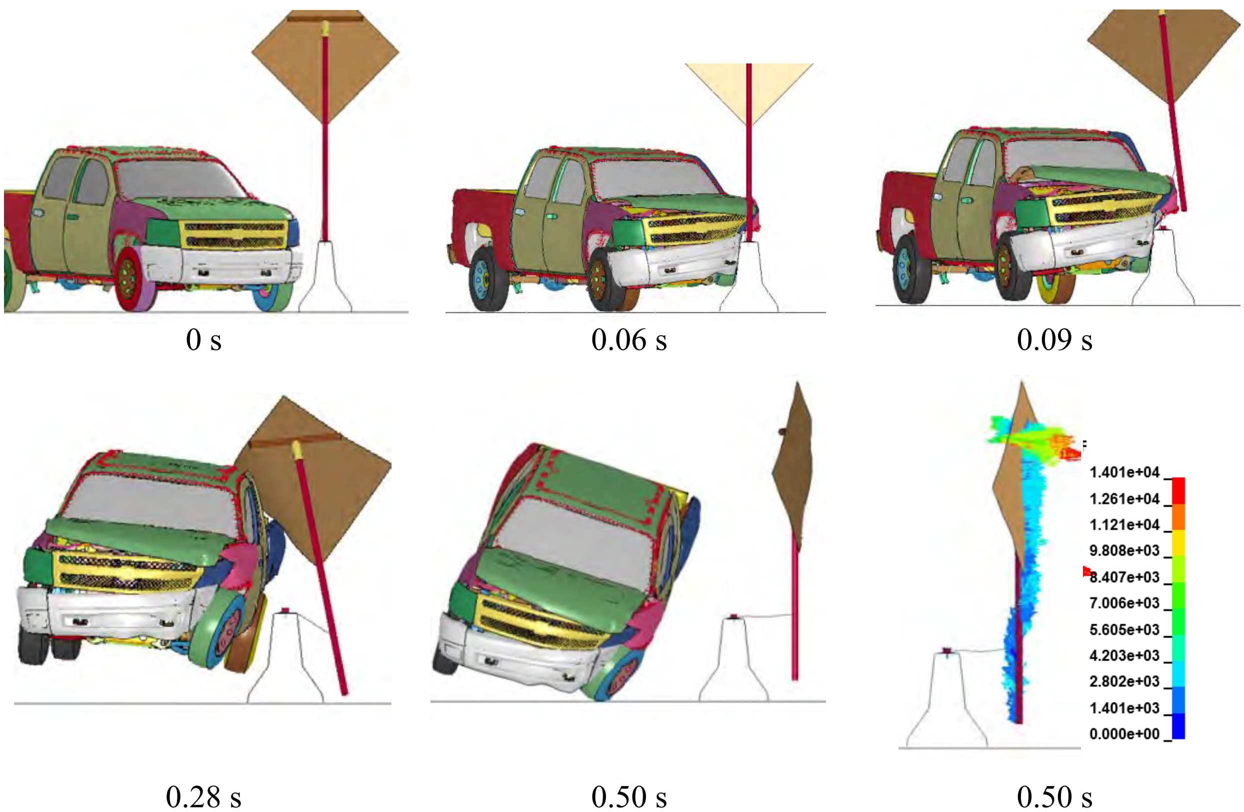


Figure 4.16. Sequential Images of *MASH* Simulation Performed on Sign Mounting Concept 3.

4.4.2 Concept 4: Bracket and Sacrificial Pin

Similar to Concept 3, this concept also includes bracket/saddle and requires different mounting details for different barrier types. To generalize the construction details, the saddle used in Concept 4 was also replaced by a rectangular base plate attached on top of the barrier. Figure 4.18 shows the finite element model of the sign mount system. As can be seen, the research team modeled the sacrificial pin using spot-welds. The spot-weld was allowed to fail once the vehicle impacted the post. The bolt at hinge was modeled using elastic beam elements surrounded by null shell elements attached to the beams using NRB constraints. The base plate and side plates were modeled using elastic shell elements.

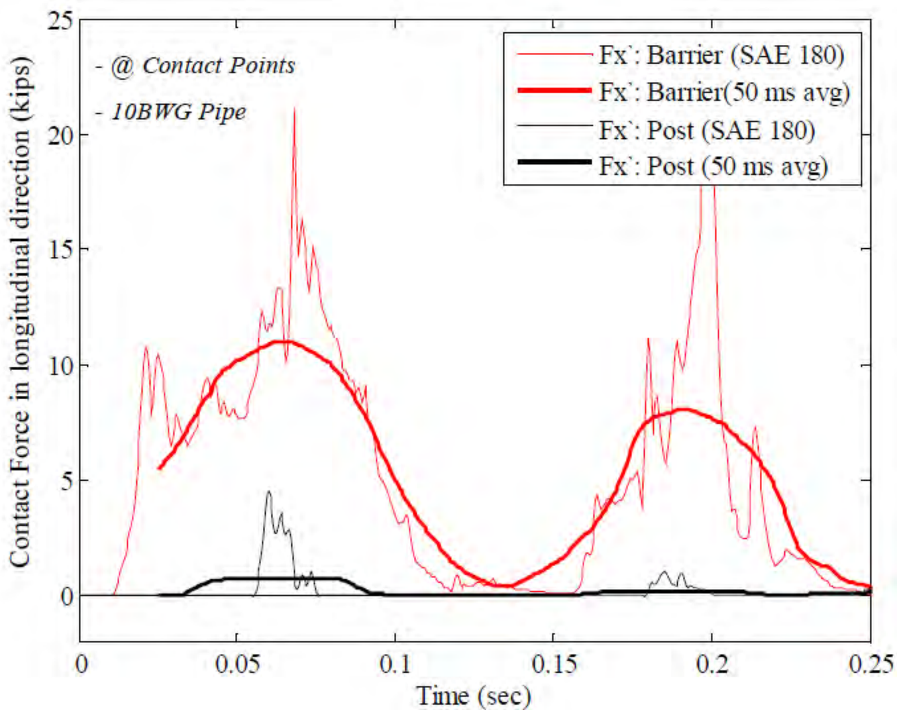


Figure 4.17. Impact Force on Barrier and Post in Direction Parallel to Barrier.

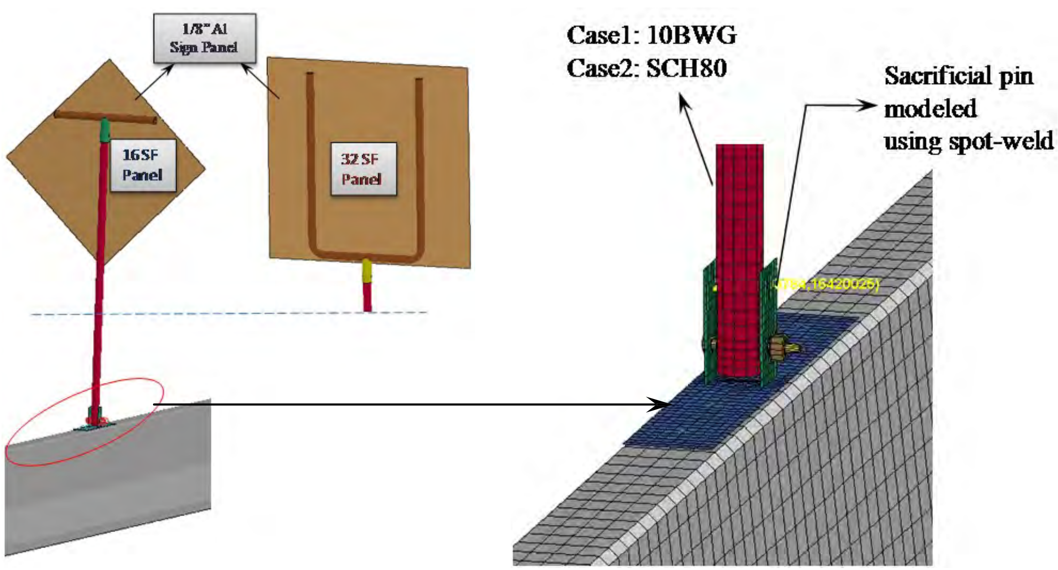


Figure 4.18. FE Model of Sign Mount Concept 4: Sacrificial Pin and Base Plate.

Simulation was performed for three cases. In the Case-1, the 16 SF panel was mounted using a 10 BWG pipe. In Case-2 the same panel was mounted using Schedule 80 pipe. In Case-3 a 32 SF sign panel was mounted using Schedule 80 pipe. Figure 4.19, Figure 4.20, and Figure 4.21 present the sequential images obtained from the three *MASH* simulations. For all cases, the post started to rotate about its hinge as the sacrificial-pin failed at 0.085 s due to the impact from the vehicle hood and fender. In each case, vehicle fender wrapped around the post and was detached from the vehicle at 0.15 s. The weaker 10 BWG post used in Case-1 rotated about the hinge with significant bending at the point of initial impact as shown in Figure 4.19. The stronger post used in Case-2 and Case-3, on the other hand, rotated abound the hinge without any significant bending. In Case-2 the edge of the sign panel impacted the roof as the vehicle exited the system without causing any significant roof deformation. Due to the higher inertia, Schedule 80 post with the larger sign panel rotated at a slower rate allowing the vehicle to exit without any contact with the panel. As shown in Figure 4.22, the barrier resisted the entire impact force in the transverse direction. Lateral impact force acting on the post was insignificant for all cases. Major impact force acting on the post was in the direction parallel to the barrier. Longitudinal impact forces acting on the system for each simulation case are presented in Figure 4.23. As can be seen from the figures, maximum 50-ms average impact force acting on the 10 BWG sign post was 8.9 kips. The maximum force acting on the Schedule 80 pipe was 9.2 kips for both 16 SF and 32 SF sign panels. Thus the increase in sign panel did not have significant effect on the performance of the Schedule 80 pipe mounted on the barrier using sacrificial pin.

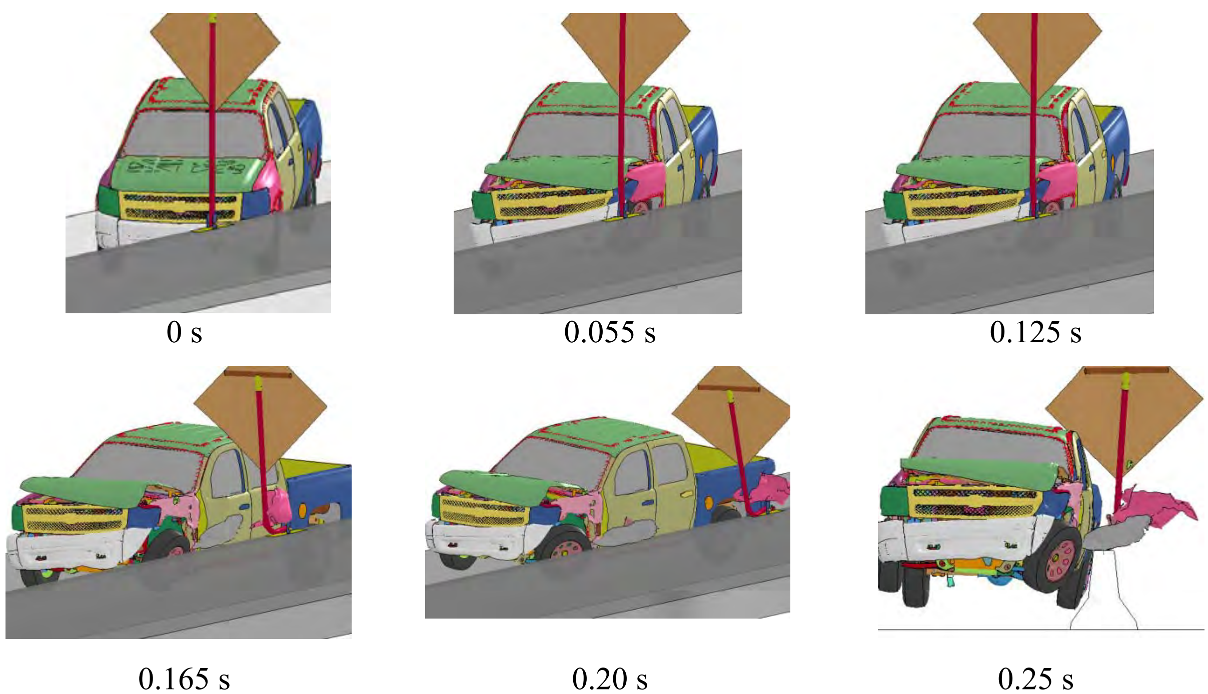


Figure 4.19. Sequential Images of *MASH* Simulation Performed on Sign Mounting Concept 4 with 16 SF Panel Mounted on a 10 BWG Pipe (Case-1).

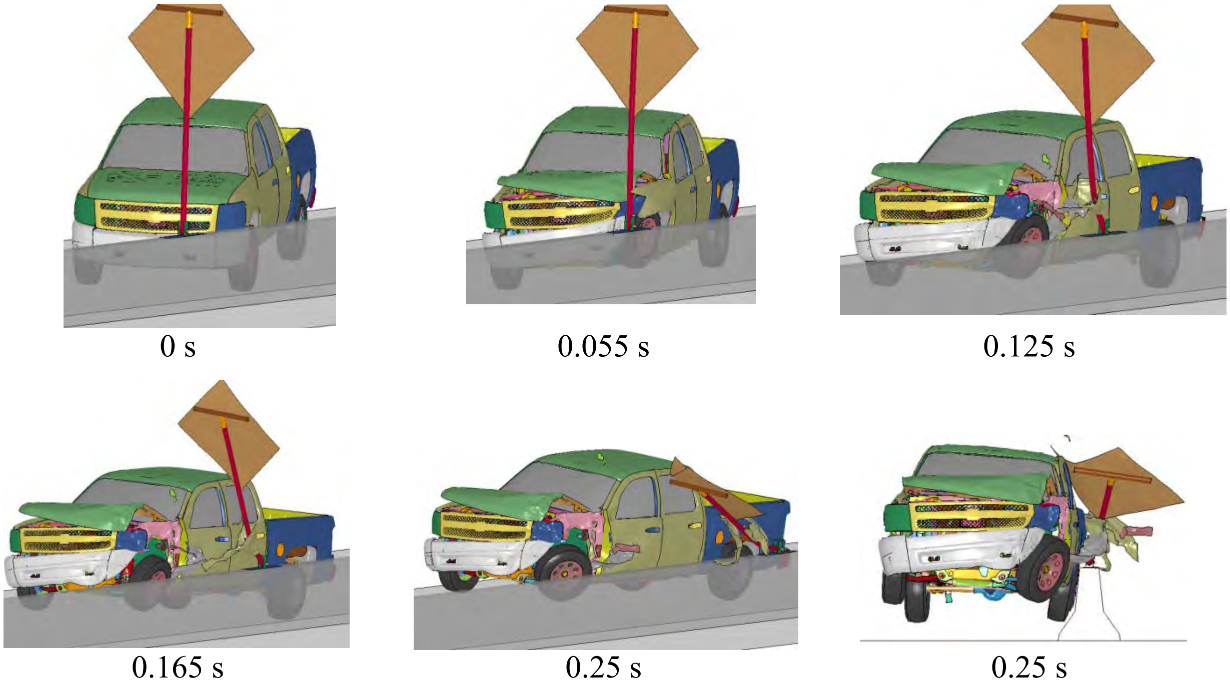


Figure 4.20. Sequential Images of *MASH* Simulation Performed on Sign Mounting Concept 4 with 16 SF Panel Mounted on Schedule 80 Pipe (Case-3).

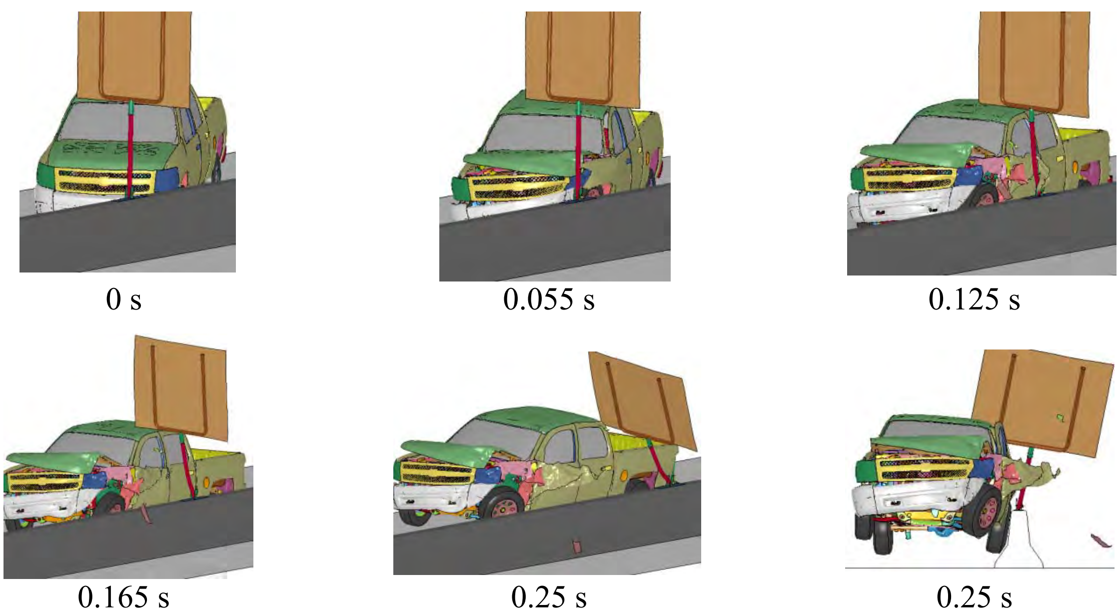


Figure 4.21. Sequential Images of *MASH* Simulation Performed on Sign Mounting Concept 4 with 32 SF Panel Mounted on Schedule 80 Pipe (Case-3).

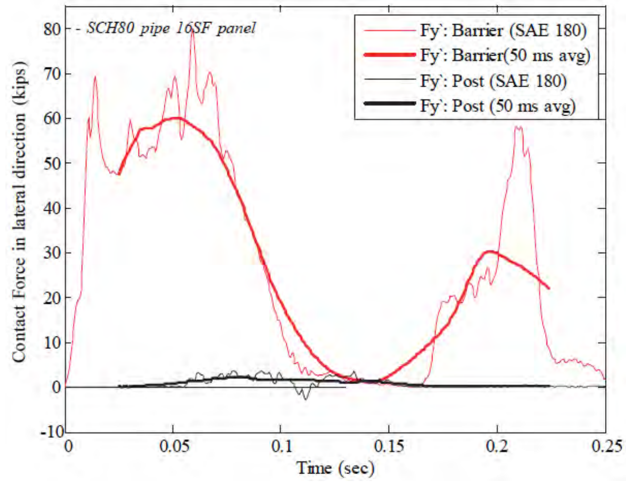
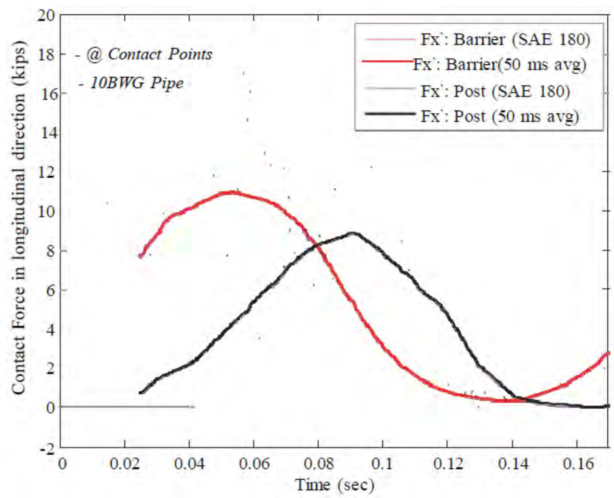
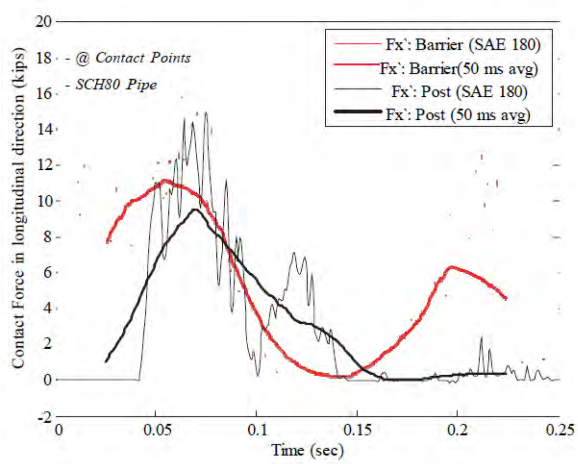


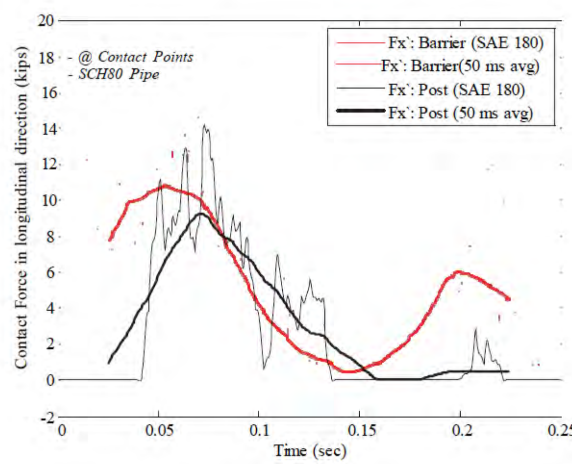
Figure 4.22. Impact Forces on Barrier and Post in Transverse Direction.



(a) Case-1 16SF panel on 10 BWG pipe



(b) Case-2: 16SF panel on SCH80 pipe



(c) Case-3: 32SF panel on SCH80 pipe

Figure 4.23. Impact Force on Barrier and Post in Direction Parallel to Barrier.

4.4.3 Concept 1: Chute Channel

In Concept 1, the sign post was mounted on a base plate placed inside a guiding channel as shown in Figure 4.24. The channel was anchored on top of the barrier, and the base plate was allowed to travel inside the channel for a certain distance in the longitudinal direction before reaching a stopper. The idea was to allow the vehicle impact force to dissipate through sliding energy.

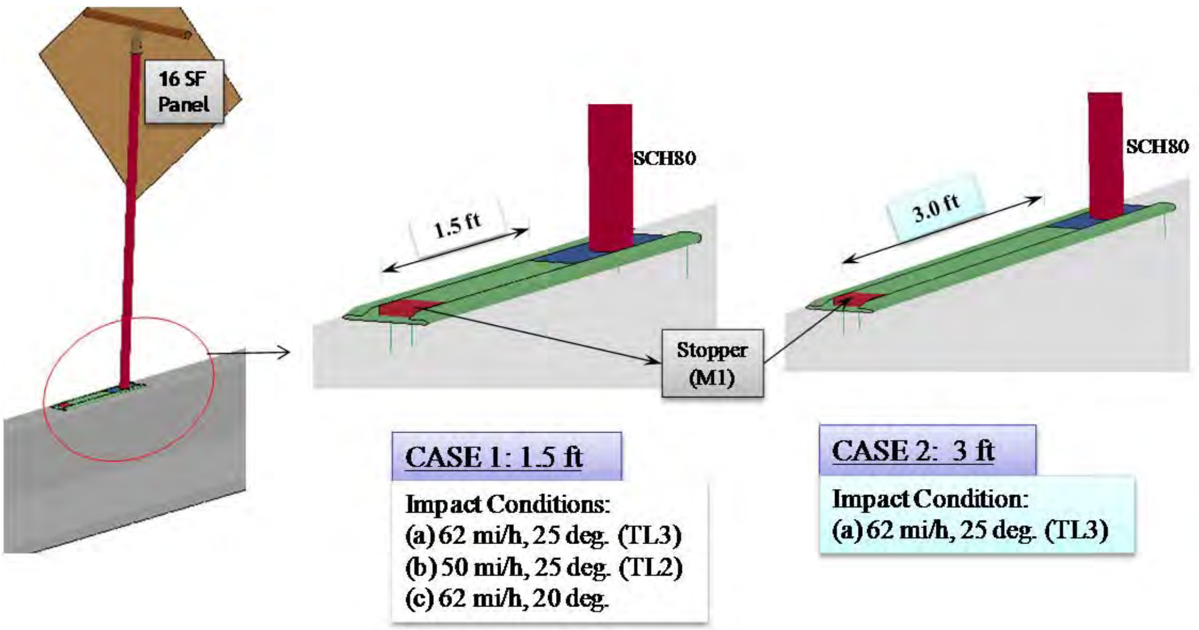


Figure 4.24. FE Model for Sign Mounting Concept 1: Chute Channel.

In the FE model, research team used piecewise linearly plastic material to model the chute channel. The base plate and the stopper was modeled using elastic material. Two cases with different base plate sliding distances were investigated. In Case-1, the sign system was allowed to slide through the channel 1.5 ft before reaching the stopper. In Case-2, this sliding distance was 3 ft. Sequential images obtained from the *MASH* TL-3 impact simulation for Case-1 and Case-2 are shown in Figure 4.25. As can be seen from the figure, as the vehicle hood impacted the post, the base pate traveled the allowed distance without any significant post deformation. Once the stopper stopped the plate movement at 0.085 s in Case-1 and 0.11 s in Case-2, the post started to bend due to the impact from the hood and fender. The fender lost contact with the post at 0.165 s in Case-1 and at 0.185 s in Case-2. In both cases, the post remained upright with minimum bending. Maximum dynamic deflection of the post relative to its base was 23.1 inches in Case-1 and 6.3 inches in Case-2. Figure 4.26 presents the impact forces acting on the barrier mounted sign system in longitudinal direction. The maximum 50-ms average impact force on the post in this direction was 12.2 kips for Case-1 and 13.2 kips for Case-2. The vehicle, in this case, lost 20 percent of its kinetic energy by the time the base plate translation was stopped by the stopper at 0.085 sec.

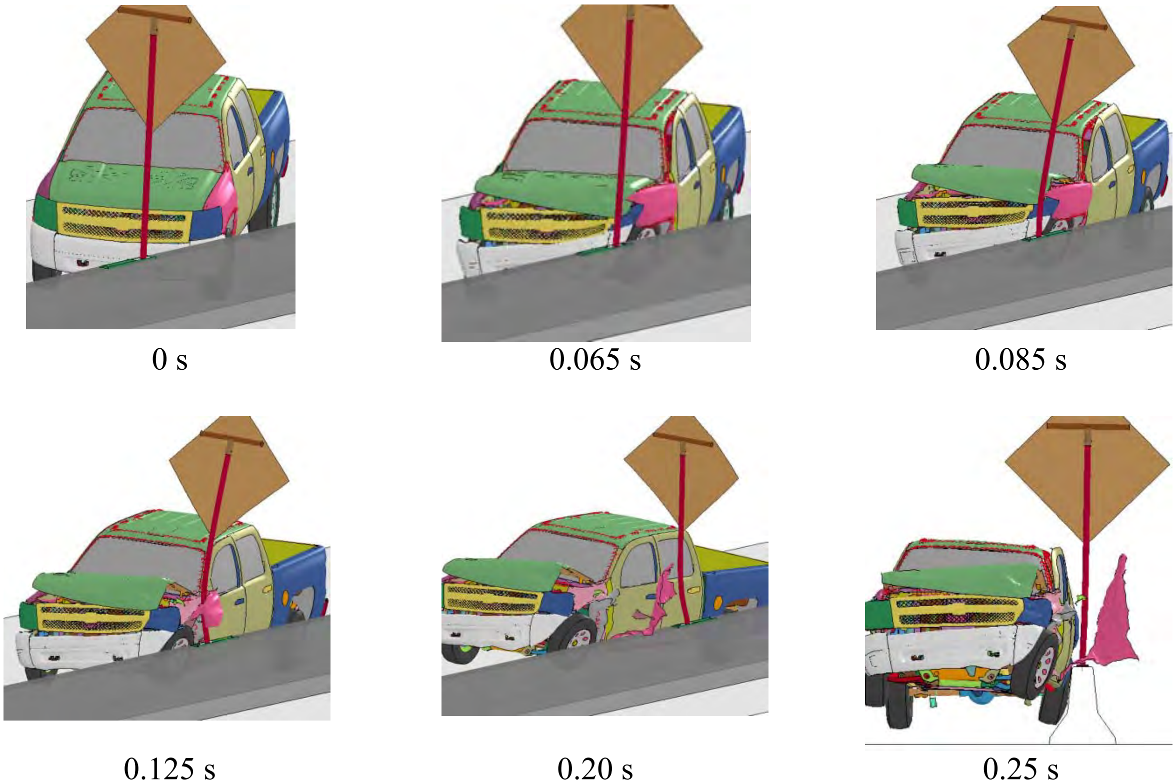
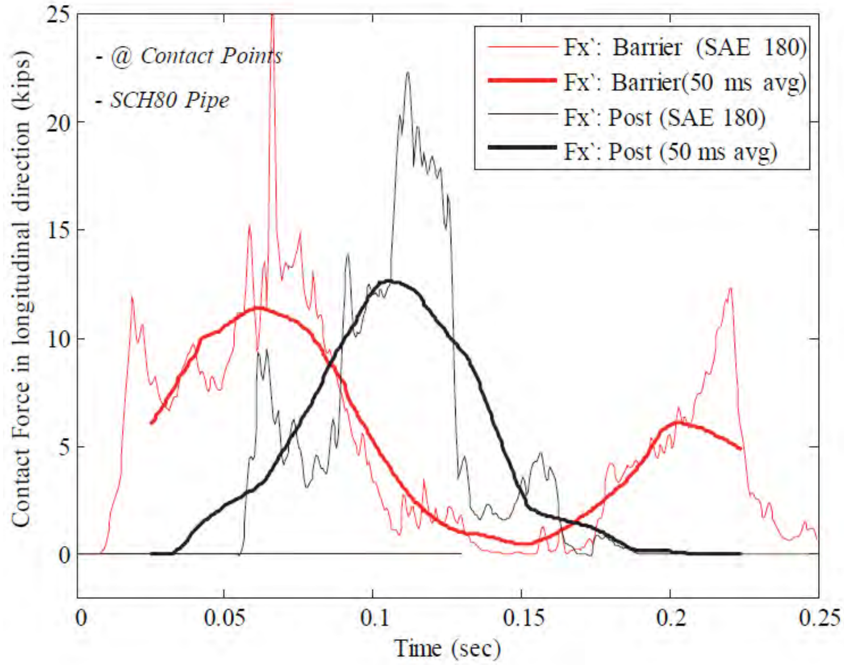


Figure 4.25. Sequential Images of *MASH* Simulation Performed on Sign Mounting Concept 1: Chute Channel.

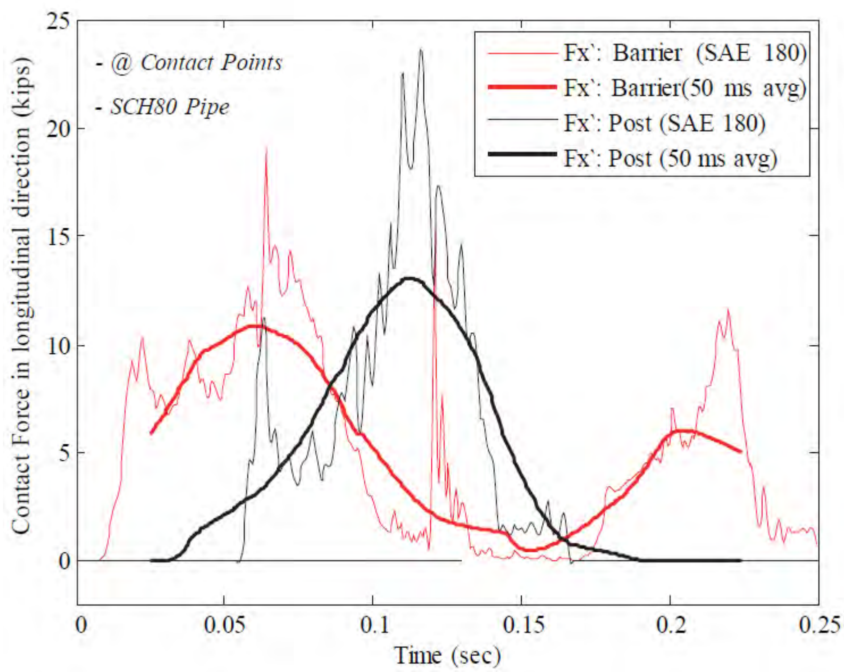
To determine the effect of vehicle impact speed and angle, two more impact simulations were performed using the model with 1.5-ft sliding distance. In the first simulation, vehicle impacted at an impact speed and angle of 50 mi/h and 25 degrees (TL-2), respectively. In the second simulation, vehicle impacted the system at a speed and angle of 62.2 mi/h and 20 degrees, respectively. The sequential images obtained from these simulations are compared in Figure 4.27.

Figure 4.28 shows the longitudinal impact forces acting on the post and barrier. As can be seen from Figure 4.27, at lower impact speed, post and base plate slid through the channel at a slower rate compared to what was observed in other simulations. Impact forces acting on the post was also lower at low speed impact. However the impact angle did not have significant effect on the impact force acting on the post.

Effect of larger size sign panel was also investigated for sign mount Concept 1 with 1.5-ft sliding distance. Figure 4.29 compares the sequential images obtained from the *MASH* TL-3 simulations performed on different size sign panels mounted using chute channel concept. As can be seen, the post with larger sign panel slid through the channel at a slower rate due to its higher inertia. Post deformations were similar for both sign panel sizes. As shown in Figure 4.30, the impact force on the post was also similar for both 16 SF and 32 SF sign panel case.

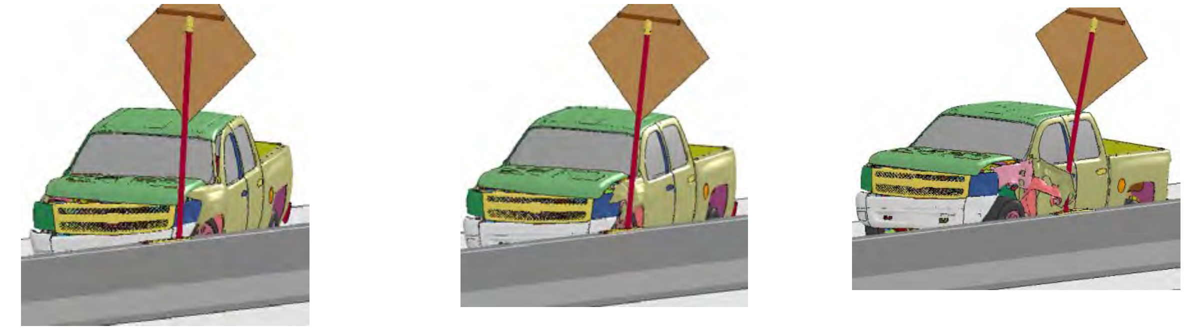


(a) Case-1a (1.5 ft Sliding Distance)



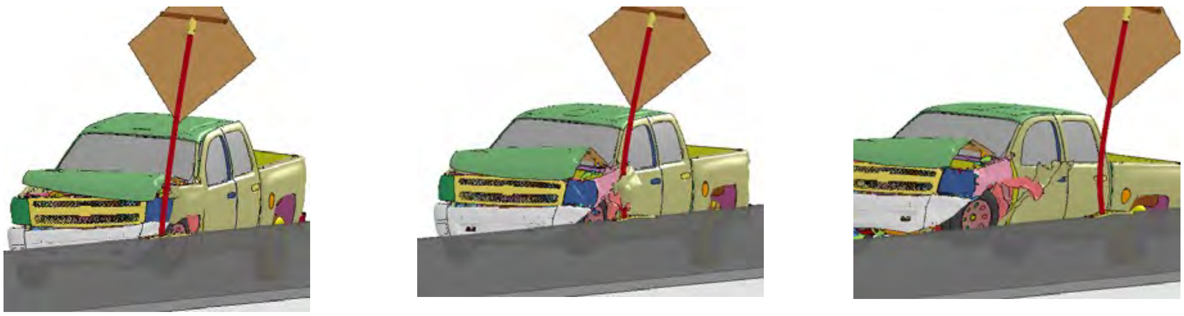
(b) Case-2 (3 ft Sliding Distance)

Figure 4.26. Impact Forces on Barrier and Post in Longitudinal Direction.



0.85 s | 0.125 s | 0.20 s

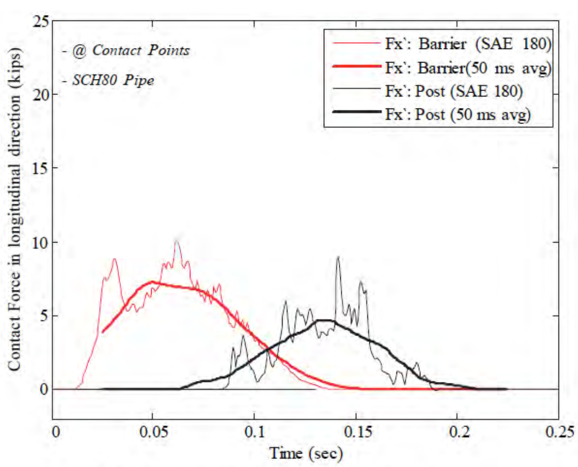
Case-1(b): Impact Speed=50 mi/h; Angle=25 degree.(*MASH* TL-2)



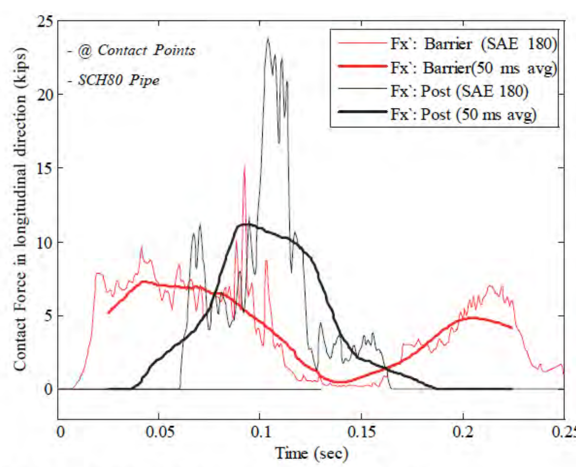
0.085 s | 0.125 s | 0.20 s

Case-1(c): Impact Speed=62.2 mi/h; Angle=20 degree

Figure 4.27. Sequential Images Obtained from Simulations Performed at Different Impact Conditions.



(a) Case-1(b): 50 mi/h; 25 degree.



(b) Case-1(c): 62.2 mi/h; Angle=20 degree

Figure 4.28. Impact Forces in Longitudinal Direction Obtained from Simulations Performed at Different Impact Conditions.

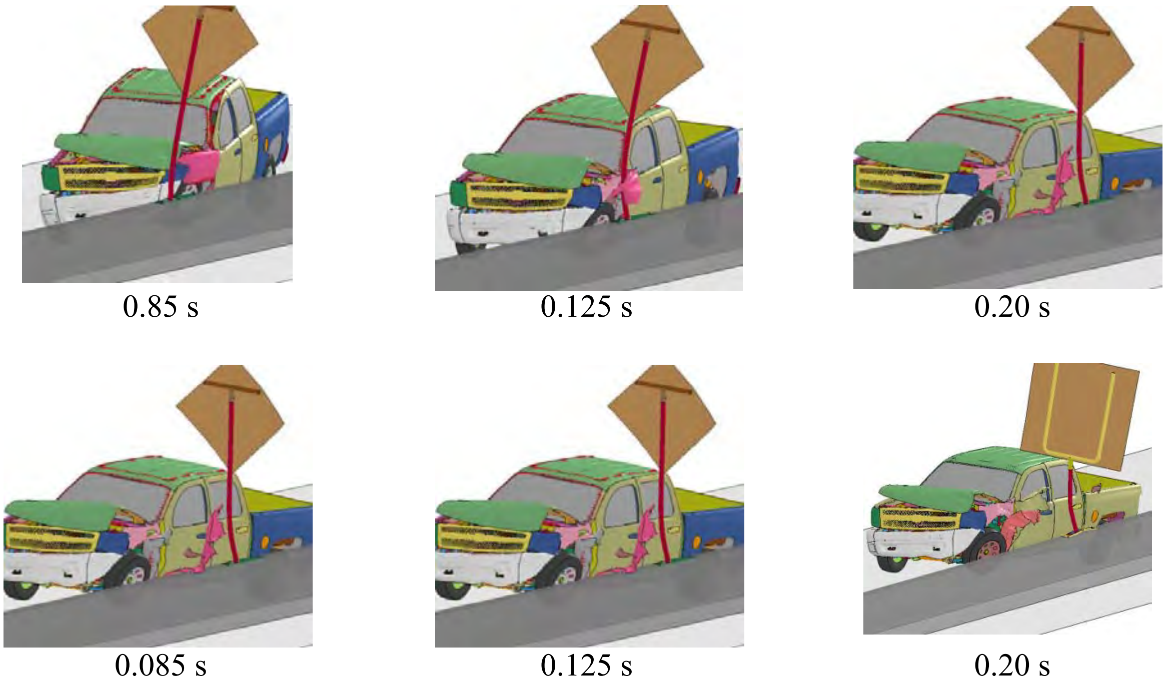


Figure 4.29. Sequential Images Obtained from Simulations Performed on Concept 1 with Different Sign Panel Sizes.

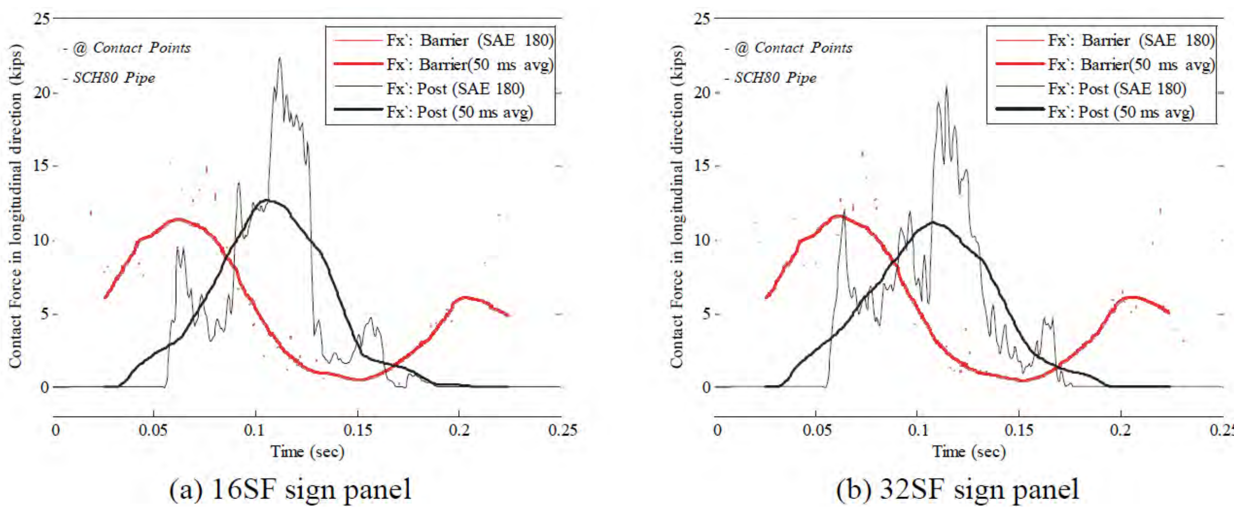


Figure 4.30. Effect of Sign Panel Size on Impact Forces Acting on Sign Mounted Barrier System.

4.4.4 Concept 6: Spread Tube

In the initial FE model for Concept 6, shown in Figure 4.31, the Schedule 80 post was attached to a 4-inch-high, 3-inch diameter Schedule 40 collar mounted on top of a 4-ft long 6-inch × 3-inch × 1/4-inch spread tube. Piecewise linearly plastic material was used to define the models for spread tube and Schedule 40 collar. The bolt was modeled using elastic beam elements surrounded by null shell elements attached to the beam using NRB. Figure 4.32(a) shows the sequential images obtained from the impact simulation performed on the model with 1/4-inch thick spread tube (Case 1). As can be seen from the figure, the fender of the errant vehicle during the simulation snagged into the post and caused the post and the material on top of the spread tube around the collar to yield. Yielding of the spread tube material can be prevented by increasing its thickness. The research team performed another impact simulation on the Concept 6 FE model with a 1/2-inch thick spread tube (Case 2). As shown in Figure 4.32(b), the tube material during this simulation did not yield and the post did not bend or deflect due to impact. Figure 4.33 shows the impact forces acting on the post for the two cases in a direction parallel to the barrier. The maximum 50-ms average impact force acting on the post with 1/4-inch thick spread tube was 18 kips. For the Schedule 80 post mounted on a 1/2-inch thick spread tube, this value was significantly low (13 kips). The bending of the post in the former case allowed it to remain engaged with the fender for longer period of time producing higher impact force.

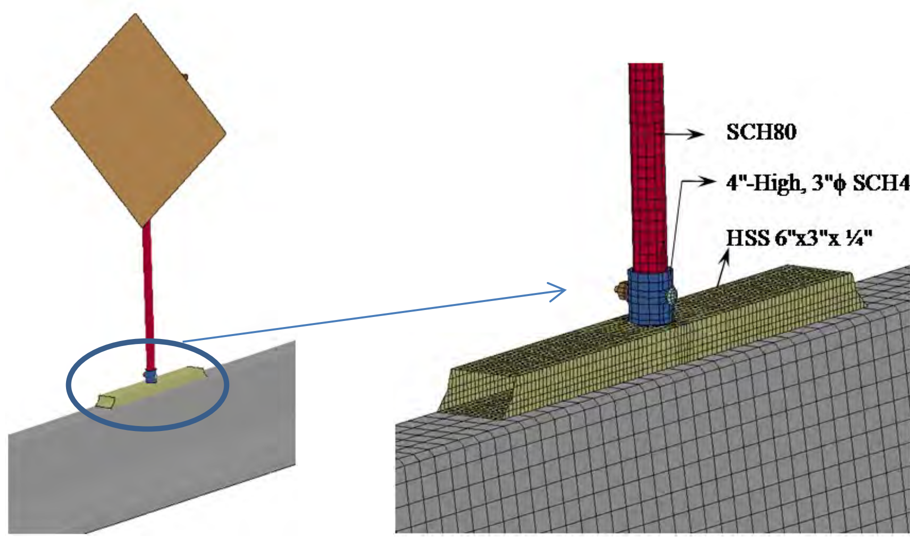
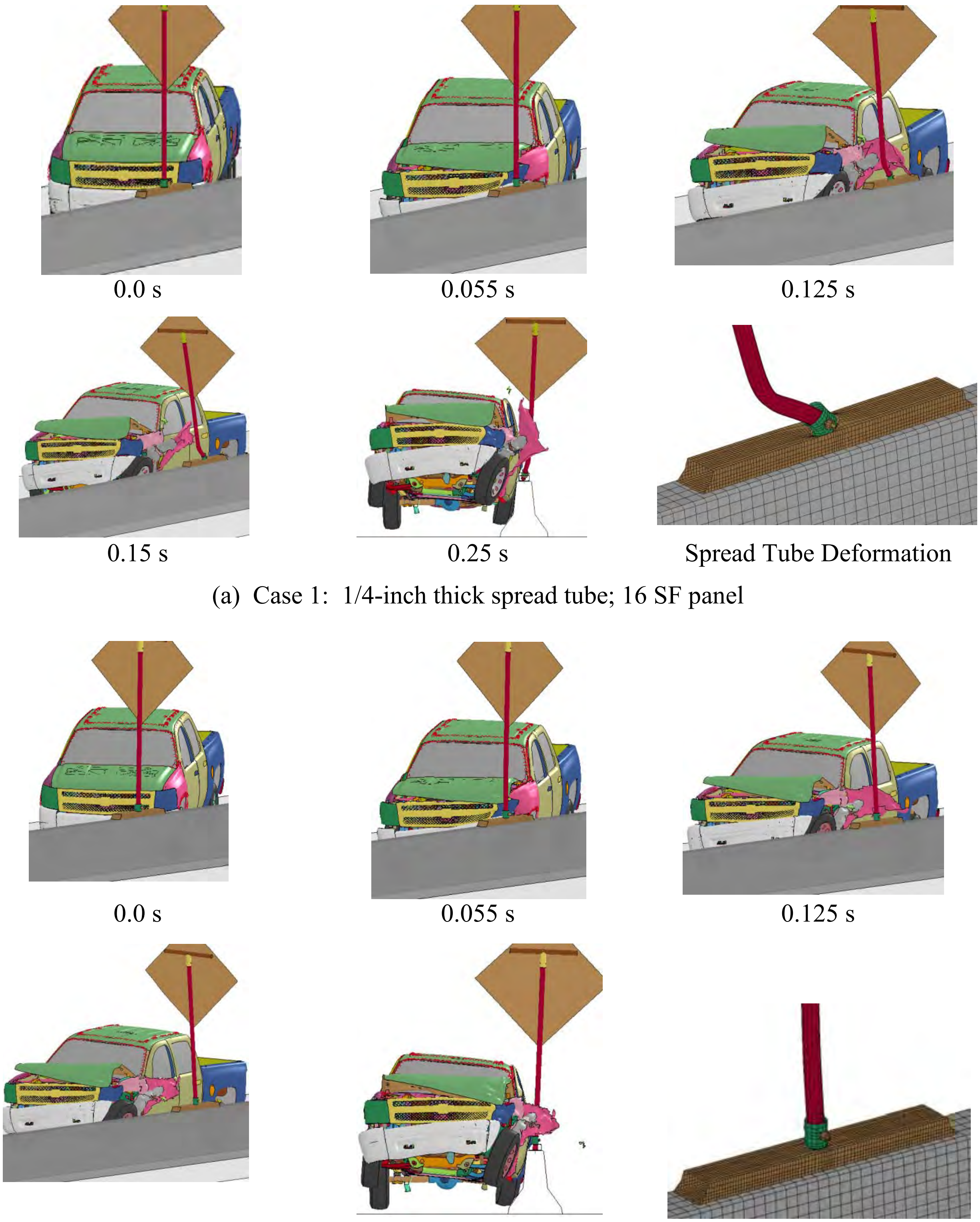


Figure 4.31. FE Model for Sign Mounting Concept 6: Spread Tube Assembly.



0.0 s | 0.055 s | 0.125 s

0.15 s | 0.25 s | Spread Tube Deformation

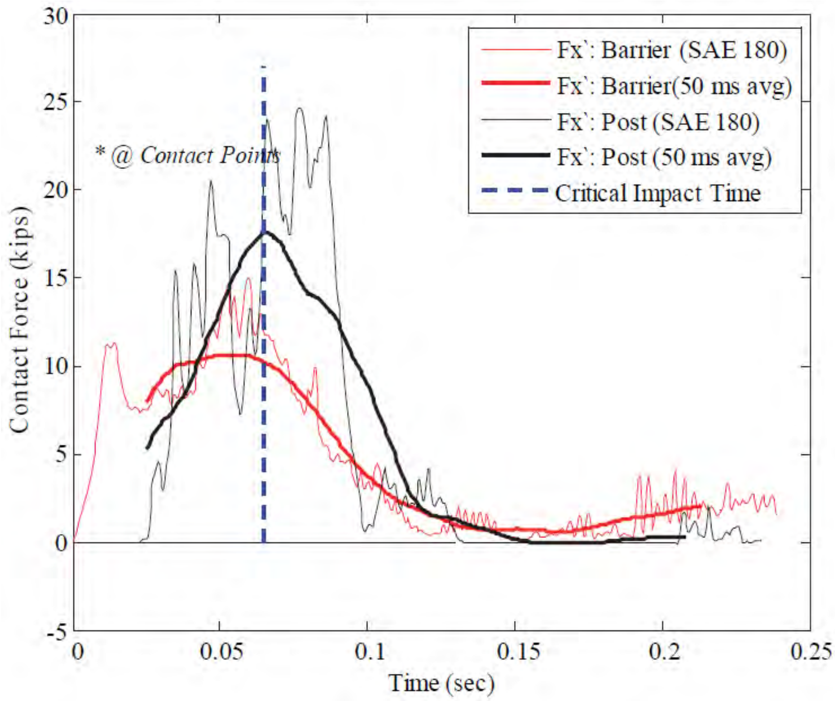
(a) Case 1: 1/4-inch thick spread tube; 16 SF panel

0.0 s | 0.055 s | 0.125 s

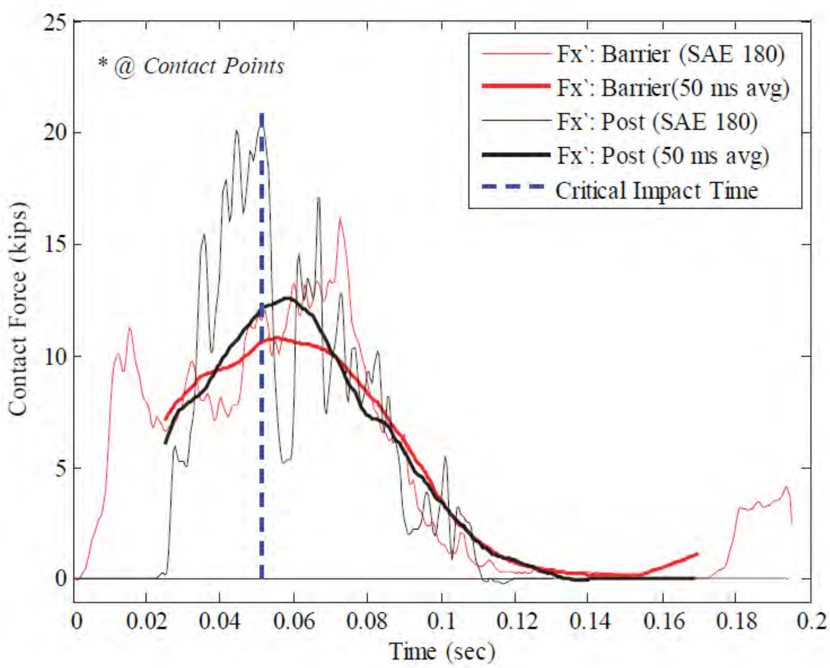
0.15 s | 0.25 s | Spread Tube Deformation

(a) Case 2: 1/2-inch thick spread tube; 16 SF panel

Figure 4.32. Sequential Images of *MASH* Simulation Performed on Sign Mounting Concept 6.



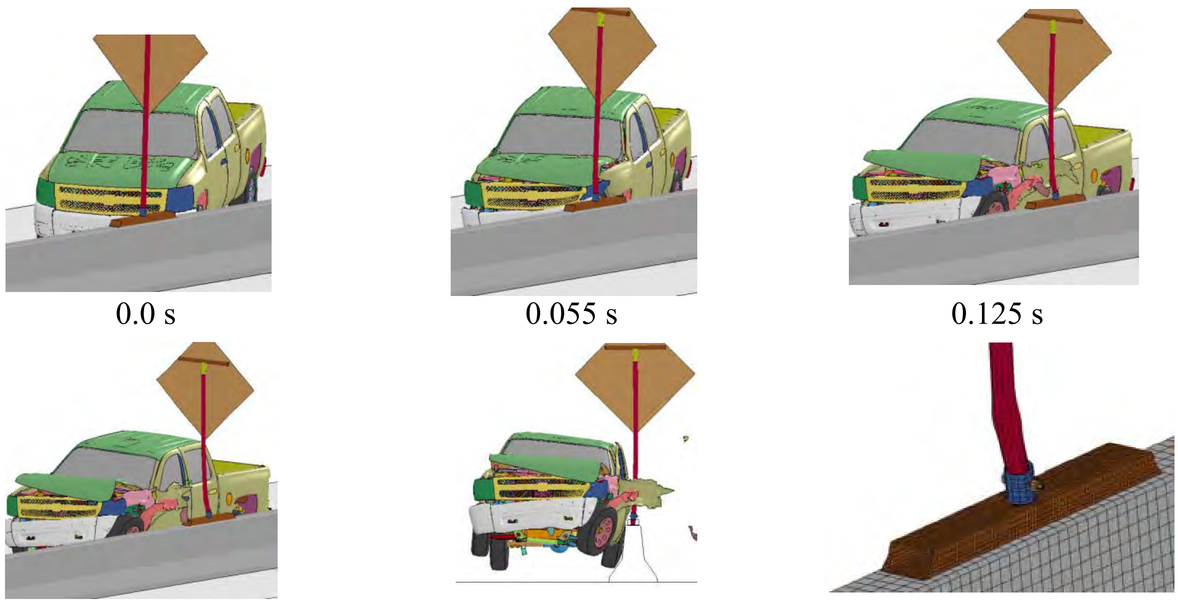
(a)



(b)

Figure 3.33. Impact Force on Barrier and Post with 16 SF Sign Panel in Direction Parallel to Barrier (a) Case-1: 1/4-inch Thick Spread Tube (b) Case-2: 1/2-inch Thick Spread Tube.

Effect of post type was also investigated for Concept 6. An impact simulation was performed on Concept 6 model with 1/2-inch thick spread tube, Schedule 40 collar, 10 BWG pipe, and 16 SF sign panel (Case 3). Sequential images obtained from *MASH TL-3* impact simulation are shown in Figure 4.34(a). As can be seen from the figure, during the impact simulation, 10 BWG pipe deformed at a point 14 inches above the barrier top. The sign panel remained upright after the impact. As can be seen in Figure 4.34(b), maximum 50-ms impact force acting on the post was 10.8 kips, slightly lower than that observed during the impact on Schedule 80 pipe. Since a panel larger than 16SF cannot be mounted on a 10 BWG pipe and use of this pipe does not provide significant improvement to the sign mount system, a Schedule 80 pipe instead of a 10 BWG pipe was selected for the next analyses.



(a) Case 3: 6-inch × 3-inch × 1/2-inch spread tube; 10 BWG Pipe; 16 SF panel

(b) Case 3

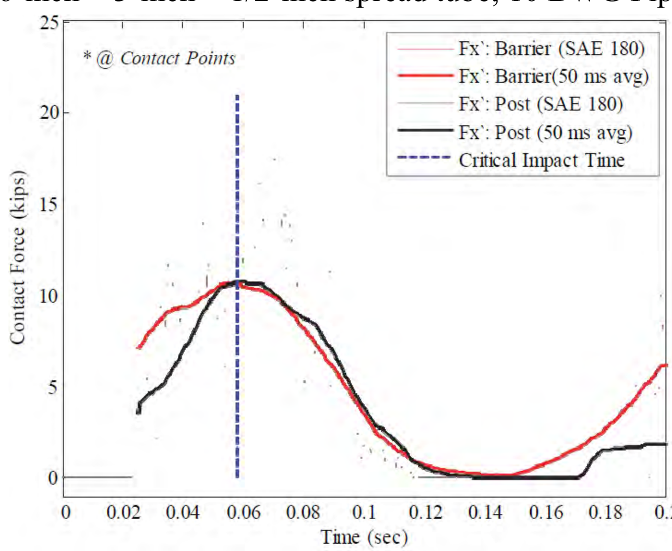
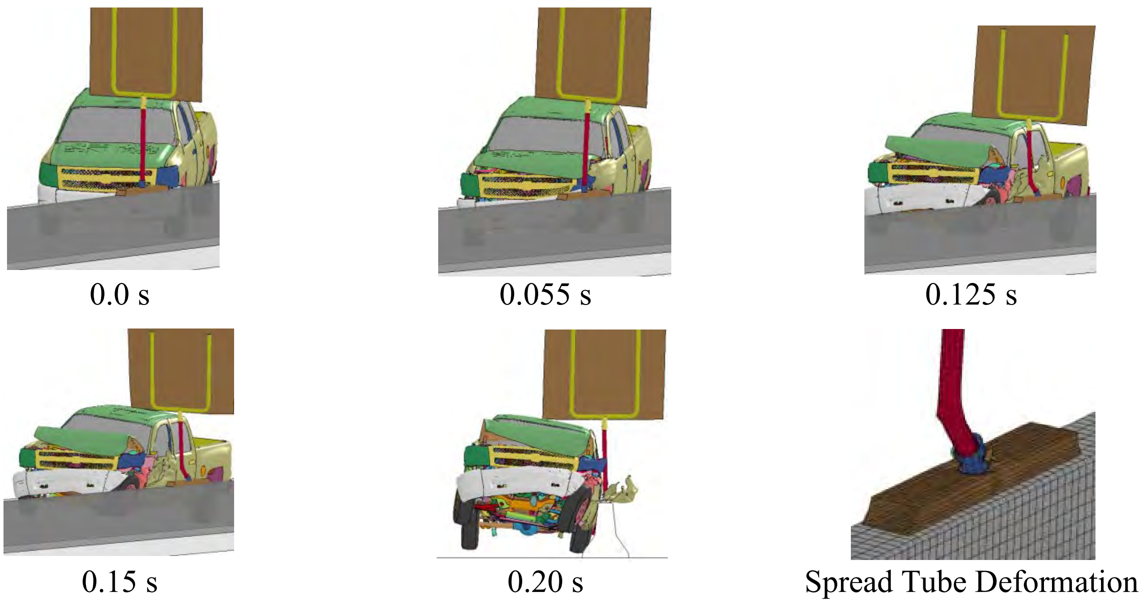


Figure 4.34. (a) Sequential Images (b) Impact Forces in Longitudinal Direction Obtained from *MASH* Simulation Performed on Concept 6 with 10 BWG Sign Post.

Research team also investigated the effect of large size sign panel mounted on a concrete barrier using Concept 6. *MASH* TL-3 impact simulation was performed on an FE model where a 32SF rectangular sign panel was mounted on an Schedule 80 pipe attached to an Schedule 40 collar mounted on top of the 1/2-inch thick spread tube attached to the New Jersey safety shape barrier (Case 4). Figure 4.35(a) shows sequential images obtained from the impact simulation. As can be seen from the figure, the fender of the errant vehicle during the simulation snagged into the post and caused the post and the material on top of the 1/2-inch thick spread tube around the collar to yield. As shown in Figure 4.35(b), impact force acting on the post with 32 SF panel was 26 kips, twice the force acting on the post with a 16 SF panel.



(a) Case 4: 6-inch × 3-inch × 1/2-inch spread tube; Schedule 80 Pipe; 32 SF panel

(b) Case 4

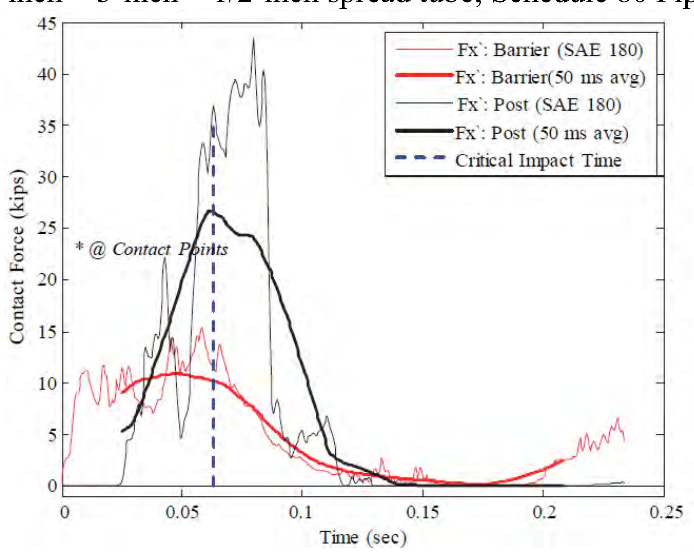


Figure 4.35. (a) Sequential Images (b) Impact Forces in Longitudinal Direction Obtained from *MASH* Simulation Performed on Concept 6 with 32 SF Sign Panel.

4.4.5 Occupant Risk Factors

Occupant risk factors, as shown in Table 4.6, were calculated for each simulation performed in this study to check if any of the concepts fail to pass the safety evaluation criteria set forth in *MASH* TL-3. *MASH* prescribes threshold values for both OIV and RDA to minimize the risk of occupant injury. To pass the occupant risk criteria, occupant impact velocities and ride down accelerations in both longitudinal and lateral directions obtained from a crash test and/or simulation must not exceed 40 ft/s and 20 Gs, respectively. As can be seen in Table 4.6, OIV and RDA values obtained from the simulations performed on each concept are below the maximum threshold values specified in *MASH*. Therefore, none of the concepts seems to produce any potential occupant risk.

Table 4.6. Occupant Risk Factors Obtained from Simulations Performed on Various Sign Mounting Concepts.

Rank	1	2			3			4		
Concepts	3 (cable)	4 (sacrificial pin)			1 (Chute Channel)			6: Spread Tube		
Case:					1.5 ft Travel		3 ft	1/4" Thick Tube	1/2" Thick Tube	
Pipe	10 BWG	Sch80	Sch80	10 BWG	Sch80	Sch80	Sch80	Sch80	Sch80	Sch80
Sign Panel		32SF	16SF	16SF	32SF	16SF	16SF	16SF	16SF	32SF
X-dir OIV (ft/s)	16.7	19.4	19.7	17.7	18.4	17.7	17.7	21.3	22.0	23.0
RDA (Gs)	−7.4	−7.1	−6.9	−6.6	−5.5	−7.1	−7.1	-	−11	−9.9
Y-dir OIV(ft/s)	25.3	24.9	24.9	25.3	25.6	25.6	25.6	25.6	24.9	24.6
RDA(Gs)	−15.5	−12.5	−11.3	−12.7	−12.4	−11.2	−11.2	-	−11.9	−8.5

4.4.6 Summary

In this study, research team performed *MASH* impact simulations on the four sign mounting concepts selected based on TxDOT rankings. Considering the results obtained from the simulations following conclusions can be drawn. The sign system mounted on a median barrier using Concept 3 (cable and shackle assembly) can detach from the slip-base connection during an impact. The detached sign system flies toward the oncoming traffic producing potential debris hazard. Thus, the TxDOT panel members and the researchers do not consider this concept feasible for the use on a median barrier.

In order to use a bracket/saddle as mounting device, its shape needs to match the shape of the barrier top. Thus, the saddle concept required different mounting details for different barrier types. Also, the bolts used to attach the saddle on the side of the barrier can potentially snag into the impacting vehicle. To avoid these inconveniences, the research team replaced the bracket/saddle used in Concept 4 with a rectangular base plate attached on top of the barrier. This sign mount concept performed as expected during the impact simulations. As for the sign post type used, a 10 BWG pipe mounted using this concept experienced larger bending compared to a Schedule 80 pipe. Also, TxDOT standards do not allow the use of sign panels larger than 16 SF on a 10 BWG pipe. Hence, research team selected Schedule 80 pipe to use in further investigations of this concept. A sacrificial pin used in Concept 4 should be designed such that the pin is capable of keeping the post upright against wind load. However, the pin must fail during a vehicular impact to allow the sign system to rotate about its hinge. The bolt used in hinge should be strong enough to withstand large shear and axial forces. Allowing some side plate twisting can reduce the shear force acting on the bolt at hinge. But this will increase the axial force in the bolt due to bending.

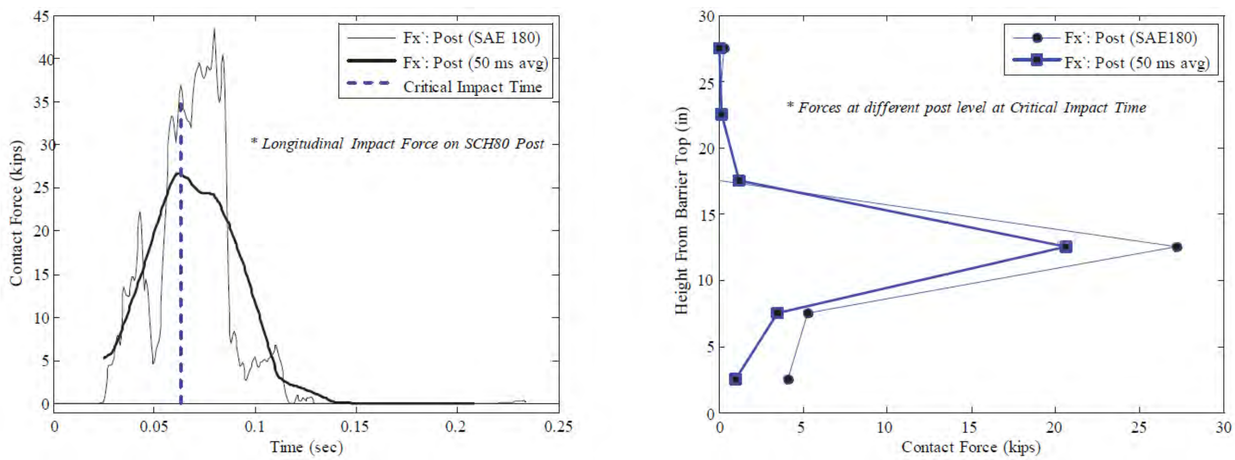
To provide uninterrupted 1.5-ft sliding in either direction for the 1-ft long post base, chute channel used in Concept 1 cannot be bolted directly on top of the barrier for a total length of 4-ft. The channel can only be bolted on top of the barrier at stopper regions. Large unsupported length caused the channel to buckle during an impact simulation. This produced large axial forces on the bolts used to attach the channel near its edges. Also, from FE simulations the "post base sliding through channel" mechanism used in Concept 1 did not show any added benefit when compared with other concepts. Thus researchers did not select this concept for further investigation.

Material on top of the 1/4-inch thick spread tube system used in Concept 6 experienced local buckling near the post region during impact simulation. This caused the Schedule 80 post to rotate about its base. Hence the researcher selected a thicker spread tube for the next simulations. The 1/2-inch thick spread tube performed significantly better allowing no bending and rotation of the sign system. The 10 BWG pipe used in this concept showed local buckling during the impact simulation. Schedule 80 post was able to withstand the impact with little deformation. The impact force obtained from the simulation was higher when a 32 SF sign panel was used instead of a 16 SF panel. During a previous crash test performed at TTI, this sign mount concept successfully passed the *MASH* criteria when used on a temporary concrete barrier. The research team expects that the same concept would also pass the *MASH* test when used on a permanent concrete barrier.

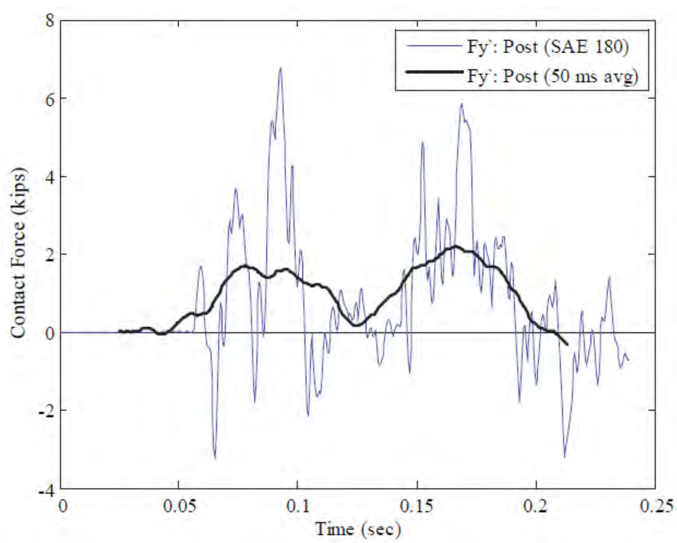
Using FE simulations, researchers compared the use of 16 SF and 32 SF sign panels. However, 6-ft wide 32 SF panels are seldom used on Texas highway median barriers. According to the panel members, largest sign panel that are used on median barriers are 4-ft × 6-ft (24 SF) HOV lane sign panels. Thus, 24 SF panel was selected for use in further investigations of Concept 4 and Concept 6.

4.5 STRUCTURAL ANALYSIS

For the structural analyses of a connection, an accurate evaluation of the impact load and its location above the barrier top was necessary. The impact load on the sign system mounted on a rigid New Jersey safety barrier was evaluated using FE simulations. For 32 SF panel mounted using Concept 6, contact forces obtained from the simulation showed that the maximum 50-ms average force acting on the post in longitudinal barrier direction was 26 kips. To determine the average impact height for the post, forces at various impact heights above the post base at critical impact time were plotted as shown in Figure 4.36(a). It was found that at the critical impact time the maximum 50-ms avg. force was acting on the post 12.5 inches above the post base. This height can be considered as moment arm for the 26 kips impact load acting on the post in the direction parallel to the barrier. As shown in Figure 4.36(b), maximum crash load acting on the post in transverse direction was 2 kips. Using these impact load values, engineering analyses were performed to develop post-barrier connection details for sign mount Concept 6. Figure 4.37 shows details of the connection. Appendix A shows the engineering calculations.

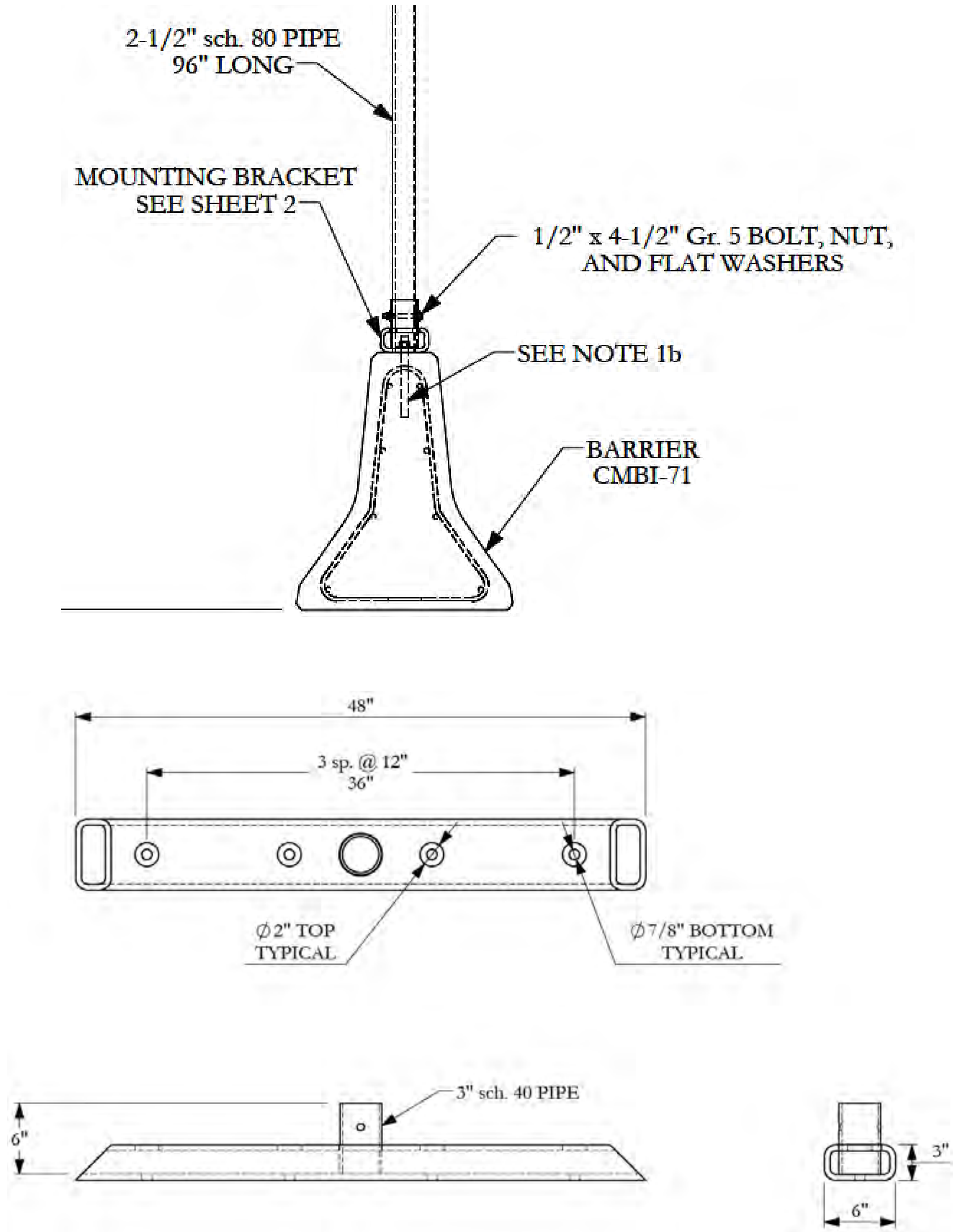


(a)



(b)

Figure 4.36. Concept 6-Case 4 (a) Longitudinal Impact Force and Impact Force Distribution along Post Height at Critical Impact Time; (b) Impact Force in Transverse Direction.



NOTE 1b: 3/4" galvanized Hilti HAS-E rods (×4), embedded 8" min., and secured with Hilti Hy 150 epoxy according to manufacturer's instructions.

Figure 4.37. Post to Barrier Connection Details for Concept 6: Spread Tube System.

CHAPTER 5. SIMULATIONS OF SELECTED MOUNTING DESIGNS CONCEPTS *

Based on TxDOT ranking of the concepts developed earlier and the initial performance assessment from simulation, key concepts were selected for further analyses. The concepts are:

- Concept 6: Schedule 80 post mounted rigidly on a spreader tube.
- Concept 4: Hinge and sacrificial pin design.
- Concept 1: Sliding chute design.
- Concept 8: Slotted 10 BWG post design.

Concepts 6, 4, and 1 belong to the original pool of concept designs; however, concept 8 was envisioned later. Also, the signs size utilized for this round of analyses is 6 ft × 4 ft (24 ft^2 in area) to give TxDOT a wider applicability of these mounting designs from 16- ft^2 to 24-ft^2 sign areas.

Details of each of the aforementioned concept were modeled, including connections, anchors bolts, and the reinforcement of barrier length under impact. Appropriate material models were assigned to the sign, the post, the mounting hardware, the concrete segment, and the connecting components. All analyses were conducted to simulate *MASH* TL-3-11 test condition. This test condition incorporates a 5004 lb test vehicle impacting the barrier at 62.2 mi/h and at an impact angle of 25 degrees.

Images of key behavior of the truck and the system are presented herein. Additionally, signals from the simulations were processed using Test Risk Assessment Program (TRAP) to calculate the occupant severity indices. TRAP takes input data from the LS-DYNA simulation run and computes the occupant impact velocity, occupant impact time, and maximum ridedown acceleration taken over a 10-millisecond time period as well as angular displacements. The TRAP results are presented for all simulations herein.

5.1 CONCEPT 6: SCHEDULE 80 POST IN SPREADER TUBE

In this concept, the Schedule 80 sign post is rigidly mounted inside a schedule 40 collar pipe. The post is placed inside a 6-inch long, 3-inch diameter schedule 40 pipe that is built inside a 6-inch wide by 2-inch deep by ¼-inch thick steel tubing as shown in Figure 5.1. The post is secured to the pipe using a through bolt. The steel tubing spread is 48 inches long with 45 degrees tapers at each end and fixed to the top of the concrete barrier user four anchor bolts rods as shown in Figure 5.1. Figure 5.2 shows that the simulation predicts little yielding in the sign post and some slight damage to the sign post under truck impact.

* TTI Proving Ground is an ISO 17025 accredited laboratory with A2LA Mechanical Testing certificate 2821.01. This certificate does not include simulation analysis.

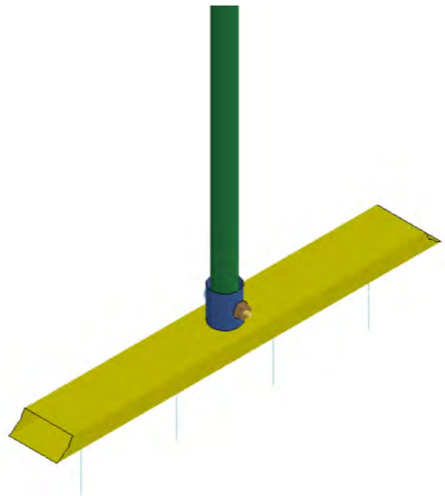


Figure 5.1. Model of Concept 6 Sign Mounting Design.

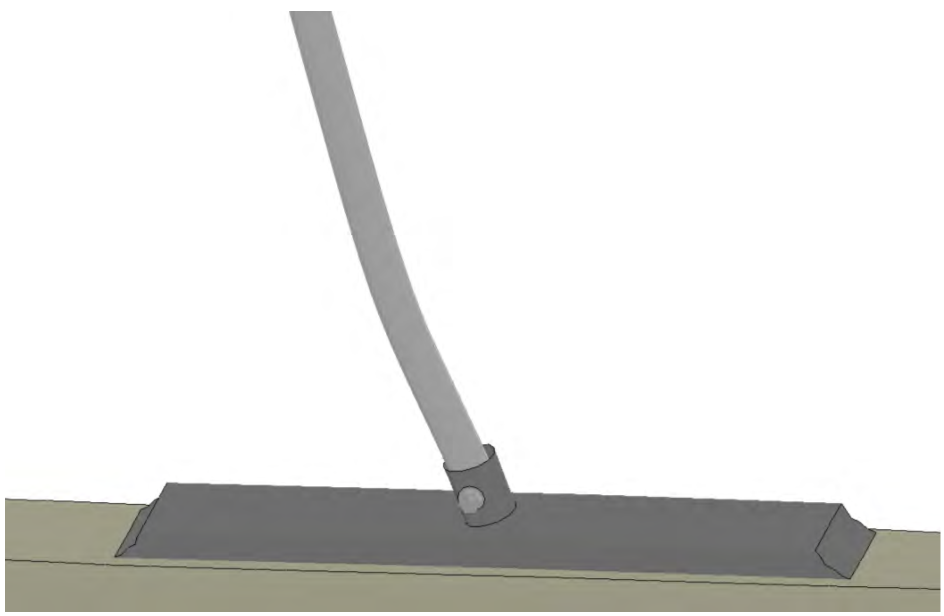


Figure 5.2. Damage to the Sign Post under Truck Impact.

Figure 5.3 shows sequential pictures of the truck model impacting the barrier at 25 inches upstream the base of the post. The simulation indicates that the system is able to contain and redirect the vehicle as shown in the sequential pictures. The vehicle had small roll, pitch, and yaw angular displacements.

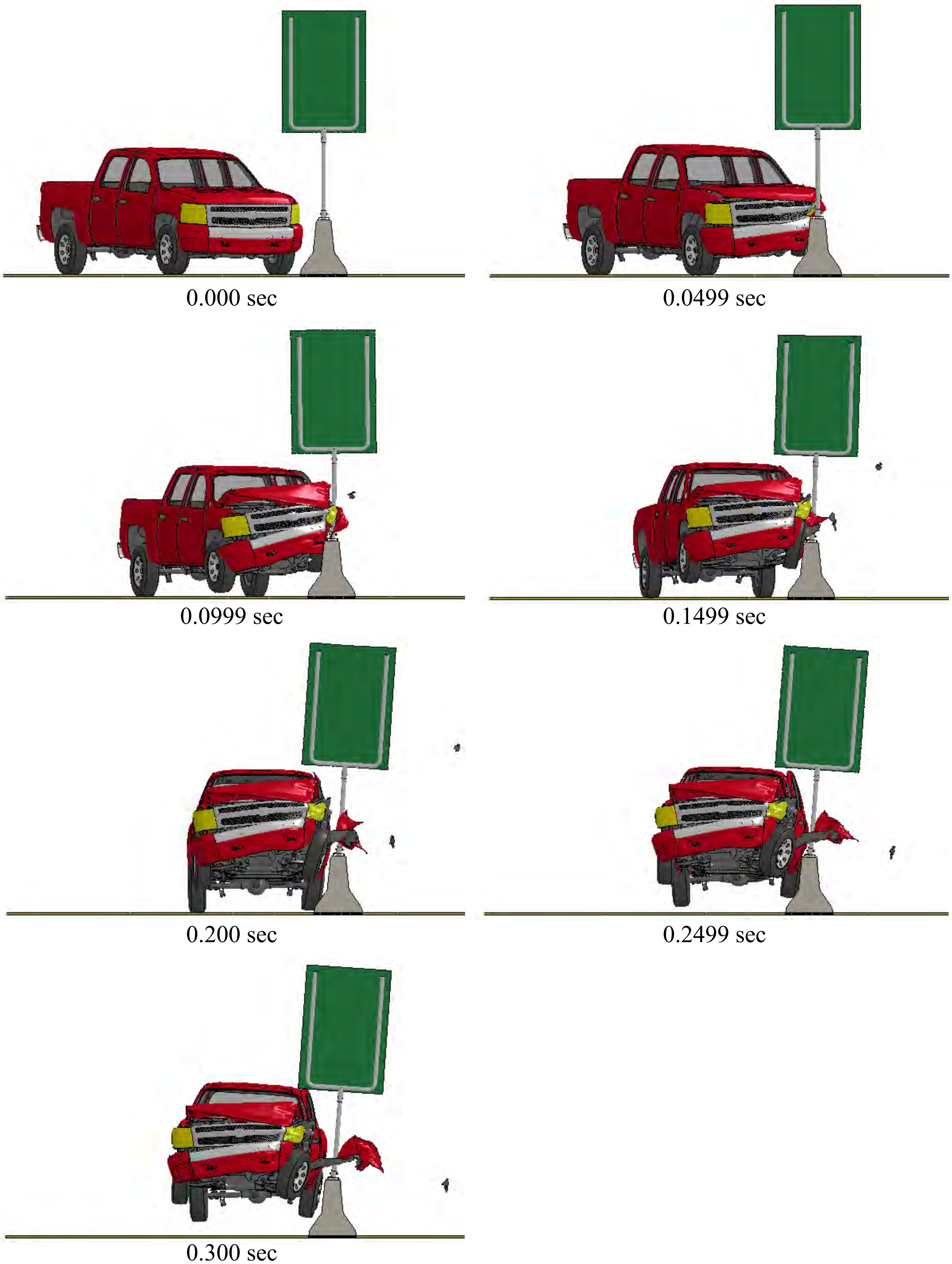


Figure 5.3. Impact View (Looking Upstream) Showing 5004-lb Test Vehicle Interacting with the Sign Post for Concept 6.

Occupant impact severity indices were all below the allowable limits of *MASH* evaluation criteria. The OIV was −24.61 ft/s (−7.5 m/sec) in lateral direction (preferred 30 ft/s [9 m/sec] and maximum allowable is 40 ft/s [12 m/sec]), while the ridedown acceleration was 11.0 Gs (preferred 15 Gs and maximum allowable is 20 Gs) in lateral direction, per the LS-DYNA simulation. Details of acceleration data are presented in Figure 5.4. Figure 5.5, Figure 5.6, and Figure 5.7 show the acceleration histories at the C.G. of the 5004-lb finite element model. The vehicular angular displacement, yaw, pitch, and roll rate are shown in Figure 5.8. Figure 5.9 presents other pertinent data from the simulation.

General Information
Test Agency: Texas A&M Transportation Institute
Test Number: MASH TL-3
Test Date: 9/10
Test Article: S80 Signpost mounted in a Spreader Tube

Test Vehicle
Description: 2007 Silverado FE Model
Test Inertial Mass: 2270 kg
Gross Static Mass: 2270 kg

Impact Conditions
Speed: 62.2 km/h
Angle: 25.0 degrees

Occupant Risk Factors
Impact Velocity (m/s) at 0.1057 seconds on left side of interior
x-direction 6.8
y-direction -7.5

THIV (km/hr): 37.6 at 0.1107 seconds on left side of interior
THIV (m/s): 10.5

Ridedown Accelerations (g's)
x-direction -5.7 (0.1079 - 0.1179 seconds)
y-direction 11.0 (0.2229 - 0.2329 seconds)

PHD (g's): 11.0 (0.2291 - 0.2391 seconds)

ASI: 1.53 (0.0463 - 0.0963 seconds)

Max. 50msec Moving Avg. Accelerations (g's)
x-direction -10.2 (0.0452 - 0.0952 seconds)
y-direction 11.3 (0.0462 - 0.0962 seconds)
z-direction -3.8 (0.1981 - 0.2481 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)
Roll -3.8 (0.3000 seconds)
Pitch -4.8 (0.2250 seconds)
Yaw -28.3 (0.2521 seconds)

Figure 5.4. Signal Data from TRAP for Concept 6.

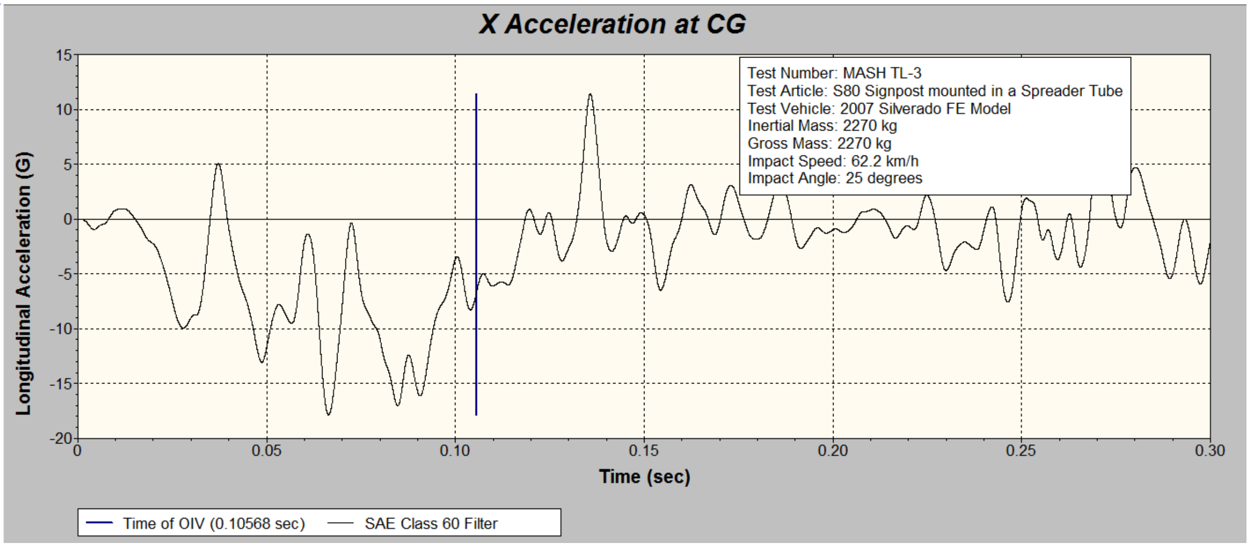


Figure 5.5. Longitudinal Acceleration History at C.G. for Concept 6.

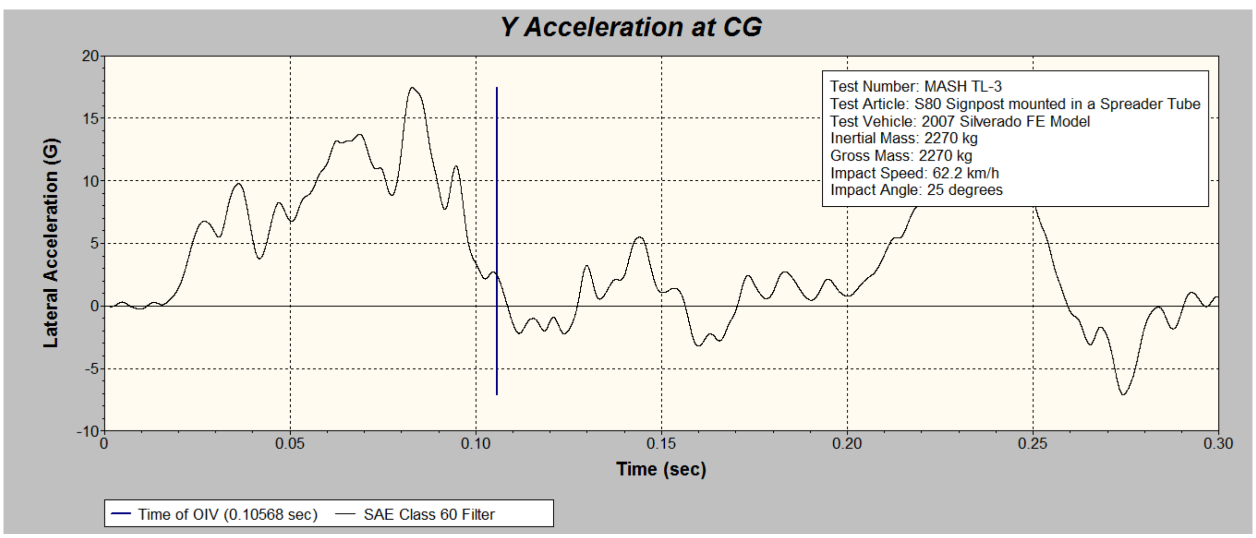


Figure 5.6. Lateral Acceleration History at C.G. for Concept 6.

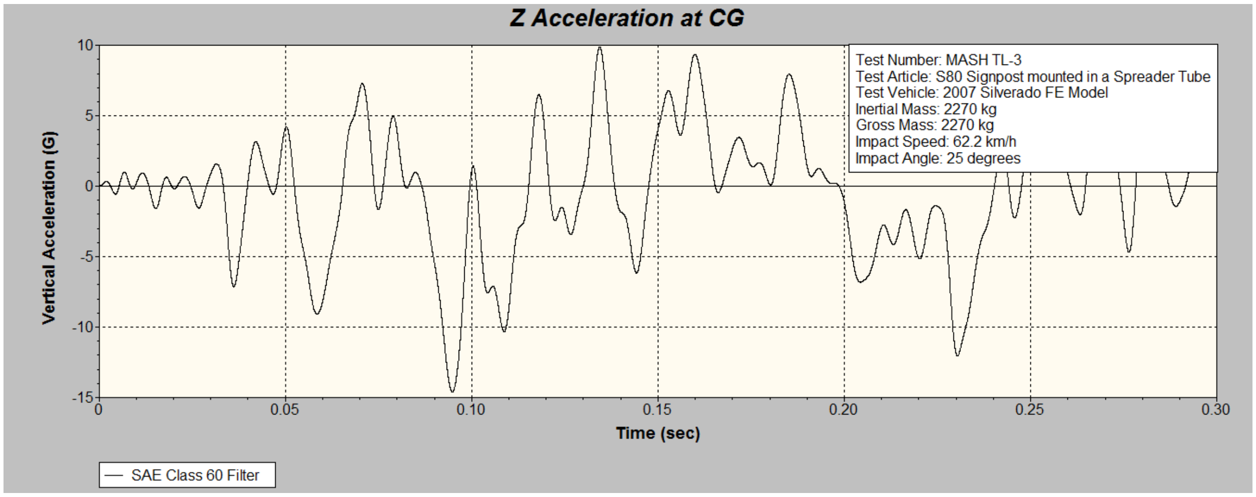
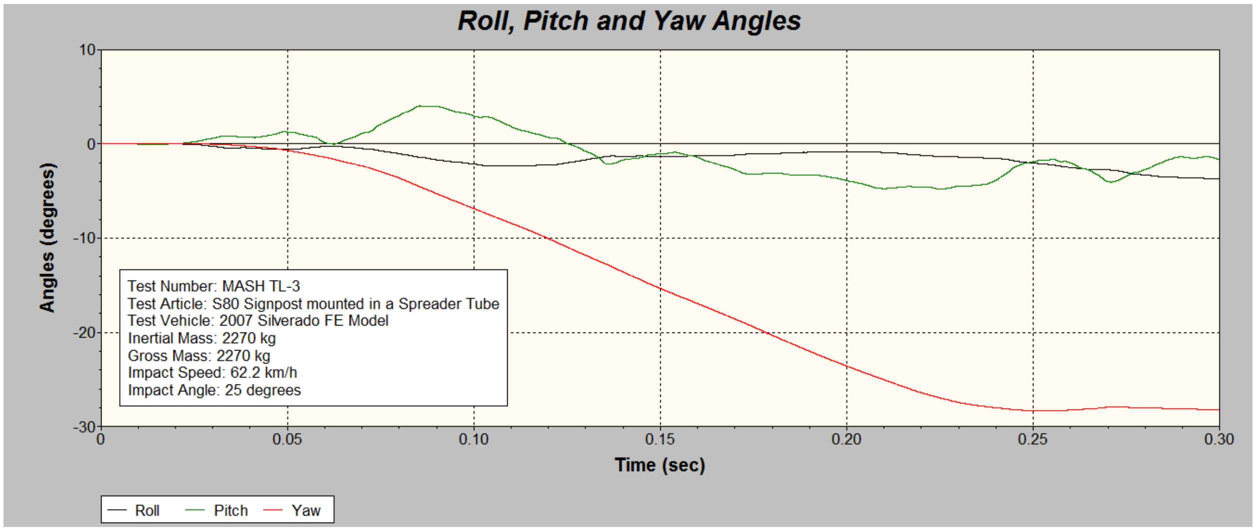


Figure 5.7. Vertical Acceleration History at C.G. for Concept 6.



Axes are vehicle-fixed.
Sequence for determining orientation:

1.) Yaw.
2.) Pitch.
3.) Roll.

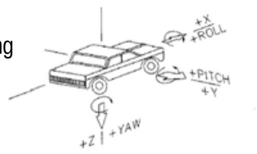
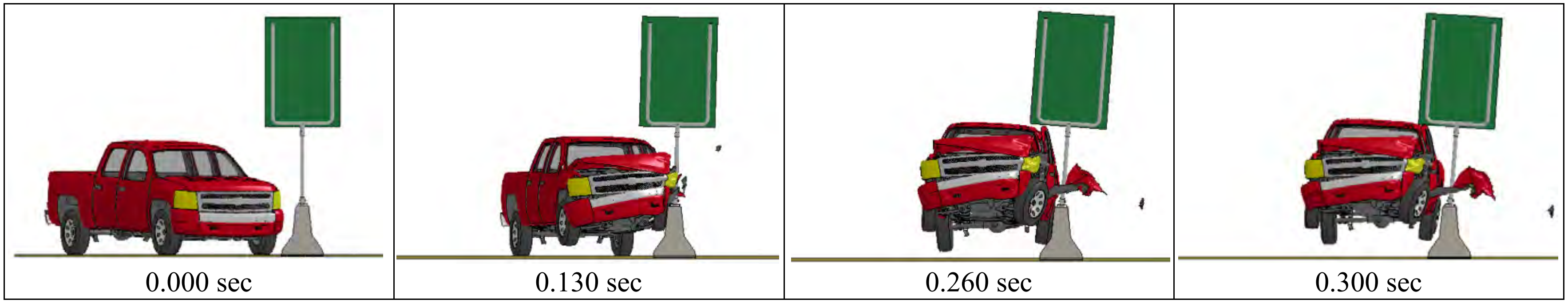


Figure 5.8. Vehicle Angular Displacement for Concept 6.



General Information	
Test Agency	Texas A&M Transportation Institute
Test Standard Test No.	MASH TL-3
Test Date	8/27/2012
Test Article	
Type	S80 Post On Barrier
Name	Concept 6
Installation Length	90 ft
Material or Key Elements	Steel Post, Spreader Tube
Soil Type and Condition	N/A
Test Vehicle	
Type/Designation	2270P
Make and Model	Chevy Silverado
Curb	5004 lb
Test Inertial	5004 lb
Dummy	No Dummy
Gross Static	5004 lb

Impact Conditions	
Speed	62.2 mi/h
Angle	25 degrees
Location/Orientation	25 inches upstrm of post
Exit Conditions	
Speed	45.6 mi/h
Angle	−29.4 degrees
Occupant Risk Values	
Impact Velocity	
Longitudinal	22.3 ft/s
Lateral	−24.6 ft/s
Ridedown Accelerations	
Longitudinal	−5.7 g
Lateral	11.0 g
THIV	37.6 km/h
ASI	11.0 g
Max. 0.050-s Average	
Longitudinal	−10.2 g
Lateral	11.3 g
Vertical	−3.8 g

Post-Impact Trajectory	
Stopping Distance	N/A
Vehicle Stability	
Maximum Yaw Angle	−28.3 degrees
Maximum Pitch Angle	−4.8 degrees
Maximum Roll Angle	−3.8 degrees
Vehicle Snagging	Yes
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	N/A
Permanent	N/A
Working Width	N/A
Vehicle Penetration	N/A
Vehicle Damage	
VDS	N/A
CDC	N/A
Max. Exterior Deformation..	
OCDI	N/A
Max. Occupant Compart. Deformation	N/A

Figure 5.9. Summary of Results for Concept 6.

5.2 CONCEPT 4: HINGE WITH SACRIFICIAL PIN

In this concept, the Schedule 80 post is held by two side plates utilizing a through bolt. The post and sign are prevented from rotating around the through bolt by adding a sacrificial pin above the pin. This pin is designed to be strong enough to withstand shear forces due to wind loads on the sign, but weak enough to release upon impact by the pickup truck. The two side plates are attached to a spreader plate that is mounted on the top face of the barrier using anchor bolts. Figure 5.10 shows the model, and Figure 5.11 shows activation of the sacrificial pin.

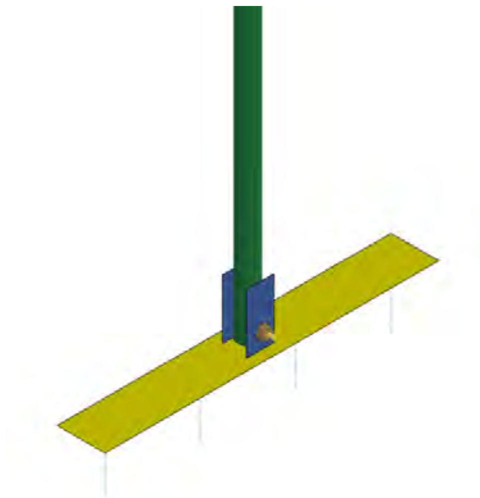


Figure 5.10. Model of Concept 4 Sign Mounting Design.

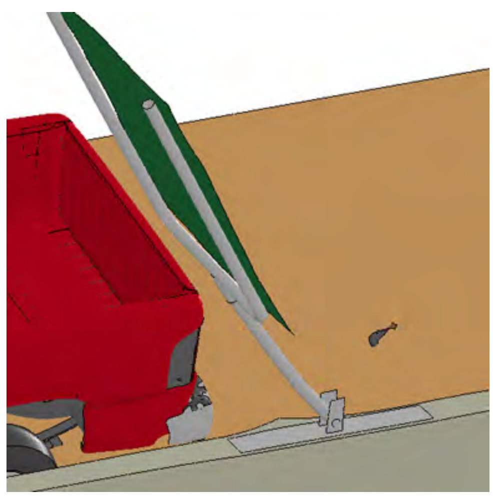


Figure 5.11. Sign Post Rotating around the Hinge Point after Impact.

Figure 5.12 shows sequential pictures of the truck model impacting into the barrier at 32 inches upstream the base of the post. The barrier and system was able to contain and redirect the vehicle very effectively. The base of the post rotated over as desired and the sign post stayed parallel to the barrier as it fell. The vehicle had small roll, pitch, and yaw angular displacements.

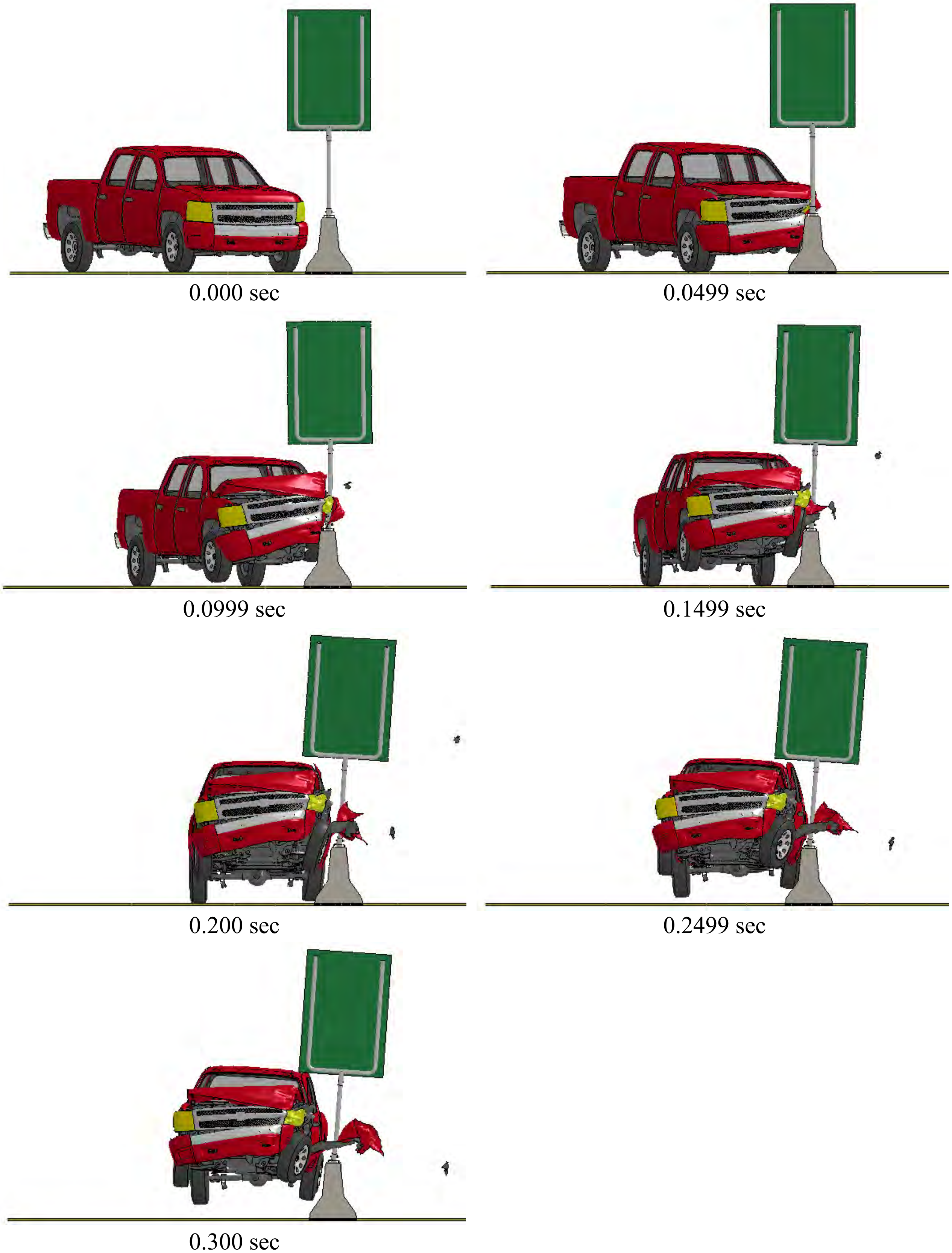


Figure 5.12. Impact View (Looking Upstream) Showing 5004-lb Test Vehicle Interacting with the Sign Post for Concept 4.

Occupant impact severity indices were all below the allowable limits of *MASH* TL-3. The OIV was −25.59 ft/s (−7.8 m/sec) in lateral direction (preferred 30 ft/s [9 m/sec] and maximum allowable is 40 ft/s [12 m/sec]), while the ridedown acceleration was 13.1 Gs (preferred 15 Gs and maximum allowable is 20 Gs) in lateral direction per the LS-DYNA simulation. Details of acceleration data are presented in Figure 5.13. Figure 5.14, Figure 5.15, and Figure 5.16 show the acceleration histories at the C.G. of the 5004-lb finite element model. Figure 5.17 shows the vehicular angular displacement, yaw, pitch, and roll rate. Figure 5.18 presents a summary of pertinent data for the simulation on Concept 4.

General Information
Test Agency: Texas A&M Transportation Institute
Test Number: MASH TL-3
Test Date: 9/10
Test Article: S80 Signpost mounted in a Rotating Base

Test Vehicle
Description: 2007 Silverado FE Model
Test Inertial Mass: 2270 kg
Gross Static Mass: 2270 kg

Impact Conditions
Speed: 62.2 km/h
Angle: 25.0 degrees

Occupant Risk Factors
Impact Velocity (m/s) at 0.1044 seconds on left side of interior
x-direction 5.9
y-direction -7.8

THIV (km/hr): 36.5 at 0.1090 seconds on left side of interior
THIV (m/s): 10.1

Ridedown Accelerations (g's)
x-direction -7.8 (0.1047 - 0.1147 seconds)
y-direction 13.1 (0.2145 - 0.2245 seconds)

PHD (g's): 13.4 (0.2187 - 0.2287 seconds)

ASI: 1.56 (0.0460 - 0.0960 seconds)

Max. 50msec Moving Avg. Accelerations (g's)
x-direction -9.2 (0.0430 - 0.0930 seconds)
y-direction 12.1 (0.0460 - 0.0960 seconds)
z-direction -3.4 (0.1882 - 0.2382 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)
Roll -7.9 (0.3000 seconds)
Pitch 3.3 (0.0914 seconds)
Yaw -28.8 (0.3000 seconds)

Figure 5.13. Signal Data from TRAP for Concept 4.

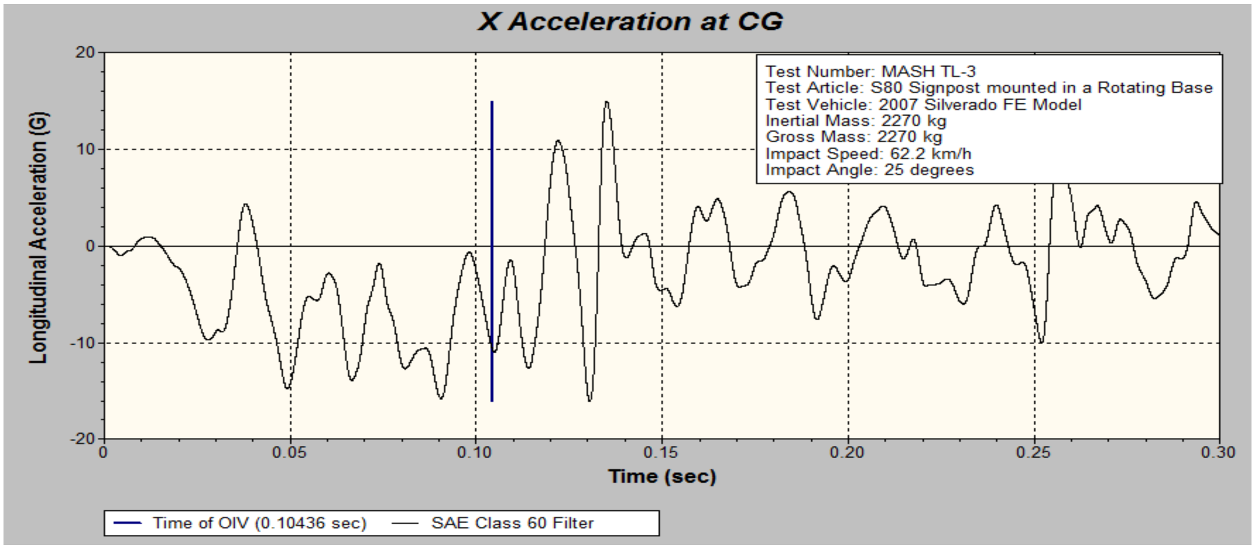


Figure 5.14. Longitudinal Acceleration History at C.G. for Concept 4.

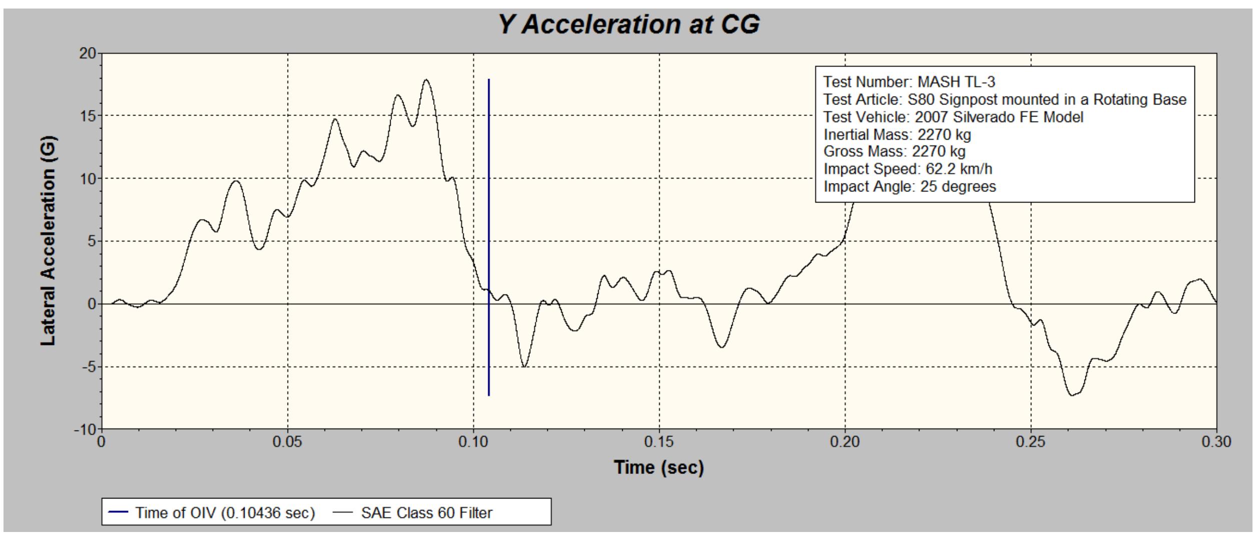


Figure 5.15. Lateral Acceleration History at C.G. for Concept 4.

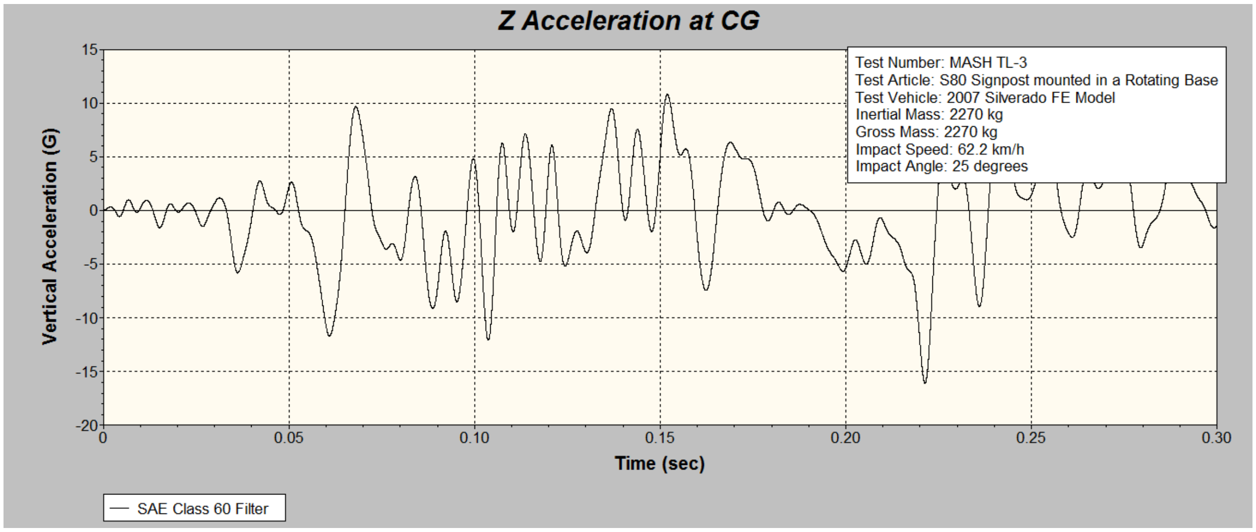
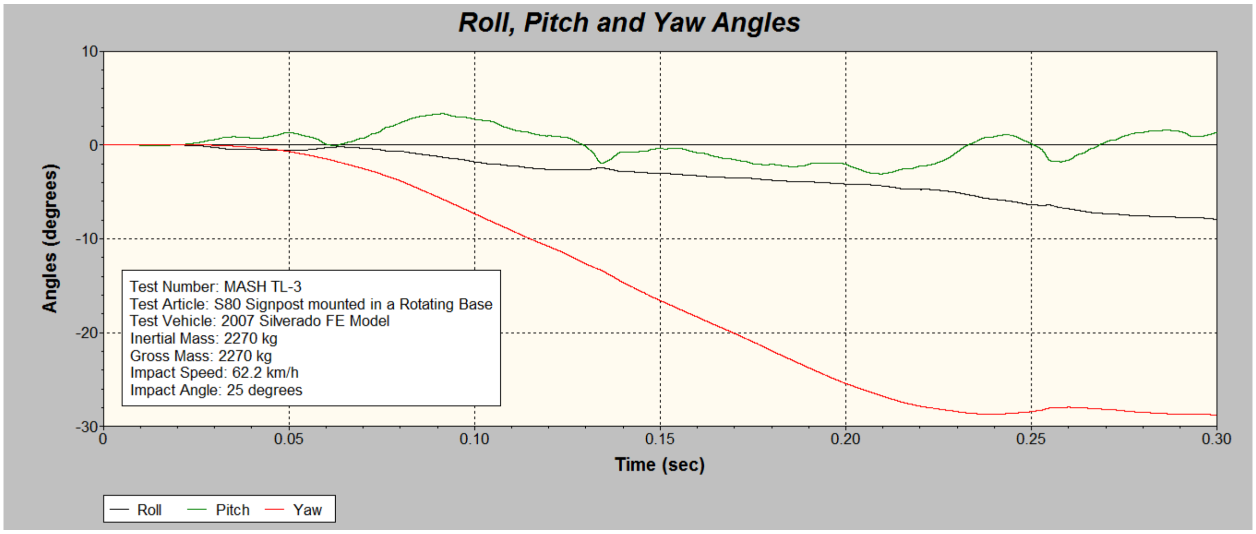


Figure 5.16. Vertical Acceleration History at C.G. for Concept 4.



Axes are vehicle-fixed.
Sequence for determining orientation:

1.) Yaw.
2.) Pitch.
3.) Roll.

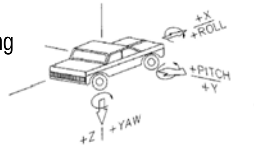
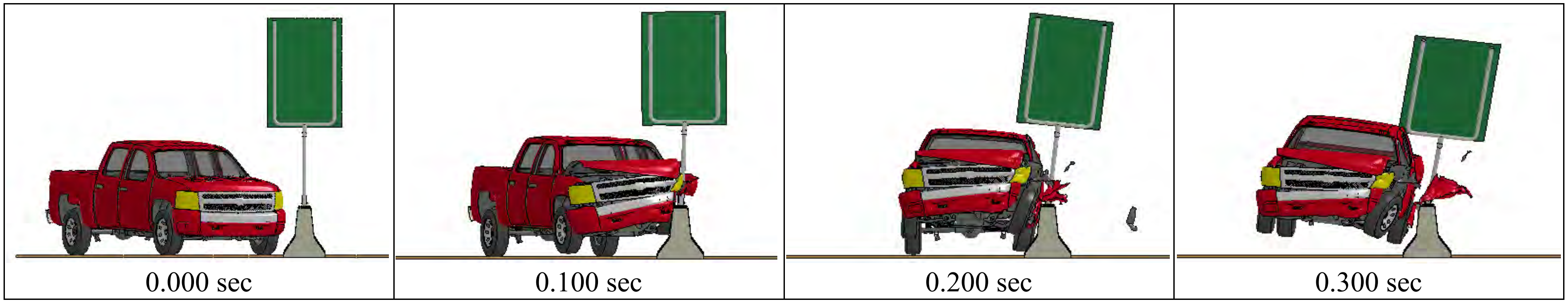


Figure 5.17. Vehicle Angular Displacement for Concept 4.



General Information

Test Agency	Texas A&M Transportation Institute
Test Standard Test No.	MASH TL-3
Test Date	8/27/2012
Test Article	
Type	S80 Post with Rotating Base
Name	Concept 4
Installation Length	90 ft
Material or Key Elements	Steel Post, Spreader Tube
Soil Type and Condition	N/A
Test Vehicle	
Type/Designation	2270P
Make and Model	Chevy Silverado
Curb	5004 lb
Test Inertial	5004 lb
Dummy	No Dummy
Gross Static	5004 lb

Impact Conditions

Speed	62.2 mi/h
Angle	25 degrees
Location/Orientation	32 inches upstrm of post
Exit Conditions	
Speed	45.6 mi/h
Angle	−29.4 degrees
Occupant Risk Values	
Impact Velocity	
Longitudinal	22.3 ft/s
Lateral	−24.6 ft/s
Ridedown Accelerations	
Longitudinal	−5.7 g
Lateral	11.0 g
THIV	37.6 km/h
ASI	11.0 g
Max. 0.050-s Average	
Longitudinal	−10.2 g
Lateral	11.3 g
Vertical	−3.8 g

Post-Impact Trajectory

Stopping Distance	N/A
Vehicle Stability	
Maximum Yaw Angle	−28.3 degrees
Maximum Pitch Angle	3.3 degrees
Maximum Roll Angle	−7.9 degrees
Vehicle Snagging	Yes
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	N/A
Permanent	N/A
Working Width	N/A
Vehicle Penetration	N/A
Vehicle Damage	
VDS	N/A
CDC	N/A
Max. Exterior Deformation .	
OCDI	N/A
Max. Occupant Compart. Deformation	N/A

Figure 5.18. Summary of Results for Concept 4.

5.3 CONCEPT 1: POST MOUNTED ON SLIDING CHUTE

The idea of this concept is to allow the sign/post assembly to slide along the barrier top face upon impact. The Schedule 80 sign post is mounted inside a Schedule 40 collar pipe that is attached to a thick plate. The plate is inserted inside a steel chute so the plate can slide along the chute, but it cannot move sideways or up and down. Figure 5.19 shows the model of the sliding chute concept. The chute is mounted to the top of the barrier via two anchor rods at each end of the chute. Hence, they will act as end stoppers to prevent the post/sliding plate from exiting the chute.

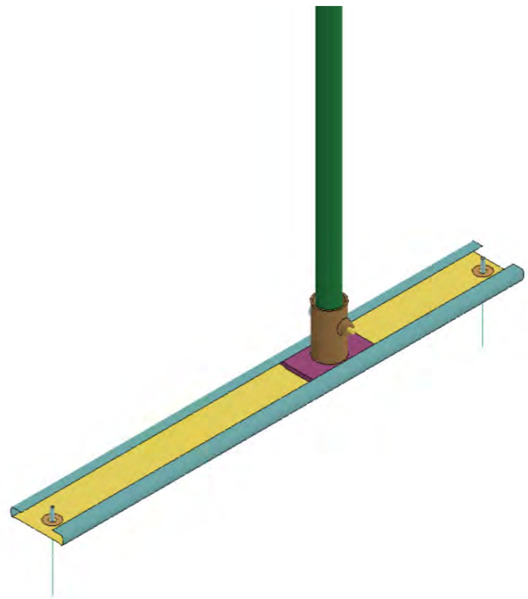


Figure 5.19. Model of Concept 1 Sign Mounting Design.

Figure 5.20 shows sequential pictures of the truck model impacting into the barrier at 54 inches upstream of the base of the post. The new system with the chute was able to contain and redirect the vehicle very effectively. The base of the post slid in the chute as desired. There was very little pitch or yaw in the run. There was some vehicular rolling toward the end, −10.4 degrees, but it is still tolerable under the *MASH* evaluation criteria. This design kept the entire sign from going over across the barrier where it could be struck by oncoming traffic. Figure 5.21 shows the displacement and deformation of the sign post and base.

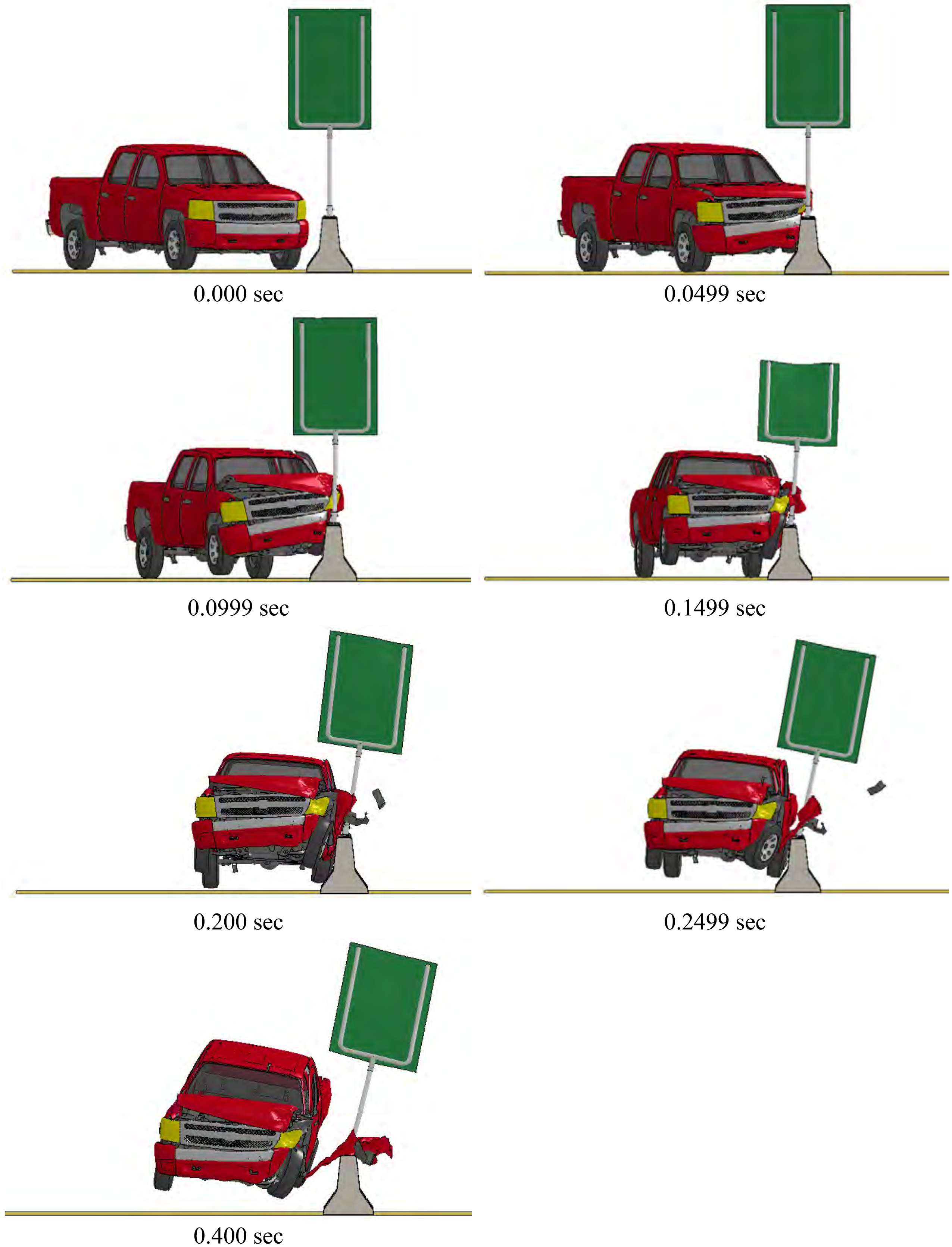


Figure 5.20. Impact View (Looking Upstream) Showing 5004-lb Test Vehicle Interacting with the Sign Post for Concept 1.

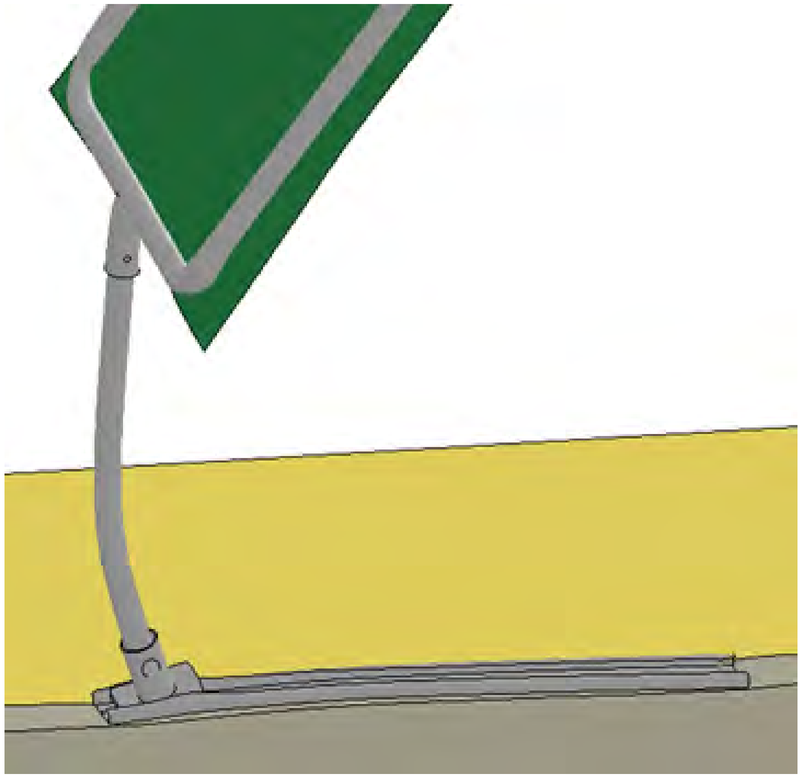


Figure 5.21. Displacement and Deformation of the Sign Post and Its Base for Concept 1.

Occupant impact severity indices were all below the allowable limits of *MASH* TL-3. The OIV was −25.26 ft/s (−7.7 m/sec) in lateral direction (preferred 30 ft/s [9 m/sec] and maximum allowable is 40 ft/s [12 m/sec]), while the ridedown acceleration was 14.7 Gs (preferred 15 Gs and maximum allowable is 20 Gs) in lateral direction per the LS-DYNA simulation. Details of acceleration data are presented in Figure 5.22. Figure 5.23, Figure 5.24, and Figure 5.25 show the acceleration histories of the truck C.G. of the 5004-lb finite element model. The vehicular angular displacement, yaw, pitch, and roll rate are shown in Figure 5.26. Figure 5.27 presents a summary of results for Concept 1.

General Information

Test Agency: Texas A&M Transportation Institute
Test Number: MASH TL-3
Test Date: 9/10
Test Article: Sliding Chute Mounted on Barrier

Test Vehicle

Description: 2007 Silverado FE Model
Test Inertial Mass: 2270 kg
Gross Static Mass: 2270 kg

Impact Conditions

Speed: 62.2 km/h
Angle: 25.0 degrees

Occupant Risk Factors

Impact Velocity (m/s) at 0.1038 seconds on left side of interior
x-direction 5.3
y-direction -7.7

THIV (km/hr): 35.8 at 0.1084 seconds on left side of interior
THIV (m/s): 9.9

Ridedown Accelerations (g's)
x-direction 9.2 (0.2455 - 0.2555 seconds)
y-direction 14.7 (0.2098 - 0.2198 seconds)

PHD (g's): 15.5 (0.2104 - 0.2204 seconds)

ASI: 1.53 (0.0447 - 0.0947 seconds)

Max. 50msec Moving Avg. Accelerations (g's)

x-direction -7.4 (0.0576 - 0.1076 seconds)
y-direction 12.5 (0.0431 - 0.0931 seconds)
z-direction -3.4 (0.1766 - 0.2266 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)

Roll -10.4 (0.3998 seconds)
Pitch 6.4 (0.3998 seconds)
Yaw -29.2 (0.3998 seconds)

Figure 5.22. Signal Data from TRAP for Concept 1.

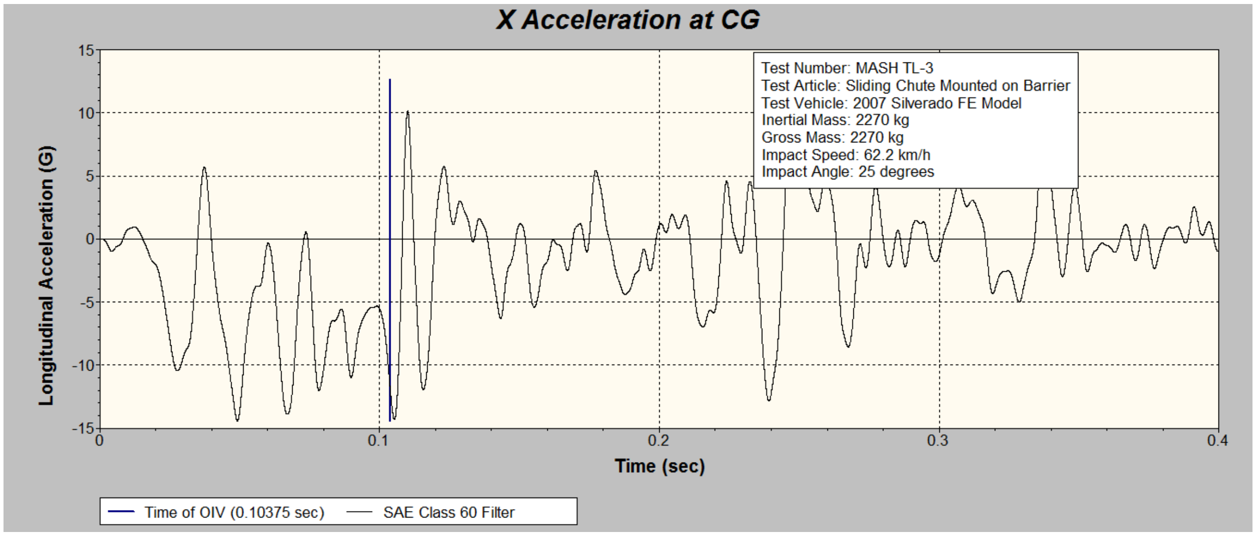


Figure 5.23. Longitudinal Acceleration History at C.G. for Concept 1.

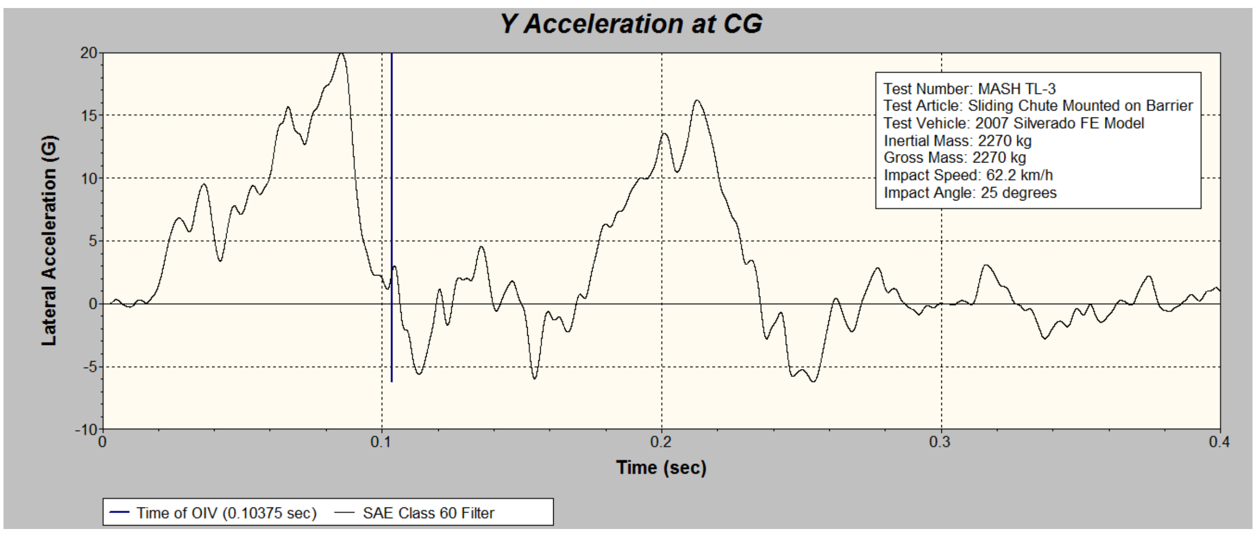


Figure 5.24. Lateral Acceleration History at C.G. for Concept 1.

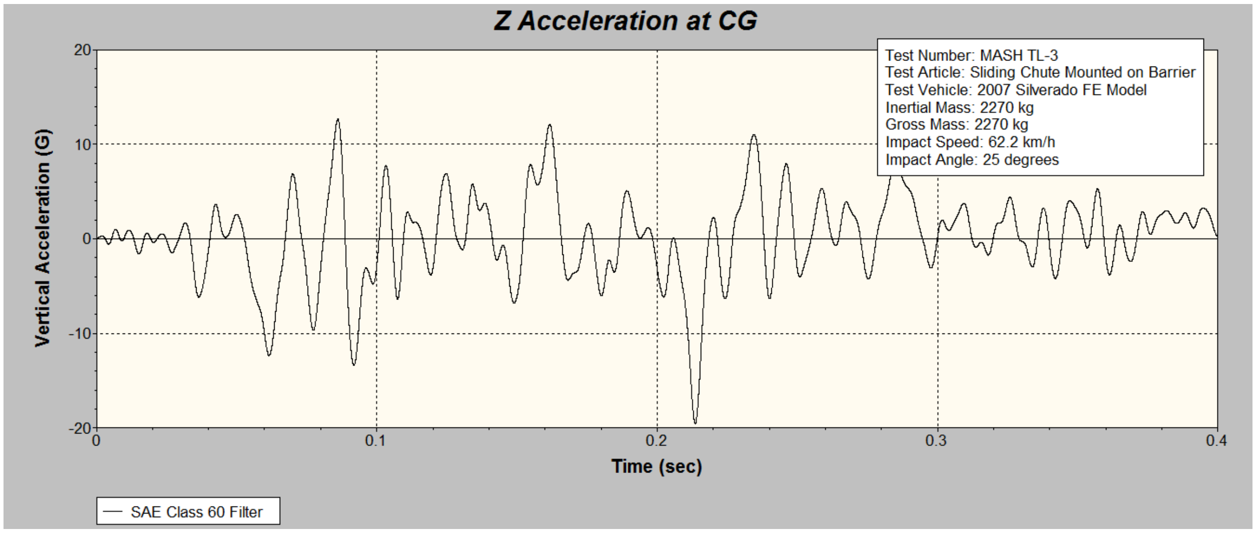


Figure 5.25. Vertical Acceleration History at C.G. for Concept 1.

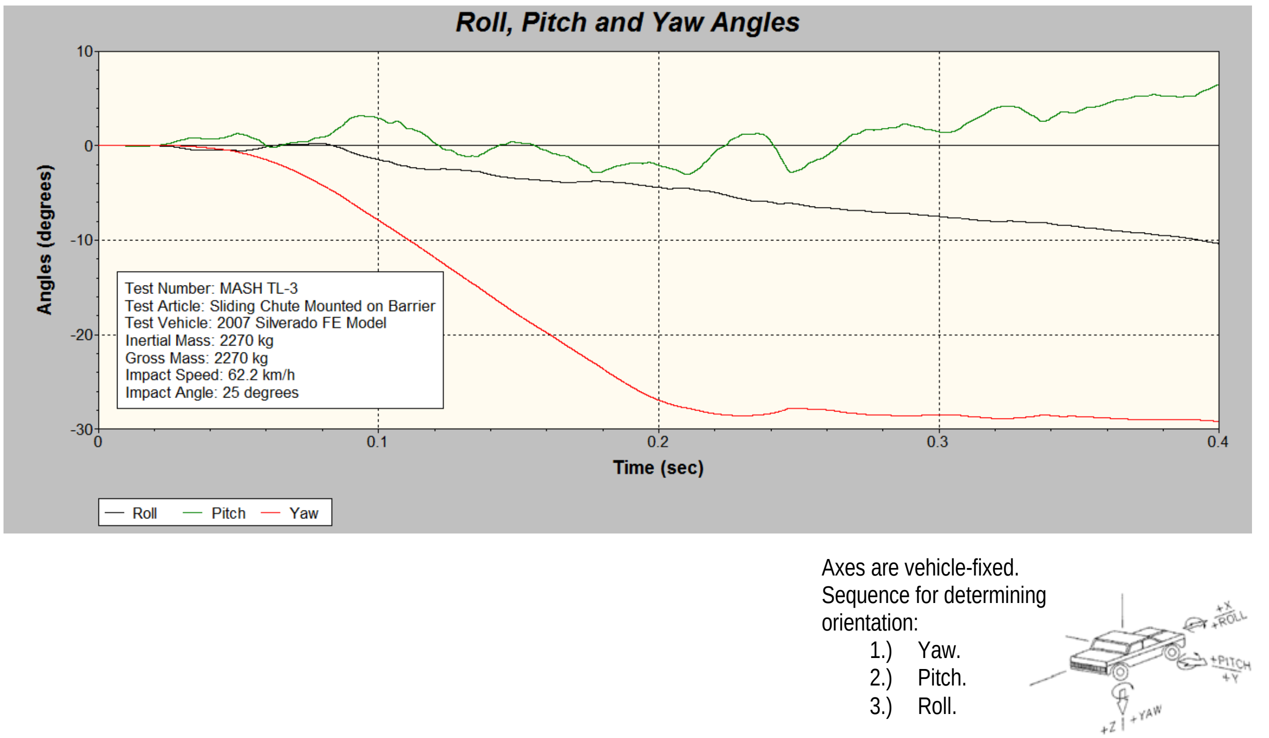
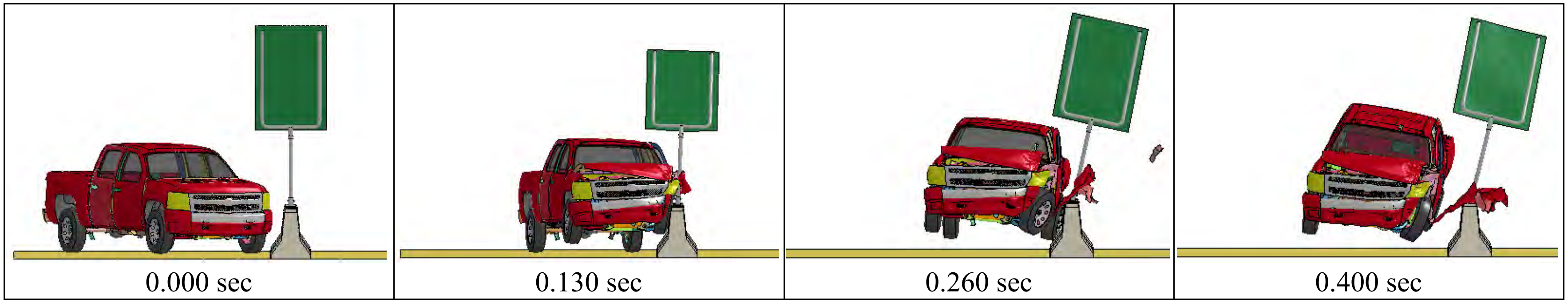


Figure 5.26. Vehicle Angular Displacement for Concept 1.



General Information	
Test Agency	Texas A&M Transportation Institute
Test Standard Test No.	MASH TL-3
Test Date	8/27/2012
Test Article	
Type	Sliding Chute on Barrier
Name	Concept 1
Installation Length	90 ft
Material or Key Elements	Steel Post and Chute
Soil Type and Condition	N/A
Test Vehicle	
Type/Designation	2270P
Make and Model	Chevy Silverado
Curb	5004 lb
Test Inertial	5004 lb
Dummy	No Dummy
Gross Static	5004 lb

Impact Conditions	
Speed	62.2 mi/h
Angle	25 degrees
Location/Orientation	54 inches upstrm of post
Exit Conditions	
Speed	48.3 mi/h
Angle	−29.4 degrees
Occupant Risk Values	
Impact Velocity	
Longitudinal	17.4 ft/s
Lateral	−25.3 ft/s
Ridedown Accelerations	
Longitudinal	9.2 g
Lateral	14.7 g
THIV	35.8 km/h
ASI	15.5 g
Max. 0.050-s Average	
Longitudinal	−7.4 g
Lateral	12.5 g
Vertical	−3.4 g

Post-Impact Trajectory	
Stopping Distance	N/A
Vehicle Stability	
Maximum Yaw Angle	−29.2 degrees
Maximum Pitch Angle	6.4 degrees
Maximum Roll Angle	−10.4 degrees
Vehicle Snagging	Yes
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	N/A
Permanent	N/A
Working Width	N/A
Vehicle Penetration	N/A
Vehicle Damage	
VDS	N/A
CDC	N/A
Max. Exterior Deformation..	
OCDI	N/A
Max. Occupant Compart. Deformation	N/A

Figure 5.27. Summary of Results for Concept 1.

5.4 CONCEPT 8: SLOTTED 10 BWG MOUNTED ON BARRIER

For the slotted concept, the base of the pole has slots cut into it to weaken the cross section and cause yielding of the post upon impact by the truck. By yielding the post, this reduces the magnitude of the impact forces experienced by the truck from those expected from a non-yielding design. The following is an analysis to determine the maximum slot size that could be cut into the sign post while still resisting the design wind load:

a. For 10 BWG pipe section:
   $Post_{OD}$ = 2.875 inches = Outer Diameter
   $Post_{ID}$ = 2.607 inches = Inner Diameter
   fy = 65 ksi = Yield Stress (from material tests of a typical post)

b. For Schedule 80 pipe section:
   $Post_{OD}$ = 2.875 inches
   $Post_{ID}$ = 2.323 inches
   fy = 65 ksi

5.4.1 10 BWG Section

Figure 5.28 shows the cross section of a 2.5-inch 10 BWG (British Wire Gauge) pipe with arbitrary slot lengths cut out. The slots are present to weaken the strong axis, as well as the weak axis.

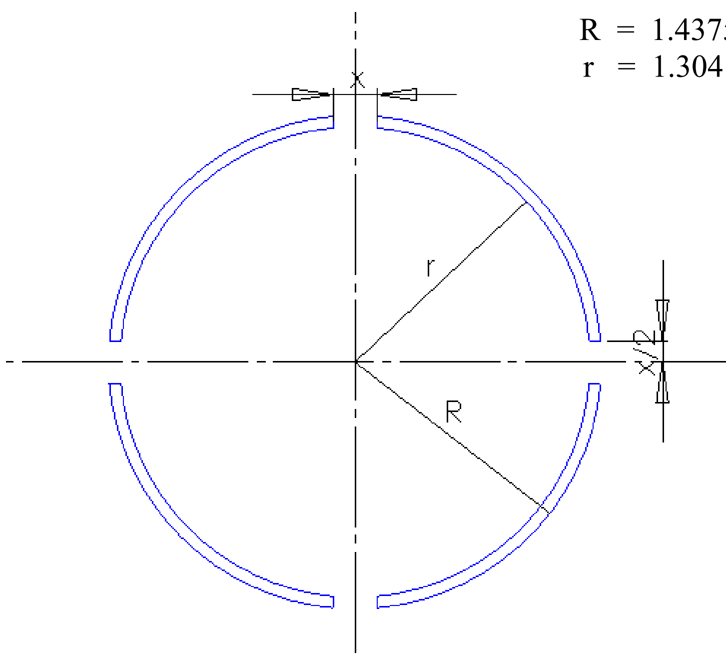


Figure 5.28. Cross Section of 2.5-inch 10 BWG Pipe.

In order to determine the maximum slot size that a particular cross section can withstand, the yield moment as a function of the slot size had to first be determined. This was determined by finding the inertia of the cross section using the method of areas formulated below:

$$I_{xx,ring} = \frac{\pi}{4}[R^4 - r^4] = 1.0827 \text{ inches}^4$$

$$I_{xx,top\ rec} = \frac{x[R-r]^3}{3} + x[R-r]\left[r + \left[\frac{R-r}{2}\right]\right]^2 = -0.2526x \text{ inch}^4$$

$$I_{xx,side\ rec} = \frac{2[R-r]x^3}{12} = -0.0223x^3 \ \text{ inch}^4$$

$$I_{xx,total} = \sum I_{xx}$$

Next, the Elastic section modulus was calculated:

$$S_x = \frac{I_{xx,total}}{y}$$

where y is the distance to the extreme fiber or in this case the outer radius. Finally, the yield moment can be calculated:

$$M_y = S_x f_y \cdot 1.33$$ * AASHTO Structural Supports 5th Edition Table 3.1

$$\boxed{M_y = 65112.64 - 30382.29x - 1341.10x^3}$$

5.4.2 Schedule 80 Section

Figure 5.29 shows the same cross section as before, but this time the dimensions are for a 2.5-inch Schedule 80 pipe section.

The same process to determine the yield moment is repeated for the Schedule 80 pipe:

$$I_{xx,ring} = \frac{\pi}{4}[R^4 - r^4] = 1.9242 \text{ inches}^4$$

$$I_{xx,top\ rec} = \frac{x[R-r]^3}{3} + x[R-r]\left[r + \left[\frac{R-r}{2}\right]\right]^2 = -0.4731x \text{ inch}^4$$

$$I_{xx,side\ rec} = \frac{2[R-r]x^3}{12} = -0.046x^3 \ \text{ inch}^4$$

$$S_x = \frac{\sum I_{xx}}{y}$$ * where y is the distance to the extreme fiber at initial yielding

$$M_y = S_x f_y \cdot 1.33$$ * AASHTO Structual Supports 5th Edition Table 3.1

$$\boxed{M_y = 115721.81 - 56903.64x - 2766.4x^3}$$

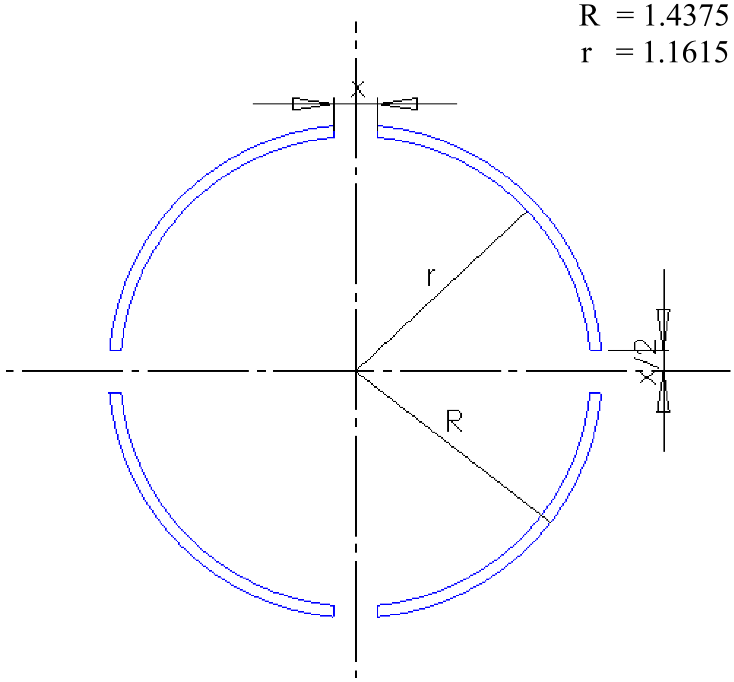


Figure 5.29. Cross Section of 2.5-inch Schedule 80 Pipe.

Next, the moment at the base of the sign due to the wind loading was calculated. This is done using the standards set in the 5th edition of the AASHTO Structural Supports Manual.

The Pressure on the sign is as formulated below:

$P_{z,sign} = 0.00256 K_z G V_v^2 I_r C_d$ (AASHTO eq. 3.8.1)

$V_v = C_v V$ = Adjusted wind velocity

$C_v = 0.84$ = Wind reduction Factor (AASHTO Table 3-4)

*Based on a 10 yr. Reoccurrence Interval

$I_r = 0.71$ (AASHTO Table 3-2)

$K_z = 0.87$ (AASHTO Table 3-5)

$G = 1.14$ (AASHTO eq. 3.8.5)

$C_d = 1.19 \; for \; \frac{Length}{Width} \approx 2$ = Wind drag coefficient

@ 100 mph Wind

$$P_{z,sign} = .00256(.87)(1.14)(.84 \cdot 100)^2(.71)(1.19)$$

$$= 15.137\, psf \;\; \rightarrow 363.28\, lb\; @\; 24\, ft^2$$

@ 95 mph Wind

$$P_{z,sign} = .00256(.87)(1.14)(.84 \cdot 95)^2(.71)(1.19)$$

$$= 13.66\, psf \;\; \rightarrow 327.85\, lb\; @\; 24\, ft^2$$

@ 90 mph Wind

$$P_{z,sign} = .00256(.87)(1.14)(.84 \cdot 90)^2(.71)(1.19)$$

$$= 12.26\, psf \;\; \rightarrow 294.26\, lb\; @\; 24ft^2$$

Next, the moment due to the wind loading can be found:

$$M_{post} = \quad 29788.96\, lb - inch\; @\; 100\, mph$$

$$26883.7\, lb - inch\; @\; 95\, mph$$

$$24129.32\, lb - inch\; @\; 90mph$$

The final step in determining the maximum slot size that each cross section can withstand can be done. Since the maximum yield moment that the cross section can withstand must be less than the moment present at the base of the post due to the wind loading, the slot size can be solved for by setting the pair equal to each other and solving. The results are shown below.

a. 10 BWG

@ 100 mph $\quad x_{max} = 1.10 inches \approx 1\frac{1}{16} inches$

@ 95 mph $\quad x_{max} = 1.184\; inches \approx 1\frac{1}{8} inches$

@ 90 mph $\quad x_{max} = 1.261\; inches \approx 1\frac{1}{4} inches$

b. Schedule 80

@ 100 mph $\quad x_{max} = 1.382\; inches \approx 1\frac{3}{8} inches$

5.4.3 Concept 8: Slotted 10 BWG with 3-inch Slots

Figure 5.30 shows the model of the 10 BWG post with four 3-inch long slots. Simulation of a 5004-lb test vehicle was calculated again at the *MASH* TL-3 crash impact level to quantify the performance of the on barrier concept.

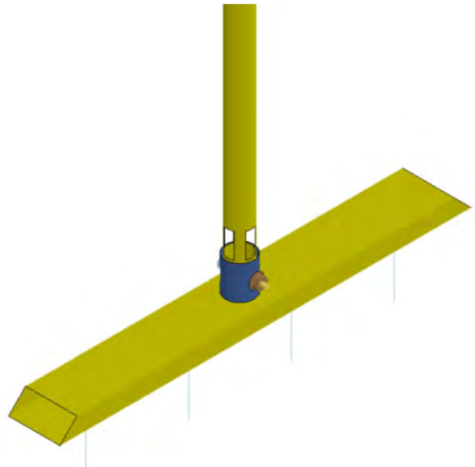


Figure 5.30. Model of Concept 8 Slotted 10 BWG Post (3-inch Slots).

Figure 5.31 shows predicted damage sustained by the sign post that indicates a collapse of the slotted section as intended. Figure 5.32 shows sequential pictures of the truck model impacting into the slotted 10 BWG sign post mounted on barrier at 42.5 inches upstream the base of the post. These sequential images show that the system was able to contain and redirect the vehicle as intended. The vehicle has a moderate roll angle of 13.3 degrees and smaller values for the pitch or yaw angles.

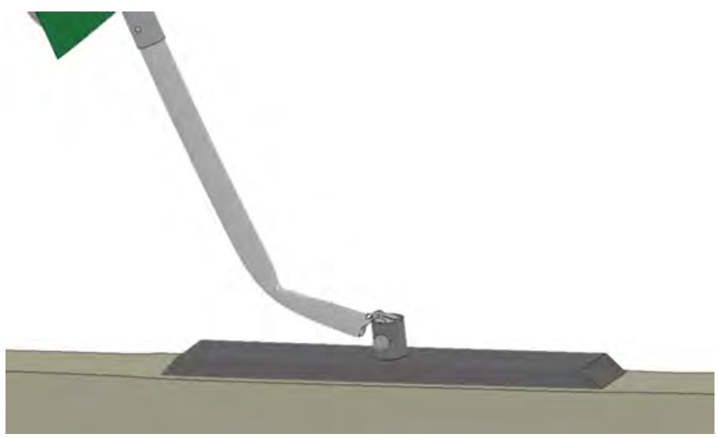


Figure 5.31. Bending of the Sign Post at the Slotted Section.

Occupant impact severity indices were all below the allowable limits of *MASH* TL-3. The OIV was −25.2 ft/s (−7.7 m/sec) in lateral direction (preferred 30 ft/s [9 m/sec] and maximum allowable is 40 ft/s [12 m/sec]) while the ridedown acceleration was 13.4 Gs (preferred 15 Gs and maximum allowable is 20 Gs) in lateral direction, per the LS-DYNA simulation. Details of acceleration data are presented in Figure 5.33. Figure 5.34, Figure 5.35, and Figure 5.36 show the acceleration histories at the C.G. of the 5004-lb finite element model. The vehicular angular displacement, yaw, pitch, and roll rate are shown in Figure 5.37. Figure 5.38 provides a summary of the data for the simulation of Concept 8 with 3-inch slots.

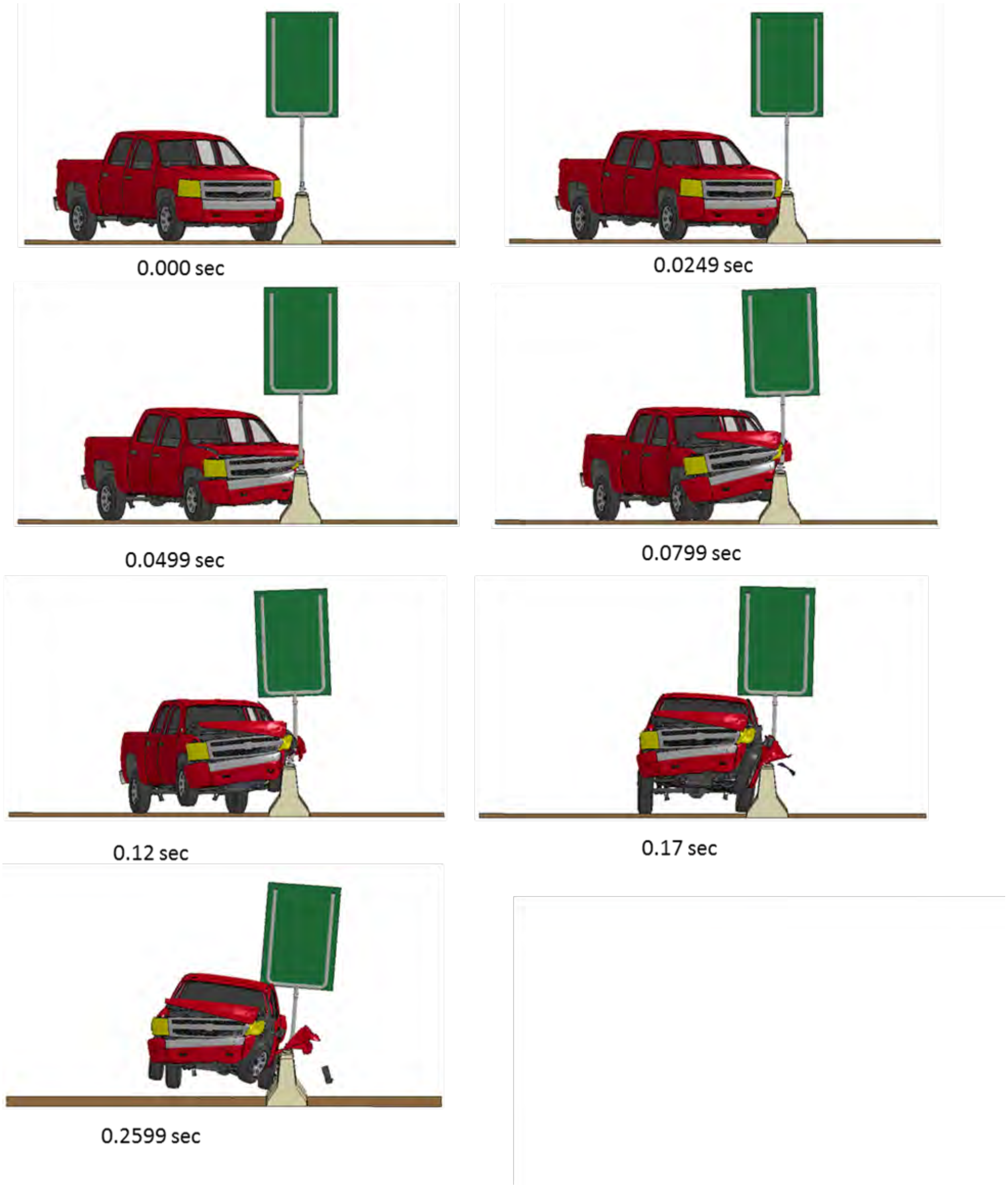


Figure 5.32. Impact View (Looking Upstream) Showing 5004-lb Test Vehicle Interacting with Sign Post for Concept 8 with 3-inch Slots.

General Information

Test Agency:	Texas A&M Transportation Institute
Test Number:	MASH TL-3
Test Date:	8/27
Test Article:	10 BWG Sign Post with 3in Slots

Test Vehicle

Description:	2007 Silverado FE Model
Test Inertial Mass:	2270 kg
Gross Static Mass:	2270 kg

Impact Conditions

Speed: 62.2 km/h
Angle: 25.0 degrees

Occupant Risk Factors

Impact Velocity (m/s)		at 0.1046 seconds on left side of interior
x-direction	5.8	
y-direction	-7.7	
THIV (km/hr):	35.5	at 0.1093 seconds on left side of interior
THIV (m/s):	9.9	
Ridedown Accelerations (g's)		
x-direction	-8.5	(0.2389 - 0.2489 seconds)
y-direction	13.4	(0.2044 - 0.2144 seconds)
PHD (g's):	13.8	(0.2044 - 0.2144 seconds)
ASI:	1.53	(0.0457 - 0.0957 seconds)

Max. 50msec Moving Avg. Accelerations (g's)

x-direction	-8.6	(0.0456 - 0.0956 seconds)
y-direction	11.9	(0.0456 - 0.0956 seconds)
z-direction	-4.2	(0.1692 - 0.2192 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)

Roll	-13.3	(0.3998 seconds)
Pitch	5.8	(0.3998 seconds)
Yaw	-29.4	(0.3998 seconds)

Figure 5.33. Signal Data from TRAP for Concept 8 with 3-inch Slots.

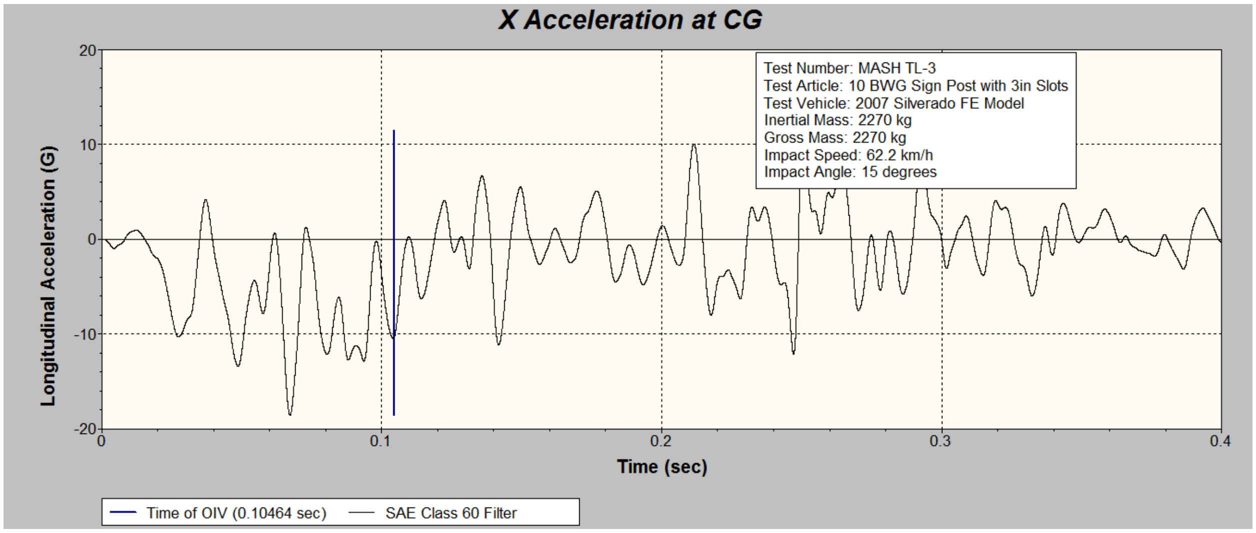


Figure 5.34. Longitudinal Acceleration History at C.G. for Concept 8 with 3-inch Slots.

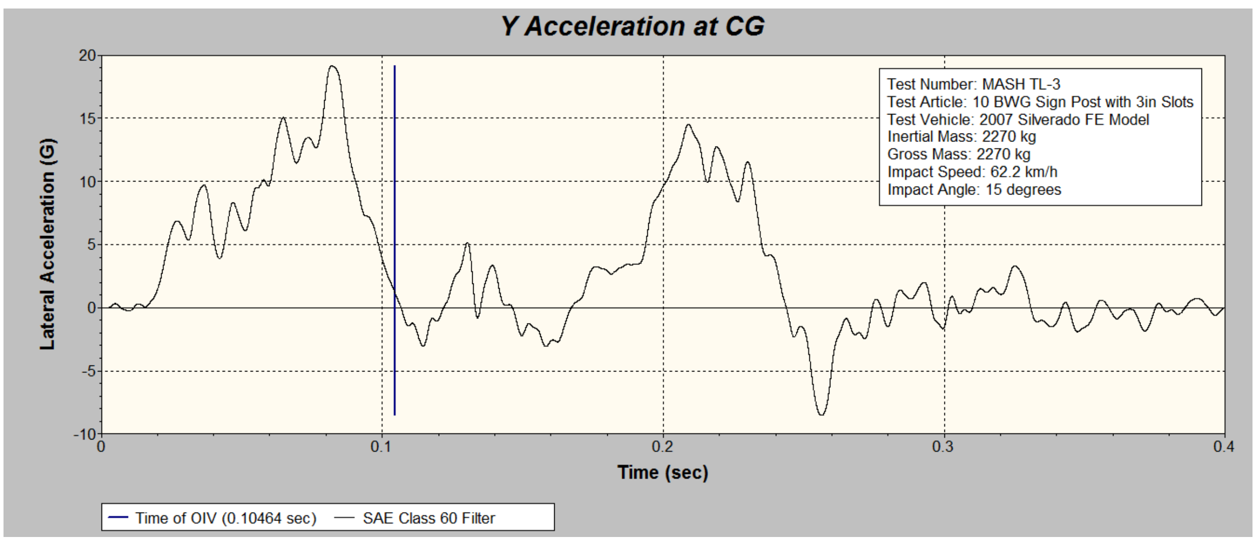


Figure 5.35. Lateral Acceleration History at C.G. for Concept 8 with 3-inch Slots.

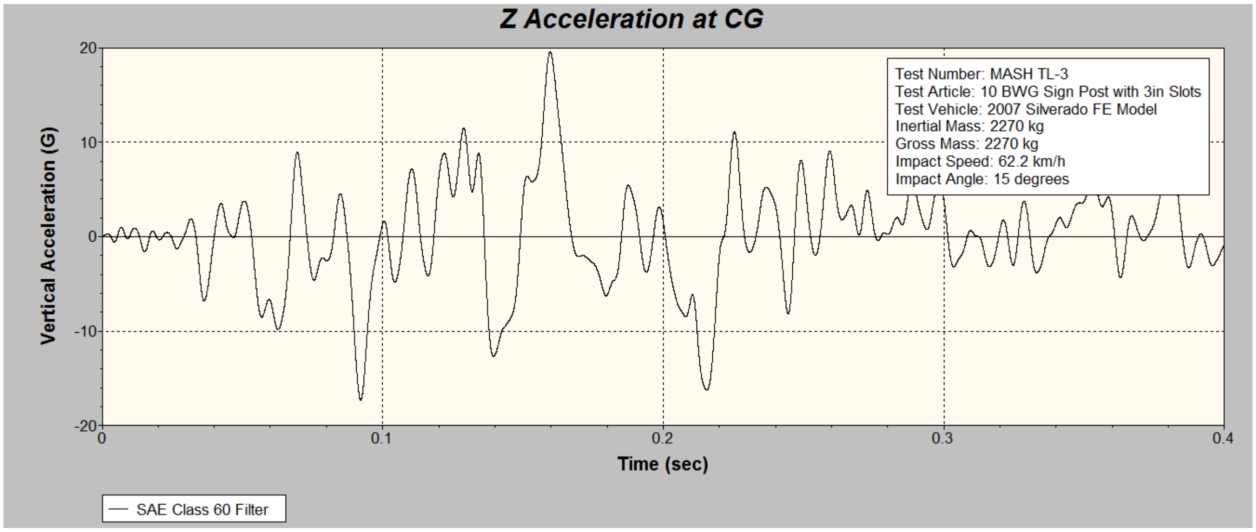
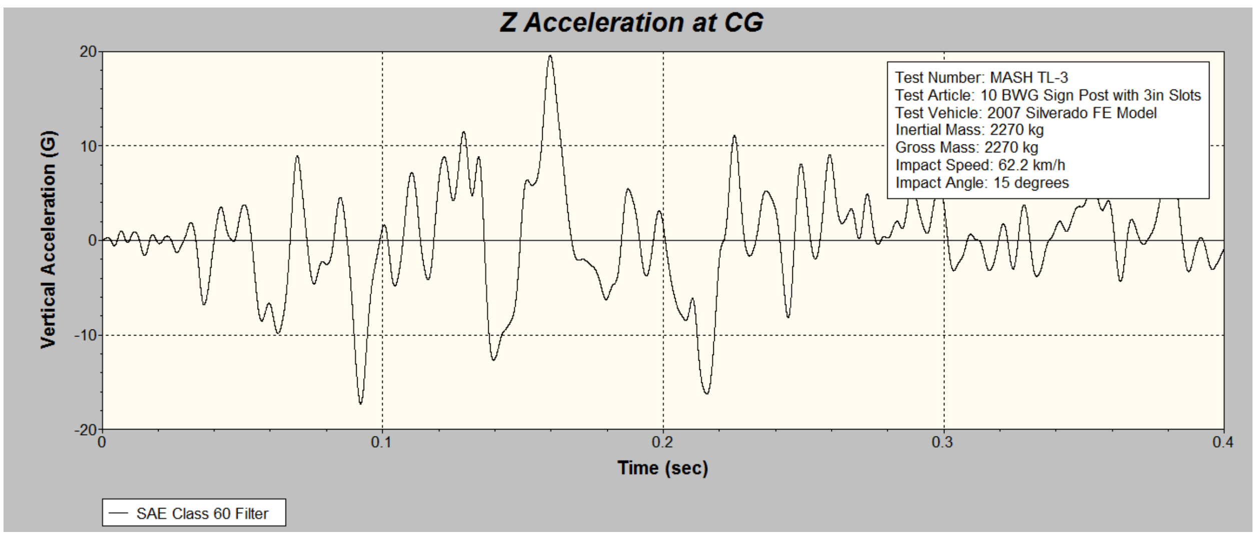


Figure 5.36. Vertical Acceleration History at C.G. for Concept 8 with 3-inch Slots.



Axes are vehicle-fixed.
Sequence for determining orientation:

1.) Yaw.
2.) Pitch.
3.) Roll.

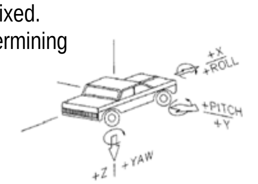
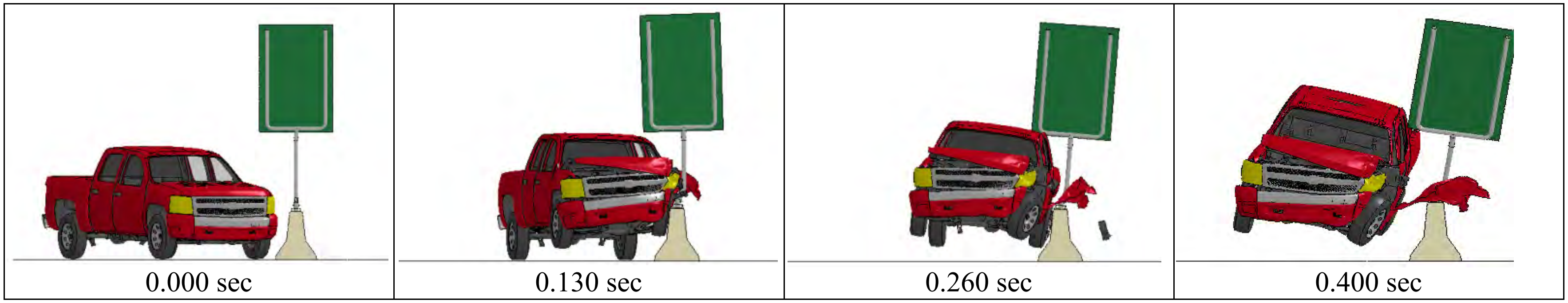


Figure 5.37. Vehicle Angular Displacement for Concept 8 with 3-inch Slots.



General Information
Test Agency .... Texas A&M Transportation Institute
Test Standard Test No. ...... MASH TL-3
Test Date 8/27/2012
Test Article
Type .... 10 BWG Slotted (3-inch)
Name .... Concept 8
Installation Length .... 90 ft
Material or Key Elements.. Slotting Sign Post
Soil Type and Condition ...... N/A
Test Vehicle
Type/Designation 2270P
Make and Model .... Chevy Silverado
Curb .... 5004 lb
Test Inertial .... 5004 lb
Dummy .... No Dummy
Gross Static .... 5004 lb

Impact Conditions
Speed .... 62.2 mi/h
Angle .... 25 degrees
Location/Orientation .... 42.5 inches upstrm of post
Exit Conditions
Speed .... 48.5 mi/h
Angle .... −29.4 degrees
Occupant Risk Values
Impact Velocity
Longitudinal .... 19.0 ft/s
Lateral .... −25.3 ft/s
Ridedown Accelerations
Longitudinal .... −8.5 g
Lateral .... 13.4 g
THIV .... 35.5 km/h
ASI .... 13.8 g
Max. 0.050-s Average
Longitudinal .... −8.6 g
Lateral .... 11.9 g
Vertical .... −4.2 g

Post-Impact Trajectory
Stopping Distance .... N/A
Vehicle Stability
Maximum Yaw Angle .... −29.4 degrees
Maximum Pitch Angle .... 5.8 degrees
Maximum Roll Angle .... −13.3 degrees
Vehicle Snagging .... Yes
Vehicle Pocketing .... No
Test Article Deflections
Dynamic .... N/A
Permanent .... N/A
Working Width .... N/A
Vehicle Penetration .... N/A
Vehicle Damage
VDS .... N/A
CDC .... N/A
Max. Exterior Deformation..
OCDI .... N/A
Max. Occupant Compart.
Deformation .... N/A

Figure 5.38. Summary of Results for Concept 8 with 3-inch Slots.

5.4.4 Concept 8: Slotted 10 BWG with 2-inch Slots

Figure 5.39 shows the model of the 10 BWG post with four 3 inch long slots concept. Simulation of a 5004-lb test vehicle was calculated again at the *MASH* TL-3 crash impact level to quantify the performance of the on barrier concept.

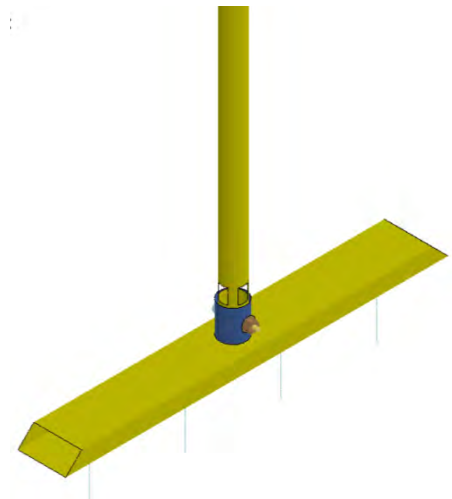


Figure 5.39. Model of Concept 8 Slotted 10 BWG Post (2-inch Long Slots).

Figure 5.40 shows predicted damage sustained by the sign post that indicates a collapse of the slotted section as intended. Figure 5.41 shows sequential pictures of the truck model impacting into the slotted 10 BWG sign post mounted on barrier at 42.5 inches upstream the base of the post. These sequential images show that the system was able to contain and redirect the vehicle as intended.

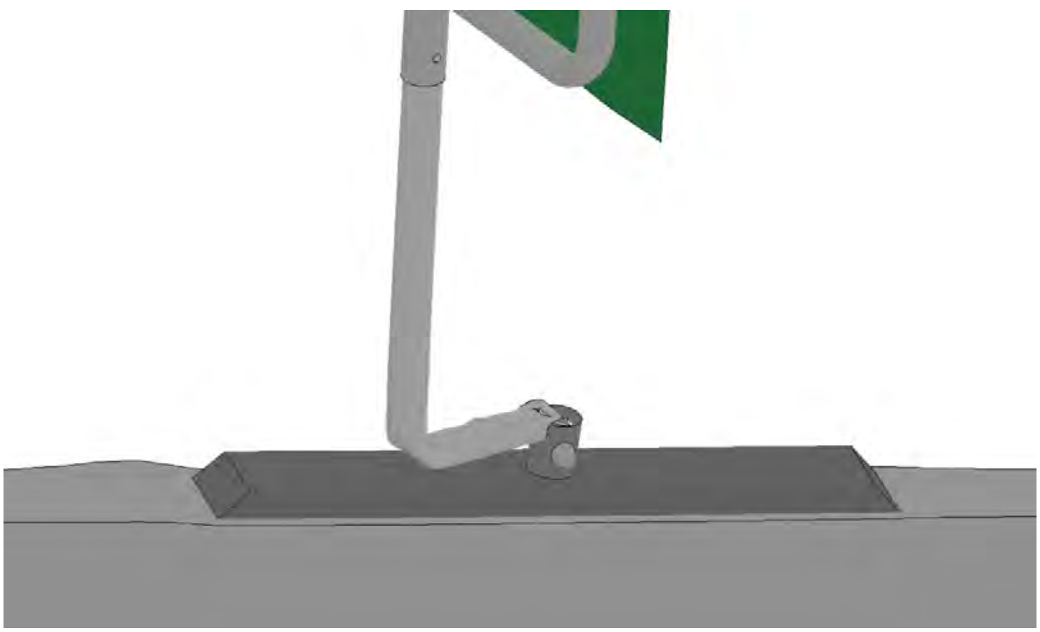


Figure 5.40. Bending of the Sign Post at the Slotted Section.

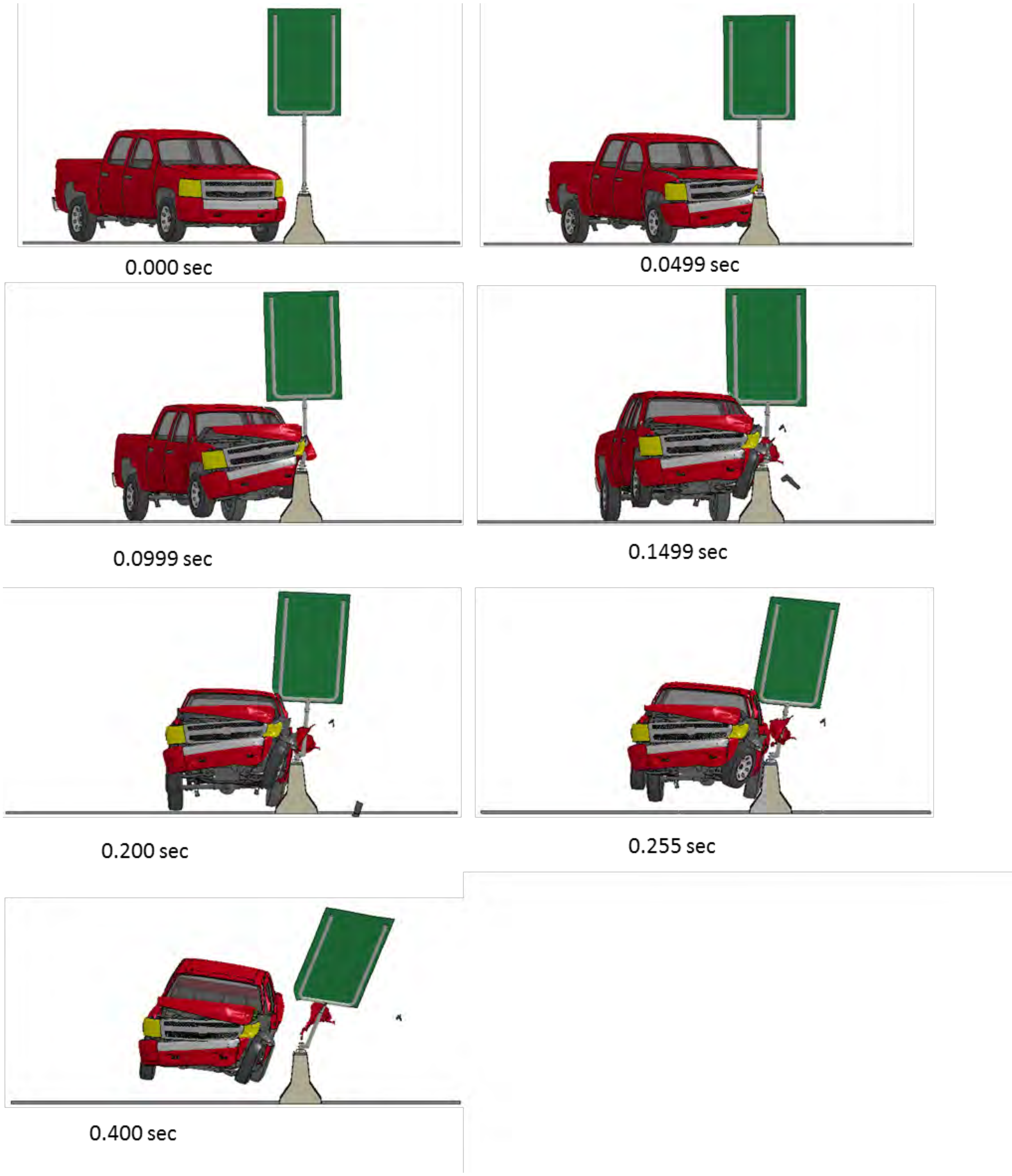


Figure 5.41. Impact View (Looking Upstream) Showing 5004-lb Test Vehicle Interacting with Sign Post for Concept 8 with 2-inch Slots.

The new system with the shortened slots was still able to contain and redirect the vehicle as shown in the sequential picture diagram. The vehicle had a moderate roll angle of 9 degrees and smaller values for the pitch or yaw angles.

Occupant impact severity indices were all below the allowable limits of *MASH* TL-3. The OIV was −24.9 ft/s (−7.6 m/sec) in lateral direction (preferred 30 ft/s [9 m/sec] and maximum allowable is 40 ft/s [12 m/sec]) while the ridedown acceleration was 12.4 Gs (preferred 15 Gs and maximum allowable is 20 Gs) in lateral direction, per the LS-DYNA simulation. Details of acceleration data are presented in Figure 5.42. Figure 5.43, Figure 5.44, and Figure 5.45 show the acceleration histories at the C.G. of the 5004 lb finite element model. The vehicular angular displacement, yaw, pitch, and roll rate are shown in Figure 5.46. Figure 5.47 presents pertinent data for Concept 8 Slotted BWG with 2-inch slots.

General Information
Test Agency: Texas A&M Transportation Institute
Test Number: MASH TL-3
Test Date: 8/28
Test Article: 10 BWG Sign Post with 2in Slots

Test Vehicle
Description: 2007 Silverado FE Model
Test Inertial Mass: 2270 kg
Gross Static Mass: 2270 kg

Impact Conditions
Speed: 62.2 km/h
Angle: 25.0 degrees

Occupant Risk Factors
Impact Velocity (m/s) at 0.1050 seconds on left side of interior
x-direction 6.0
y-direction -7.6

THIV (km/hr): 36.3 at 0.1098 seconds on left side of interior
THIV (m/s): 10.1

Ridedown Accelerations (g's)
x-direction -8.1 (0.1470 - 0.1570 seconds)
y-direction 12.4 (0.2058 - 0.2158 seconds)

PHD (g's): 12.7 (0.2059 - 0.2159 seconds)

ASI: 1.54 (0.0460 - 0.0960 seconds)

Max. 50msec Moving Avg. Accelerations (g's)
x-direction -8.9 (0.0460 - 0.0960 seconds)
y-direction 11.9 (0.0454 - 0.0954 seconds)
z-direction -3.8 (0.1752 - 0.2252 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)
Roll -9.0 (0.3998 seconds)
Pitch 4.8 (0.3882 seconds)
Yaw -28.7 (0.2395 seconds)

Figure 5.42. Signal Data from TRAP for Concept 8 with 2-inch Slots.

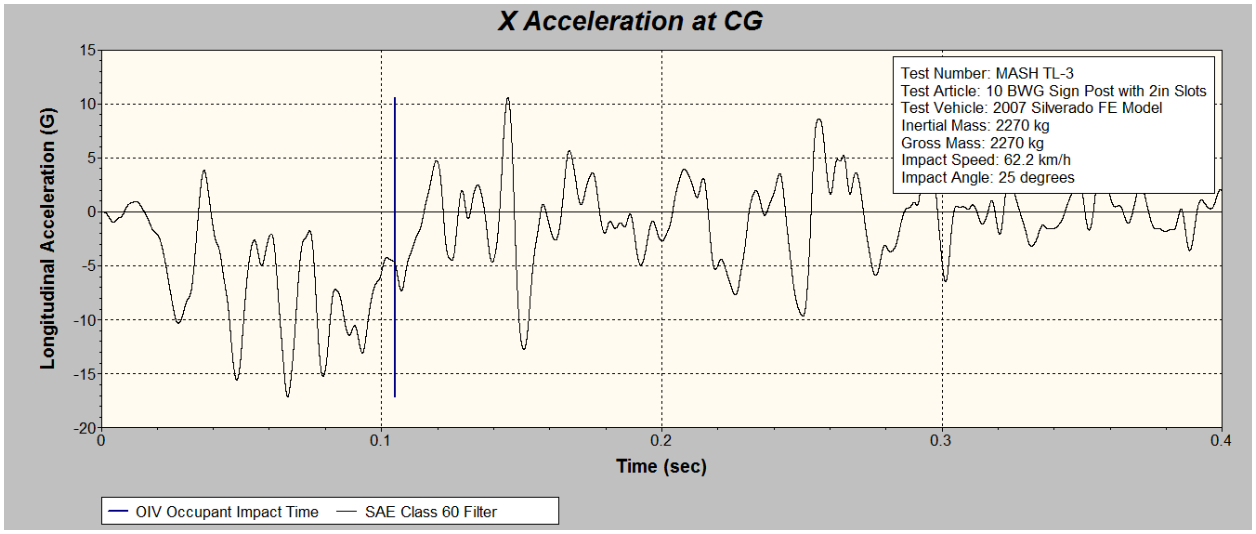


Figure 5.43. Longitudinal Acceleration History at C.G. for Concept 8 with 2-inch Slots.

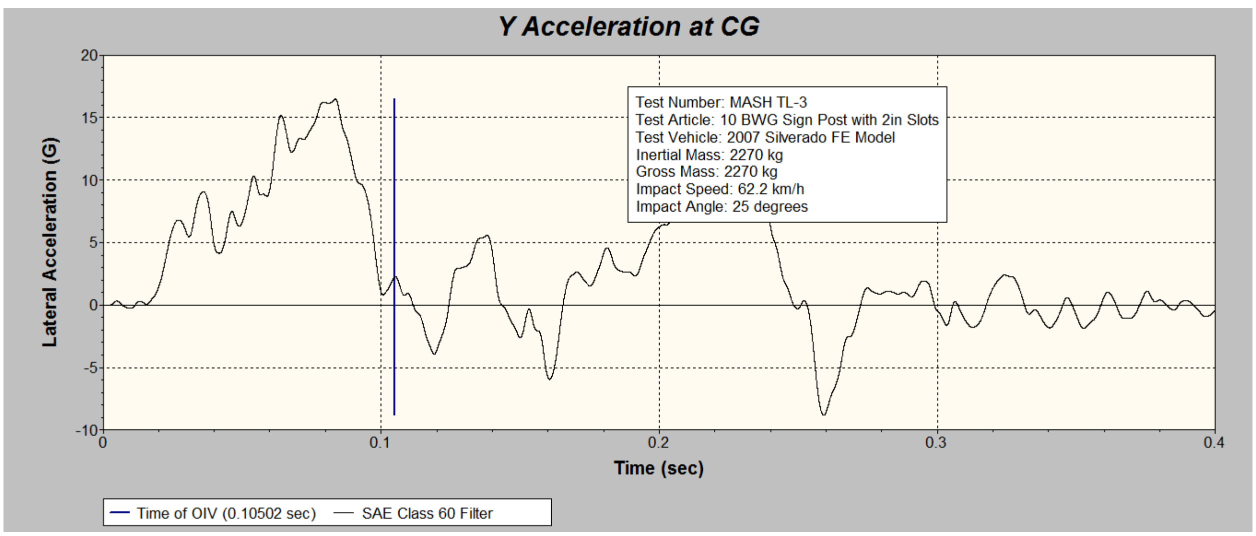


Figure 5.44. Lateral Acceleration History at C.G. for Concept 8 with 2-inch Slots.

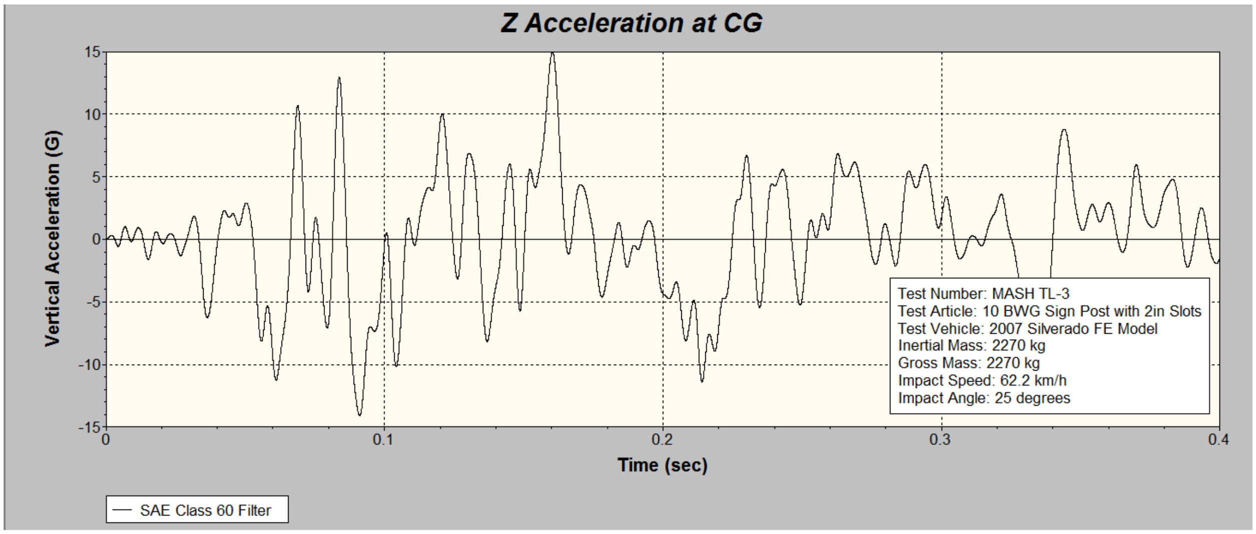
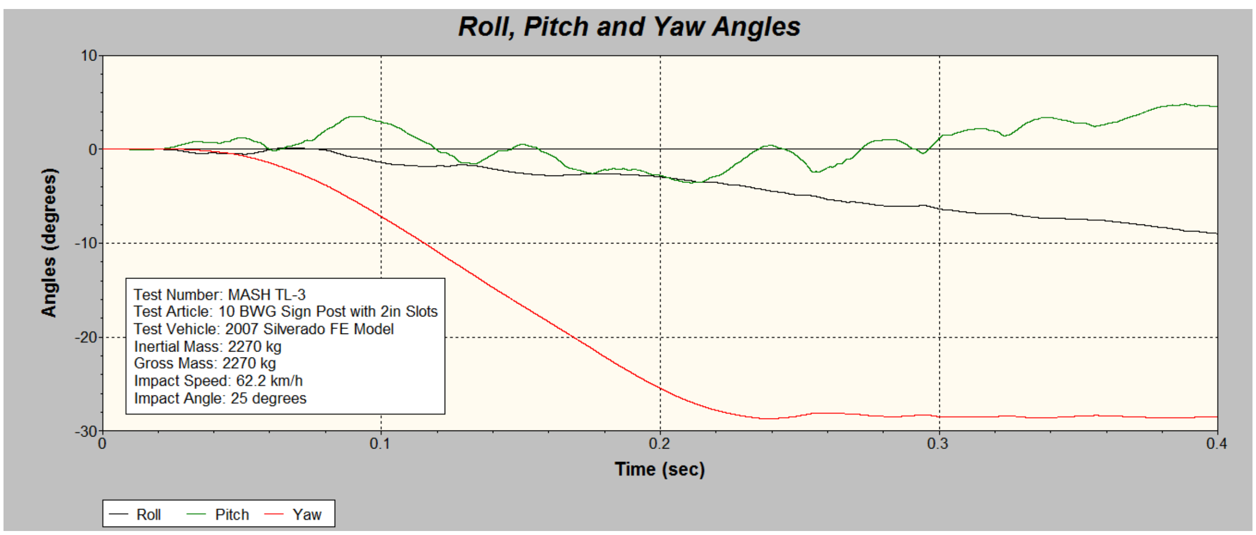


Figure 5.45. Vertical Acceleration History at C.G. for Concept 8 with 2-inch Slots.



Axes are vehicle-fixed.
Sequence for determining orientation:

1.) Yaw.
2.) Pitch.
3.) Roll.

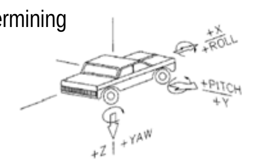
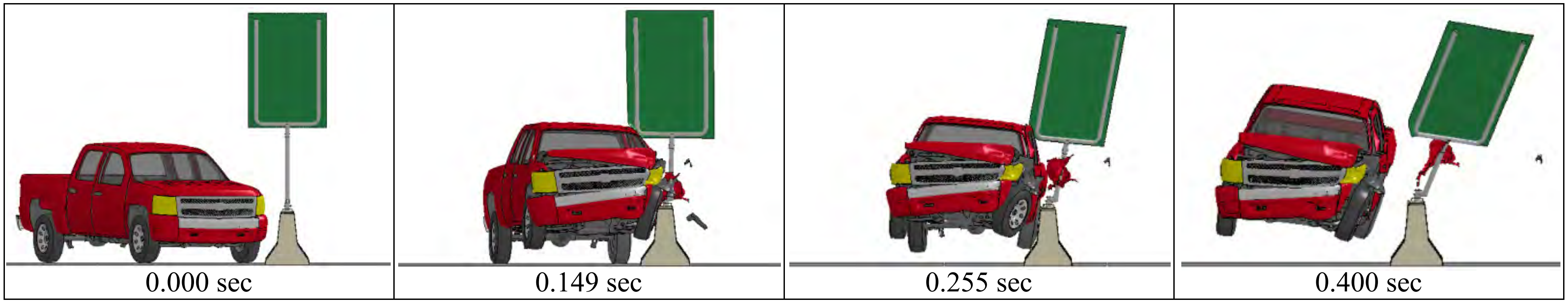


Figure 5.46. Vehicle Angular Data for Concept 8 with 2-inch



General Information
Test Agency .... Texas A&M Transportation Institute
Test Standard Test No. ...... MASH TL-3
Test Date 8/27/2012
Test Article
Type................................. 10 BWG Slotted (2-inch)
Name............................... Concept 8
Installation Length .... 90 ft
Material or Key Elements.. Slotting Sign Post
Soil Type and Condition ...... N/A
Test Vehicle
Type/Designation 2270P
Make and Model .... Chevy Silverado
Curb................................. 5004 lb
Test Inertial .... 5004 lb
Dummy............................. No Dummy
Gross Static .... 5004 lb

Impact Conditions
Speed ....62.2 mi/h
Angle..............................25 degrees
Location/Orientation ....4.25 inches upstrm of post
Exit Conditions
Speed ....47.4 mi/h
Angle..............................−28.6 degrees
Occupant Risk Values
Impact Velocity
Longitudinal 19.7ft/s
Lateral ....−24.9 ft/s
Ridedown Accelerations
Longitudinal ....−8.1 g
Lateral ....12.4 g
THIV ....36.3 km/hr
ASI..................................12.7 g
Max. 0.050-s Average
Longitudinal ....−8.9 g
Lateral ....11.9 g
Vertical ....−3.8 g

Post-Impact Trajectory
Stopping Distance................N/A
Vehicle Stability
Maximum Yaw Angle...........−29.4 degrees
Maximum Pitch Angle ....5.8 degrees
Maximum Roll Angle ....−13.3 degrees
Vehicle Snagging.................Yes
Vehicle Pocketing ....No
Test Article Deflections
Dynamic..............................N/A
Permanent...........................N/A
Working Width ....N/A
Vehicle Penetration ....N/A
Vehicle Damage
VDS ....N/A
CDC ....N/A
Max. Exterior Deformation..
OCDI ....N/A
Max. Occupant Compart.
Deformation ....N/A

Figure 5.47. Summary of Results for Concept 8 with 2-inch Slots.

5.5 SUMMARY OF SIMULATION

Detailed finite element simulation of the four selected concepts was performed using 6 ft × 4 ft sign size. Three concepts, the spread tube, the rotating post with sacrificial pin and the sliding chute mounting were simulated using a 2.5-inch nominal size Schedule 80 post. The fourth concept, the slotted post, was simulated using a 2.5-inch nominal size 10 BWG post. The results of all simulations indicated that these four concepts would pass *MASH* 3-11 test conditions within the accepted evaluation criteria.

CHAPTER 6. CRASH TESTS AND EVALUATION

6.1 INTRODUCTION

6.1.1 Crash Test Matrix

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

- **MASH Test Designation 3-10:** A 2425-lb vehicle impacting the critical impact point (CIP) of the length of need (LON) of the barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. This test investigates a barrier's ability to successfully contain and redirect a small passenger vehicle.
- **MASH Test Designation 3-11:** A 5000-lb pickup truck impacting the CIP of the LON of the barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. This test investigates a barrier's ability to successfully contain and redirect light trucks and sport utility vehicles.

Also, according to *MASH*, three tests are recommended to evaluate sign supports to TL-3:

- **MASH Test 3-60:** A 2425 lb vehicle impacting the device at a nominal impact speed of 30 mi/h and critical impact angle (CIA) judged to have the greatest potential for test failure. This test will investigate a device's ability to successfully activate by breakaway, fracture, or yielding mechanism during low-speed impacts with a small vehicle.
- **MASH Test 3-61:** A 2425 lb vehicle impacting the device at a nominal impact speed of 62 mi/h and CIA judged to have the greatest potential for test failure. This will evaluate the behavior of the device during high-speed impacts with a small vehicle.
- **MASH Test 3-62:** A 5000 lb vehicle impacting the device at a nominal impact speed of 62 mi/h and CIA judged to have the greatest potential for test failure. This will evaluate the behavior of the device during high-speed impacts with a pickup truck.

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

6.1.2 Evaluation Criteria

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

6.2 CRASH TEST INSTALLATION

For all four tests, the test article consists of three key assemblies, the barrier assembly, the sign panel assembly, and the sign mounting assembly. All tests share the same barrier and sign panel assemblies. Each test has a different sign mounting assembly design.

The same 32-inch height barrier assembly was used for all four tests conducted under this project. The barrier assembly consists of three TxDOT 30-ft New Jersey (NJ) shape CMB barriers that were placed longitudinally next to each other, which resulted in a 90-ft long NJ shape barrier. The 30-ft barriers were secured to each other via a steel grid inserted at their end openings, and the steel grid and the cavities were filled with concrete. Figure 6.1 shows the details of steel grid/concrete connection details. This 90-ft NJ barrier was placed against an existing TxDOT T223 bridge rail. The 90-ft NJ barrier was secured to the T223 bridge rail by using nine ¾-inch diameter wedge anchors and concrete to fill the gap between the NJ barrier and the T223 bridge rail as shown in Figure 6.2. Hence, the NJ barrier was fully secured and would respond as a permanent concrete barrier due to the aforementioned extensive anchoring schemes. Figure 6.3 shows the sign assembly, which consisted of a 48-inch × 72-inch × ⅛-inch aluminum sign with standard TxDOT U-bracket and hardware assembly.

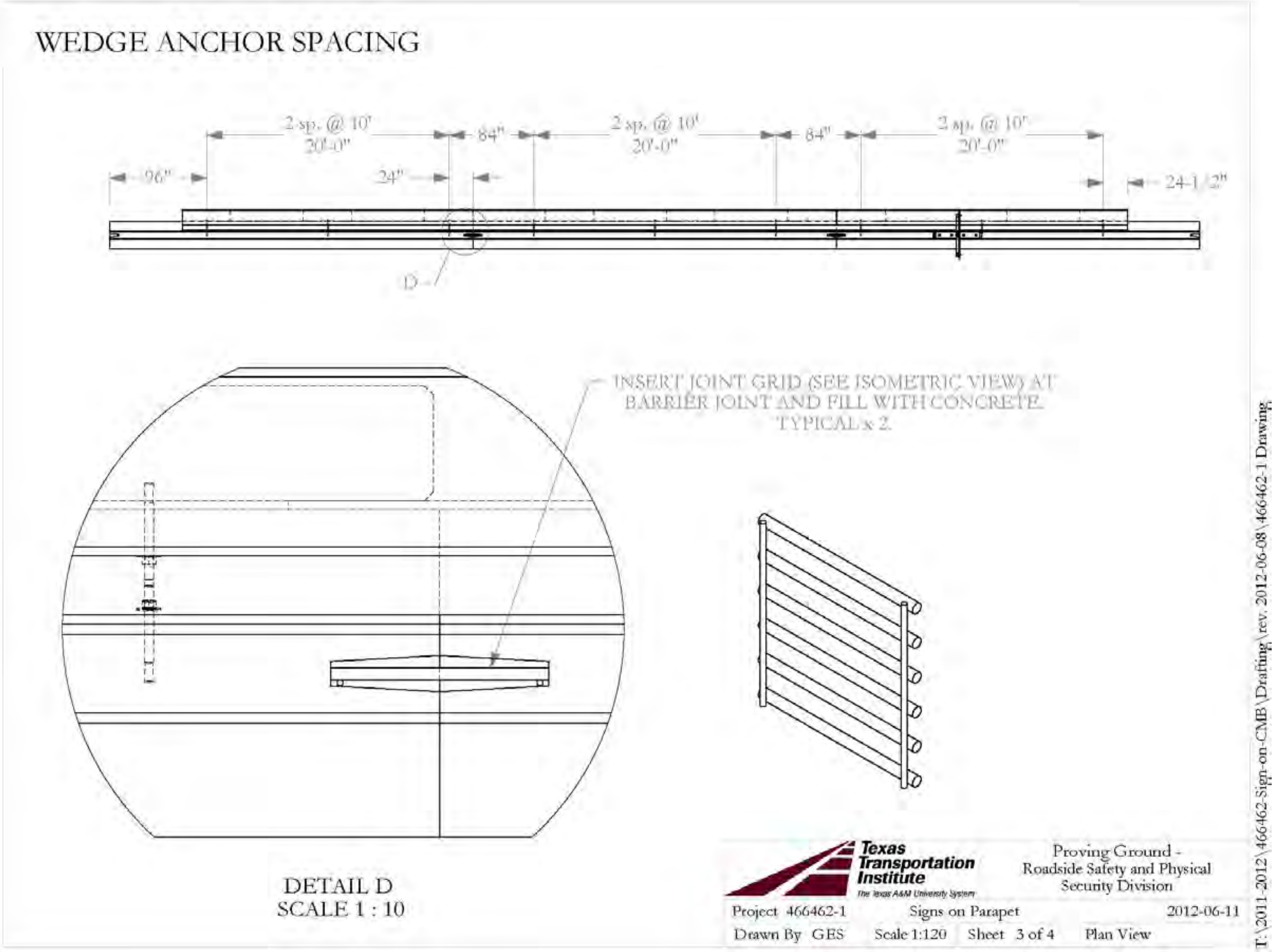


Figure 6.1. Details of the Spread Tube Sign Support System on CMB for Test No. 466462-1.

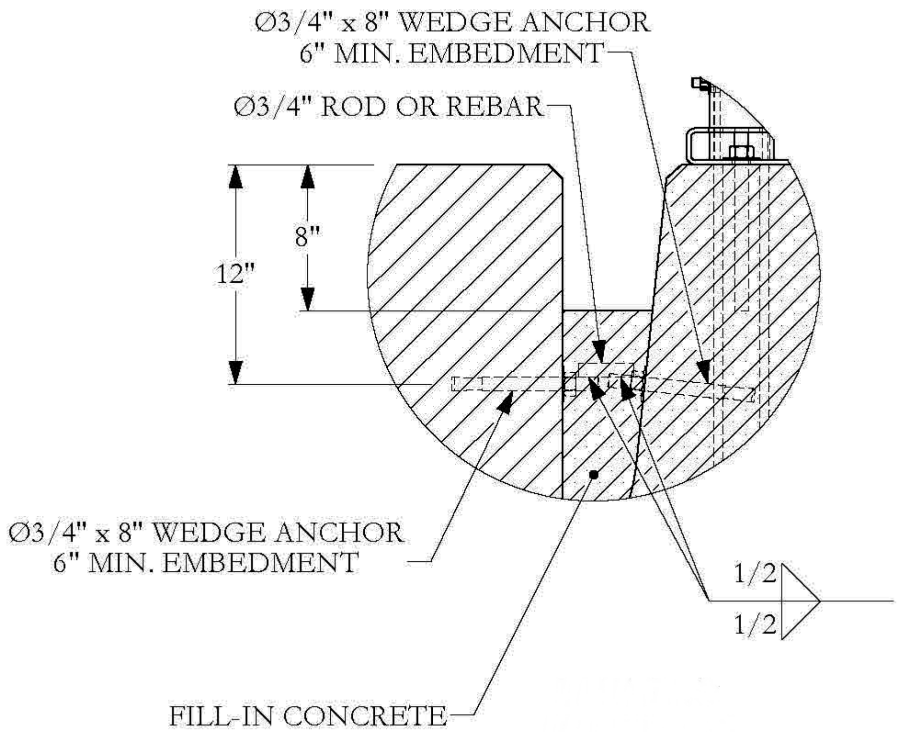


Figure 6.2. Gap between NJ Barrier and T223 Bridge Rail.

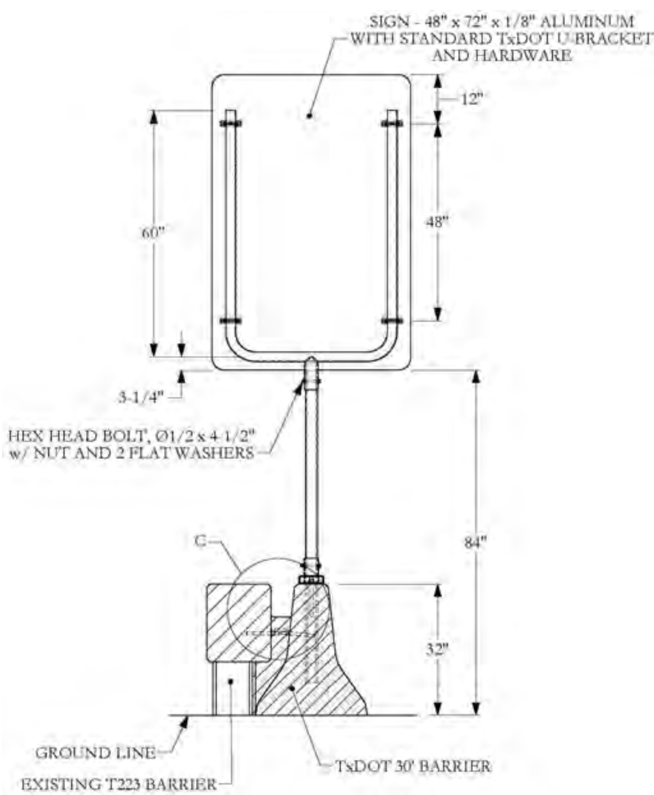


Figure 6.3. Sign and Post Assembly.

6.3 CRASH TEST NO. 466462-1 ON SPREAD TUBE SIGN SUPPORT SYSTEM ON CMB

6.3.1 Test Article Design and Construction – Spread Tube Sign Support System on CMB

For test 466462-1, the sign post is a standard 2.5-inch diameter Schedule 80 post. Figure 6.4 shows the post is mounted inside a 6-inch long, 3-inch diameter schedule 40 pipe that is built inside a 6-inch wide × 2-inch deep × ¼-inch thick steel tubing. The post is secured to the pipe using a ½-inch diameter through bolt. The steel tubing is 48 inches long with a 45-degree taper at each end and fixed to the top of the concrete barrier using four 8-inch long, ¾-inch diameter anchor rods. Additional details for the installation are provided in Appendix C1 and C2. Figure 6.5 presents photographs of the completed test installation prior to the test.

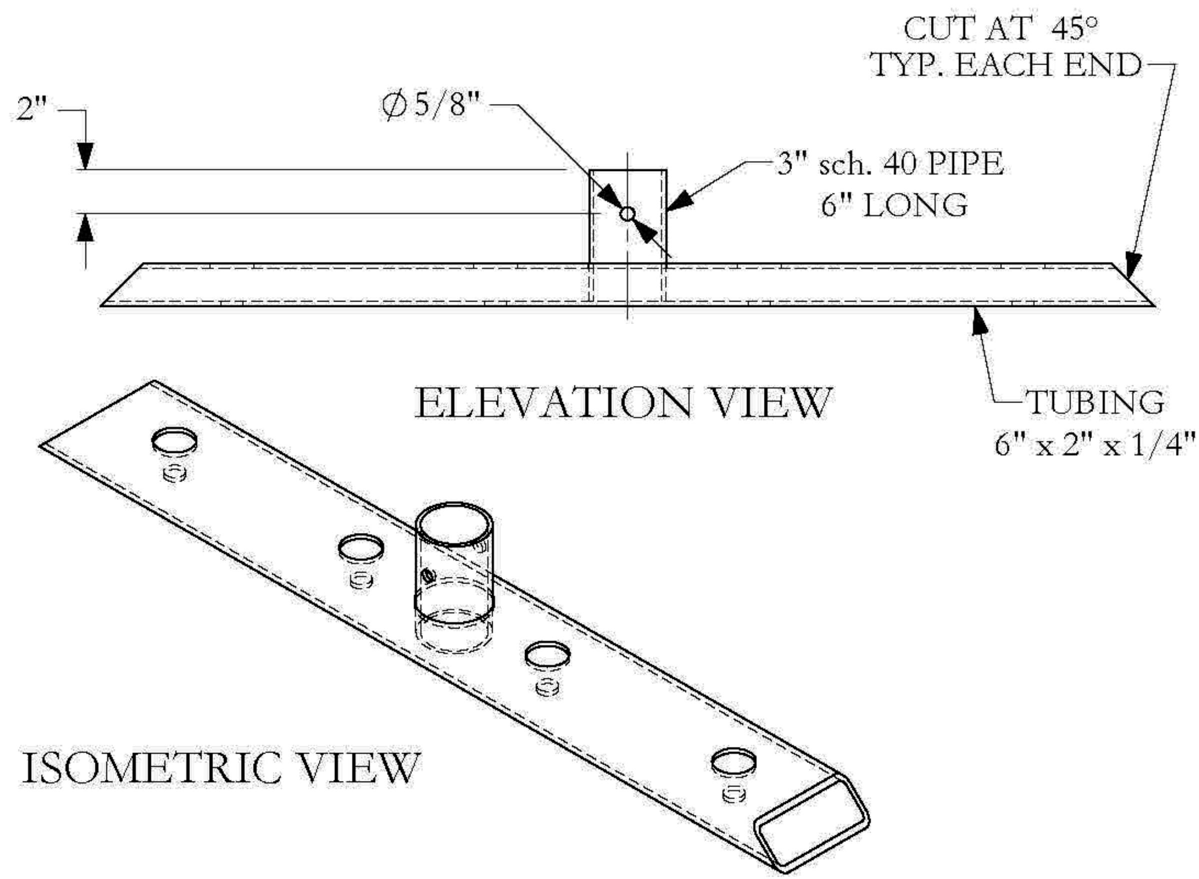


Figure 6.4. Spread Tube Sign Support System on CMB.

Figure 6.5. Spread Tube Sign Support System on CMB before Test No. 466462-1.

6.3.2 Target and Actual Impact Conditions

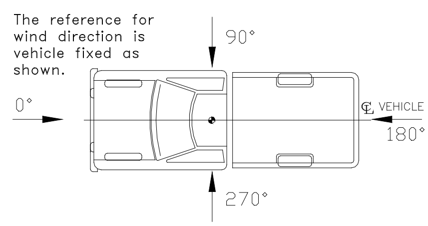
MASH test 3-11 involves a 2270P vehicle weighing 5000 lb ±100 lb and impacting the barrier at an impact speed of 62.2 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target impact point was 36 inches upstream of the spread tube sign support system. The 2006 Dodge Ram 1500 used in the test weighed 5050 lb, and the actual impact speed and angle were 61.6 mi/h and 25.0 degrees, respectively. The actual impact point was 42.5 inches upstream of the spread tube sign support system. Target impact severity (IS) was 115.2 kip*ft, and actual IS was 114.4 kip*ft, where IS is required to be no less than 8 percent.

6.3.3 Test Vehicle

A 2006 Dodge Ram 1500 pickup truck, shown in Figures 6.6 and 6.7, was used for the crash test. Test inertia weight of the vehicle was 5050 lb, and its gross static weight was 5050 lb. The height to the lower edge of the vehicle bumper was 13.75 inches, and it was 25.38 inches to the upper edge of the bumper. The height to the vehicle's center of gravity was 28.03 inches. Tables C1 and C2 in Appendix C3 give additional dimensions and information on the test vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be unrestrained just prior to impact.

6.3.4 Weather Conditions

The test was performed on the morning of June 11, 2012. Weather conditions at the time of testing were as follows: wind speed: 13 mi/h; wind direction: 173 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 94°F, relative humidity: 57 percent.



6.3.5 Test Description

The 2006 Dodge Ram 1500 pickup truck, traveling at an impact speed of 61.6 mi/h, impacted the barrier 42.5 inches upstream of the spread tube sign support system at an impact angle of 25.0 degrees. At approximately 0.029 s after impact, the right front corner of the vehicle impacted the sign support, and at 0.052 s, the vehicle began to redirect. The rear of the vehicle contacted the barrier at 0.113 s, and the vehicle lost contact with the sign support at 0.123 s. The vehicle began traveling parallel with the barrier at 0.231 s. At 0.364 s, the vehicle lost contact with the barrier and was traveling at an exit speed and angle of 46.2 mi/h and 0.8 degrees. Brakes on the vehicle were not applied, and the vehicle subsequently came to rest 198 ft downstream of impact and 15 ft toward the field side of the installation. Figure C1 in Appendix C4 show sequential photographs of the test period.

Figure 6.6. Vehicle/Spread Tube Sign Support System on CMB Geometrics for Test No. 466462-1.

Figure 6.7. Vehicle before Test No. 466462-1.

6.3.6 Damage to Test Installation

Figures 6.8 and 6.9 show damage to the spread tube sign support system and the barrier. The barrier face was marred with tire marks and scrapings. The sign support was leaning downstream and a piece of the sheet metal from the vehicle was wrapped around the lower portion of the support. The 2270P vehicle was in contact with the barrier 218 inches. Vehicle penetration (formerly working width) was 20.4 inches. No movement was noted in the barrier.

6.3.7 Vehicle Damage

Figure 6.10 presents the damage sustained by the vehicle. The right upper and lower ball joints and A-arms, the right frame rail, left rear U-bolts, and drive shaft were deformed. The front bumper, hood, right front fender, right front door and door glass, right exterior bed, right rear door, right front tire and wheel rim, right rear tire and wheel rim, left rear tire and wheel rim, and rear bumper were also damaged. During the test, the windshield sustained stress cracks, and as the vehicle exited the barrier, the hood flew up and contacted the windshield and causing the windshield to break and deform. However, contact with the sign support and barrier did not cause the majority of the damage. Maximum exterior crush to the vehicle was 18.0 inches in the side plane at the right front corner at bumper height. Deformation of 7.5 inches was noted in the windshield; this was caused by the hood of the vehicle and not from interaction with the sign support or barrier. Maximum occupant compartment deformation caused by interaction with the sign support and barrier was 1.5 inches in the floor pan on the right side. Tables C3 and C4 in Appendix C4 provide maximum exterior crush and occupant compartment deformation of the vehicle.

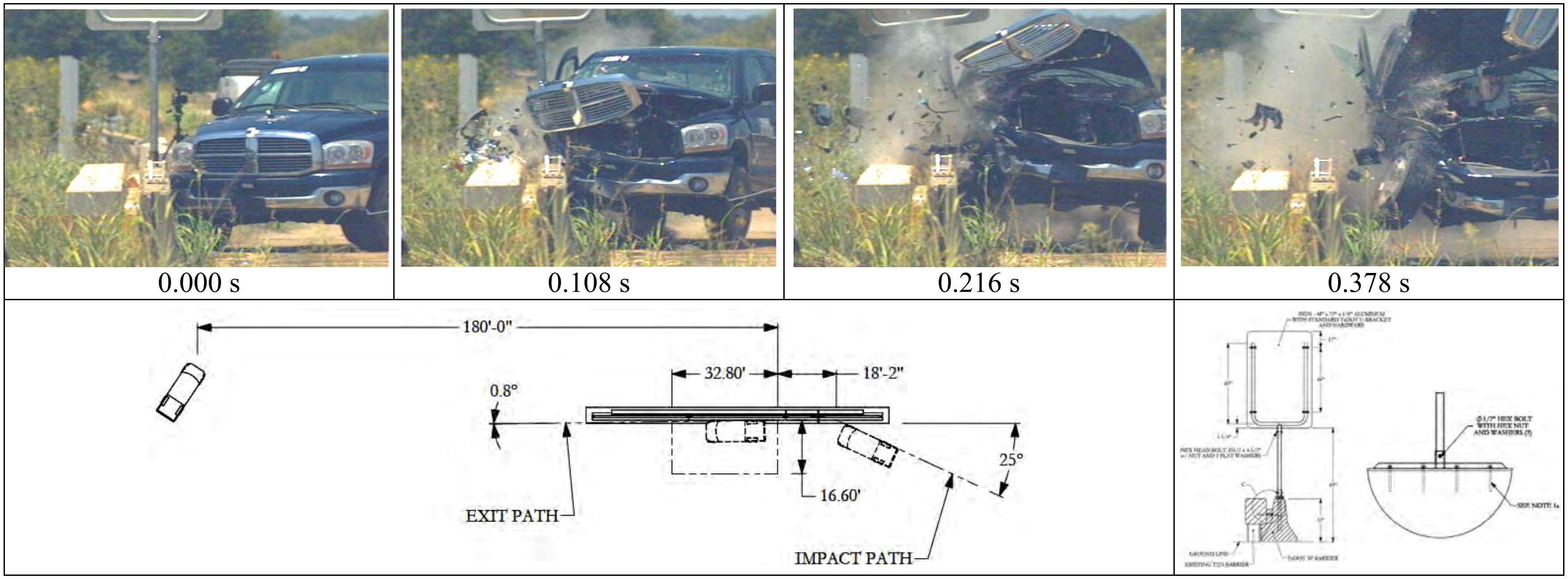
6.3.8 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 21.6 ft/s at 0.094 s, the highest 0.010-s occupant ridedown acceleration was 5.2 Gs from 0.230 to 0.240 s, and the maximum 0.050-s average acceleration was −9.6 Gs between 0.021 and 0.071 s. In the lateral direction, the occupant impact velocity was 25.3 ft/s at 0.094 s, the highest 0.010-s occupant ridedown acceleration was 6.6 Gs from 0.253 to 0.263 s, and the maximum 0.050-s average was −14.1 Gs between 0.034 and 0.084 s. Theoretical Head Impact Velocity (THIV) was 37.1 km/h or 10.3 m/s at 0.092 s; Post-Impact Head Decelerations (PHD) was 7.8 Gs between 0.227 and 0.237 s; and Acceleration Severity Index (ASI) was 1.70 between 0.034 and 0.084 s. Figure 6.11 summarizes the data and other pertinent information from the test. Vehicle angular displacements and accelerations versus time traces are presented in Appendix C5 Figure C2 and Appendix C6 Figures C3 through C8, respectively.

Figure 6.8. Vehicle/Spread Tube Sign Support System on CMB Positions after Test No. 466462-1.

Figure 6.9. Spread Tube Sign Support System on CMB after Test No. 466462-1.

Figure 6.10. Vehicle after Test No. 466462-1.



General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-11
TTI Test No.	466462-1
Test Date	2012-06-11

Test Article

Type	Sign Support on CMB
Name	Spread Tube Sign Support System
Installation Length/Height	Barrier 90 ft long × 32 inches high/ Sign mounting height at 84.5 inches
Material or Key Elements	6-inch long, 3-inch diameter schedule 40 pipe inside a 6 inch wide × 2-inch deep × ¼-inch thick steel tubing

Soil Type and Condition ..... Barrier placed on concrete surface, dry

Test Vehicle

Type/Designation	2270P
Make and Model	2006 Dodge Ram 1500 Pickup
Curb	4969 lb
Test Inertial	5050 lb
Dummy	No dummy
Gross Static	5050 lb

Impact Conditions

Speed	61.6 mi/h
Angle	25.0 degrees
Impact Severity	114.4 kip*ft
Location/Orientation	42.5 inches upstrm of support

Exit Conditions

Speed	46.2 mi/h
Angle	0.8 degrees

Occupant Risk Values

Impact Velocity	
Longitudinal	21.6 ft/s
Lateral	25.3 ft/s
Ridedown Accelerations	
Longitudinal	5.2 G
Lateral	6.6 G
THIV	37.1 km/h
PHD	7.8 G
ASI	1.70
Max. 0.050-s Average	
Longitudinal	-9.6 G
Lateral	-14.1 G
Vertical	-4.6 G

Post-Impact Trajectory

Stopping Distance	198 ft dwnstrm 15 ft twd field side

Vehicle Stability

Maximum Yaw Angle	27 degrees
Maximum Pitch Angle	9 degrees
Maximum Roll Angle	12 degrees
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	None measureable
Permanent	None measureable
Working Width	None measureable
Vehicle Penetration	20.4 inches

Vehicle Damage

VDS	01RFQ5
CDC	01FREW4
Max. Exterior Deformation	18.0 inches
OCDI	RF0000000
Max. Occupant Compartment Deformation	1.5 inches

Figure 6.11. Summary of Results for *MASH* Test 3-11 on the Spread Tube Sign Support System on CMB.

6.3.9 Assessment of Test Results on Spread Tube Sign Support System on CMB

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

6.3.9.1 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 barrier on which the spread tube sign support system was mounted contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. The sign support did not interfere with the ability of the barrier to contain and redirect the vehicle. No movement of the barrier was seen. (PASS)

6.3.9.2 Occupant Risk

D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.
Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 inches).

Results: No detached elements, fragments, or other debris was present from the barrier or the sign support to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. (PASS)
Deformation of 7.5 inches was noted in the windshield; this was caused by the hood of the vehicle and not from interaction with the sign support or barrier. Maximum occupant compartment deformation caused by interaction with the sign support and barrier was 1.5 inches in the floor pan on the right side. (PASS)

F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.

Results: The 2270 vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 12 degrees and 9 degrees, respectively. (PASS)

H. Occupant impact velocities should satisfy the following:
Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
30 ft/s	*40 ft/s*

Results: Longitudinal occupant impact velocity was 21.6 ft/s, and lateral occupant impact velocity was 25.3 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:
Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Maximum longitudinal ridedown acceleration was 5.2 G, and maximum lateral ridedown acceleration was 6.6 G. (PASS)

6.3.9.3 Vehicle Trajectory

For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).

Result: The 2270P vehicle crossed the exit box within the specified criteria. (PASS)

6.3.10 Conclusions – Spread Tube Sign Support System on CMB

The spread tube sign support system mounted on top of the CMB performed acceptably for *MASH* test 3-11.

6.4 CRASH TEST NO. 466462-2a ON BRACKET AND SACRIFICIAL PIN SIGN SUPPORT ON CMB

6.4.1 Test Article Design and Construction – Bracket and Sacrificial Pin Sign Support on CMB

The design used for test 466462-2a consisted of the same sign assembly and post details used in test 466462-1. However, the sign post is mounted to the barrier by attaching it to two trapezoidal side plates. The ¾-inch thick plates hold the post via a ¾-inch diameter bolt and a 5/16-inch diameter sacrificial bolt. Both bolts are designed to keep the sign up under wind loading. However, the sacrificial bolt would break upon excessive longitudinal forces on the post due to impact. Hence, this the sign assembly would pivot around the ¾-inch hinge bolt under excessive impact force. The bolts are secured to the side plates/base pivot assembly. The plates are welded to a 20-inch × 6-inch × ½-inch thick plate. This mounting assembly is attached to the top face of the barrier via two anchor rods; each is 8 inches long, ¾-inch diameter. Figures 6.12 and 6.13 show the details of the mounting bracket, and additional details are provided in Appendix D1 and D2. Figure 6.14 presents photographs of the completed installation.

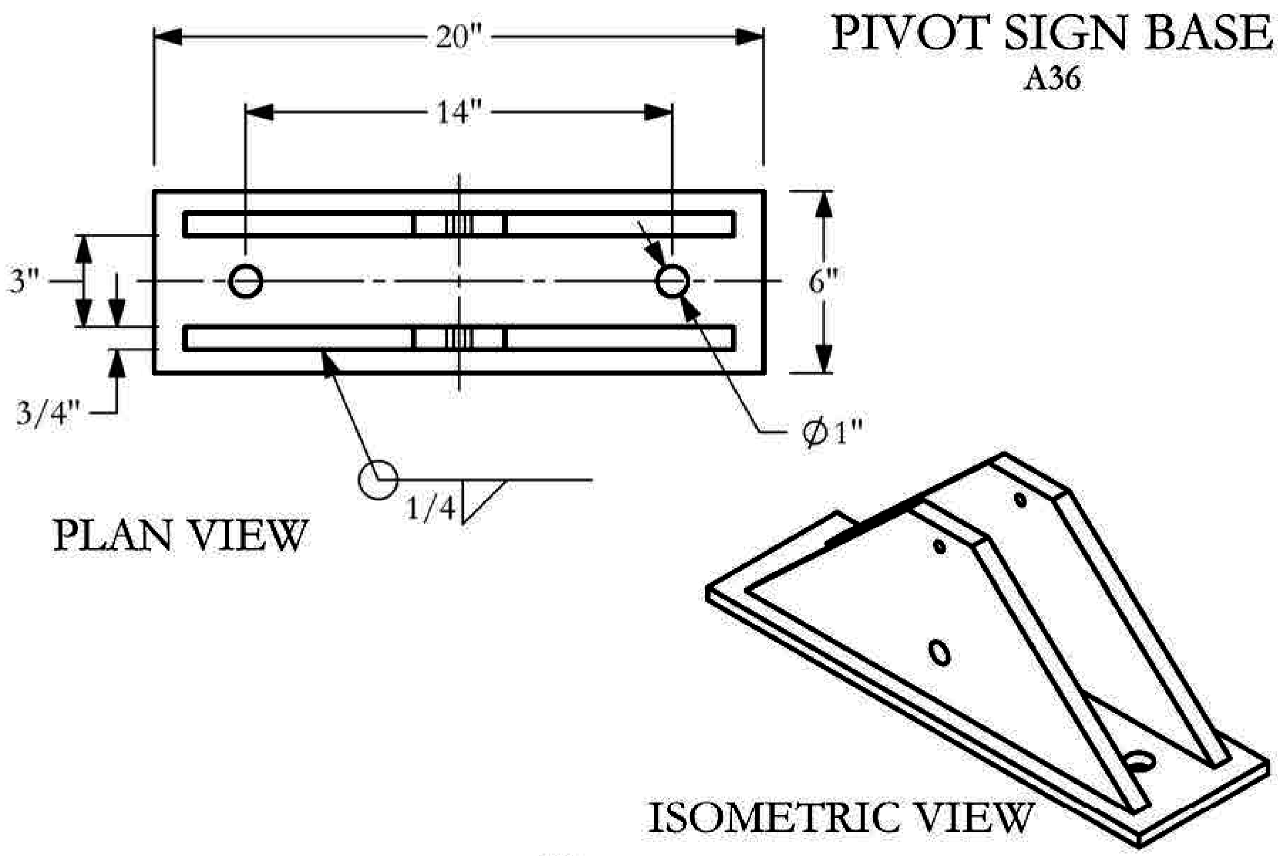


Figure 6.12. Isometric and Plan Views of the Bracket and Sacrificial Pin Sign Support.

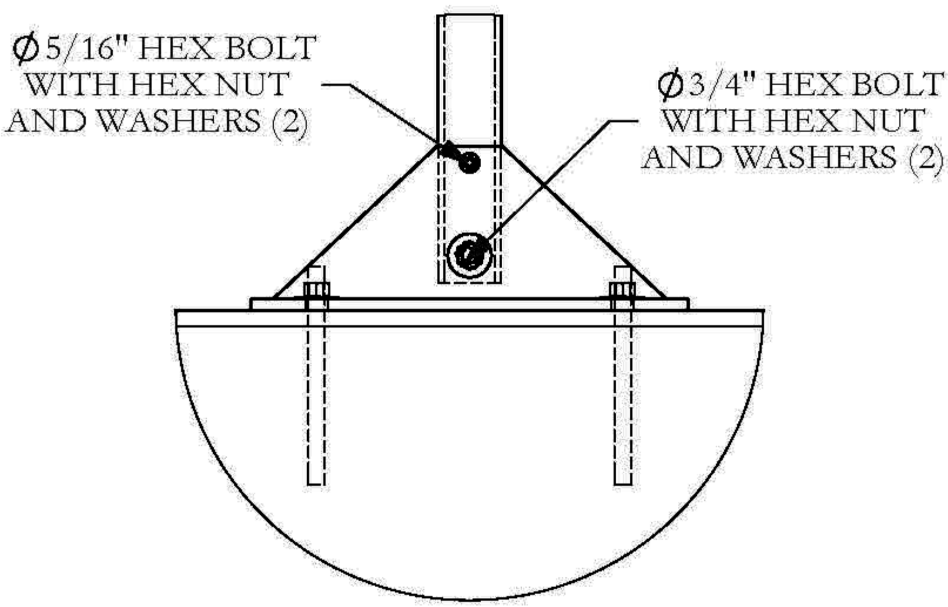


Figure 6.13. Mounting Assembly.

Figure 6.14. Bracket and Sacrificial Pin Sign Support on CMB before Test No. 466462-2a.

6.4.2 Target and Actual Impact Conditions

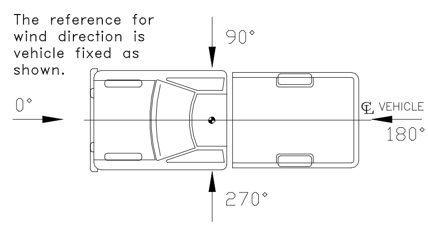
MASH test 3-11 involves a 2270P vehicle weighing 5000 lb ±100 lb and impacting the barrier at an impact speed of 62.2 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target impact point was 36 inches upstream of the bracket and sacrificial pin sign support. The 2007 Dodge Ram 1500 pickup truck used in the test weighed 4995 lb and the actual impact speed and angle were 63.0 mi/h and 25.0 degrees, respectively. The actual impact point was 34.2 inches upstream of the bracket and sacrificial pin sign support. Target IS was 115.2 kip*ft, and actual IS was 119.1 kip*ft, where IS is required to be no less than 8 percent.

6.4.3 Test Vehicle

A 2007 Dodge Ram 1500 pickup truck, shown in Figures 6.15 and 6.16, was used for the crash test. Test inertia weight of the vehicle was 4995 lb, and its gross static weight was 4995 lb. The height to the lower edge of the vehicle bumper was 13.75 inches, and it was 25.38 inches to the upper edge of the bumper. The height to the vehicle's center of gravity was 28.12 inches. Tables D1 and D2 in Appendix D3 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be unrestrained just prior to impact.

6.4.4 Weather Conditions

The test was performed on the morning of June 6, 2012. Weather conditions at the time of testing were as follows: wind speed: 6 mi/h; wind direction: 180 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 87°F, relative humidity: 59 percent.



6.4.5 Test Description

The 2007 Dodge Ram 1500 pickup truck, traveling at an impact speed of 63.2 mi/h, impacted the barrier 34.2 inches upstream of the bracket and sacrificial pin sign support, at an impact angle of 25.0 degrees. At approximately 0.026 s after impact, the right front corner of the vehicle contacted the sign support, and the vehicle began to redirect at 0.030 s. The support began to deflect toward the side opposite impact at 0.040 s, and the vehicle began traveling parallel with the barrier at 0.193 s. The rear of the vehicle contacted the barrier at 0.204 s, and the vehicle lost contact with the sign support at 0.251 s. At 0.301 s, the vehicle lost contact with the barrier and was traveling at an exit speed and angle of 49.5 mi/h and 2.5 degrees. Brakes on the vehicle were applied at 1.35 s, and the vehicle subsequently came to rest 177 ft downstream of impact with the centerline of the vehicle aligned with the centerline of the barrier and the vehicle facing toward the field side. Figure D1 in Appendix D4 show sequential photographs of the test period.

Figure 6.15. Vehicle/Bracket and Sacrificial Pin Sign Support on CMB Geometrics for Test No. 466462-2a.

Figure 6.16. Vehicle before Test No. 466462-2a.

6.4.6 Damage to Test Installation

Figures 6.17 and 6.18 show damage to the bracket and sacrificial pin sign support and barrier. The barrier face was marred with tire marks and scrapings. The sign support was leaning downstream and several small pieces of the sheet metal from the vehicle were found in the pivot channel. The 2270P vehicle was in contact with the barrier 140 inches. Vehicle penetration (formerly working width) was 14.3 inches. No movement was noted in the barrier.

6.4.7 Vehicle Damage

Figure 6.19 presents the damage sustained by the vehicle. The right upper and lower ball joints, right upper and lower A-arms, and the right frame rail were deformed. The front bumper, hood, right front fender, right front door and door glass, right rear cab corner right exterior bed, right rear door, right front tire and wheel rim, right rear tire and wheel rim, and rear bumper were also damaged. Maximum exterior crush to the vehicle was 13.0 inches in the side plane at the right front corner at bumper height. Maximum occupant compartment deformation caused by interaction with the sign support and barrier was 2.5 inches in the firewall area on the right side. Figure 6.20 show the interior of the vehicle. Tables D3 and D4 in Appendix D3 provide maximum exterior crush and occupant compartment deformation of the vehicle.

6.4.8 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 19.7 ft/s at 0.089 s, the highest 0.010-s occupant ridedown acceleration was 4.2 Gs from 0.220 to 0.230 s, and the maximum 0.050-s average acceleration was −9.0 Gs between 0.020 and 0.070 s. In the lateral direction, the occupant impact velocity was 26.9 ft/s at 0.089 s, the highest 0.010-s occupant ridedown acceleration was 8.0 Gs from 0.221 to 0.231 s, and the maximum 0.050-s average was −15.1 Gs between 0.036 and 0.086 s. THIV was 37.0 km/h or 10.3 m/s at 0.088 s; PHD was 8.8 Gs between 0.221 and 0.231 s; and ASI was 1.83 between 0.036 and 0.086 s. Figure 6.21 summarizes the data and other pertinent information from the test. Vehicle angular displacements and accelerations versus time traces are presented in Appendix D5, Figure D2 and Appendix D6, Figures D3 through D8, respectively.

Figure 6.17. Vehicle/Bracket and Sacrificial Pin Sign Support on CMB after Test No. 466462-2a.

Figure 6.18. Bracket and Sacrificial Pin Sign Support on CMB after Test No. 466462-2a.

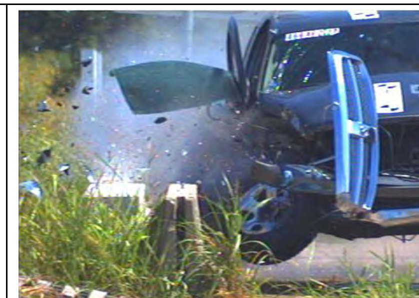
Figure 6.19. Vehicle after Test No. 466462-2a.

Figure 6.20. Interior of Vehicle for Test No. 466462-2a.

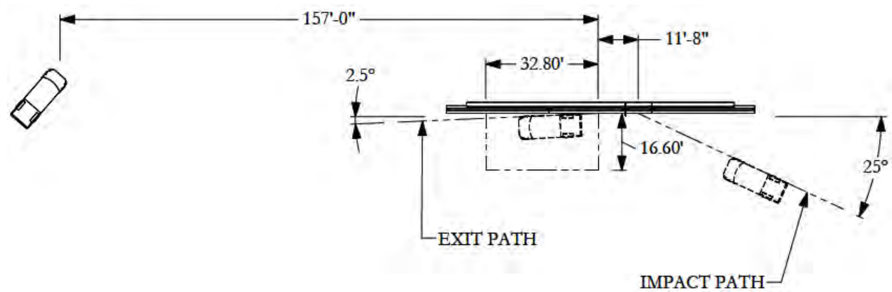
0.000 s

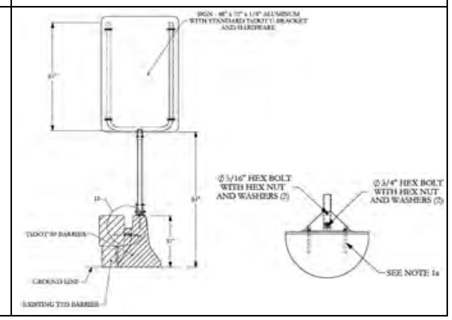
0.120 s

0.240 s



0.360 s





General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-11
TTI Test No.	466462-2a
Test Date	2012-07-06
Test Article	
Type	Sign Support on CMB
Name	Bracket & Sacrificial Pin Sign Support
Installation Length/Height	Barrier 90 ft long × 32 inches high/ Sign mounting height at 84.5 inches
Material or Key Elements	xxx
Soil Type and Condition	Barrier placed on concrete surface, dry
Test Vehicle	
Type/Designation	2270P
Make and Model	2007 Dodge Ram 1500 Pickup
Curb	4936 lb
Test Inertial	4995 lb
Dummy	No dummy
Gross Static	4995 lb

Impact Conditions	
Speed	63.2 mi/h
Angle	25.0 degrees
Impact Severity	119.1 kip*ft
Location/Orientation	34.2 inches upstrm of sign support
Exit Conditions	
Speed	49.5 mi/h
Angle	2.5 degrees
Occupant Risk Values	
Impact Velocity	
Longitudinal	19.7 ft/s
Lateral	26.9 ft/s
Ridedown Accelerations	
Longitudinal	4.2 G
Lateral	8.0 G
THIV	37.0 km/h
PHD	8.8 G
ASI	1.83
Max. 0.050-s Average	
Longitudinal	-9.0 G
Lateral	-15.1 G
Vertical	-4.8 G

Post-Impact Trajectory	
Stopping Distance	177 ft dwnstrm Aligned w/CMB
Vehicle Stability	
Maximum Yaw Angle	26 degrees
Maximum Pitch Angle	9 degrees
Maximum Roll Angle	8 degrees
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	None measureable
Permanent	None measureable
Working Width	None measureable
Vehicle Penetration	14.3 inches
Vehicle Damage	
VDS	01RFQ5
CDC	01FREW4
Max. Exterior Deformation	13.0 inches
OCDI	RF0020000
Max. Occupant Compartment Deformation	2.5 inches

Figure 6.21. Summary of Results for *MASH* Test 3-11 on the Bracket and Sacrificial Pin Sign Support on CMB.

6.4.9 Assessment of Test Results – Bracket and Sacrificial Pin Sign Support on CMB

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

6.4.9.1 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 barrier on which the bracket and sacrificial pin sign support was mounted contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. The sign support did not interfere with the ability of the barrier to contain and redirect the vehicle. No movement of the barrier was noted. (PASS)

6.4.9.2 Occupant Risk

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

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

Results: No detached elements, fragments, or other debris from the barrier or the sign support was present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. (PASS)

Maximum occupant compartment deformation caused by interaction with the sign support and barrier was 1.5 inches in the floor pan on the right side. (PASS)

F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.

Results: The 2270 vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 8 degrees and 9 degrees, respectively. (PASS)

H. Occupant impact velocities should satisfy the following:

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
30 ft/s	*40 ft/s*

Results: Longitudinal occupant impact velocity was 19.7 ft/s, and lateral occupant impact velocity was 26.9 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Maximum longitudinal ridedown acceleration was 4.2 G, and maximum lateral ridedown acceleration was 8.0 G. (PASS)

6.4.9.3 Vehicle Trajectory

For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).

Result: The 2270P vehicle crossed the exit box within the specified criteria. (PASS)

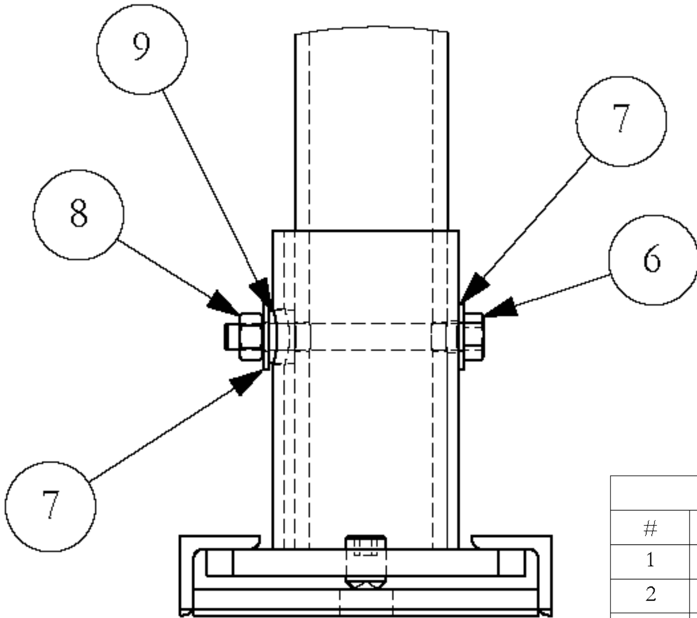
6.4.10 Conclusions – Bracket and Sacrificial Pin Sign Support on CMB

The CMB with bracket and sacrificial pin sign support mounted on top performed acceptably for *MASH* test 3-11.

6.5 CRASH TEST NO. 466462-3 ON THE CHUTE CHANNEL SIGN SUPPORT ON CMB

6.5.1 Test Article Design and Construction – Chute Channel Sign Support on CMB

In the installation for test 466462-3, the sign post is mounted to a collar and slide assembly. The collar and slide assembly is placed in the middle of the 76-inch long chute with four screw sets to prevent it from sliding due to wind loading. The built up chute is mounted to the top face of the barrier using two anchor rods at each end; each is 8-inch long, ¾-inch diameter. Figure 6.22 shows the collar and slide assembly and the chute details. Additional details are provided in Appendix E1 and E2. Figure 6.13 presents photographs of the completed installation prior to test 466462-3.



SIGN ASSEMBLY PARTS		
#	PART NAME	QTY.
1	Slide Assembly	1
2	Pipe, 2-1/2" sch. 80	1
3	Sign, 1/8" thick aluminum	1
4	U-Bracket	1
5	Sign Attachment Bracket	4
6	Bolt, 1/2 x 4-1/2 hex	2
7	Washer, 1/2 flat	4
8	Nut, 1/2 hex	2
9	Bushing, McMaster-Carr #92415A147	1

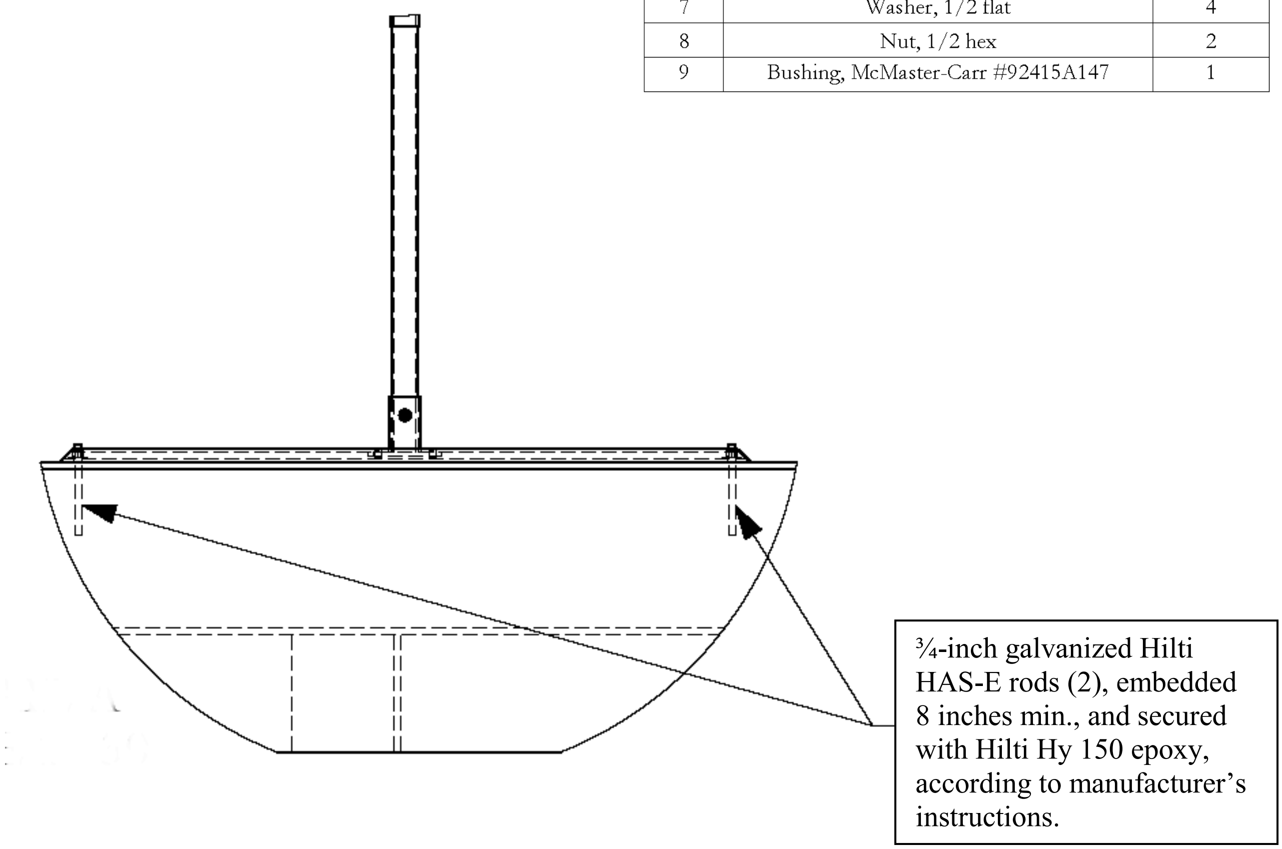


Figure 6.22. Details of the Chute Channel Sign Support on CMB.

Figure 6.23. Chute Channel Sign Support on CMB before Test No. 466462-3.

6.5.2 Target and Actual Impact Conditions

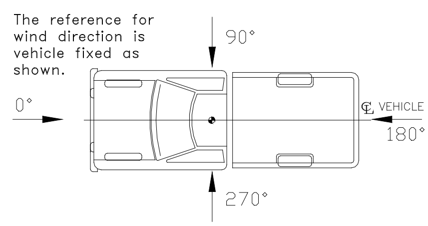
MASH test 3-11 involves a 2270P vehicle weighing 5000 lb ±100 lb and impacting the test article at an impact speed of 62.2 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target impact point was 42.5 inches upstream of the sign support post. The 2006 Dodge Ram 1500 pickup used in the test weighed 5029 lb and the actual impact speed and angle were 62.9 mi/h and 24.4 degrees, respectively. The actual impact point was 34.7 inches upstream from the centerline of the sign support. Target IS was 115.2 kip*ft, and actual IS was 118.8 kip*ft, where IS is required to be no less than 8 percent.

6.5.3 Test Vehicle

A 2006 Dodge Ram 1500 pickup, shown in Figures 6.24 and 6.25, was used for the crash test. Test inertia weight of the vehicle was 5029 lb, and its gross static weight was 5029 lb. The height to the lower edge of the vehicle bumper was 13.75 inches, and it was 25.38 inches to the upper edge of the bumper. The height to the vehicle's center of gravity was 28.19 inches. Tables E1 and E2 in Appendix E3 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.

6.5.4 Weather Conditions

The test was performed on the morning of August 16, 2012. Weather conditions at the time of testing were as follows: wind speed: 11 mi/h; wind direction: 205 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 89°F, relative humidity: 64 percent.



6.5.5 Test Description

The 2006 Dodge Ram 1500 pickup, traveling at an impact speed of 62.9 mi/h, impacted barrier with the chute channel sign support mounted on top 34.7 inches upstream of the centerline of the sign support at an impact angle of 24.4 degrees. At approximately 0.027 s after impact, the vehicle contacted the chute channel sign support, and at 0.047 s, the vehicle began to redirect. The sign support began to slide down the chute at 0.052 s, and the vehicle lost contact with the sign support at 0.104 s. The sign support stopped sliding down the chute at 0.126 s, and the rear of the vehicle contacted the barrier at 0.0183 s. At 0.359 s, the vehicle lost contact with the barrier and was traveling at an exit speed and angle of 51.5 mi/h and 5.1 degrees, respectively. Brakes on the vehicle were applied at 1.33 s, and the vehicle came to rest 220 ft downstream of impact and 67 ft toward traffic lanes from the traffic face of the barrier. Figures E1 and E2 in Appendix E4 show sequential photographs of the test period.

Figure 6.24. Vehicle/Chute Channel Sign Support on CMB Geometrics for Test No. 466462-3.

Figure 6.25. Vehicle before Test No. 466462-3.

6.5.6 Damage to Test Installation

Figures 6.26 and 6.27 present the damage to the barrier and the chute channel sign support mounted on top the barrier. The sight support slid down the chute 27.6 inches, and the flange on the impact side of the chute was deformed upward 0.25 inch 18 inches downstream of centerline (see Figure 6.23). Vehicle penetration (formerly working width) was 25.9 inches. The vehicle was in contact with the barrier 148 inches.

6.5.7 Vehicle Damage

Figure 6.28 shows damage to the 2270P vehicle. The right front frame rail and right upper and lower A-arms were deformed. Also damaged were the front bumper, hood, right front tire and wheel rim, right front fender, right front door and door glass, right rear door, right rear corner of the exterior cab, right exterior bed, right rear wheel rim, rear bumper, and tailgate. The windshield sustained stress cracks in the right lower corner. Maximum exterior crush to the vehicle was 14.0 inches in the side plane at the right front corner at bumper height. Maximum occupant compartment deformation was 1.75 inches in the right side firewall area. Figure 6.29 presents the interior of the vehicle. Tables E3 and E4 in Appendix E3 provide maximum exterior crush and occupant compartment deformation of the vehicle.

6.5.8 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 16.4 ft/s at 0.090 s, the highest 0.010-s occupant ridedown acceleration was 4.5 Gs from 0.180 to 0.190 s, and the maximum 0.050-s average acceleration was −8.5 Gs between 0.021 and 0.071 s. In the lateral direction, the occupant impact velocity was 28.5 ft/s at 0.090 s, the highest 0.010-s occupant ridedown acceleration was 9.0 Gs from 0.200 to 0.210 s, and the maximum 0.050-s average was −16.4 Gs between 0.038 and 0.088 s. THIV was 36.8 km/h or 10.2 m/s at 0.088 s; PHD was 9.0 Gs between 0.200 and 0.210 s; and ASI was 1.94 between 0.038 and 0.088 s. Figure 6.30 summarizes the data and other pertinent information from the test. Vehicle angular displacements and accelerations versus time traces are presented in Appendix E5, Figure E3 and Appendix E6, Figures E4 through E9, respectively.

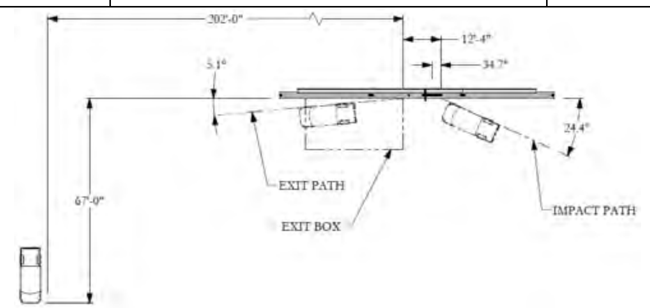
Figure 6.26. Vehicle/Chute Channel Sign Support on CMB after Test No. 466462-3.

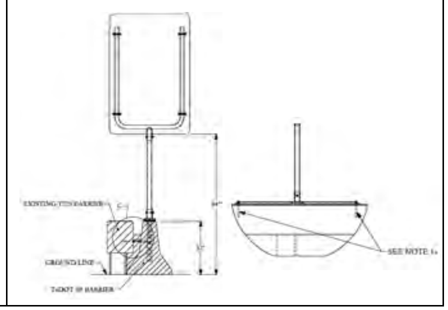
Figure 6.27. Chute Channel Sign Support on CMB after Test No. 466462-3.

Figure 6.28. Vehicle after Test No. 466462-3.

Figure 6.29. Interior of Vehicle for Test No. 466462-3.

0.000 s | 0.110 s | 0.220 s | 0.330 s





General Information
Test Agency .... Texas A&M Transportation Institute (TTI)
Test Standard Test No. .... *MASH* Test 3-11
TTI Test No. 466462-3
Test Date 2012-08-16
Test Article
Type .... Sign Support on CMB
Name .... Chute Channel Sign Support
Installation Length/Height ...... Barrier 90 ft long × 32 inches high/ Sign mounting height at 85.5 inches
Material or Key Elements xxx
Soil Type and Condition .... Barrier placed on concrete surface, dry
Test Vehicle
Type/Designation 2270P
Make and Model.................... 2006 Dodge Ram 1500 Pickup
Curb .... 5118 lb
Test Inertial .... 5029 lb
Dummy.................................. No dummy
Gross Static.......................... 5029 lb

Impact Conditions
Speed ....62.9 mi/h
Angle ....24.4 degrees
Impact Severity.................118.8 kip*ft
Location/Orientation ....34.7 inches upstrm support
Exit Conditions
Speed ....51.5 mi/h
Angle ....5.1 degrees
Occupant Risk Values
Impact Velocity
Longitudinal...................16.4 ft/s
Lateral ....28.5 ft/s
Ridedown Accelerations
Longitudinal...................4.5 G
Lateral ....9.0 G
THIV ....36.8 km/h
PHD ....9.0 G
ASI 1.94
Max. 0.050-s Average
Longitudinal...................-8.5 G
Lateral ....-16.4 G
Vertical ....-4.2 G

Post-Impact Trajectory
Stopping Distance .... 220 ft dwnstrm 67 ft twd traffic
Vehicle Stability
Maximum Yaw Angle................. 31 degrees
Maximum Pitch Angle................ 10 degrees
Maximum Roll Angle.................. 11 degrees
Vehicle Snagging....................... No
Vehicle Pocketing...................... No
Test Article Deflections
Dynamic .... None measureable
Permanent................................ None measureable
Working Width .... None measureable
Vehicle Penetration .... 25.9 inches
Vehicle Damage
VDS.. 01RFQ4
CDC 01FREW3
Max. Exterior Deformation .... 14.0 inches
OCDI RF0010000
Max. Occupant Compartment Deformation......................... 1.75 inches

Figure 6.30. Summary of Results for *MASH* Test 3-11 on the Chute Channel Sign Support on CMB.

6.5.9 Assessment of Test Results

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

6.5.9.1 Structural Adequacy

A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.

<u>Results</u>: The barrier on which the chute channel sign support was mounted contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. The sign support did not interfere with the ability of the barrier to contain and redirect the vehicle. No movement of the barrier was noted. (PASS)

6.5.9.2 Occupant Risk

D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.
Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 inches).

<u>Results</u>: No detached elements, fragments, or other debris from the barrier or the sign support was present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. (PASS)
Maximum occupant compartment deformation caused by interaction with the sign support and barrier was 1.75 inches in the firewall on the right side. (PASS)

F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.

Results: The 2270 vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 11 degrees and 10 degrees, respectively. (PASS)

H. Occupant impact velocities should satisfy the following:

Longitudinal and Lateral Occupant Impact Velocity	
Preferred	*Maximum*
30 ft/s	*40 ft/s*

Results: Longitudinal occupant impact velocity was 16.4 ft/s, and lateral occupant impact velocity was 28.5 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations	
Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Longitudinal occupant ridedown acceleration was 4.5 G, and lateral occupant ridedown acceleration was 9.0 G. (PASS)

6.5.9.3 Vehicle Trajectory

For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).

Result: The 2270P vehicle crossed the exit box within the specified criteria. (PASS)

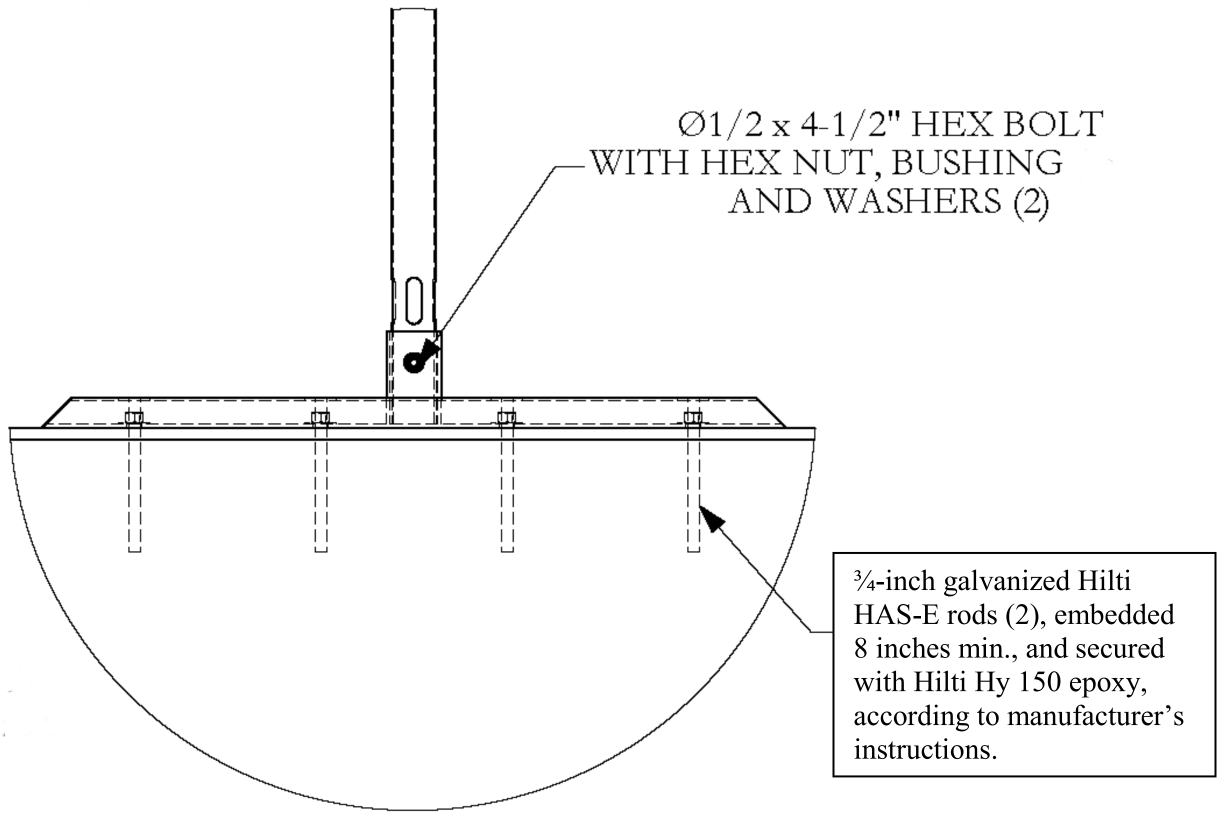
6.5.10 Conclusions

The CMB with chute channel sign support mounted on top performed acceptably for *MASH* test 3-11.

6.6 CRASH TEST NO. 466462-4 ON SLOTTED 10 BWG SIGN SUPPORT ON CMB

6.6.1 Test Article Design and Construction – Slotted 10 BWG Sign Support on CMB

The installation for test 466462-4 uses the same post mounting assembly incorporated in test 46646-1 except for the sign post. The sign post is 10 BWG with four symmetrical 3-inch long slots placed around the post just above the schedule 40 collar. There is a bushing between the post and the collar on the ¾-inch bolt that goes though the sign post and the collar. This bushing helps reduce the post from vibrating within the collar. Figure 6.31 shows details of the 10 BWG slotted sign post, and additional details may be found in Appendix F1 and F2. Figure 6.32 presents photographs of the completed installation for test 466462-4.



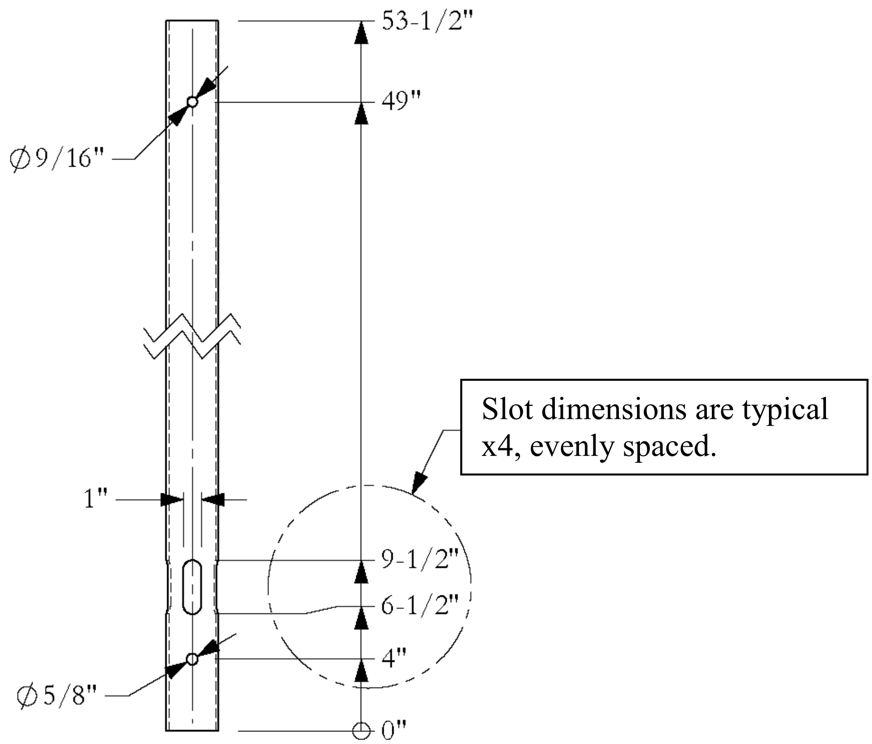


Figure 6.31. Details of the Slotted 10 BWG Sign Support.

Figure 6.32. Slotted 10 BWG Sign Support on CMB before Test No. 466462-4.

6.6.2 Target and Actual Impact Conditions

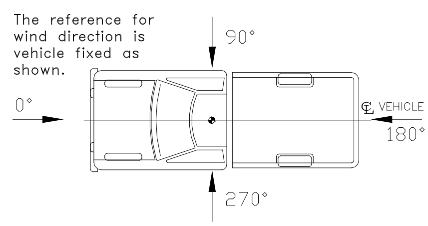
MASH test 3-11 involves a 2270P vehicle weighing 5000 lb ±100 lb and impacting the test article at an impact speed of 62.2 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target impact point was 42.5 inches upstream of the sign support. The 2006 Dodge Ram 1500 pickup truck used in the test weighed 5011 lb, and the actual impact speed and angle were 62.5 mi/h and 25.8 degrees, respectively. The actual impact point was 43.0 inches upstream of the centerline of the sign support. Target IS was 115.2 kip*ft, and actual IS was 124.0 kip*ft, where IS is required to be no less than 8 percent.

6.6.3 Test Vehicle

The 2006 Dodge Ram 1500 pickup truck, shown in Figures 6.33 and 6.34, was used for the crash test. Test inertia weight of the vehicle was 5011 lb, and its gross static weight was 5011 lb. The height to the lower edge of the vehicle bumper was 13.75 inches, and it was 25.38 inches to the upper edge of the bumper. The height to the vehicle's center of gravity was 28.50 inches. Tables F1 and F2 in Appendix F3 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.

6.6.4 Weather Conditions

The test was performed on the afternoon of August 28, 2012. Weather conditions at the time of testing were as follows: wind speed: 9 mi/h; wind direction: 355 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 95°F, relative humidity: 48 percent.



6.6.5 Test Description

The 2006 Dodge Ram 1500 pickup truck, traveling at an impact speed of 62.5 mi/h, impacted the barrier on which the slotted 10 BWG sign support was mounted at 43.0 inches upstream of the sign support at 25.8 degrees. At approximately 0.024 s after impact, the vehicle began to redirect, and at 0.030 s, the right front corner of the vehicle contacted the sign support. The vehicle lost contact with the support at 0.106 s, and the vehicle became parallel with the barrier at 0.191 s. The rear of the vehicle contacted the barrier at 0.211 s, and then contacted the sign support at 0.226 s. At 0.320 s, the vehicle lost contact with the barrier and was traveling at an exit speed and angle of 49.4 mi/h and 3.5 degrees, respectively. Brakes on the vehicle were applied at 1.49 s after impact, and the vehicle subsequently came to rest 200 ft downstream of impact and aligned with the traffic face of the barrier. Figures F1 and F2 in Appendix F4 show sequential photographs of the test period.

Figure 6.33. Vehicle/Slotted 10 BWG Sign Support on CMB Geometrics for Test No. 466462-4.

Figure 6.34. Vehicle before Test No. 466462-4.

6.6.6 Damage to Test Installation

Figures 6.35 and 6.36 present the damage to the barrier and the slotted 10 BWG sign support mounted on top the barrier. The sight support was leaning downstream at 115 degrees and toward the field side 89.0 inches (working width). The 2270P vehicle was in contact with the barrier 164.5 inches. Vehicle penetration (formerly working width) was 20.6 inches. No movement was noted in the barrier.

6.6.7 Vehicle Damage

Figure 6.37 shows the damage sustained by the vehicle. The right front upper and lower A-arms and right frame rail were deformed. Also damaged were the front bumper, grill, radiator and supports, hood, right front tire and wheel rim, right front fender, right front and rear doors, right rear exterior bed, right rear wheel rim, rear bumper, and left rear wheel rim. Maximum exterior crush to the vehicle was 18.0 inches in the side plane at bumper height at the right front corner. Maximum occupant compartment deformation was 3.0 inches in the firewall on the right side. Tables F3 and F4 in Appendix F3 provide maximum exterior crush and occupant compartment deformation of the vehicle.

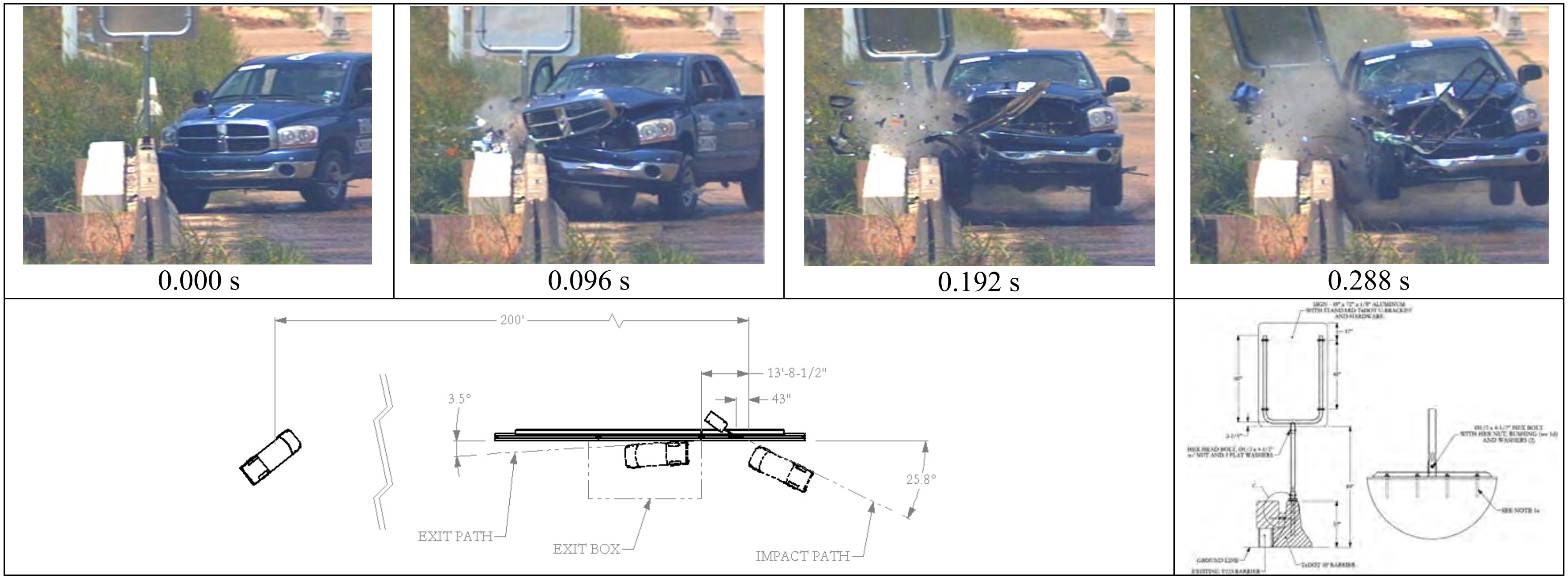
6.6.8 Occupant Risk Factors

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 20.0 ft/s at 0.088 s, the highest 0.010-s occupant ridedown acceleration was 5.1 Gs from 0.096 to 0.106 s, and the maximum 0.050-s average acceleration was −9.9 Gs between 0.020 and 0.070 s. In the lateral direction, the occupant impact velocity was 28.2 ft/s at 0.088 s, the highest 0.010-s occupant ridedown acceleration was 7.4 Gs from 0.227 to 0.237 s, and the maximum 0.050-s average was −16.0 Gs between 0.030 and 0.080 s. THIV was 38.4 km/h or 10.7 m/s at 0.087 s; PHD was 7.7 Gs between 0.227 and 0.237 s; and ASI was 1.91 between 0.032 and 0.082 s. Figure 6.38 summarizes these data and other pertinent information from the test. Vehicle angular displacements and accelerations versus time traces are presented in Appendix F5, Figure F3 and Appendix F6, Figures F4 through F9.

Figure 6.35. Vehicle/Slotted 10 BWG Sign Support on CMB after Test No. 466462-4.

Figure 6.36. Slotted 10 BWG Sign Support on CMB after Test No. 466462-4.

Figure 6.37. Vehicle after Test No. 466462-4.



General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	*MASH* Test 3-11
TTI Test No.	466462-4
Test Date	2012-08-28
Test Article	
Type	Sign Support on CMB
Name	Slotted 10 BWG Sign Support
Installation Length/Height	Barrier 90 ft long × 32 inches high/ Sign mounting height at 84.5 inches
Material or Key Elements	xxx
Soil Type and Condition	Barrier placed on concrete surface, dry
Test Vehicle	
Type/Designation	2270P
Make and Model	2006 Dodge Ram 1500 Pickup
Curb	4868 lb
Test Inertial	5011 lb
Dummy	No dummy
Gross Static	5011 lb

Impact Conditions	
Speed	62.5 mi/h
Angle	25.8 degrees
Impact Severity	124.0 kip*ft
Location/Orientation	43.0 inches upstrm of support
Exit Conditions	
Speed	49.4 mi/h
Angle	3.5 degrees
Occupant Risk Values	
Impact Velocity	
Longitudinal	20.0 ft/s
Lateral	28.2 ft/s
Ridedown Accelerations	
Longitudinal	5.1 G
Lateral	7.4 G
THIV	38.4 km/h
PHD	7.7 G
ASI	1.91
Max. 0.050-s Average	
Longitudinal	-9.9 G
Lateral	-16.0 G
Vertical	-4.1 G

Post-Impact Trajectory	
Stopping Distance	200 ft dwnstrm Aligned w/CMB
Vehicle Stability	
Maximum Yaw Angle	30 degrees
Maximum Pitch Angle	9 degrees
Maximum Roll Angle	13 degrees
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	None measureable
Permanent	None measureable
Working Width (sign panel)	89.0 inches
Vehicle Penetration	20.6 inches
Vehicle Damage	
VDS	01RFQ4
CDC	01FREW30
Max. Exterior Deformation	18.0 inches
OCDI	RF0020000
Max. Occupant Compartment Deformation	3.0 inches

Figure 6.38. Summary of Results for *MASH* Test 3-11 on the Slotted 10 BWG Sign Support on CMB.

6.6.9 Assessment of Test Results

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

6.6.9.1 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 barrier on which the slotted 10 BWG sign support was mounted contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. The sign support did not interfere with the ability of the barrier to contain and redirect the vehicle. No movement of the barrier was noted. (PASS)

6.6.9.2 Occupant Risk

D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.
Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 inches).

Results: No detached elements, fragments, or other debris from the barrier or the sign support was present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. (PASS)
Maximum occupant compartment deformation caused by interaction with the sign support and barrier was 3.0 inches in the firewall on the right side. (PASS)

F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.

Results: The 2270 vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 13 degrees and 9 degrees, respectively. (PASS)

H. Occupant impact velocities should satisfy the following:

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
30 ft/s	*40 ft/s*

Results: Longitudinal occupant impact velocity was 20.0 ft/s, and lateral occupant impact velocity was 28.2 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Longitudinal occupant ridedown acceleration was 5.1 G, and lateral occupant ridedown acceleration was 7.4 G. (PASS)

6.6.9.3 Vehicle Trajectory

For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).

Result: The 2270P vehicle crossed the exit box within the specified criteria. (PASS)

6.6.10 Conclusions

The CMB with slotted 10 BWG sign support mounted on top performed acceptably for *MASH* test 3-11.

CHAPTER 7. SUMMARY AND CONCLUSIONS

7.1 SUMMARY OF CRASH TEST RESULTS

7.1.1 Crash Test No. 466462-1 on the Spread Tube Sign Support System Mounted on CMB

The barrier on which the spread tube sign support system was mounted contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. The sign support did not interfere with the ability of the barrier to contain and redirect the vehicle. No movement in the barrier was seen. No detached elements, fragments, or other debris from the barrier or the sign support was present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Deformation of 7.5 inches was noted in the windshield; this was caused by the hood of the vehicle and not from interaction with the sign support or barrier. Maximum occupant compartment deformation caused by interaction with the sign support and barrier was 1.5 inches in the floor pan on the right side. The 2270 vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 12 degrees and 9 degrees, respectively. Occupant risk factors were within the limits specified in *MASH*. The 2270P vehicle crossed the exit box within the specified criteria.

7.1.2 Crash Test No. 466462-2a on the Bracket and Sacrificial Pin Sign Support Mounted on CMB

The barrier on which the bracket and sacrificial pin sign support was mounted contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. The sign support did not interfere with the ability of the barrier to contain and redirect the vehicle. No movement of the barrier was seen. No detached elements, fragments, or other debris from the barrier or the sign support was present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation caused by interaction with the sign support and barrier was 1.5 inches in the floor pan on the right side. The 2270 vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 8 degrees and 9 degrees, respectively. Occupant risk factors were within the limits specified in *MASH*. The 2270P vehicle crossed the exit box within the specified criteria.

7.1.3 Crash Test No. 466462-3 on the Chute Channel Sign Support Mounted on CMB

The barrier on which the chute channel sign support was mounted contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. The sign support did not interfere with the ability of the barrier to contain and redirect the vehicle. No movement of the barrier was noted. No detached elements, fragments, or other debris from the barrier or the sign support was present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation caused by interaction with the barrier was 1.75 inches in the firewall on the right side. The 2270 vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 11 degrees and 10 degrees, respectively. Occupant risk factors were within the limits specified in *MASH*. The 2270P vehicle crossed the exit box within the specified criteria.

7.1.4 Crash Test No. 466462-4 on the Slotted 10 BWG Sign Support on CMB

The barrier on which the slotted 10 BWG sign support was mounted contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. The sign support did not interfere with the ability of the barrier to contain and redirect the vehicle. No movement of the barrier was noted. No detached elements, fragments, or other debris from the barrier or the sign support was present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation caused by interaction with the sign support and barrier was 3.0 inches in the firewall on the right side. The 2270 vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 13 degrees and 9 degrees, respectively. Occupant risk factors were within the limits specified in *MASH*. The 2270P vehicle crossed the exit box within the specified criteria.

7.2 CONCLUSIONS

The following sign support designs were crash tested mounted on a concrete median barrier, and were evaluated according to *MASH* guidelines for longitudinal barriers:

- Spread Tube Sign Support System.
- Bracket and Sacrificial Pin Sign Support System.
- Chute Channel Sign Support System.
- Slotted 10 BWG Sign Support System.

None of the above sign support systems interfered with the ability of the concrete median barrier to contain and redirect the 2270P vehicles. As indicated in Tables 7.1 through 7.4, each of the systems performed successfully according to the *MASH* criteria for longitudinal barriers.

Table 7.1. Performance Evaluation Summary for *MASH* Test 3-11 on the Spread Tube Sign Support System on CMB.

Test Agency: Texas A&M Transportation Institute — Test No.: 466462-1 — Test Date: 2012-06-11

***MASH* Test 3-11 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 barrier on which the sign support was mounted contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. The sign support did not interfere with the ability of the barrier to contain and redirect the vehicle. No movement in the barrier was seen.	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 barrier or the sign support was present to penetrate or to show potential for penetrating the occupant compartment, or to present 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.	Deformation of 7.5 inches was noted in the windshield; this was caused by the hood of the vehicle and not from interaction with the sign support or barrier. Maximum occupant compartment deformation caused by interaction with the sign support and barrier was 1.5 inches in the floor pan on the right side.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270 vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 12 degrees and 9 degrees, respectively.	Pass
H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.	Longitudinal occupant impact velocity was 21.6 ft/s, and lateral occupant impact velocity was 25.3 ft/s.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.	Maximum longitudinal ridedown acceleration was 5.2 G, and maximum lateral ridedown acceleration was 6.6 G.	Pass
Vehicle Trajectory *For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).*	The 2270P vehicle crossed the exit box within the specified criteria.	Pass

Table 7.2. Performance Evaluation Summary for *MASH* Test 3-11 on the Bracket and Sacrificial Pin on CMB.

Test Agency: Texas A&M Transportation Institute | Test No.: 466462-2a | Test Date: 2012-07-06

***MASH* Test 3-11 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 barrier on which the bracket and sacrificial pin sign support was mounted contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. The sign support did not interfere with the ability of the barrier to contain and redirect the vehicle.	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 barrier or the sign support was present to penetrate or to show potential for penetrating the occupant compartment, or to present 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 caused by interaction with the sign support and barrier was 1.5 inches in the floor pan on the right side.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270 vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 8 degrees and 9 degrees, respectively.	Pass
H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.	Longitudinal occupant impact velocity was 19.7 ft/s, and lateral occupant impact velocity was 26.9 ft/s.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.	Maximum longitudinal ridedown acceleration was 4.2 G, and maximum lateral ridedown acceleration was 8.0 G.	Pass
Vehicle Trajectory *For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).*	The 2270P vehicle crossed the exit box within the specified criteria.	Pass

Table 7.3. Performance Evaluation Summary for *MASH* Test 3-11 on the Chute Channel Sign Support on CMB.

Test Agency: Texas A&M Transportation Institute | Test No.: 466462-3 | Test Date: 2012-08-16

***MASH* Test 3-11 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 barrier on which the chute channel sign support was mounted contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. The sign support did not interfere with the ability of the barrier to contain and redirect the vehicle. No movement of the barrier was noted.	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 barrier or the sign support was present to penetrate or to show potential for penetrating the occupant compartment, or to present 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 caused by interaction with the barrier and sign support was 1.75 inches in the firewall on the right side.	Pass
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 2270 vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 11 degrees and 10 degrees, respectively.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.*	Longitudinal occupant impact velocity was 16.4 ft/s, and lateral occupant impact velocity was 28.5 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.*	Longitudinal occupant ridedown acceleration was 4.5 G, and lateral occupant ridedown acceleration was 9.0 G.	Pass
Vehicle Trajectory *For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).*	The 2270P vehicle crossed the exit box within the specified criteria.	

Table 7.4. Performance Evaluation Summary for *MASH* Test 3-11 on the Slotted 10 BWG Sign Support on CMB.

Test Agency: Texas A&M Transportation Institute — Test No.: 466462-4 — Test Date: 2012-08-28

***MASH* Test 3-11 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 barrier on which the slotted 10 BWG sign support was mounted contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. The sign support did not interfere with the ability of the barrier to contain and redirect the vehicle. No movement of the barrier was noted.	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 barrier or the sign support was present to penetrate or to show potential for penetrating the occupant compartment, or to present 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 caused by interaction with the sign support and barrier was 3.0 inches in the firewall on the right side.	Pass
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 2270 vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 13 degrees and 9 degrees, respectively.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.*	Longitudinal occupant impact velocity was 20.0 ft/s, and lateral occupant impact velocity was 28.2 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.*	Longitudinal occupant ridedown acceleration was 5.1 G, and lateral occupant ridedown acceleration was 7.4 G.	Pass
Vehicle Trajectory *For redirective devices, the vehicle shall exit the barrier within the exit box (not less than 32.8 ft).*	The 2270P vehicle crossed the exit box within the specified criteria.	Pass

CHAPTER 8. IMPLEMENTATION STATEMENT

New sign post on median barrier mounting designs have been developed and tested that allow placement of sign systems, with up to 4-ft × 6-ft sign, on permanent median or roadside barriers. These mounting designs were tested on the 32-inch tall NJ barrier because it is considered the most critical barrier profile. Hence, it is expected that these designs are applicable for F-shape and single slope profiles as long as they have a minimum of 32-inch height from the roadway surface.

This project developed crashworthy sign post mounting designs for placement on top of median barriers. Several concepts were developed during the early tasks of the project. Once these concepts were simulated, TxDOT prioritized them for further simulations and eventual crash testing.

The four concepts identified as having implementation potential are:

- Concept 6: Schedule 80 post mounted rigidly on a spreader tube.
- Concept 4: hinge and sacrificial pin design.
- Concept 1: Sliding base and chute design.
- Concept 8: slotted 10 BWG post (with 2-inch or 3-inch long slots).

The aforementioned concepts were simulated using a sign panel of 4 ft × 6 ft. The simulations indicated that these concepts were likely to pass *MASH* evaluation criteria, and subsequently all these concepts were crash tested under *MASH* TL 3-11 test conditions. Only the 3-inch long slot design variation was tested for Concept 8.

Once crash tested, all concepts passed *MASH* evaluation criteria. Incidentally, for Concept 6, the test vehicle had 7.5 inches of deformation of the windshield due to hood of the vehicle releasing during impact and rotating back toward the windshield. Nevertheless, Concepts 4, 1, and 8 passed all *MASH* evaluation criteria.

Hence, the recommended designs for implementations are:

- Concept 1: Sliding base and chute design.
- Concept 8: Slotted 10 BWG post with 3 inches long slots.
- Concept 4: Hinge and sacrificial pin design.

The sliding base and chute design (Concept 1) is the preferred design for implementation among the three listed above. The sign/post assembly would move along the chute once impacted by an errant pick-up. The sign for the slotted 10 BWG post (Concept 8) leaned down downstream and had 89.0 inches of maximum permanent deflection on the field side. So, Concept 8 will need enough clearance (i.e., wide shoulder width on the other side). Practically, Concept 8 should be used on roadside barriers or bridge rails. As for the hinge and sacrificial pin design (Concept 4), it did not activate in the crash test. Thus, it is not expected to activate for less severe impacts (nuisance hits). However, if activated, and the sign would lay down on the face of the barrier, then a clearance of 2 ft minimum is needed for the shoulder side on each side of the barrier.

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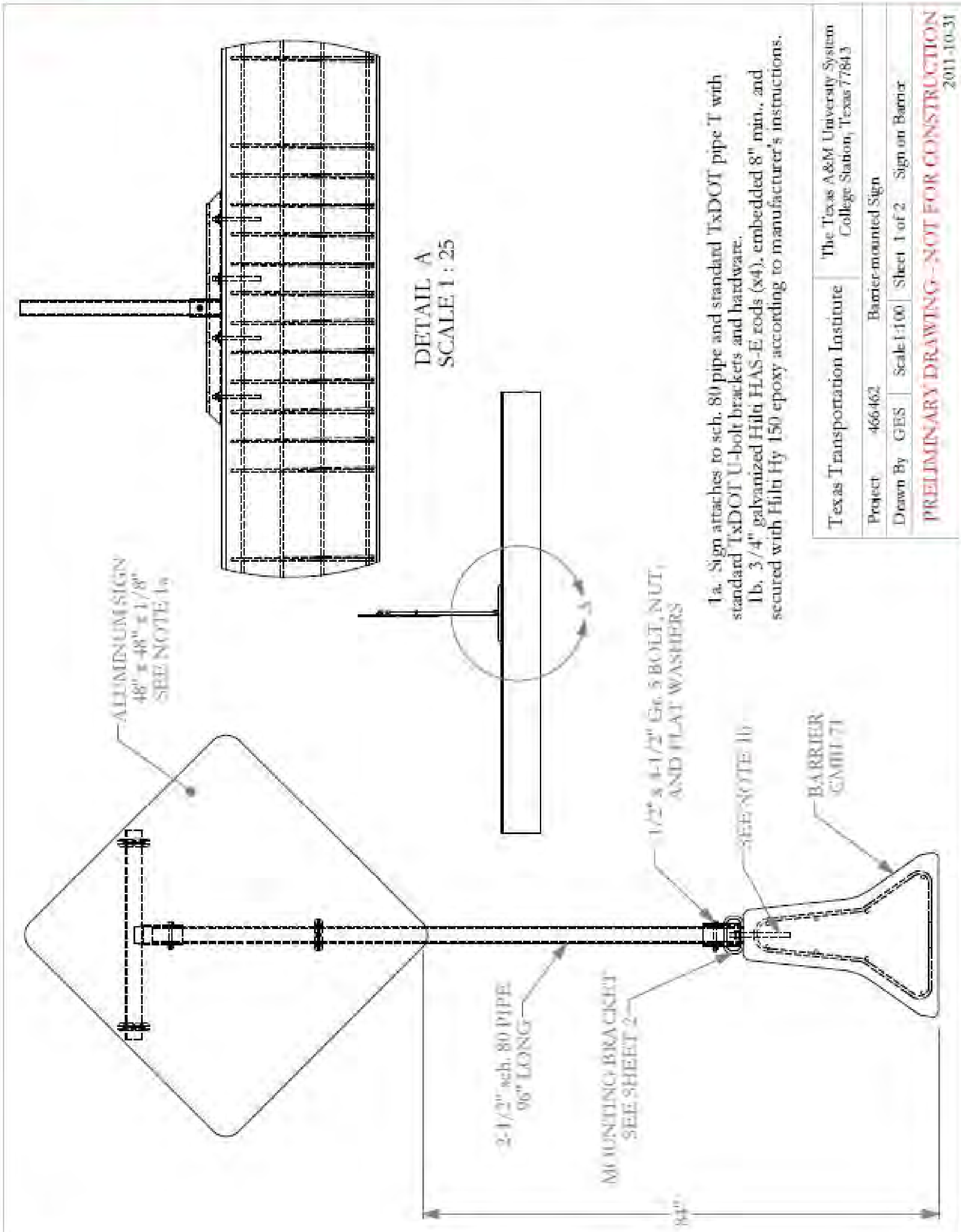
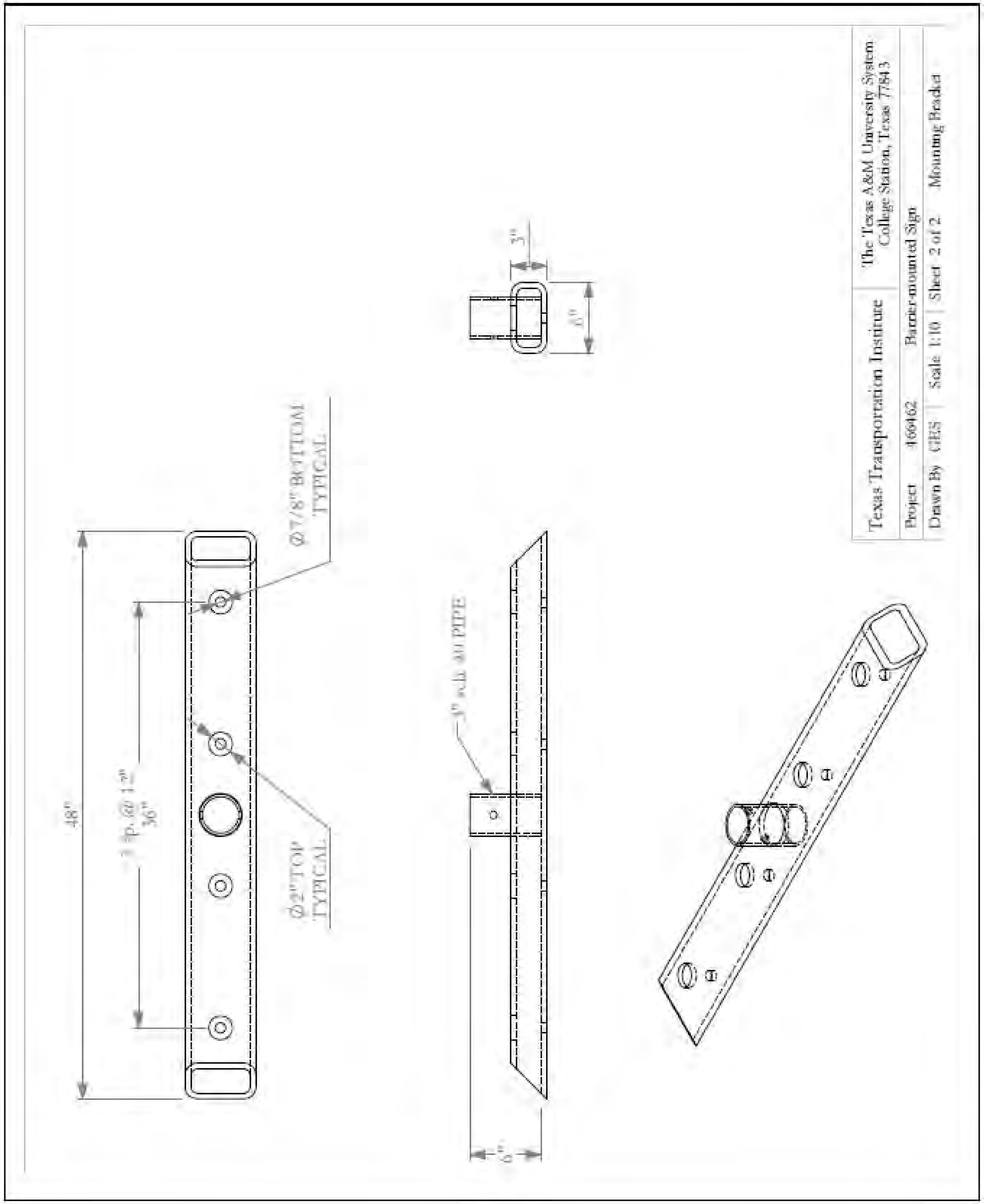
APPENDIX A. ENGINEERING CALCULATIONS

Texas Transportation Institute

Subject: TxDOT Project 0-6646 - Sign Mounts on Rigid Barriers - Concept 6




48"
3 sp. @ 12"
36"
Ø2" TOP
TYPICAL
Ø7/8" BOTTOM
TYPICAL
3" sch. 40 PIPE
6"
3"
6"
Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843
Project 466462
Barrier-mounted Sign
Drawn By CES
Scale 1:10
Sheet 2 of 2
Mounting Bracket

MCAD 14 CALCS.

Texas Transportation Institute

Subject: **TxDOT Project 0-6646 - Sign Mounts on Rigid Barriers- Concept 6**

1.) Design Input information:

1a.) Pipe post properties:

2.5" Dia. Schedule 80 Pipe

$Post_{od} := 2.875in$ $\quad F_{ypost} := 50ksi$

$Post_{id} := 2.323in$

$$Z_{post} := \frac{Post_{od}^{3}}{6} - \frac{Post_{id}^{3}}{6}$$

$Z_{post} = 1.871 \cdot in^{3}$

$S_{post} := 1.34in^{3}$

1b.) Sleeve Properties

3" Sch. 40 Pipe $\quad F_{ysleeve} := 50ksi$

$Sleeve_{od} := 3.5in$

$Sleeve_{id} := 3.068in$

$$Z_{tubesleeve} := \frac{Sleeve_{od}^{3}}{6} - \frac{Sleeve_{id}^{3}}{6}$$

$Z_{tubesleeve} = 2.333 \cdot in^{3}$

$S_{tubesleeve} := 1.72in^{3}$ Section modulus for the selected tube size

1c.) HSS6x3x1/4" Tube Properties

$Area_{tube} := 4.09in^{2}$

$J_{tube} := 15.1in^{4}$

2.) Crash Loads from Truck:

$F_x := 26.8\text{kips}$ Force on the sign in the longitudinal direction

$F_y := 2\text{kips}$ Force on the sign in the transverse direction

$d := 12.5\text{in}$ Height of force (in.)

$M_x := F_x \cdot d \qquad M_x = 27.917 \cdot \text{kip} \cdot \text{ft}$

$M_y := F_y \cdot d \qquad M_y = 2.083\,\text{kip} \cdot \text{ft}$

3.) Given the following Design information & Details. Design Sign Support Posts and Connections for Concept 6

Design Wind Speed: $V_{wind} := 100\frac{mile}{hr}$ $\quad mph \equiv \frac{mile}{hr}$ $\quad psf \equiv \frac{lbf}{ft^2}$ $\quad ksi \equiv \frac{kip}{in^2}$

Reference: Standards Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals Published By AASHTO, 4th Edition 2001

$K_z := 0.87$ See Table 3-5 page 3-11 for Height 16.4 feet or less Interim 2002

$I_r := 0.54$ See Table 3-2 page 3-10 (0.80)

$G := 1.14$ See Section 3.8.5, page 3-12 (1.14)

$C_{dsign} := 1.12$ Wind Drag Coefficient as per Table 3-6, page 3-17 with Length/width ratio = 1.0

For 2.5" square tubing: $cr := 0.375in$ $\quad d_{tube} := 2.5in$ $\quad rs := \frac{cr}{d_{tube}}$ $\quad rs = 0.15$

therefore:

$C_{dtube} := 1.25$

3a.) Calculate the design wind pressure on the sign & post:

$$P_{zsign} := 0.00256K_z \cdot G \cdot \left(\frac{V_{wind}}{mph}\right)^2 \cdot I_r \cdot C_{dsign} \cdot psf$$

$P_{zsign} = 15.356 \cdot psf$ pressure on sign panel (psf)

$$P_{zpost} := 0.00256 \cdot K_z \cdot G \cdot \left(\frac{V_{wind}}{mph}\right)^2 \cdot I_r \cdot C_{dtube} \cdot psf$$

$P_{zpost} = 17.138 \cdot psf$ pressure on post (psf)

Texas Transportation Institute

Subject: **TxDOT Project 0-6646 - Sign Mounts on Rigid Barriers - Concept 6**

3b.) Calculate the Wind Moment on Sign for

$V_{wind} = 100 \cdot mph$ wind speed

$Area_{sign} := 4ft \cdot 4ft$ Sign Area

$Sign_{arm} := 83.75in$ moment arm of the sign area used in the wind load moment calculations

$Area_{post} := 2.25in \cdot 51in$ Post Area

$Post_{arm} := \frac{51in}{2}$ moment arm of the post area used in the wind load moment calculations

$$M_{wind} := \left(Area_{sign} \cdot Sign_{arm} \cdot P_{zsign}\right) + \left(Area_{post} \cdot Post_{arm} \cdot P_{zpost}\right)$$

$M_{wind} = 1.744 \cdot kip \cdot ft$ Wind moment on sign post (Kip*ft)

3c.) Check Post sleeve:

$S_{tubesleeve} = 1.72 \cdot in^3$

$F_{ysleeve} = 50 \cdot ksi$ Yield Strength of tube sleeve material (ksi)

$M_{tubesleeve} := S_{tubesleeve} \cdot F_{ysleeve}$

$M_{tubesleeve} = 7.167 \cdot kip \cdot ft$ greater than $M_{wind} = 1.744 \cdot kip \cdot ft$ .... o.k. !! .....

$M_x = 27.917 \cdot kip \cdot ft$ N.G.

3d.) Check 2.5" Schedule 80 Post

Determine bending moment in tube just above the top of the 12" tall sleeve

$$M_{windpost} := \left[Area_{sign} \cdot P_{zsign} \cdot \left(Sign_{arm} - 6.5in\right)\right] + \left[Area_{post} \cdot P_{zpost} \cdot \left(Post_{arm} - 6.5in\right)\right]$$

$M_{windpost} = 1.603 \cdot kip \cdot ft$ Design moment for post @ 90 mph just above tube sleeve

Check tube post

$S_{post} = 1.34 \cdot in^3$ Section modulus of post

$F_{ypost} = 50 \cdot ksi$ Yield strength of post

$$M_{post} := S_{post} \cdot F_{ypost}$$

$M_{post} = 5.583 \cdot kip \cdot ft$ ... post o.k. for wind loading

$M_x = 27.917 \cdot kip \cdot ft$ N.G. for impact

4.) Calculate the Ultimate transverse Load Resistance of a single 3/4 inch Hilti anchor considering edge, spacing and temperature reductions based on The Bond Strength of The HILTI HY 150 Adhesive Strength:

As per page 1420, 2006 Hilti Product Technical Guide,
HIT HY 150 Epoxy System, Average values for 4000 psi concrete:

$$\mathbf{Tension} := \begin{pmatrix} 3927 \\ 8885 \\ 12140 \end{pmatrix} \mathbf{lbf} \qquad \mathbf{Shear} := \begin{pmatrix} 7680 \\ 17355 \\ 32180 \end{pmatrix} \mathbf{lbf}$$

This information from the Allowable Bond/Concrete
Capacity for Hilti HIT HY 150 with concrete
strength = to 4000 psi

Actual Embedment Depth (inches), see Hilti guide

$$\mathbf{kips} \equiv \mathbf{1000lbf}$$

$$\mathbf{Depth_{embed}} := \begin{pmatrix} 3.375 \\ 6.625 \\ 10.0 \end{pmatrix} \mathbf{in} \qquad \mathbf{h_{ef}} := \mathbf{7in}$$

Actual Embedment Depth of Anchors used in the Design

Use Hilti Hight Strength Super HAS A193 Galvanized , 7/8" Dia. Rods:

$$\mathbf{HIT_{ultimatetensile}} := \mathbf{linterp}\left(\mathbf{Depth_{embed}}, \mathbf{Tension}, \mathbf{h_{ef}}\right)$$

Interpolate for Embedment Depth, h_{ef}

$$\mathbf{HIT_{ultimateshear}} := \mathbf{linterp}\left(\mathbf{Depth_{embed}}, \mathbf{Shear}, \mathbf{h_{ef}}\right)$$

$$\mathbf{HIT_{ultimatetensile}} = \mathbf{9.247 \cdot kips}$$

Allowable tension bond Strength based on actual anchor embedment

$$\mathbf{HIT_{ultimateshear}} = \mathbf{19.002 \cdot kips}$$

Allowable shear strength of anchor based on actual anchor embedment

Subject: TxDOT Project 0-6646 - Sign Mounts on Rigid Barriers

$Temperature := 130\ °F$ Max Temperature for Temperature Reduction used in Design

Check Load Adjustment Factors for Anchor Spacings & Clearance:

From page 168, Hilti 2006 Technical Guide

$S_{act} := 8.0in$ Actual anchor spacing (inches)

$C_{act} := 4in$ edge distance (inches) from concrete edge to Centerline of tension bolts

$h_{nom} := 6.625in$ Standard embedment depth (inches), see page 140 Table 4.2.5.3 for 3/4-inch Dia. Anchor

$h_{ef} = 7 \cdot in$ Actual embedment depth (in.)

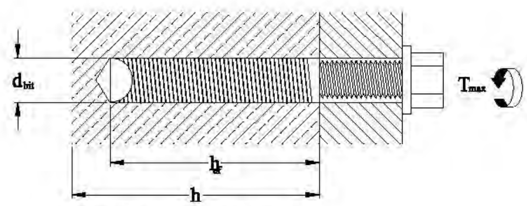
See Design Information Page 168 Tech Guide 2006

$S_{min} := 0.5 \cdot h_{ef}$ $S_{min} = 3.5 \cdot in$

$S_{cr} := 1.5 \cdot h_{ef}$ $S_{cr} = 10.5 \cdot in$

$C_{min} := 0.5 \cdot h_{ef}$ $C_{min} = 3.5 \cdot in$

$C_{cr} := 1.5 \cdot h_{ef}$ $C_{cr} = 10.5 \cdot in$



ANCHOR GEOMETRY

**** Calculate Hilti Reduction Factors for Spacing Tension & Shear ******

$$f_A := \begin{vmatrix} f_A \leftarrow 0.3 \cdot \left(\frac{S_{act}}{h_{ef}}\right) + 0.55 \quad \text{if } S_{cr} \ge S_{act} \ge S_{min} \\ f_A \leftarrow 1.0 \quad \text{if } S_{act} \ge S_{cr} \\ f_A \leftarrow 0 \quad \text{if } S_{act} < S_{min} \end{vmatrix}$$

$f_A = 0.893$

***** Calculate Reduction Factors for Edge Distance Tension, "f_{RN}" *******

$$f_{RN} := \begin{vmatrix} f_{RN} \leftarrow 0.3 \cdot \left(\frac{C_{act}}{h_{ef}}\right) + 0.55 \quad \text{if } C_{cr} \ge C_{act} \ge C_{min} \\ f_{RN} \leftarrow 1.0 \quad \text{if } C_{act} \ge C_{cr} \\ f_{RN} \leftarrow 0 \quad \text{if } C_{act} < C_{min} \end{vmatrix}$$

$f_{RN} = 0.721$

Calculate Reduction Factors for Edge Distance Shear, "f_{RVperp}"

$$f_{RVperp} := \begin{vmatrix} f_{RVperp} \leftarrow 0.54 \cdot \left(\frac{C_{act}}{h_{ef}}\right) - 0.09 \quad \text{if } C_{cr} \ge C_{act} \ge C_{min} \\ f_{RVperp} \leftarrow 1.0 \quad \text{if } C_{act} \ge C_{cr} \\ f_{RVperp} \leftarrow 0 \quad \text{if } C_{act} < C_{min} \end{vmatrix}$$

$f_{RVperp} = 0.219$

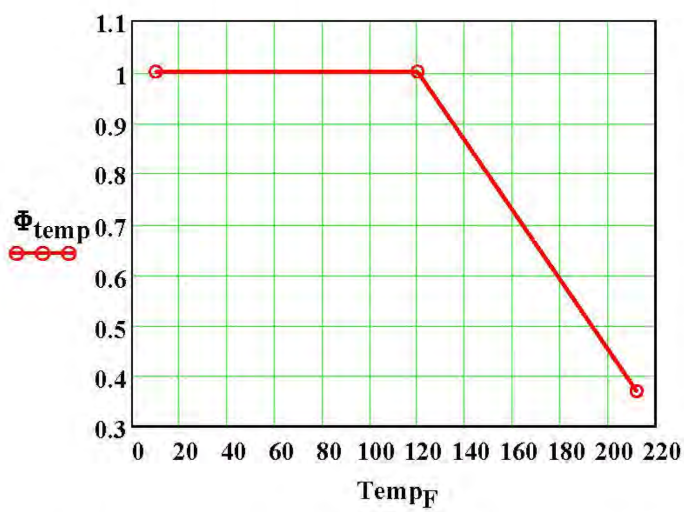
Calculate total combined Reduction Factors for tension & shear:

$f_{RVperp} = 0.219$ $\quad f_A = 0.893$ $\quad f_{RN} = 0.721$

$$\Phi_{temp} := \begin{pmatrix} 1.0 \\ 1.0 \\ 0.37 \end{pmatrix} \qquad Temp := \begin{pmatrix} 10 \\ 120 \\ 212 \end{pmatrix} °F$$

$$Temp = \begin{pmatrix} 260.928 \\ 322.039 \\ 373.15 \end{pmatrix} K \qquad Temp = \begin{pmatrix} 260.928 \\ 322.039 \\ 373.15 \end{pmatrix} K$$

$$Temp_F := \frac{\left[(Temp - 273.15K)\cdot\frac{9}{5}\right] + 32K}{K}$$ Temperature conversion



$$\Phi_{tempreduce} := \text{linterp}\left(Temp, \Phi_{temp}, Temperature\right)$$

Calculate total Reduction for anchor bond strength considering the previous factors:

$$\Phi_{tension} := \overrightarrow{\left(f_A \cdot f_{RN} \cdot \Phi_{tempreduce}\right)} \qquad \Phi_{shear} := \overrightarrow{\left(f_A \cdot f_{RVperp}\right)}$$

$$\Phi_{tension} = 0.6 \qquad \Phi_{shear} = 0.195$$

$$\Phi R_{tension} := \Phi_{tension} \cdot HIT_{ultimatetensile} \qquad \Phi R_{shear} := \Phi_{shear} \cdot HIT_{ultimateshear}$$

$$\Phi R_{tension} = 5.548 \cdot kips \qquad \Phi R_{shear} = 3.708 \cdot kips$$

Hilti Factored Anchor Strengths for 3/4-inch Dia Anchors with

5.) Check anchor strength based on Transverse impact loading

$M_y = 2.083 \cdot kip \cdot ft$ This is the moment from transverse crash loading

$$M_{x4anchors} := 2.5in \cdot 4 \cdot \Phi R_{tension}$$

$M_{x4anchors} = 4.624 \cdot kip \cdot ft$ .... ok!

6.) Check Anchor Strength & Tube Strength for HSS6x3x1/2 Tube 4 feet in length w/ 4

with 4'-0" Tube with 4~Hilti anchors Tube Support is acceptable as per RISA-3D Analysis

MCAD 14 CALCS.

APPENDIX B. CRASH TEST PROCEDURES

B.1 TEST FACILITY

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

The Texas A&M Transportation Institute Proving Ground is a 2000-acre complex of research and training facilities located 10 miles northwest of the main campus of Texas A&M University. The site, formerly an Air Force base, has large expanses of concrete runways and parking aprons well-suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for construction and testing of the signs mounted on CMBs 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 × 15 ft blocks nominally 6 inches deep. The apron is over 60 years old, and the joints have some displacement, but are otherwise flat and level.

B.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 existed with this system. Just prior to impact with the installation, the test vehicle was released to be unrestrained. The vehicle remained free-wheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site, after which the brakes were activated to bring it to a safe and controlled stop.

B.3 DATA ACQUISITION SYSTEMS

B.3.1 Vehicle Instrumentation and Data Processing

The test vehicle was instrumented with a self-contained, on-board data acquisition system. The signal conditioning and acquisition system is a 16-channel, Tiny Data Acquisition System (TDAS) Pro produced by Diversified Technical Systems, Inc. The accelerometers, that measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra small size, solid state units designs 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 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 are returned to the factory annually for complete recalibration. Accelerometers and rate transducers are also calibrated annually with traceability to the National Institute for Standards and Technology. 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 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. Rate of rotation data is measured with an expanded uncertainty of ±0.7 percent at a confidence factor of 95 percent (k=2).

B.3.2 Anthropomorphic Dummy Instrumentation

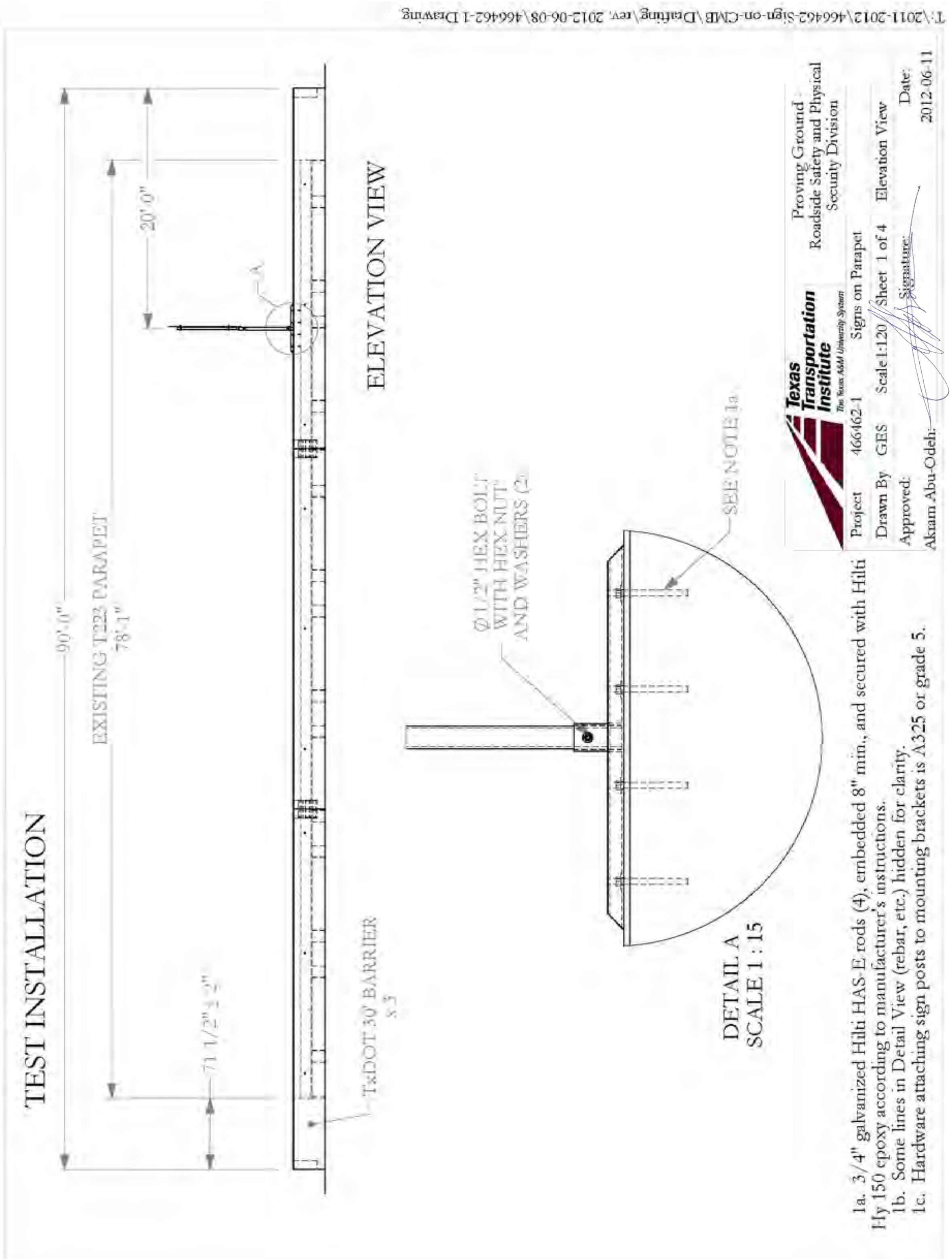
Use of a dummy in the 2270P vehicle is optional according to *MASH*, and no dummy was used in the tests with the 2270P vehicle.

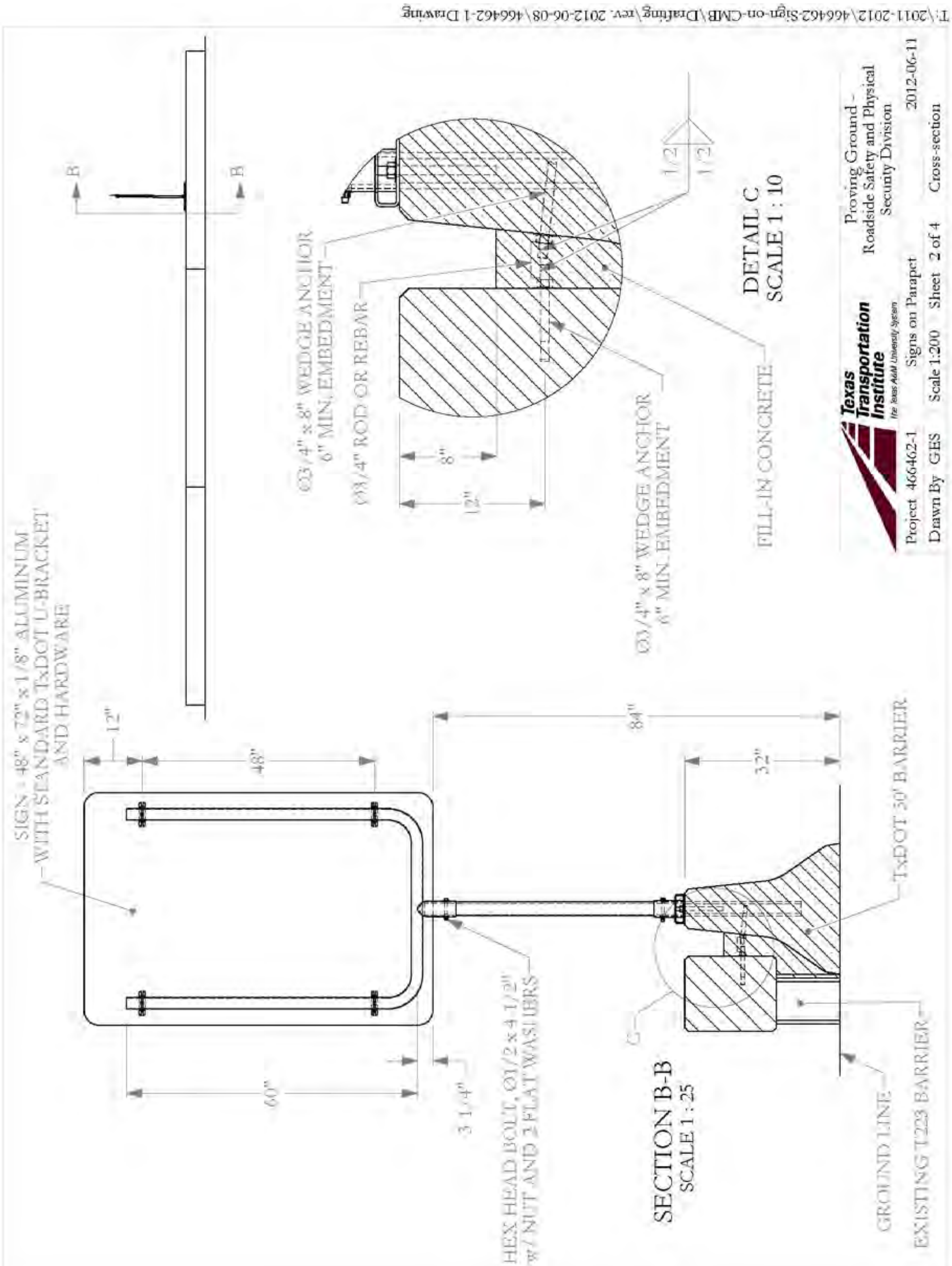
B.3.3 Photographic Instrumentation and Data Processing

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

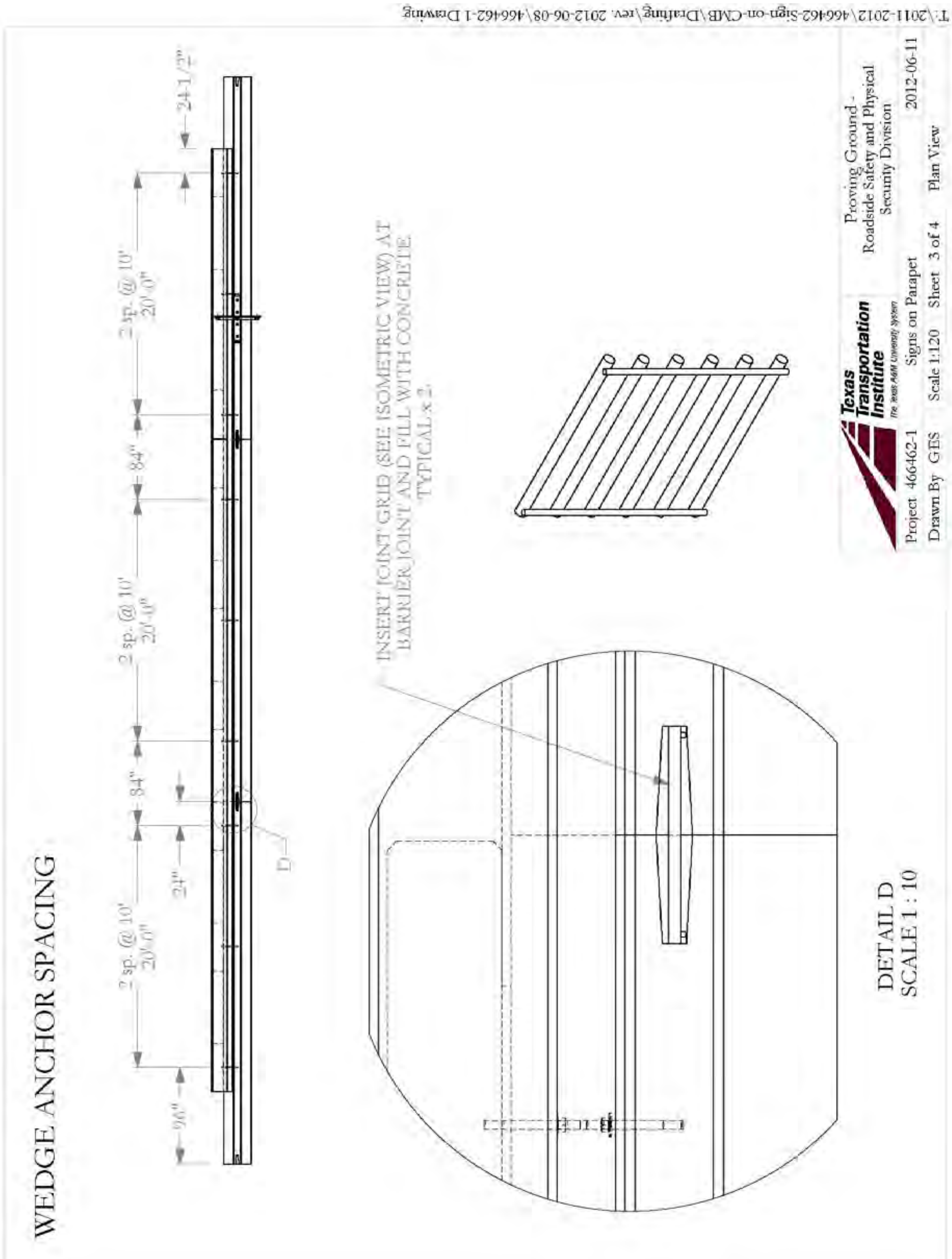
APPENDIX C. CRASH TEST NO. 466462-1

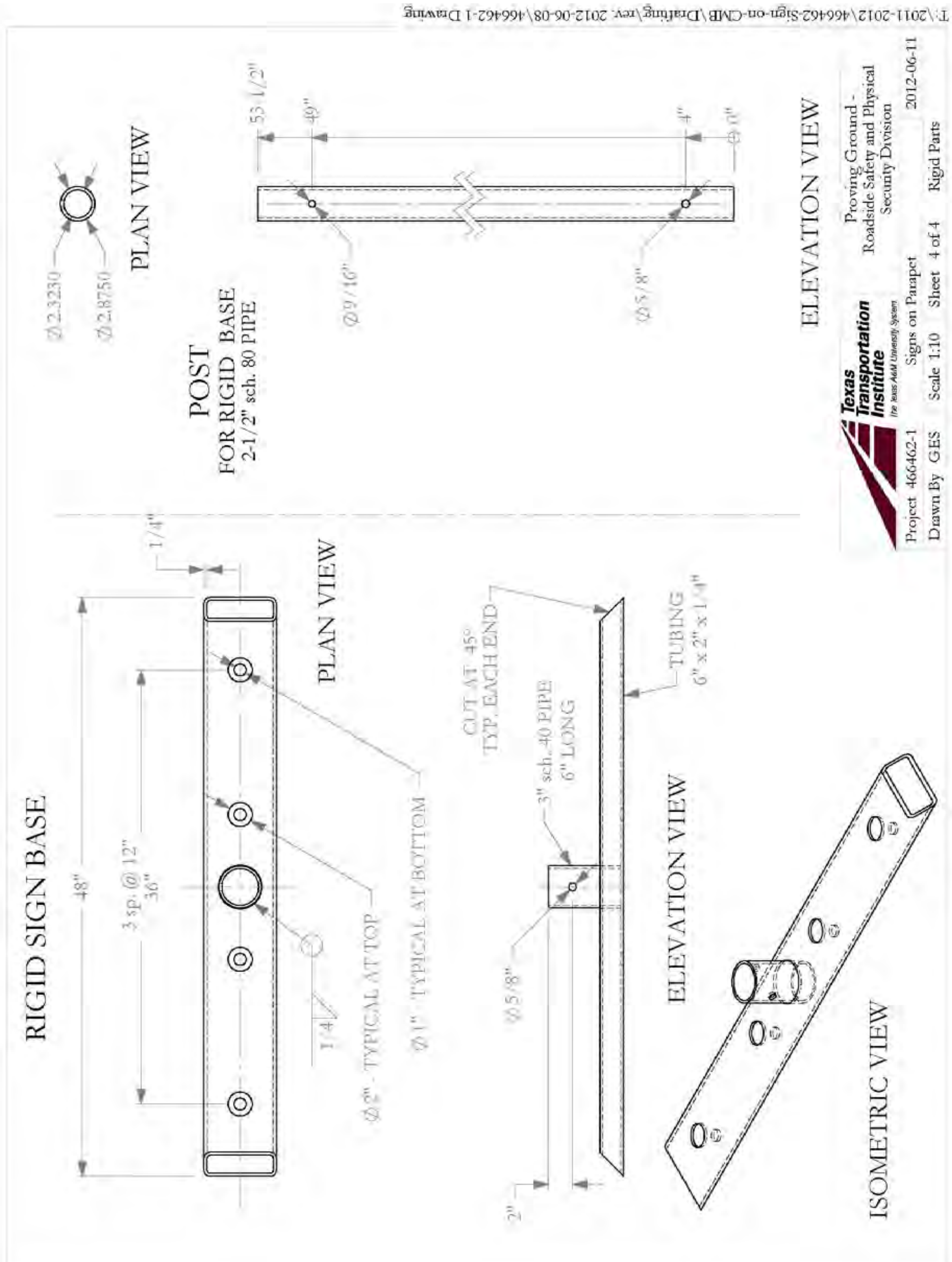
C1. DETAILS OF THE TEST ARTICLE





T:\2011-2012\466462-Sign-on-CMB\Drafting\rev. 2012-06-08\466462-1 Drawing
SIGN - 48" x 72" x 1/8" ALUMINUM
WITH STANDARD TxDOT U-BRACKET
AND HARDWARE
12"
48"
60"
3 1/4"
84"
32"
B
B
HEX HEAD BOLT, Ø1/2 x 4 1/2"
w/ NUT AND 2 FLAT WASHERS
C
SECTION B-B
SCALE 1 : 25
TxDOT 30' BARRIER
GROUND LINE
EXISTING T223 BARRIER
Ø3/4" x 8" WEDGE ANCHOR
6" MIN. EMBEDMENT
Ø3/4" ROD OR REBAR
8"
12"
Ø3/4" x 8" WEDGE ANCHOR
6" MIN. EMBEDMENT
FILL-IN CONCRETE
1/2
1/2
DETAIL C
SCALE 1 : 10
Texas Transportation Institute
The Texas A&M University System
Proving Ground -
Roadside Safety and Physical
Security Division
Project 466462-1
Drawn By GES
Signs on Parapet
Scale 1:200
Sheet 2 of 4
2012-06-11
Cross-section


T:\2011-2012\466462-Sign-on-CMB\Drafting\rev. 2012-06-08\466462-1 Drawing
WEDGE ANCHOR SPACING
96"
2 sp. @ 10'
20'-0"
24"
84"
2 sp. @ 10'
20'-0"
84"
2 sp. @ 10'
20'-0"
24-1/2"
D
INSERT JOINT GRID (SEE ISOMETRIC VIEW) AT
BARRIER JOINT AND FILL WITH CONCRETE
TYPICAL x 2
DETAIL D
SCALE 1 : 10
Texas Transportation Institute
The Texas A&M University System
Proving Ground -
Roadside Safety and Physical
Security Division
Project 466462-1
Signs on Parapet
2012-06-11
Drawn By GES
Scale 1:120
Sheet 3 of 4
Plan View



RIGID SIGN BASE
48"
3 sp. @ 12"
36"
1/4"
PLAN VIEW
Ø2" TYPICAL AT TOP
Ø1" TYPICAL AT BOTTOM
1/4
CUT AT 45°
TYP. EACH END
3" sch. 40 PIPE
6" LONG
Ø5/8"
2"
TUBING
6" x 2" x 1/4"
ELEVATION VIEW
ISOMETRIC VIEW
POST
FOR RIGID BASE
2-1/2" sch. 80 PIPE
Ø2.3230
Ø2.8750
PLAN VIEW
53 1/2"
49"
4"
0"
Ø9/16"
Ø5/8"
ELEVATION VIEW
Texas Transportation Institute
The Texas A&M University System
Proving Ground - Roadside Safety and Physical Security Division
Project 466462-1
Drawn By GES
Signs on Parapet
Scale 1:10
Sheet 4 of 4
Rigid Parts
2012-06-11
T:\2011-2012\466462-Sign-on-CMB\Drafting\rev. 2012-06-08\466462-1 Drawing

C2. CERTIFICATION DOCUMENTATION

MATERIAL USED

TEST NUMBER	466462-1
TEST NAME	Sign on Barrier
DATE	2012-06-11

DATE RECEIVED	ITEM NUMBER	DESCRIPTION	SUPPLIER	HEAT #
2012-04-11	U-Bracket-1	2-7/8" OD sign bracket	Trinity	generic Trinity
2010-05-11	Tubing 6x2-1	6x2x1/4 x 20' A500 gr. 5 ORA	Mack Bolt & Steel	921034
2012-01-18	Bolt 0.500-11	1/2 -13 x 4-1/2 gr. 5	Fastenal	1WG14
2011-06-28	Washer 0.5000-02	1/2 flat	Best Products Co.	
2011-06-28	Nut 0.5000-02	1/2 hex gr. 5	Best Products Co.	315702

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111

A

Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207

Sales Order: 1151007
Customer PO: Samples
BOL # 41575
Document # 1

Print Date: 4/10/12
Project: SAMPLES
Shipped To: TX
Use State: TX

Trinity Highway Products. LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SMALL SIGNS SUPPORT **

NCHRP Report 350 Compliant

Pieces	Description	Part No
9	1.500PS12@144	720018G
11	1.750PS12@144	720087G
1	2.000PS12@24 ANCH	720253G
2	2.875RD10 U BKT HDG	720852G
1	2.000PS14@24 ANCH	721116G

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

TL -3 or TL-4 COMPLIANT when installed according to manufactures specifications

Steel. The steel shall be in accordance with the standard specification for hot rolled carbon sheet steel, structural quality, ASTM A 1011, Grade 50. The average minimum yield strength after cold-forming shall be a minimum of 50,000 psi.

Coating. The posts shall be hot-dipped galvanized steel in accordance with ASTM A 653, G90, structural quality, Grade 50, Class 1. The corner weld shall be zinc coated after scarfing operation. The steel shall also be coated with a chromate conversion coating and a clear organic polymer topcoat. Both the interior and the exterior of the post shall be galvanized. Modifications made to the post after the initial fabrication, such as additional welding or other alterations shall be galvanized.

CERTIFICATION. The fabricator shall furnish to the engineer, a certification stating that the posts furnished comply with all requirements of this specification. The certification shall include or have attached specific results of tests of the mechanical and chemical properties of the steel conforming to section 2.1 and 2.2 of this specification. A certification shall be submitted with the bid

State of Texas, County of Tarrant. Sworn and Subscribed before me this 10th day of April, 2012

Notary Public:
Commission Expires:

/ JOMARY LUGINSLAND
MY COMMISSION EXPIRES
May 24, 2015

Jomary Luginsland

Trinity Highway Products, LLC
Certified By: Luis Ortiz
Quality Assurance

1 of 1

18Aug09 8:45 T E S T C E R T I F I C A T E No: CHI 614195

Sold By:
INDEPENDENCE TUBE CORPORATION
6226 W. 74TH STREET
CHICAGO, IL 60638
Tel: 708-496-0380 Fax: 708-563-1950

P/O No 6219002
Rel
S/O No CHI 162535-003
B/L No CHI 93892-002 Shp 19Aug09
Inv No Inv

Sold To: (144)
NAMASCO-EAST
500 COLONIAL PARKWAY
SUITE 500
ROSWELL, GA 30076

Ship To: (21)
NAMASCO-BUDA
2560 SOUTH LOOP 4
BUDA, TX

Tel: 678-259-8845 Fax: 571 323-0613

CERTIFICATE of ANALYSIS and TESTS Cert. No: CHI 614195
17Aug09

Part No 005
TUBING A500 GRADE B(C)
6" X 2" X 1/4" X 40'

	Pcs	Wgt
	54	26,373

Heat Number	Tag No	Pcs	Wgt
921034	533564	18	8,791
	YLD=54861/TEN=66278/ELG=36.41		
921034	533565	18	8,791
921034	533566	18	8,791

Heat Number *** Chemical Analysis ***
921034 C=0.2100 Mn=0.8300 P=0.0110 S=0.0060 Si=0.0200 Al=0.0470
Cu=0.0200

T/R FAX

Test Report Clerk
MELTED IN U.S.A.

WE PROUDLY MANUFACTURE ALL OF OUR HSS IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED,
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.
****
CURRENT STANDARDS:
.... A500/A500M-07
.... A513-07
.... A252-98 (2002)

Page: 1 .... Last

Jinn Her Enterprise Co., Ltd.

No. 107, SHIN-LO ST, KANGSHAN, 820 KAOHSIUNG, TAIWAN R. O. C
TEL : +886 (07) 6228801 FAX : +886 (07) 6223750 - +886 (07) 6211503

CERTIFICATE OF INSPECTION

1 / 1

CUSTOMER NAME	: FASTENAL COMPANY PURCHASING-IMPORT TRAFFIC	REPORT NO	: JH11092918015
CUSTOMER'S ADDRESS	: 4730 SERVICE DRIVE, WINONA MN. 55987 U.S.A., TEL : 507-453-8086 FAX: 507-494-7833	REPORT DATE	: 2011/10/19
		BOLT LOT NO	: B087766Y1
		BOLT MATERIAL	: SCR435
ORDER NUMBER	: 180050104	BOLT HEAT NO	: 1WG14
PART NUMBER	: 15221	NUT LOTNO	:
DESCRIPTION	: HEX CAP SCREW G8 HD MARK:6 RADIAL LINES & "FNL"	NUT MATERIAL	:
		NUT HEAT NO	:
		WASHER LOT NO	:
SIZE	: 1/2-13X4-1/2	WASHER MATERIAL	:
FINISH	: H.T. ZINC YELLOW 5 MICRON	WASHER HEAT NO	:
QUANTITY	: 1500.0	ASSEMBLY LOT NO	:
BOLT MFR.	: JINN HER ENTERPRISE CO.,LTD.	BOLT MFR. DATE	: 2011/9/2
NUT MFR.	:	NUT MFR. DATE	:
WASHER MFR.	:	WASHER MFR. DATE	:

BOLT DIMENSIONAL INSPECTION — INSPECTION : 2011/09/23
SPECIFICATION : ASME B18.2.1 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
WIDTH ACROSS CORNERS	JIS B1071	21.34-21.99	mm	21.46-21.53	8	8	0
WIDTH ACROSS FLATS	JIS B1071	18.70-19.05	mm	18.77-18.81	8	8	0
HEIGHT	JIS B1071	7.67-8.20	mm	7.83-7.87	8	8	0
BODY DIA.	JIS B1071	12.53-12.70	mm	12.54-12.56	8	8	0
BODY LENGTH	JIS B1071	MIN 72.65	mm	74.07-74.16	8	8	0
GRIP LENGTH	JIS B1071	MAX 82.55	mm	76.86-77.11	8	8	0
LENGTH	JIS B1071	111.76-114.30	mm	113.57-113.71	8	8	0
THREAD	ASME B1.3M	NONE	N/A	PASS	8	8	0

BOLT MECHANICAL INSPECTION — INSPECTION : 2011/09/15
SPECIFICATION : SAE J121 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
COMPLETELY DEC. DEPTH	SAE J121	MAX 0.015	mm	PASS	1	1	0
BASE METAL	SAE J121	MIN 0.813	mm	PASS	1	1	0

BOLT MECHANICAL INSPECTION — INSPECTION : 2011/09/15
SPECIFICATION : SAE J429 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
SURFACE HARDNESS	SAE J429	MAX 58.6	HR30N	55-56	8	8	0
CORE HARDNESS	SAE J429	33.0-39.0	HRC	38-38	8	8	0
TENSILE STRENGTH	SAE J429	MIN 150.0	ksi	170-172	4	4	0
PROOF LOAD	SAE J429	MIN 120.0	ksi	PASS	1	1	0

BOLT FINISH INSPECTION — INSPECTION : 2011/09/23
SPECIFICATION : ASTM F1941 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
THICKNESS OF COATING	ASTM A754/A754M	MIN 5.00000	um	8.14000-9.26000	4	4	0

BOLT APPEARANCE INSPECTION — INSPECTION : 2011/09/23
SPECIFICATION : SAE J1061 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
GENERAL WORKMANSHIP	VISION	NONE	N/A	PASS	8	8	0

CHEMICAL ANALYSIS %

HEAT NO	C-x100	MN-x100	P-x1000	S-x1000	SI-x100	CU-x100	NI-x100	CR-x100	MO-x100	AL-x1000	B-x10000	V-x100
1WG14	36	72	14	9	20	1	3	102				

BOLT MARKING

Remark : 1.Lab is accredited according to ISO/IEC17025 requirements. This certificate is valid with signature of Yi-Sung Chen.

2.This test certificate is responsible for designated samples only. This test certificate only relates to the items listed and tested, it's not allowed to be partially used.

3.The above composition is quoted from original mill certs which is not in the scope of Lab Accreditation.

4.This test certificate in accordance with EN 10204 type 3.1.

5.Unless specified by the customer, the latest version of the testing specs was used.

6.Quality System conforms to ISO 9001 requirements and certified by TUV .

180050104

15221

B087766Y1

SUPER CHENG INDUSTRIAL CO.,LTD.

NO. 18 BEN-GONG 2nd ROAD., BEN CHOU INDUSTRIAL PARK, KAOHSIUNG COUNTY 820, TAIWAN R.O.C.
TEL：886-7-6225326-30(5 LINES)　FAX：886-7-6215377/6212335/6235829

CERTIFICATE OF INSPECTION

CERT. #：S62-1010-03　　ISSUED DATE：2010/11/12　　PAGE 1 OF 1

CLIENT：SUPER CHENG INDUSTRIAL CO., LTD.
ADDRESS：NO. 18 BEN-GONG 2nd ROAD., BEN CHOU INDUSTRIAL PARK, KAOHSIUNG COUNTY 820, TAIWAN R.O.C.

PURCHASER：FASTENAL COMPANY PURCHASING　　PO #：180038281
PART#1136310　　QTY SHIPPED：112,500 PCS

COMMODITY：GRADE 5 FIN HEX NUT　　FINISH：TRIVALENT ZINC
SIZE：1/2-13　　LOT#：S62-1010-03　　SAMPLING PLAN：ANSI/ASME B18.18.2M-93
QTY：587270 PCS　　MATERIAL：SWRCH10A　　HEAT NO.：315702
MANUFACTURER：SUPER CHENG IND. CO., LTD.　　MANU. DATE：2010/10/27

DIMENSIONAL INSPECTION　　SPEC.：ANSI/ASME B18.2.2-87　　SAMPLED BY：HUI HUA YU

ITEM	SAMPLE SIZE	SPECIFIED	ACTUAL RESULT	JUDGMENT
APPEARANCE	100	ASTM F812-07	GOOD	OK
W.A.F.	32	0.750 ~ 0.736 in.	0.743 ~ 0.741 in.	OK
W.A.C.	8	0.866 ~ 0.840 in.	0.852 ~ 0.848 in.	OK
THICKNESS	8	0.448 ~ 0.427 in.	0.447 ~ 0.439 in.	OK
THREAD	32	ANSI/ASME B1.1	PASS	OK

MECHANICAL PROPERTIES　　SPEC.：SAE J995-99　　SAMPLED BY：HUI HUA YU

ITEM	SAMPLE SIZE	TEST METHOD	SPECIFIED	ACTUAL RESULT	JUDGMENT
HARDNESS	8	ASTM F606-09	MAX HRB107	98.0 ~ 94.0 HRBW	PASS
PROOF LOAD	4	ASTM F606-09	MIN 17000LB	17163 ~ 17152 LB	PASS

REMARK：1、THIS REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL WITHOUT WRITTEN APPROVAL OF THE LAB.
2、THIS INSPECTION CERTIFICATE IS FOR RESPONSIBILITY UNDER SAMPLE ONLY
3、ABOVE SAMPLES TESTED CONFORM TO THE FASTENER SPECIFICATION OR STANDARDS

LAB. DIRECTOR(SIGNATORY)：

表單編號：LQC 10E Rev.0

C3. VEHICLE PROPERTIES AND INFORMATION

Table C1. Vehicle Properties for Test No. 466462-1.

Date: 2012-06-11 Test No.: 466462-1 VIN No.: 1DTHA182X65608283

Year: 2006 Make: Dodge Model: 1500 RAM

Tire Size: 265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 215075

Note any damage to the vehicle prior to test: ______

● Denotes accelerometer location.

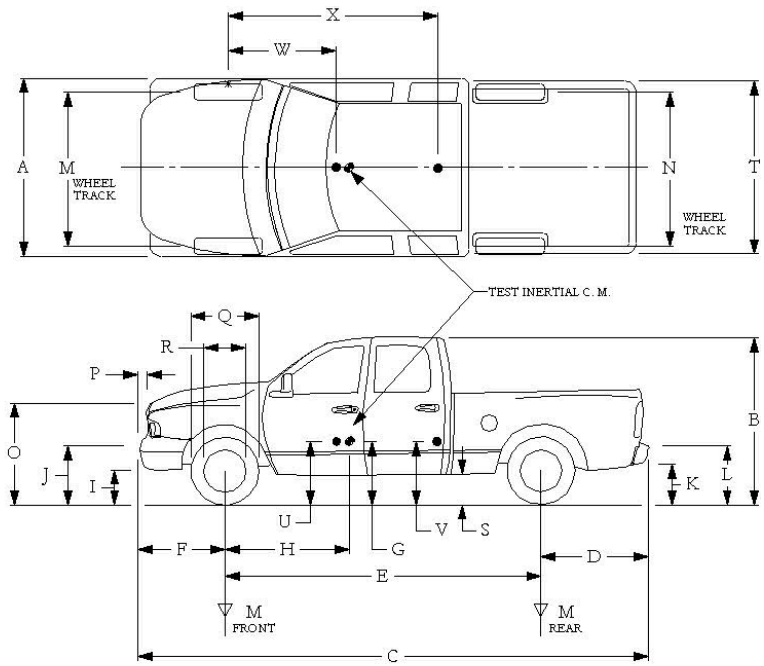
NOTES: ______

Engine Type: V-8
Engine CID: 4.7 liter

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

Optional Equipment: ______

Dummy Data:
Type: No dummy
Mass: ______
Seat Position: ______



Geometry: inches

A	78.25	F	36.00	K	20.50	P	2.88	U	28.50
B	75.00	G	28.03	L	29.12	Q	31.25	V	29.50
C	223.75	H	60.96	M	68.50	R	18.38	W	59.50
D	47.25	I	13.75	N	68.00	S	12.00	X	78.00
E	140.50	J	25.38	O	44.50	T	77.50		

Wheel Center Height Front	14.25	Wheel Well Clearance (Front)	5.00	Bottom Frame Height - Front	17.125
Wheel Center Height Rear	14.25	Wheel Well Clearance (Rear)	10.25	Bottom Frame Height - Rear	24.75

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2863	2859	
Back	3900	M_{rear}	2106	2191	
Total	6700	M_{Total}	4969	5050	

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

Mass Distribution:
lb LF: 1442 RF: 1417 LR: 1125 RR: 1066

Table C2. Vehicle Parametric Measurements for Test No. 466462-1.

Date: 2012-06-11 Test No.: 466462-1 VIN: 1DTHA182X65608283

Year: 2006 Make: Dodge Model: 1500 RAM

Body Style: Quad Cab Mileage: 215075

Engine: V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 158 lb in front of bed (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70R17

Measured Vehicle Weights: (lb)

LF:	1442	RF:	1417	Front Axle:	2859
LR:	1125	RR:	1066	Rear Axle:	2191
Left:	2567	Right:	2483	Total:	5050

5000 ±110 lb allowed

Wheel Base: 140.5 inches (148 ±12 inches allowed)   Track: F: 68.5 inches R: 68 inches

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

Center of Gravity, SAE J874 Suspension Method

X: 60.96 inches Rear of Front Axle (63 ±4 inches allowed)

Y: -0.57 inches Left - Right + of Vehicle Centerline

Z: 28.0313 inches Above Ground (minumum 28.0 inches allowed)

Hood Height: 44.50 inches (43 ±4 inches allowed)   Front Bumper Height: 25.38 inches

Front Overhang: 36.00 inches (39 ±3 inches allowed)   Rear Bumper Height: 29.12 inches

Overall Length: 223.75 inches

237 ±13 inches allowed

Table C3. Exterior Crush Measurements for Test No. 466462-1.

Date: 2012-06-11 Test No.: 466462-1 VIN No.: 1DTHA182X65608283

Year: 2006 Make: Dodge Model: 1500 RAM

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ ≥ 4 inches ________	Bowing: B1 _____ X1 _____ B2 _____ X2 _____ Bowing constant $\frac{X1+X2}{2}$ = _______

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bumper ht	23	17	32	0	2.5	4	8	11	17	+16
2	Side plane at bumper ht	23	18	42	0	4	9	14	16	18	+72
	Measurements recorded										
	in inches										

[1]Table taken from National Accident Sampling System (NASS).

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

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

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

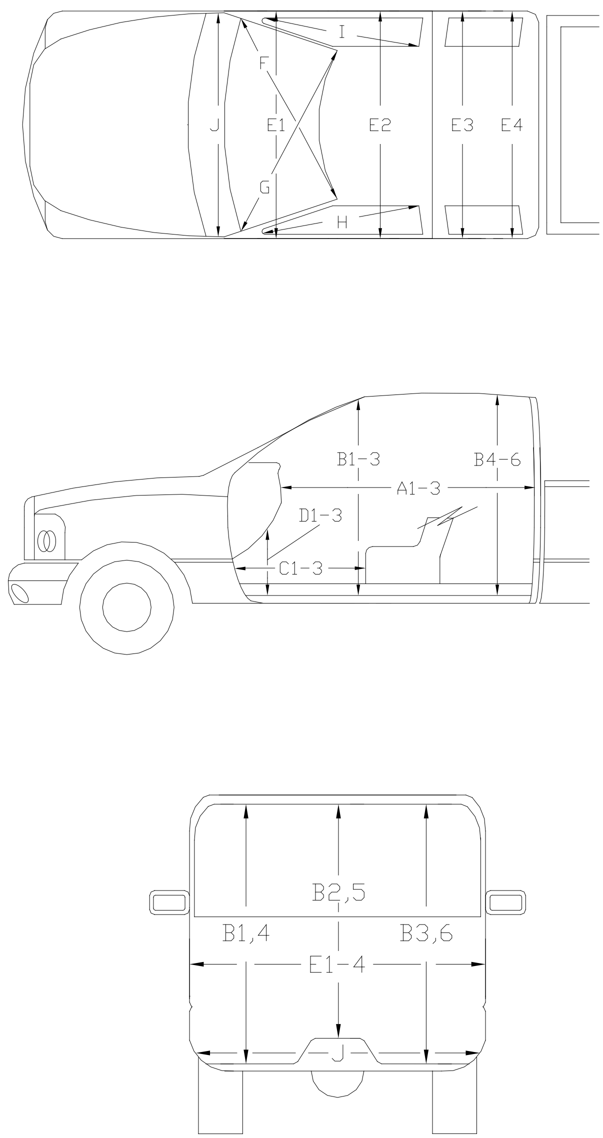
***Measure and document on the vehicle diagram the location of the maximum crush.

Note: Use as many lines/columns as necessary to describe each damage profile.

Table C4. Occupant Compartment Measurements for Test No. 466462-1.

Date: 2012-06-11 Test No.: 466462-1 VIN No.: 1DTHA182X65608283

Year: 2006 Make: Dodge Model: 1500 RAM



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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	64.50	64.50
A2	64.50	64.50
A3	65.00	65.00
B1	45.25	45.25
B2	39.00	37.75
B3	45.25	45.75
B4	42.12	42.12
B5	42.50	42.50
B6	42.12	42.12
C1	27.00	27.00
C2	----	----
C3	26.50	19.00
D1	12.75	12.75
D2	----	----
D3	11.62	12.00
E1	62.75	62.50
E2	64.50	65.50
E3	64.00	64.00
E4	64.38	64.38
F	59.50	59.50
G	59.50	59.50
H	39.00	39.00
I	39.00	39.00
J*	62.00	60.50

C4. SEQUENTIAL PHOTOGRAPHS

Figure C1. Sequential Photographs for Test No. 466462-1 (Frontal and Field Side Barrier Views).

Figure C1. Sequential Photographs for Test No. 466462-1 (Frontal and Field Side Barrier Views) (continued).

C5. VEHICLE ANGULAR DISPLACEMENTS

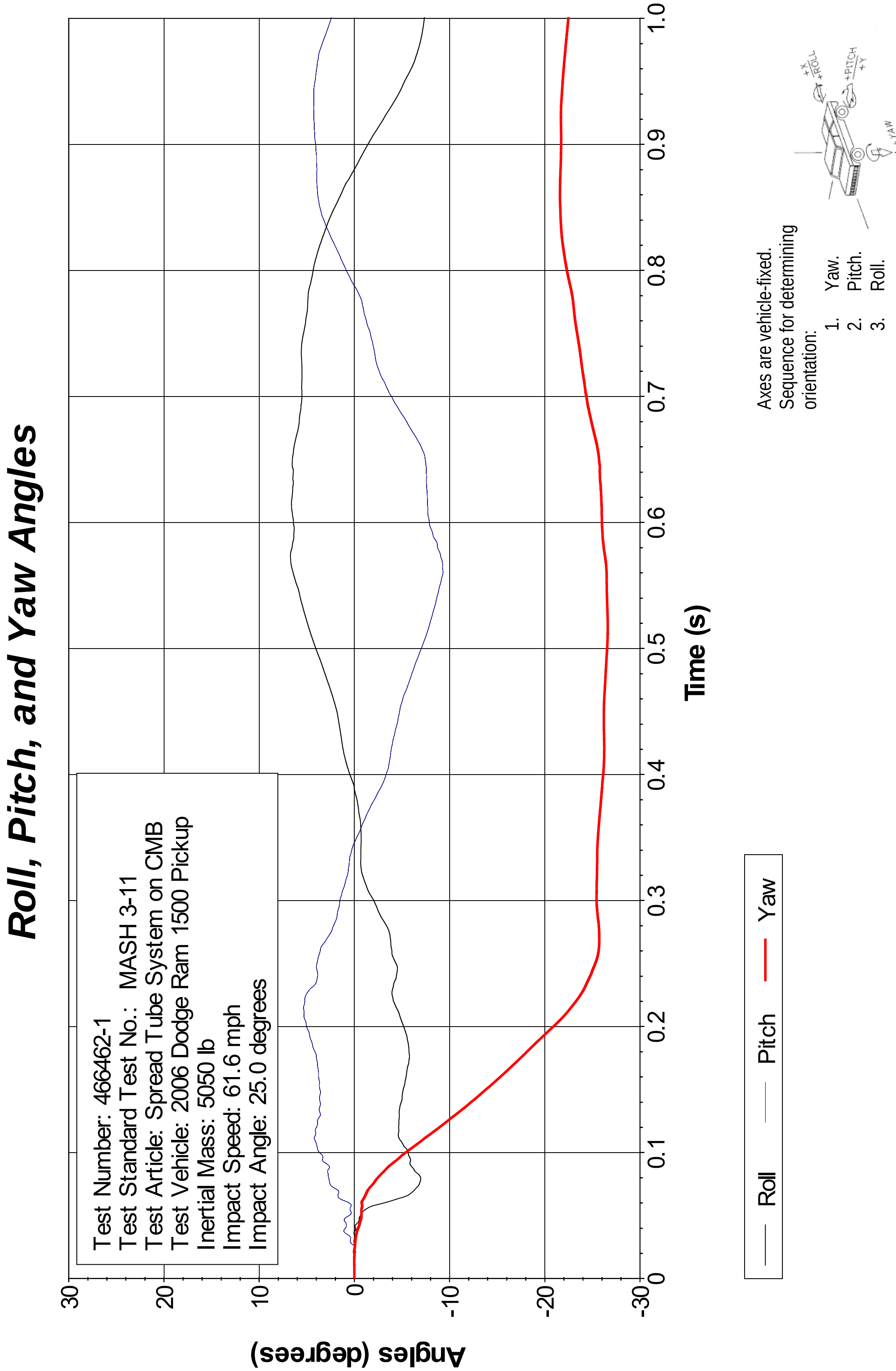


Figure C2. Vehicle Angular Displacements for Test No. 466462-1.

C6. VEHICLE ACCELERATIONS

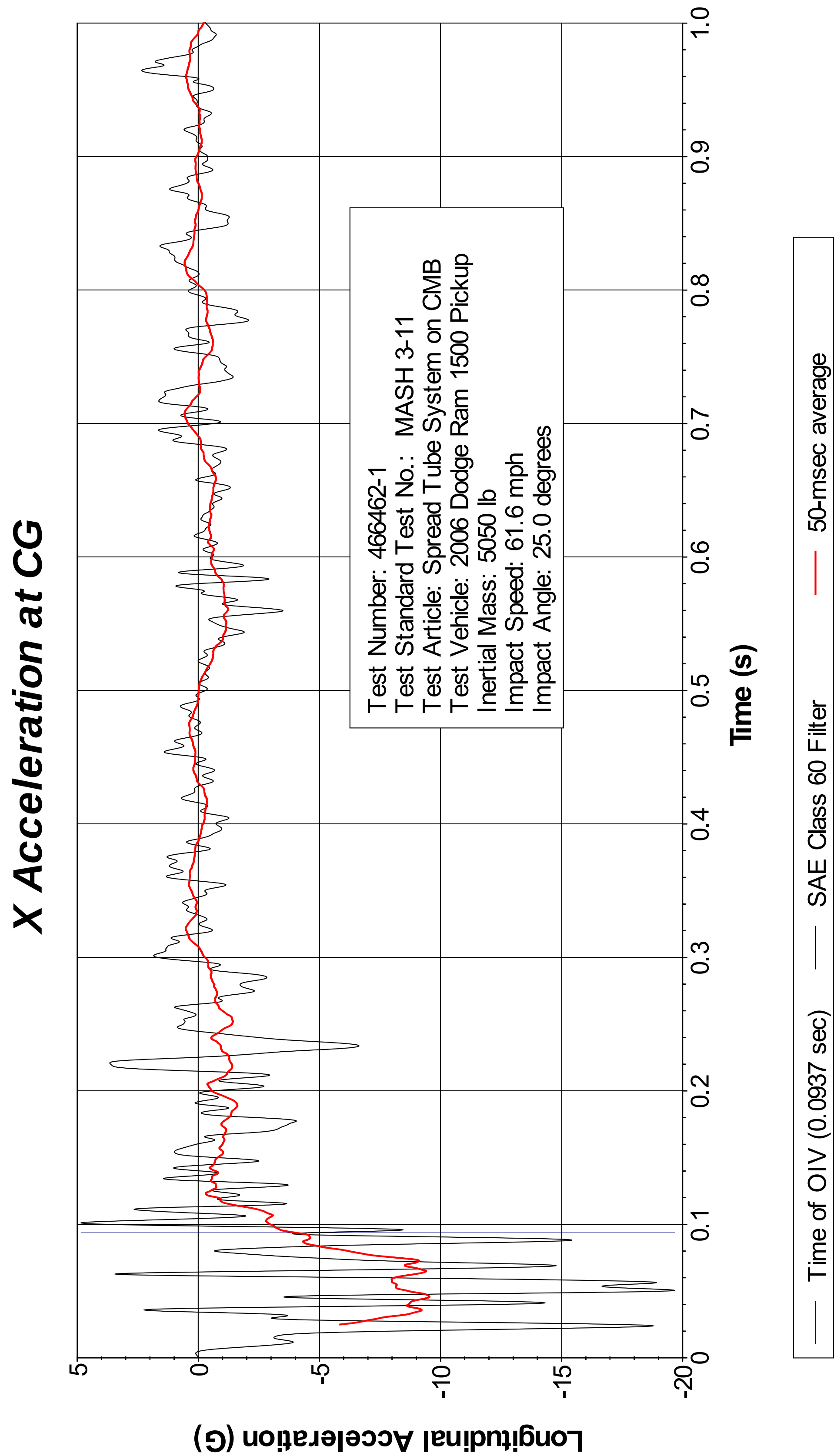


Figure C3. Vehicle Longitudinal Accelerometer Trace for Test No. 466462-1 (Accelerometer Located at Center of Gravity).

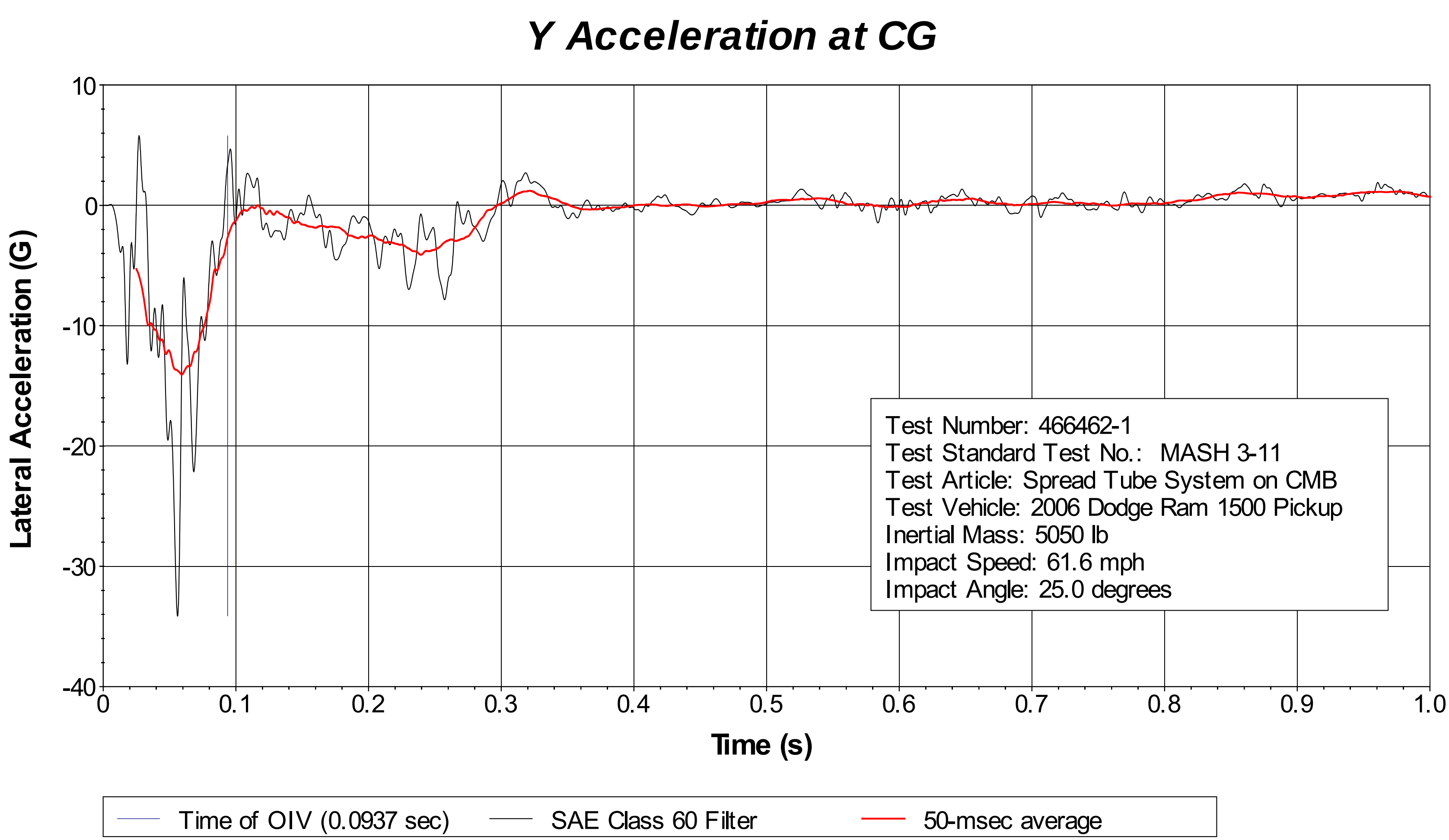


Figure C4. Vehicle Lateral Accelerometer Trace for Test No. 466462-1 (Accelerometer Located at Center of Gravity).

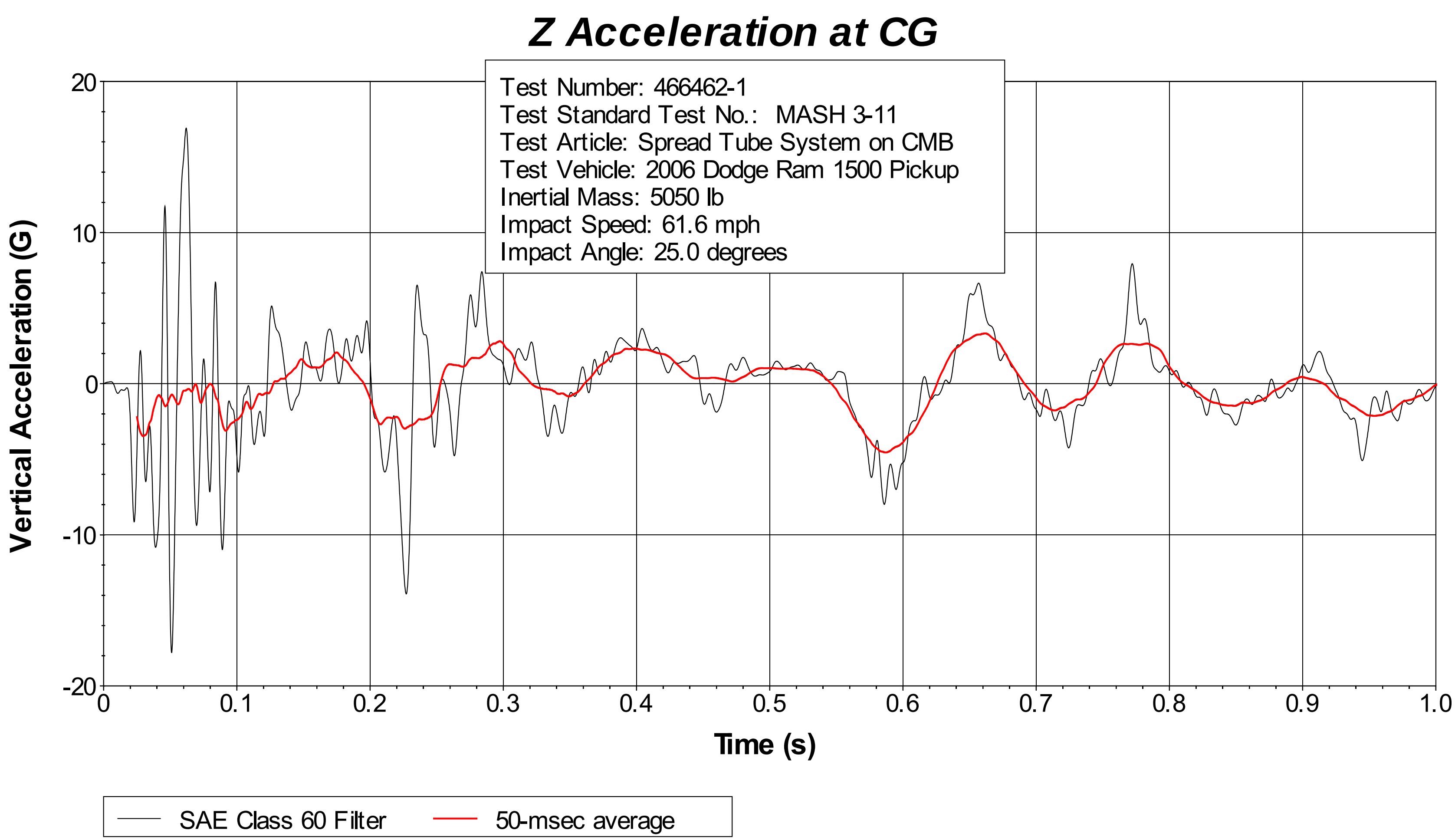


Figure C5. Vehicle Vertical Accelerometer Trace for Test No. 466462-1 (Accelerometer Located at Center of Gravity).

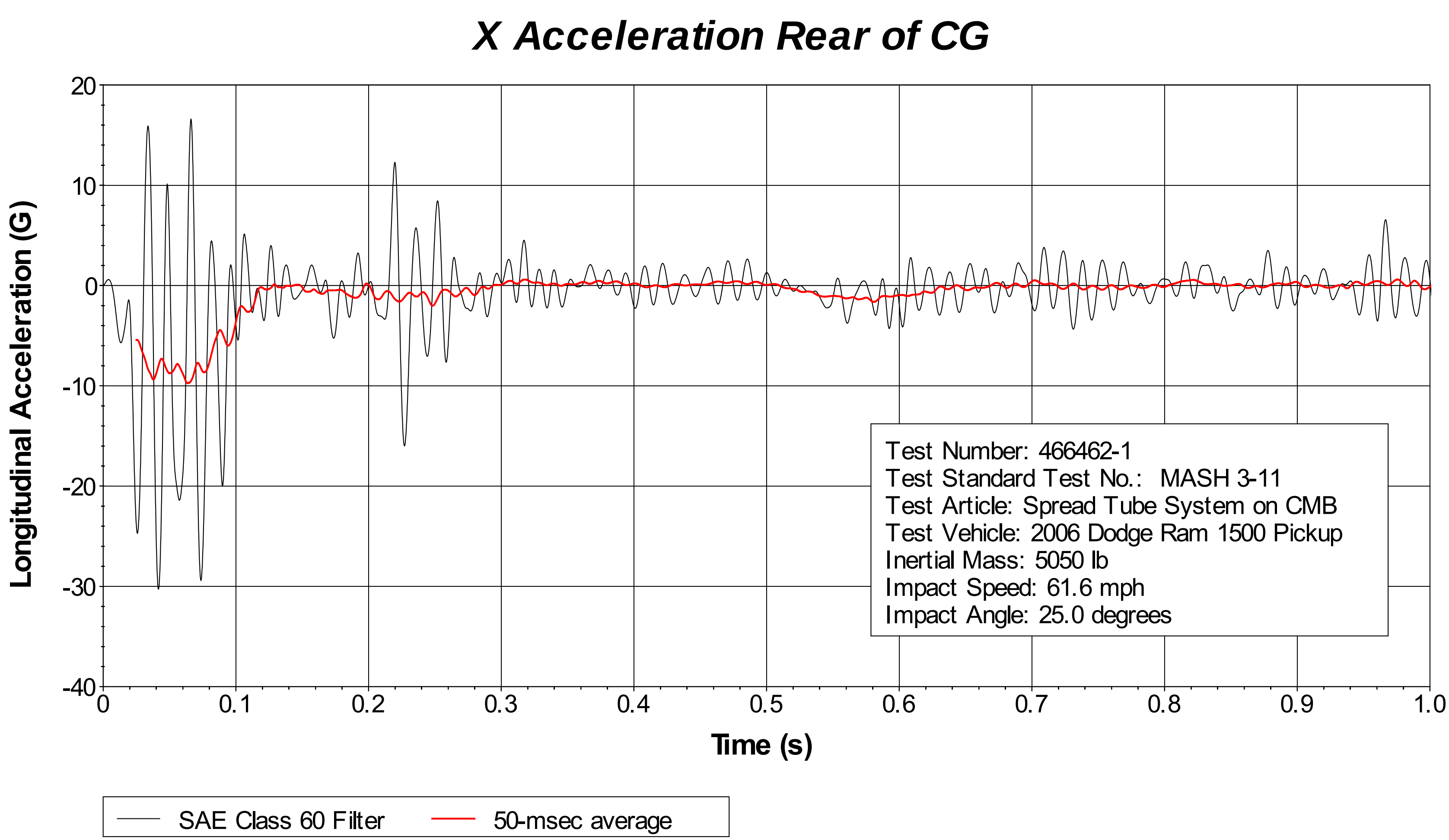


Figure C6. Vehicle Longitudinal Accelerometer Trace for Test No. 466462-1 (Accelerometer Located Rear of Center of Gravity).

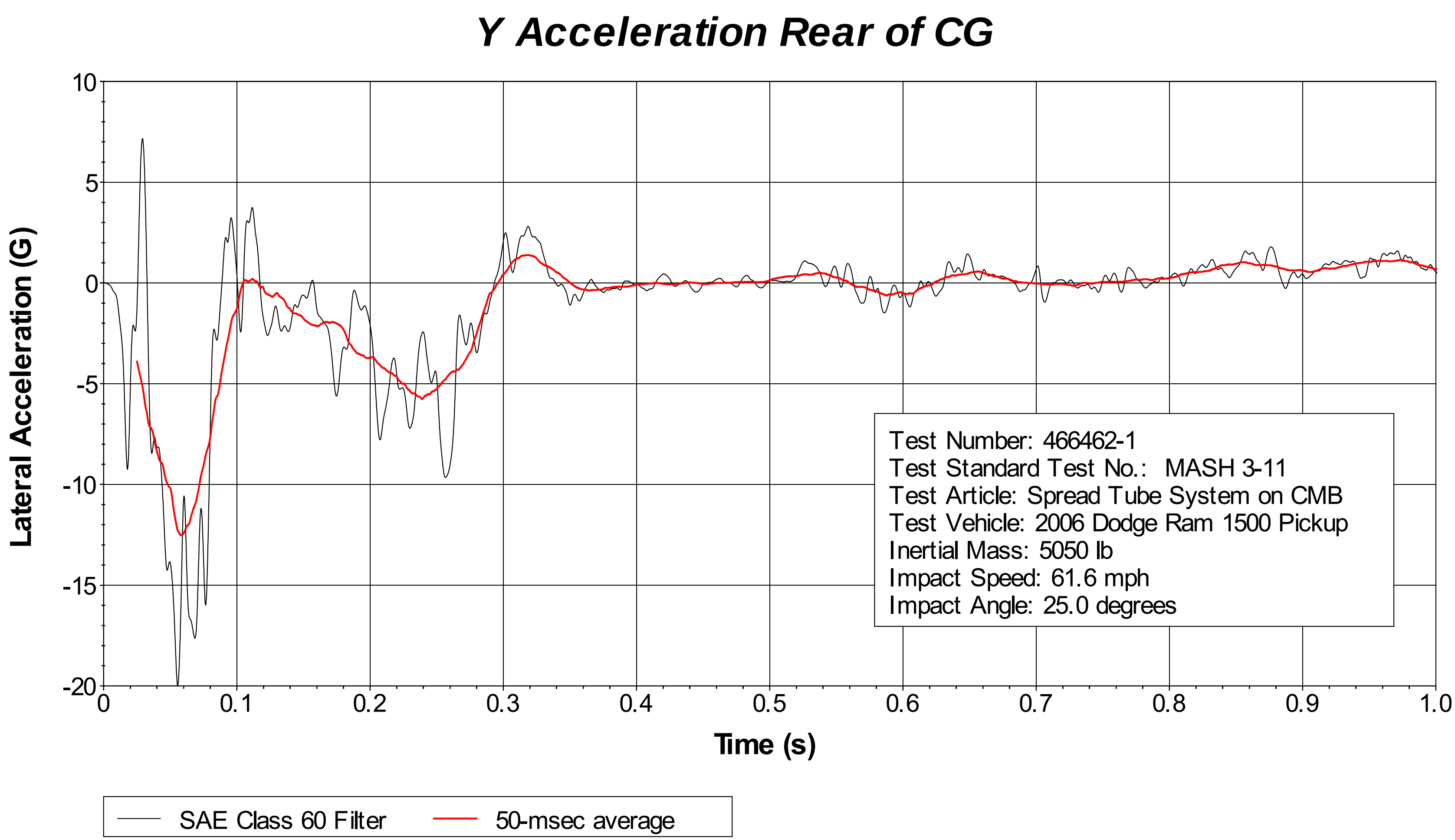


Figure C7. Vehicle Lateral Accelerometer Trace for Test No. 466462-1 (Accelerometer Located Rear of Center of Gravity).

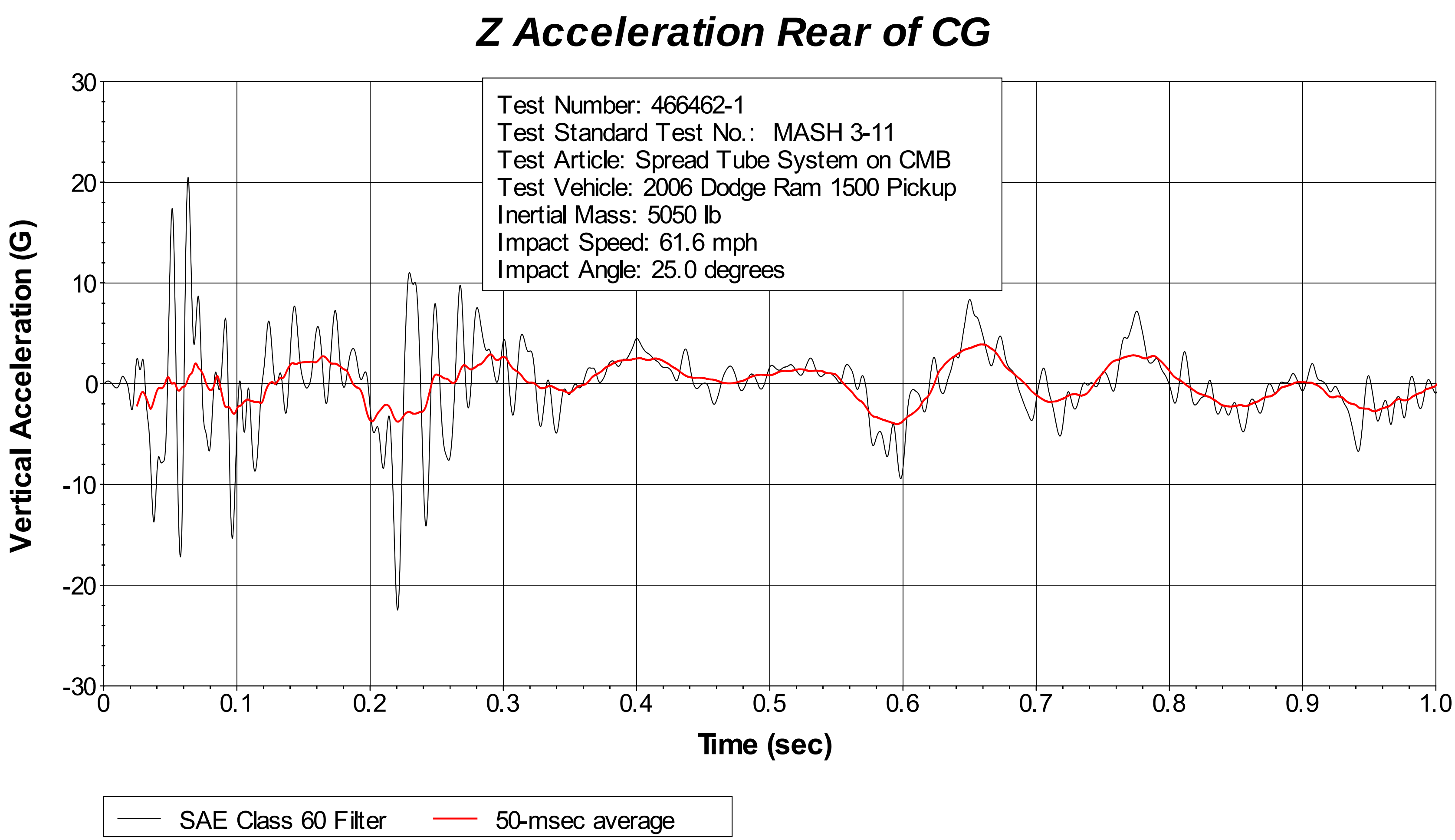
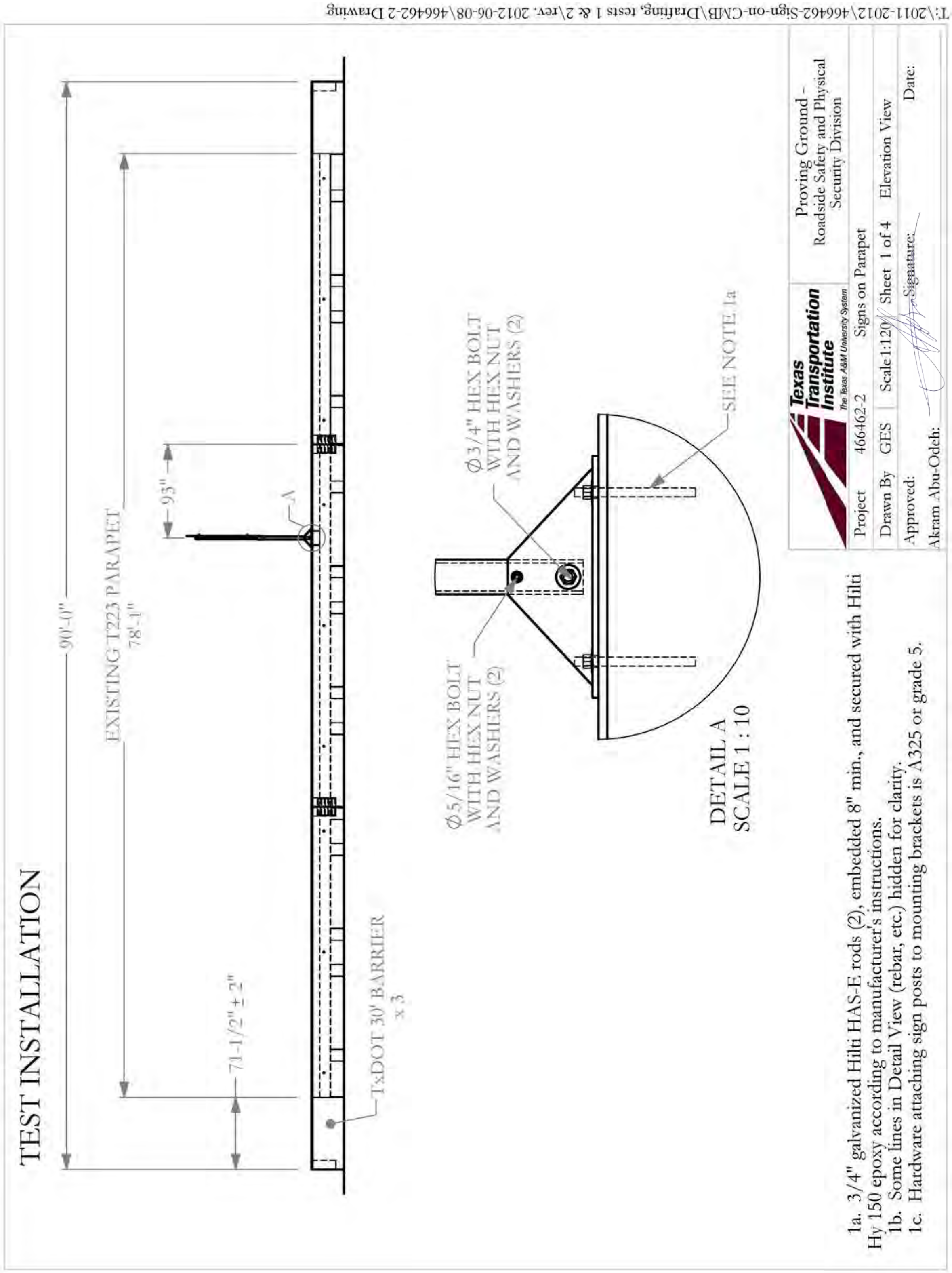
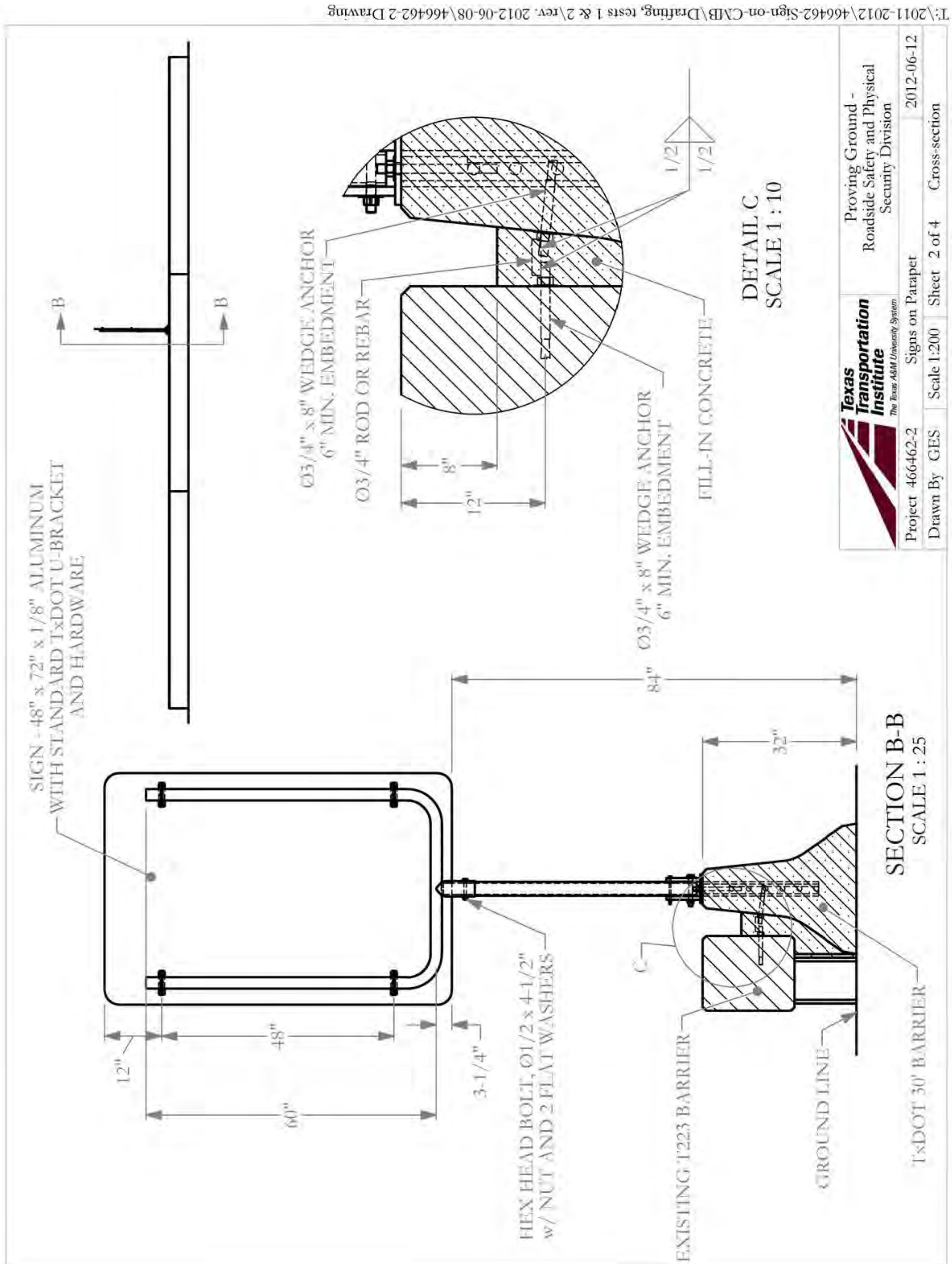


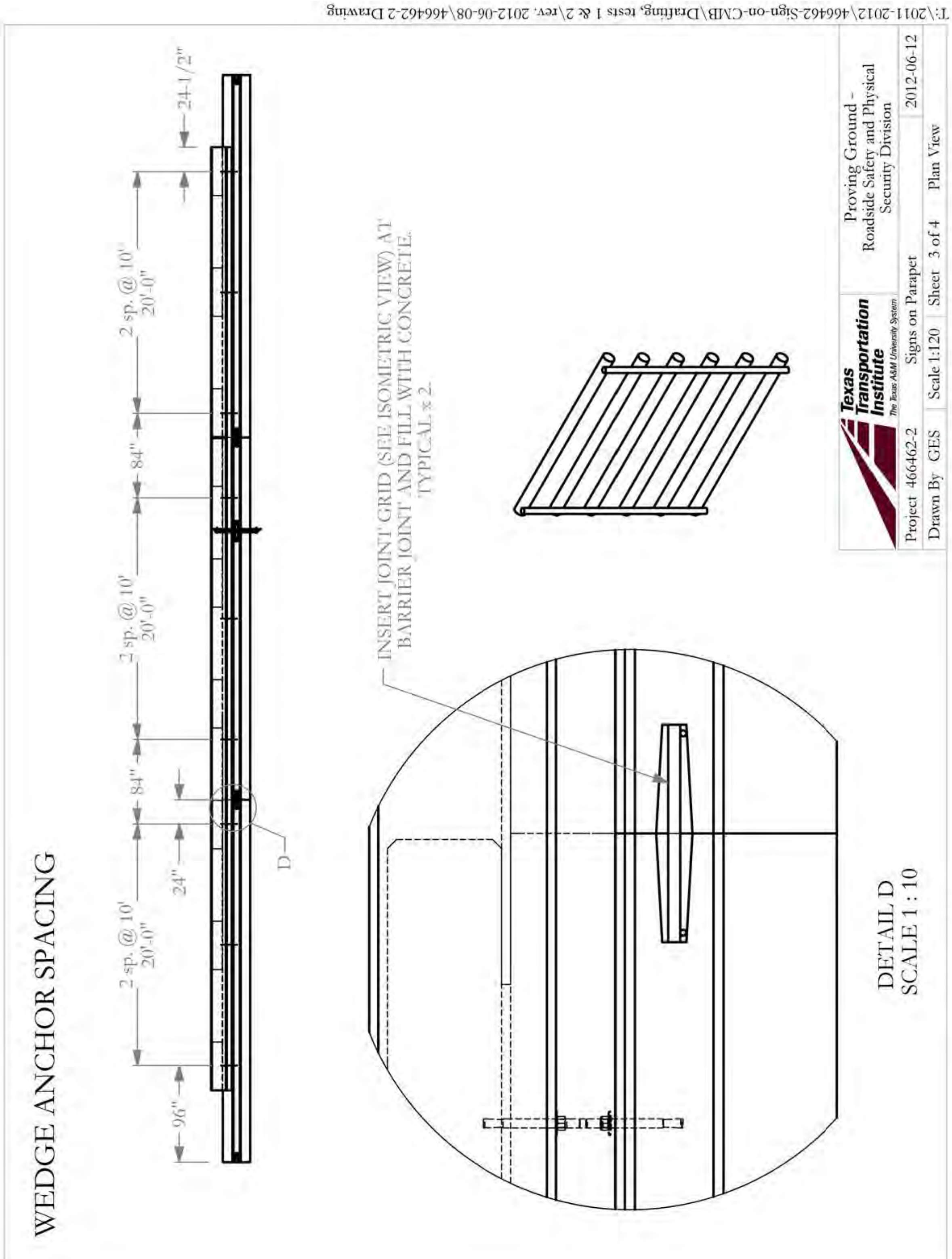
Figure C8. Vehicle Vertical Accelerometer Trace for Test No. 466462-1 (Accelerometer Located Rear of Center of Gravity).

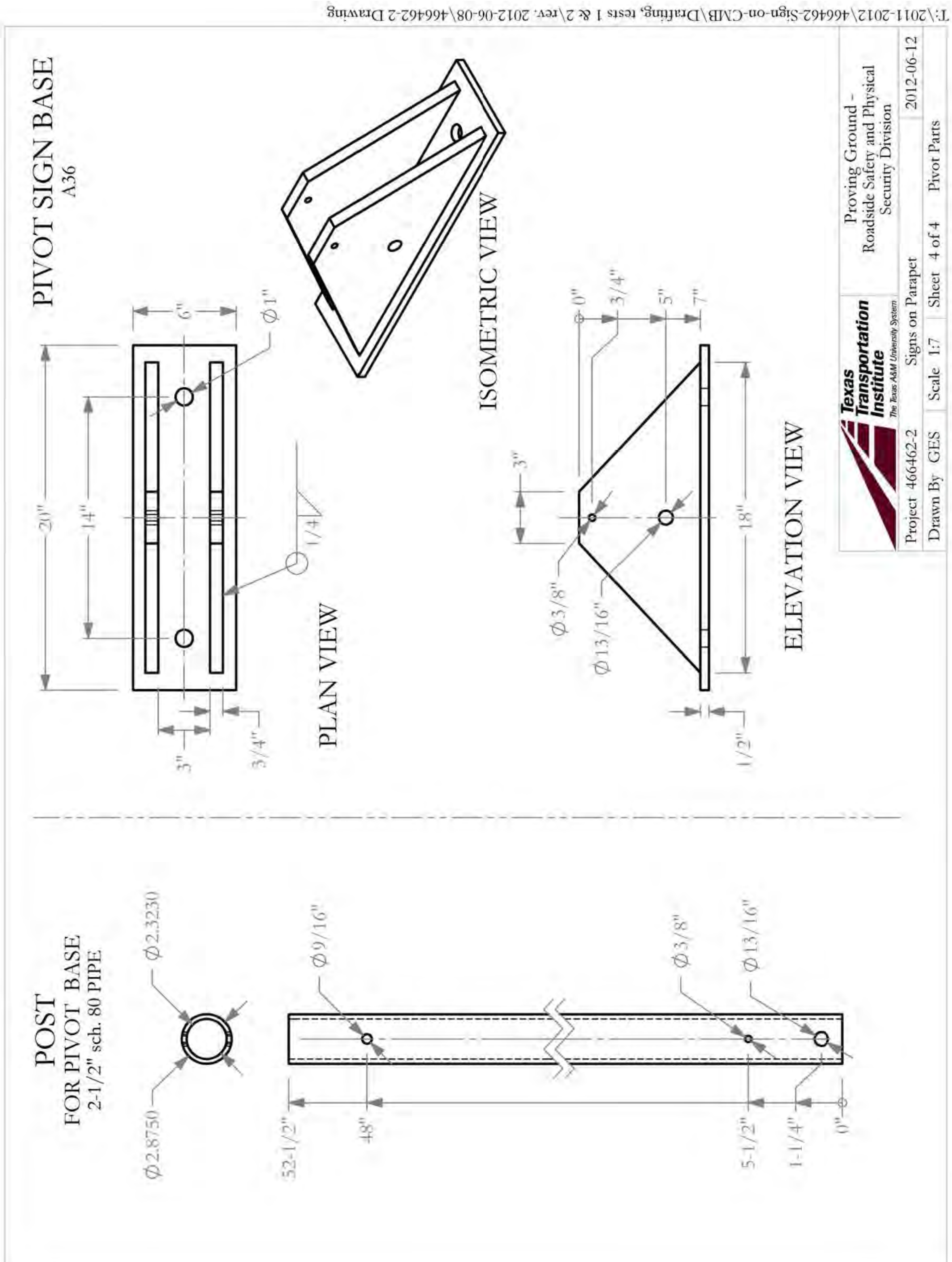
APPENDIX D. CRASH TEST NO. 466462-2A

D1. DETAILS OF THE TEST ARTICLE




T:\2011-2012\466462-Sign-on-CMB\Drafting, tests 1 & 2\rev. 2012-06-08\466462-2 Drawing
SIGN - 48" x 72" x 1/8" ALUMINUM WITH STANDARD TxDOT U-BRACKET AND HARDWARE
B
B
12"
48"
60"
3-1/4"
84"
32"
HEX HEAD BOLT, Ø1/2 x 4-1/2" w/ NUT AND 2 FLAT WASHERS
C
EXISTING T223 BARRIER
GROUND LINE
TxDOT 30" BARRIER
SECTION B-B
SCALE 1 : 25
Ø3/4" x 8" WEDGE ANCHOR 6" MIN. EMBEDMENT
Ø3/4" ROD OR REBAR
8"
12"
Ø3/4" x 8" WEDGE ANCHOR 6" MIN. EMBEDMENT
FILL-IN CONCRETE
1/2
1/2
DETAIL C
SCALE 1 : 10
Texas Transportation Institute
The Texas A&M University System
Proving Ground - Roadside Safety and Physical Security Division
Project 466462-2
Signs on Parapet
2012-06-12
Drawn By GES
Scale 1:200
Sheet 2 of 4
Cross-section


T:\2011-2012\46462-Sign-on-CMB\Drafting, tests 1 & 2\rev. 2012-06-08\466462-2 Drawing
WEDGE ANCHOR SPACING
96"
2 sp. @ 10'
20'-0"
24"
84"
2 sp. @ 10'
20'-0"
84"
2 sp. @ 10'
20'-0"
24-1/2"
D
INSERT JOINT GRID (SEE ISOMETRIC VIEW) AT BARRIER JOINT AND FILL WITH CONCRETE.
TYPICAL x 2.
DETAIL D
SCALE 1 : 10
Texas Transportation Institute
The Texas A&M University System
Proving Ground -
Roadside Safety and Physical Security Division
Project 466462-2
Signs on Parapet
2012-06-12
Drawn By GES
Scale 1:120
Sheet 3 of 4
Plan View



T:\2011-2012\466462-Sign-on-CMB\Drafting, tests 1 & 2\rev. 2012-06-08\466462-2 Drawing
PIVOT SIGN BASE
A36
20"
14"
6"
Ø1"
1/4
3"
3/4"
PLAN VIEW
ISOMETRIC VIEW
0"
3/4"
5"
7"
3"
Ø3/8"
Ø13/16"
18"
1/2"
ELEVATION VIEW
POST
FOR PIVOT BASE
2-1/2" sch. 80 PIPE
Ø2.3230
Ø2.8750
Ø9/16"
Ø3/8"
Ø13/16"
52-1/2"
48"
5-1/2"
1-1/4"
0"
Proving Ground - Roadside Safety and Physical Security Division
Texas Transportation Institute
The Texas A&M University System
Project 466462-2
Signs on Parapet
2012-06-12
Drawn By GES
Scale 1:7
Sheet 4 of 4
Pivot Parts

D2. CERTIFICATION DOCUMENTATION

MATERIAL USED

TEST NUMBER	466462-2a
TEST NAME	Sign on Barrier
DATE	2012-07-06

DATE RECEIVED	ITEM NUMBER	DESCRIPTION	SUPPLIER	HEAT #
2012-04-11	U-Bracket-1	2-7/8" OD sign bracket	Trinity	generic Trinity
2010-12-08	Strap 6-02	6 x 1/2 x 20'	Mack Bolt & Steel	several - see list
2012-01-18	Bolt 0.500-11	1/2 -13 x 4-1/2 gr. 5	Fastenal	1WG14
2011-06-28	Washer 0.5000-02	1/2 flat	Best Products Co.	
2011-06-28	Nut 0.5000-02	1/2 hex gr. 5	Best Products Co.	315702

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111

A

Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207

Sales Order: 1151007
Customer PO: Samples
BOL # 41575
Document # 1

Print Date: 4/10/12
Project: SAMPLES
Shipped To: TX
Use State: TX

Trinity Highway Products. LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SMALL SIGNS SUPPORT **

NCHRP Report 350 Compliant

Pieces	Description	Part No
9	1.500PS12@144	720018G
11	1.750PS12@144	720087G
1	2.000PS12@24 ANCH	720253G
2	2.875RD10 U BKT HDG	720852G
1	2.000PS14@24 ANCH	721116G

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

TL -3 or TL-4 COMPLIANT when installed according to manufactures specifications

Steel. The steel shall be in accordance with the standard specification for hot rolled carbon sheet steel, structural quality, ASTM A 1011, Grade 50. The average minimum yield strength after cold-forming shall be a minimum of 50,000 psi.

Coating. The posts shall be hot-dipped galvanized steel in accordance with ASTM A 653, G90, structural quality, Grade 50, Class 1. The corner weld shall be zinc coated after scarfing operation. The steel shall also be coated with a chromate conversion coating and a clear organic polymer topcoat. Both the interior and the exterior of the post shall be galvanized. Modifications made to the post after the initial fabrication, such as additional welding or other alterations shall be galvanized.

CERTIFICATION. The fabricator shall furnish to the engineer, a certification stating that the posts furnished comply with all requirements of this specification. The certification shall include or have attached specific results of tests of the mechanical and chemical properties of the steel conforming to section 2.1 and 2.2 of this specification. A certification shall be submitted with the bid

State of Texas, County of Tarrant. Sworn and Subscribed before me this 10th day of April, 2012

Notary Public:
Commission Expires:

JOMARY LUGINSLAND
MY COMMISSION EXPIRES
May 24, 2015

Trinity Highway Products, LLC
Certified By:
Quality Assurance

1 of 1

B/L# 322931

NUCOR BAR MILL - JEWETT
8812 HIGHWAY 79 WEST
JEWETT, TEXAS 75846 PH (903) 626-4461

Date 12/16/04

CERTIFIED MILL TEST REPORT

43263
METALS SUPPLY CO.,LTD
P.O. BOX 24040

HOUSTON TX 77229-4040

43263
METAL SUPPLY COMPANY

CLUTE TX

SIZE / GRADE	HEAT NUMBER	CUSTOMER PO NUMBER	C	Mn	Si	S	P	V	Nb	Cu	Cr	Ni	Mo	Sn	Bend Test
1/2 X 6 ASTM A529-04 GRADE 55	400-3487	P28117	.21	.93	.24	.047	.010	.004	.011	.41	.12	.14	.039	.020	
1/2 X 6 A36-04/A709-04/SA36-98	400-3532	P28694	.13	.60	.18	.049	.009	.004	.001	.42	.09	.13	.032	.017	
1/2 X 6 A36-04/A709-04/SA36-98	400-3533	P28694	.15	.62	.18	.039	.009	.003	.001	.38	.10	.15	.036	.013	
1/2 X 6 A36-04/A709-04/SA36-98	400-3534	P28694	.15	.67	.17	.040	.009	.004	.001	.43	.13	.15	.037	.018	
3/8 X 8 A36-04/A709-04/SA36-98	400-3101	P28842	.13	.64	.17	.041	.011	.005	.002	.44	.13	.14	.041	.020	
3/4 ROUNDS A36-04/A709-04/SA36-98	400-2355	P28117	.12	.76	.21	.030	.010	.004	.002	.42	.10	.13	.035	.014	

HEAT NUMBER	Tensile 1	Yield 1	Elong% 1	Tensile 2	Yield 2	Elong% 2
400-3487	84800	60600	21	84900	59900	22
400-3532	65500	46000	23	65800	45800	23
400-3533	67600	47000	24	68100	46800	24
400-3534	70800	48000	24	70700	49000	25
400-3101	66500	46700	28	67900	47600	25
400-2355	70700	50300	23	71000	51000	23

ELONGATION IN 8 INCH SCALE/TENSILE & YIELD SHOWN IN PSI
MELTED AND MANUFACTURED IN U.S.A.

ALL MATERIAL STRAND CAST AND HOT ROLLED

CHIEF METALLURGIST
By Traffic

Jinn Her Enterprise Co., Ltd.

No. 107, SHIN-LO ST, KANGSHAN, 820 KAOHSIUNG, TAIWAN R. O. C
TEL : +886 (07) 6229801 FAX : +886 (07) 6223750 • +886 (07) 6211503

CERTIFICATE OF INSPECTION

CUSTOMER NAME	: FASTENAL COMPANY PURCHASING-IMPORT TRAFFIC	REPORT NO	: JH11092918015
CUSTOMER'S ADDRESS	: 4730 SERVICE DRIVE, WINONA MN. 55987 U.S.A.,TEL : 507-453-8086 FAX: 507-494-7833	REPORT DATE BOLT LOT NO BOLT MATERIAL	: 2011/10/19 : B087766Y1 : SCR435
ORDER NUMBER	: 180050104	BOLT HEAT NO	: 1WG14
PART NUMBER	: 15221	NUT LOTNO	:
DESCRIPTION	: HEX CAP SCREW G8 HD MARK:6 RADIAL LINES & "FNL"	NUT MATERIAL NUT HEAT NO WASHER LOT NO	: : :
SIZE	: 1/2-13X4-1/2	WASHER MATERIAL	:
FINISH	: H.T. ZINC YELLOW 5 MICRON	WASHER HEAT NO	:
QUANTITY	: 1500.0	ASSEMBLY LOT NO	:
BOLT MFR.	: JINN HER ENTERPRISE CO.,LTD.	BOLT MFR. DATE	: 2011/9/2
NUT MFR.	:	NUT MFR. DATE	:
WASHER MFR.	:	WASHER MFR. DATE	:

BOLT DIMENSIONAL INSPECTION — INSPECTION : 2011/09/23
SPECIFICATION : ASME B18.2.1 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
WIDTH ACROSS CORNERS	JIS B1071	21.34-21.99	mm	21.46-21.53	8	8	0
WIDTH ACROSS FLATS	JIS B1071	18.70-19.05	mm	18.77-18.81	8	8	0
HEIGHT	JIS B1071	7.67-8.20	mm	7.83-7.87	8	8	0
BODY DIA.	JIS B1071	12.53-12.70	mm	12.54-12.56	8	8	0
BODY LENGTH	JIS B1071	MIN 72.65	mm	74.07-74.16	8	8	0
GRIP LENGTH	JIS B1071	MAX 82.55	mm	76.86-77.11	8	8	0
LENGTH	JIS B1071	111.76-114.30	mm	113.57-113.71	8	8	0
THREAD	ASME B1.3M	NONE	N/A	PASS	8	8	0

BOLT MECHANICAL INSPECTION — INSPECTION : 2011/09/15
SPECIFICATION : SAE J121 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
COMPLETELY DEC. DEPTH	SAE J121	MAX 0.015	mm	PASS	1	1	0
BASE METAL	SAE J121	MIN 0.813	mm	PASS	1	1	0

BOLT MECHANICAL INSPECTION — INSPECTION : 2011/09/15
SPECIFICATION : SAE J429 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
SURFACE HARDNESS	SAE J429	MAX 58.6	HR30N	55-56	8	8	0
CORE HARDNESS	SAE J429	33.0-39.0	HRC	38-38	8	8	0
TENSILE STRENGTH	SAE J429	MIN 150.0	ksi	170-172	4	4	0
PROOF LOAD	SAE J429	MIN 120.0	ksi	PASS	1	1	0

BOLT FINISH INSPECTION — INSPECTION : 2011/09/23
SPECIFICATION : ASTM F1941 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
THICKNESS OF COATING	ASTM A754/A754M	MIN 5.00000	um	8.14000-9.26000	4	4	0

BOLT APPEARANCE INSPECTION — INSPECTION : 2011/09/23
SPECIFICATION : SAE J1061 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
GENERAL WORKMANSHIP	VISION	NONE	N/A	PASS	8	8	0

CHEMICAL ANALYSIS %

HEAT NO	C-x100	MN-x100	P-x1000	S-x1000	SI-x100	CU-x100	NI-x100	CR-x100	MO-x100	AL-x1000	B-x10000	V-x100
1WG14	36	72	14	9	20	1	3	102				

BOLT MARKING

Remark : 1.Lab is accredited according to ISO/IEC17025 requirements. This certificate is valid with signature of Yi-Sung Chen.

2.This test certificate is responsible for designated samples only. This test certificate only relates to the items listed and tested, it's not allowed to be partially used.

3.The above composition is quoted from original mill certs which is not in the scope of Lab Accreditation.

4.This test certificate in accordance with EN 10204 type 3.1.

5.Unless specified by the customer, the latest version of the testing specs was used.

6.Quality System conforms to ISO 9001 requirements and certified by TUV .

180050104

15221

B087766Y1

SUPER CHENG INDUSTRIAL CO.,LTD.

NO. 18 BEN-GONG 2nd ROAD., BEN CHOU INDUSTRIAL PARK, KAOHSIUNG COUNTY 820, TAIWAN R.O.C.
TEL：886-7-6225326-30(5 LINES) FAX：886-7-6215377/6212335/6235829

CERTIFICATE OF INSPECTION

CERT. #： S62-1010-03 ISSUED DATE： 2010/11/12 PAGE 1 OF 1

CLIENT：SUPER CHENG INDUSTRIAL CO., LTD.
ADDRESS：NO. 18 BEN-GONG 2nd ROAD., BEN CHOU INDUSTRIAL PARK, KAOHSIUNG COUNTY 820, TAIWAN R.O.C.

PURCHASER：FASTENAL COMPANY PURCHASING PO #：180038281
PART#1136310 QTY SHIPPED：112,500 PCS

COMMODITY：GRADE 5 FIN HEX NUT FINISH： TRIVALENT ZINC
SIZE： 1/2-13 LOT#： S62-1010-03 SAMPLING PLAN：ANSI/ASME B18.18.2M-93
QTY： 587270 PCS MATERIAL： SWRCH10A HEAT NO.： 315702
MANUFACTURER：SUPER CHENG IND. CO., LTD. MANU. DATE： 2010/10/27

DIMENSIONAL INSPECTION SPEC.：ANSI/ASME B18.2.2-87 SAMPLED BY： HUI HUA YU

ITEM	SAMPLE SIZE	SPECIFIED	ACTUAL RESULT	JUDGMENT
APPEARANCE	100	ASTM F812-07	GOOD	OK
W.A.F.	32	0.750 ~ 0.736 in.	0.743 ~ 0.741 in.	OK
W.A.C.	8	0.866 ~ 0.840 in.	0.852 ~ 0.848 in.	OK
THICKNESS	8	0.448 ~ 0.427 in.	0.447 ~ 0.439 in.	OK
THREAD	32	ANSI/ASME B1.1	PASS	OK

MECHANICAL PROPERTIES SPEC.：SAE J995-99 SAMPLED BY： HUI HUA YU

ITEM	SAMPLE SIZE	TEST METHOD	SPECIFIED	ACTUAL RESULT	JUDGMENT
HARDNESS	8	ASTM F606-09	MAX HRB107	98.0 ~ 94.0 HRBW	PASS
PROOF LOAD	4	ASTM F606-09	MIN 17000LB	17163 ~ 17152 LB	PASS

REMARK：1、THIS REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL WITHOUT WRITTEN APPROVAL OF THE LAB.
2、THIS INSPECTION CERTIFICATE IS FOR RESPONSIBILITY UNDER SAMPLE ONLY
3、ABOVE SAMPLES TESTED CONFORM TO THE FASTENER SPECIFICATION OR STANDARDS

LAB. DIRECTOR(SIGNATORY)：

表單編號：LQC 10E Rev.0

D3. VEHICLE PROPERTIES AND INFORMATION

Table D1. Vehicle Properties for Test No. 466462-2a.

Date: 2012-07-06 Test No.: 466462-2a VIN No.: 1D7HA182675243649

Year: 2007 Make: Dodge Model: RAM 1400

Tire Size: 265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 142470

Note any damage to the vehicle prior to test: ______

● Denotes accelerometer location.

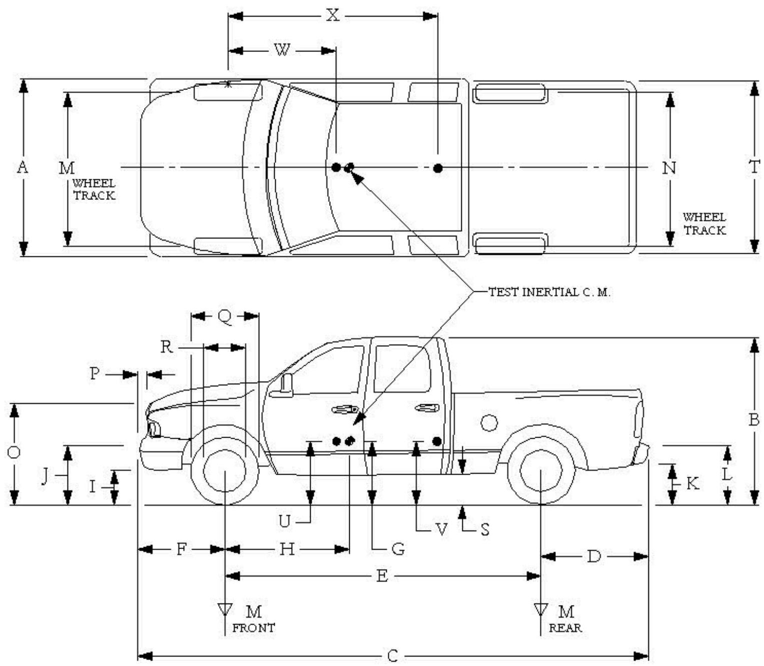
NOTES: ______

Engine Type: V-8
Engine CID: 5.7 liter

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

Optional Equipment: ______

Dummy Data:
Type: No dummy
Mass: ______
Seat Position: ______



Geometry: inches

A	78.25	F	36.00	K	20.50	P	2.88	U	28.50
B	75.00	G	28.125	L	29.12	Q	31.25	V	29.50
C	223.75	H	58.65	M	68.50	R	18.38	W	59.00
D	47.25	I	13.75	N	44.50	S	12.00	X	78.00
E	140.50	J	25.38	O		T	77.50		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	5.00	Bottom Frame Height - Front	17.12
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	10.25	Bottom Frame Height - Rear	24.75

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2829	2910	
Back	3900	M_{rear}	2107	2085	
Total	6700	M_{Total}	4936	4995	

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

Mass Distribution:
lb LF: 1422 RF: 1488 LR: 1050 RR: 1035

Table D2. Vehicle Parametric Measurements for Test No. 466462-2a.

Date: 2012-07-06 Test No.: 466462-2a VIN: 1D7HA182675243649

Year: 2007 Make: Dodge Model: RAM 1500

Body Style: Quad Cab Mileage: 142470

Engine: V-8 5.7 liter Transmission: Automatic

Fuel Level: Empty Ballast: 100 lb in front of bed (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70R17

Measured Vehicle Weights: (lb)

LF:	1422	RF:	1488	Front Axle:	2910
LR:	1050	RR:	1035	Rear Axle:	2085
Left:	2472	Right:	2523	Total:	4995

5000 ±110 lb allowed

Wheel Base: 140.5 inches Track: F: 68.5 inches R: 68 inches

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

Center of Gravity, SAE J874 Suspension Method

X: 58.65 inches Rear of Front Axle (63 ±4 inches allowed)

Y: 0.35 inches Left - Right + of Vehicle Centerline

Z: 28.125 inches Above Ground (minumum 28.0 inches allowed)

Hood Height: 44.50 inches Front Bumper Height: 25.375 inches

43 ±4 inches allowed

Front Overhang: 36.00 inches Rear Bumper Height: 29.125 inches

39 ±3 inches allowed

Overall Length: 223.75 inches

237 ±13 inches allowed

Table D3. Exterior Crush Measurements for Test No. 466462-2a.

Date: 2012-07-06 Test No.: 466462-2a VIN No.: 1D7HA182675243649

Year: 2007 Make: Dodge Model: RAM 1400

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	**Side Damage**
Undeformed end width ________	Bowing: B1 _____ X1 _____
Corner shift: A1 ________	B2 _____ X2 _____
A2 ________	
End shift at frame (CDC)	Bowing constant
(check one)	$\frac{X1+X2}{2}$ = _______
< 4 inches ________	
≥ 4 inches ________	

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bumper ht	10	12	20	0	2	3 ½	4	8	12	+14 ½
2	Side plane at bumper ht	10	13	52	1	4	6 ½	8	10½	13	+76
	Measurements recorded										
	in inches										

[1]Table taken from National Accident Sampling System (NASS).

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

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

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

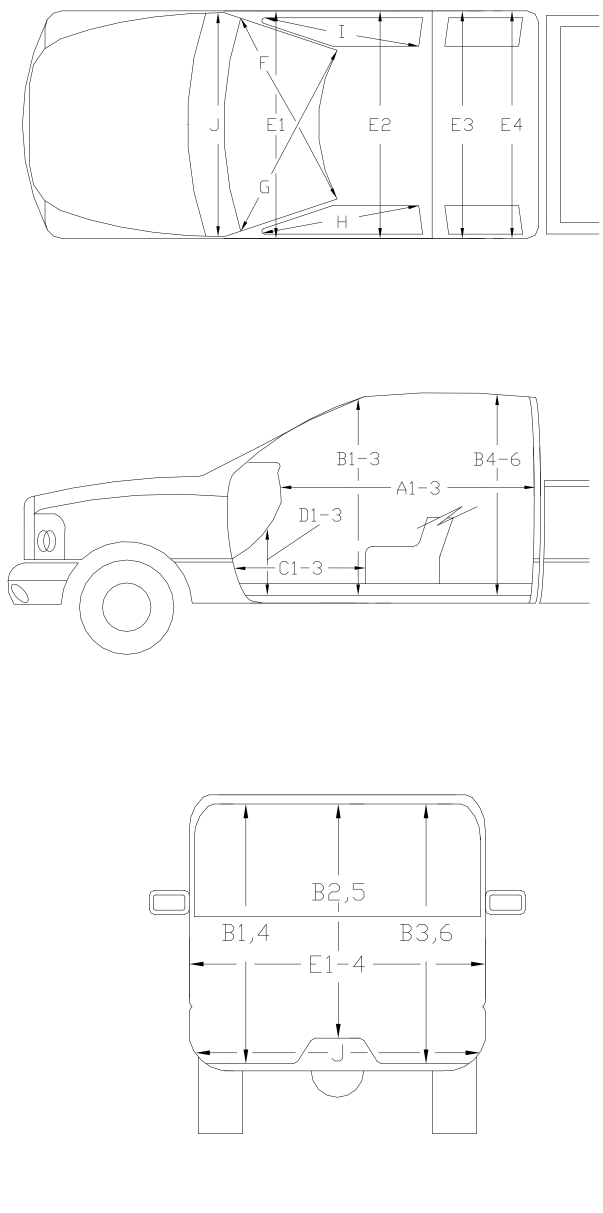
***Measure and document on the vehicle diagram the location of the maximum crush.

Note: Use as many lines/columns as necessary to describe each damage profile.

Table D4. Occupant Compartment Measurements for Test No. 466462-2a.

Date: 2012-07-06 Test No.: 466462-2a VIN No.: 1D7HA182675243649

Year: 2007 Make: Dodge Model: RAM 1400



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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	64.50	64.50
A2	64.50	64.50
A3	65.00	64.00
B1	45.25	45.25
B2	39.50	39.50
B3	45.25	45.25
B4	42.25	42.25
B5	44.75	44.75
B6	42.25	42.25
C1	29.00	29.00
C2	----	----
C3	27.50	25.00
D1	12.75	12.75
D2	----	----
D3	11.50	11.75
E1	62.75	63.00
E2	64.25	66.12
E3	63.75	63.75
E4	64.25	64.25
F	60.00	60.00
G	60.00	60.00
H	39.00	39.00
I	39.00	39.00
J*	62.00	59.75

D4. SEQUENTIAL PHOTOGRAPHS

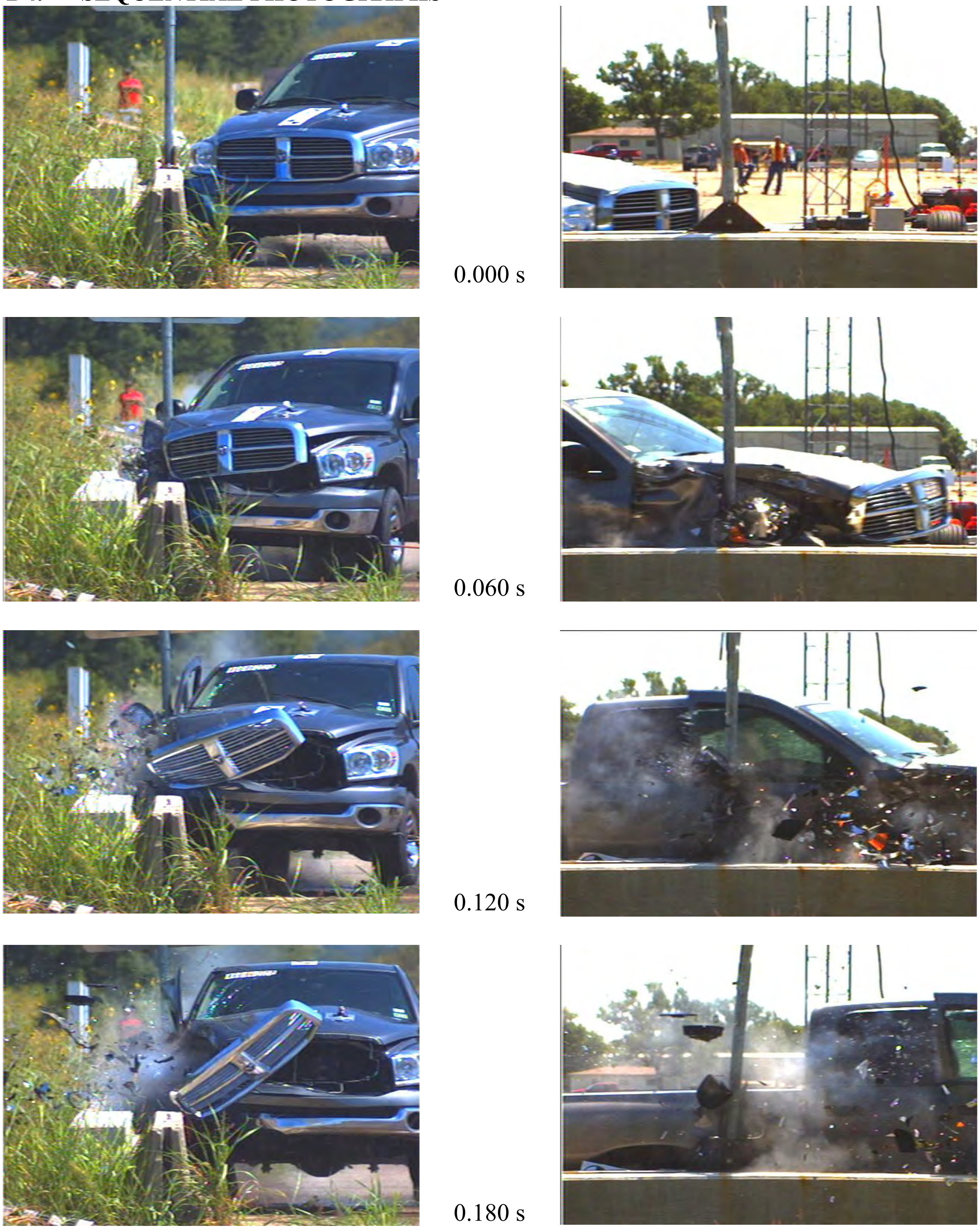


Figure D1. Sequential Photographs for Test No. 46642-2a (Frontal and Field Side Barrier Views).


0.240s



0.300 s



0.360 s



0.420 s


Figure D1. Sequential Photographs for Test No. 466462-2a (Frontal and Field Side Barrier Views) (continued).

D5. VEHICLE ANGULAR DISPLACEMENTS

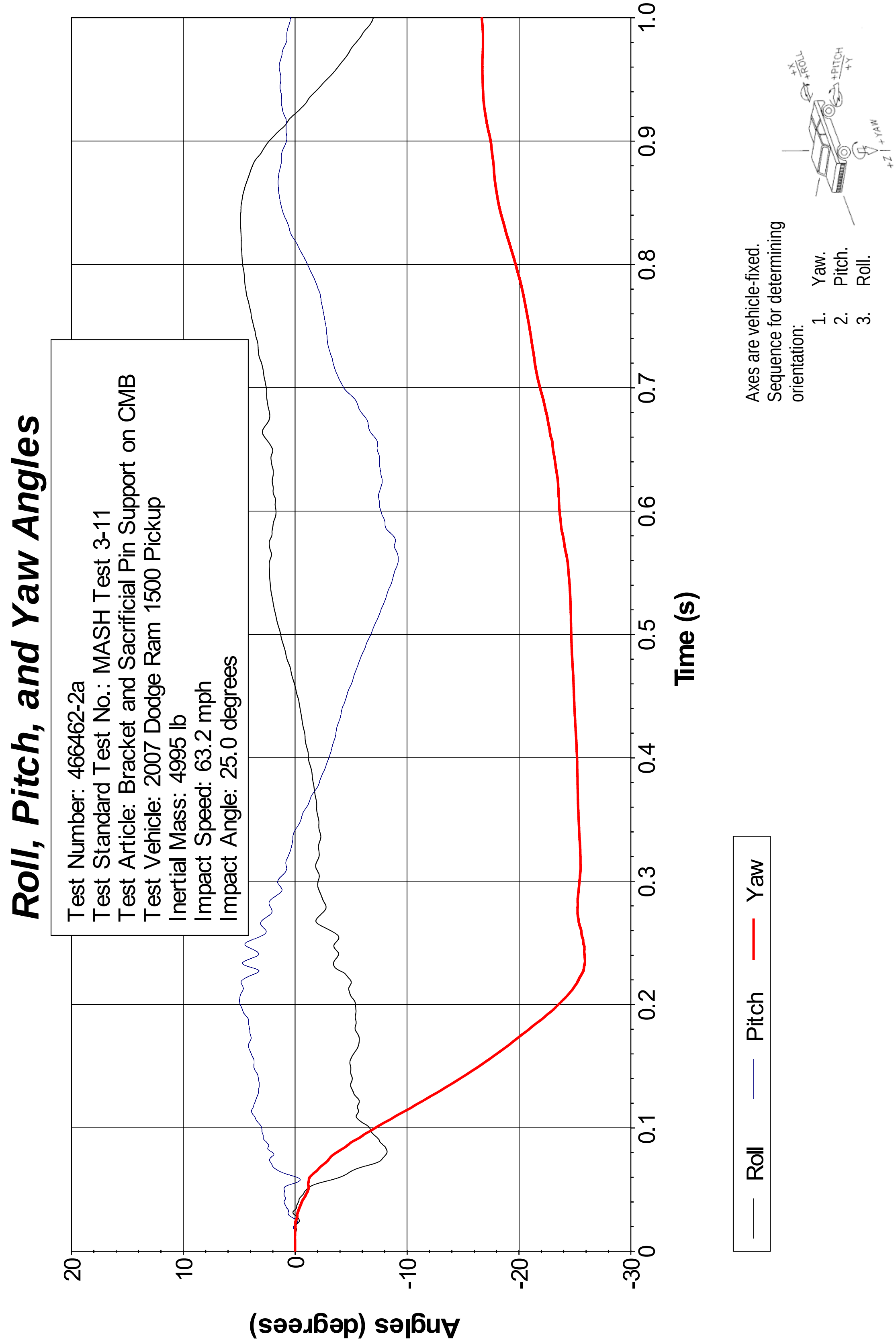


Figure D2. Vehicle Angular Displacements for Test No. 466462-2a.

D6. VEHICLE ACCELERATIONS

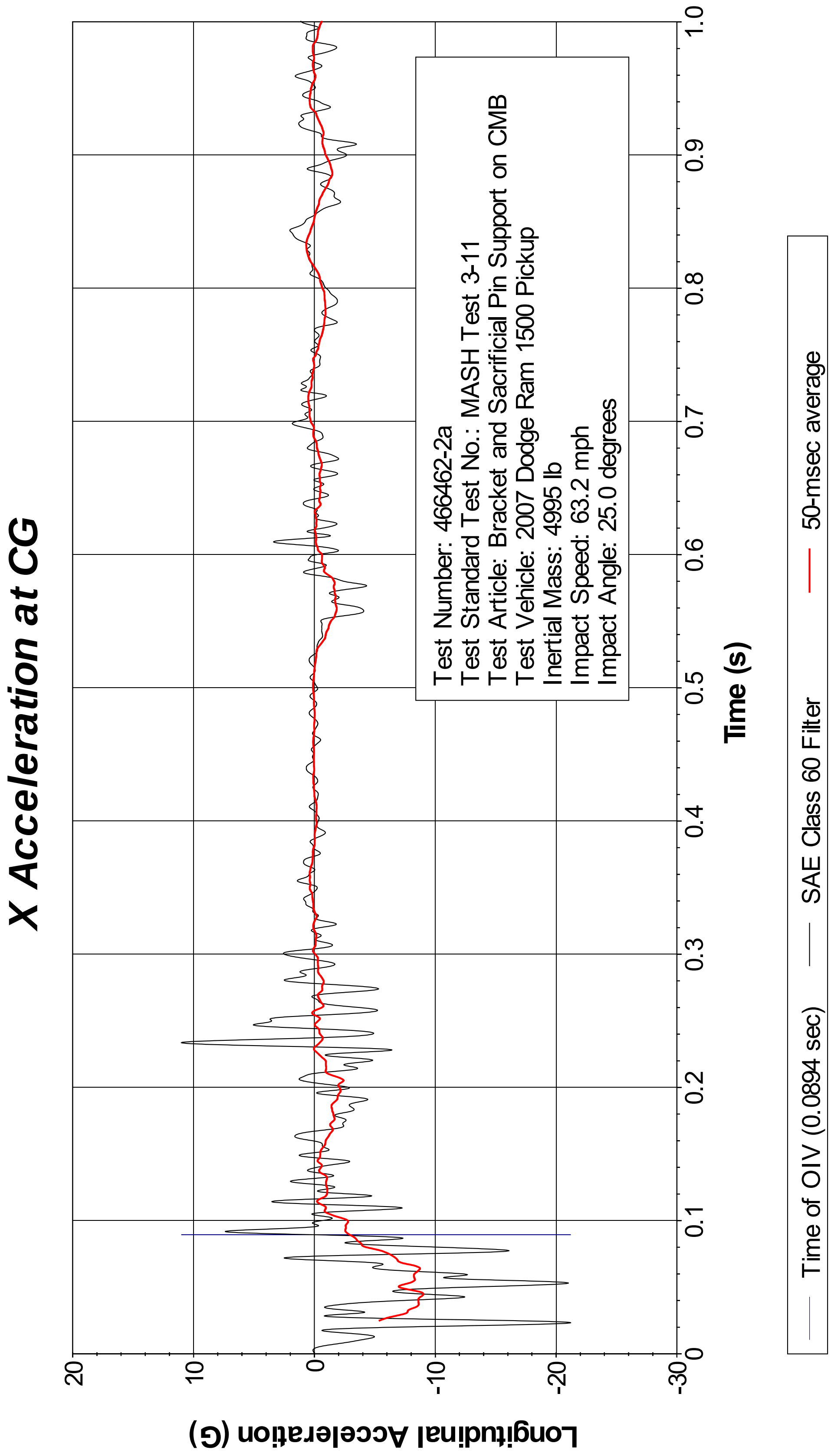


Figure D3. Vehicle Longitudinal Accelerometer Trace for Test No. 466462-2a (Accelerometer Located at Center of Gravity).

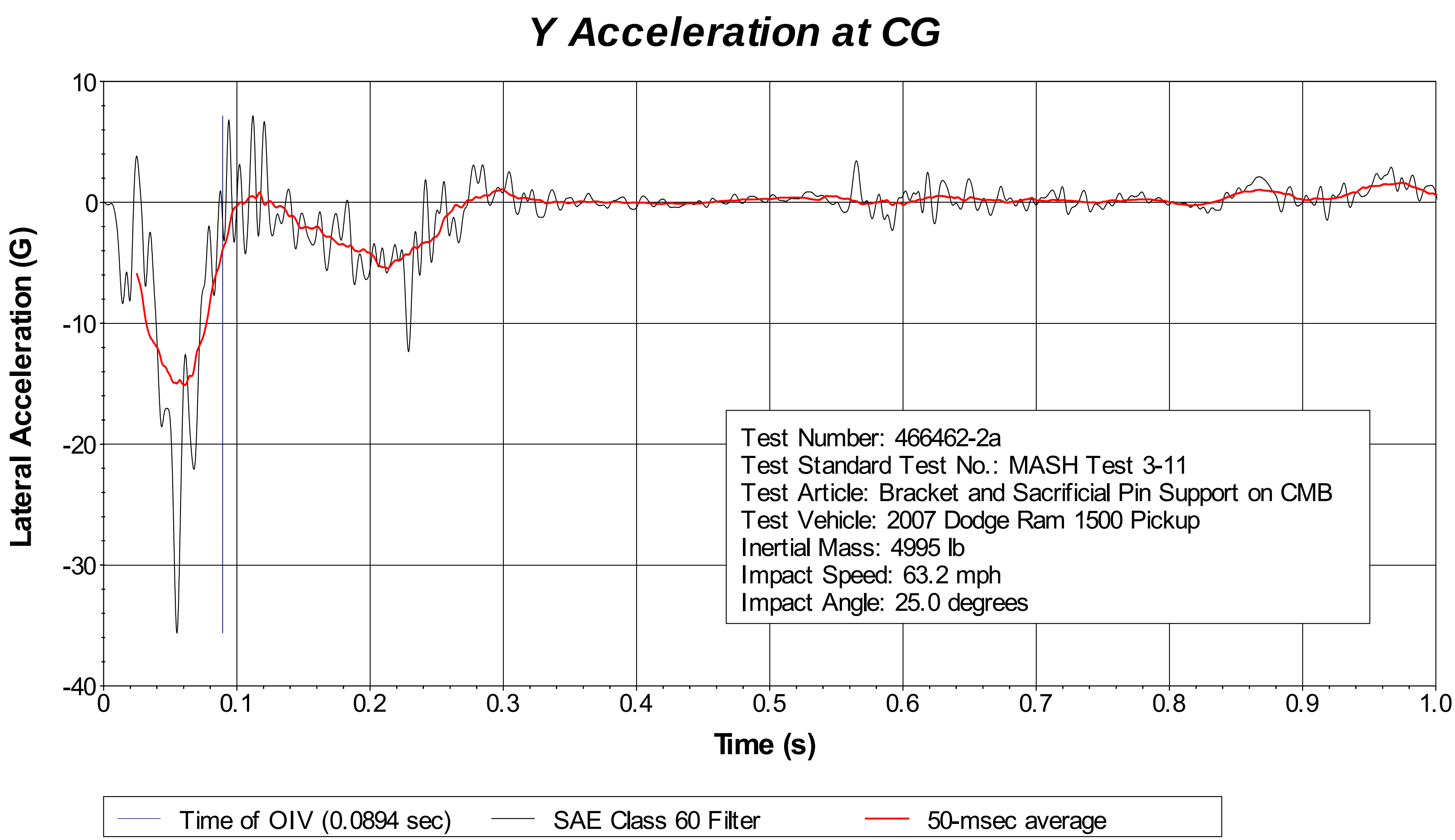


Figure D4. Vehicle Lateral Accelerometer Trace for Test No. 466462-2a (Accelerometer Located at Center of Gravity).

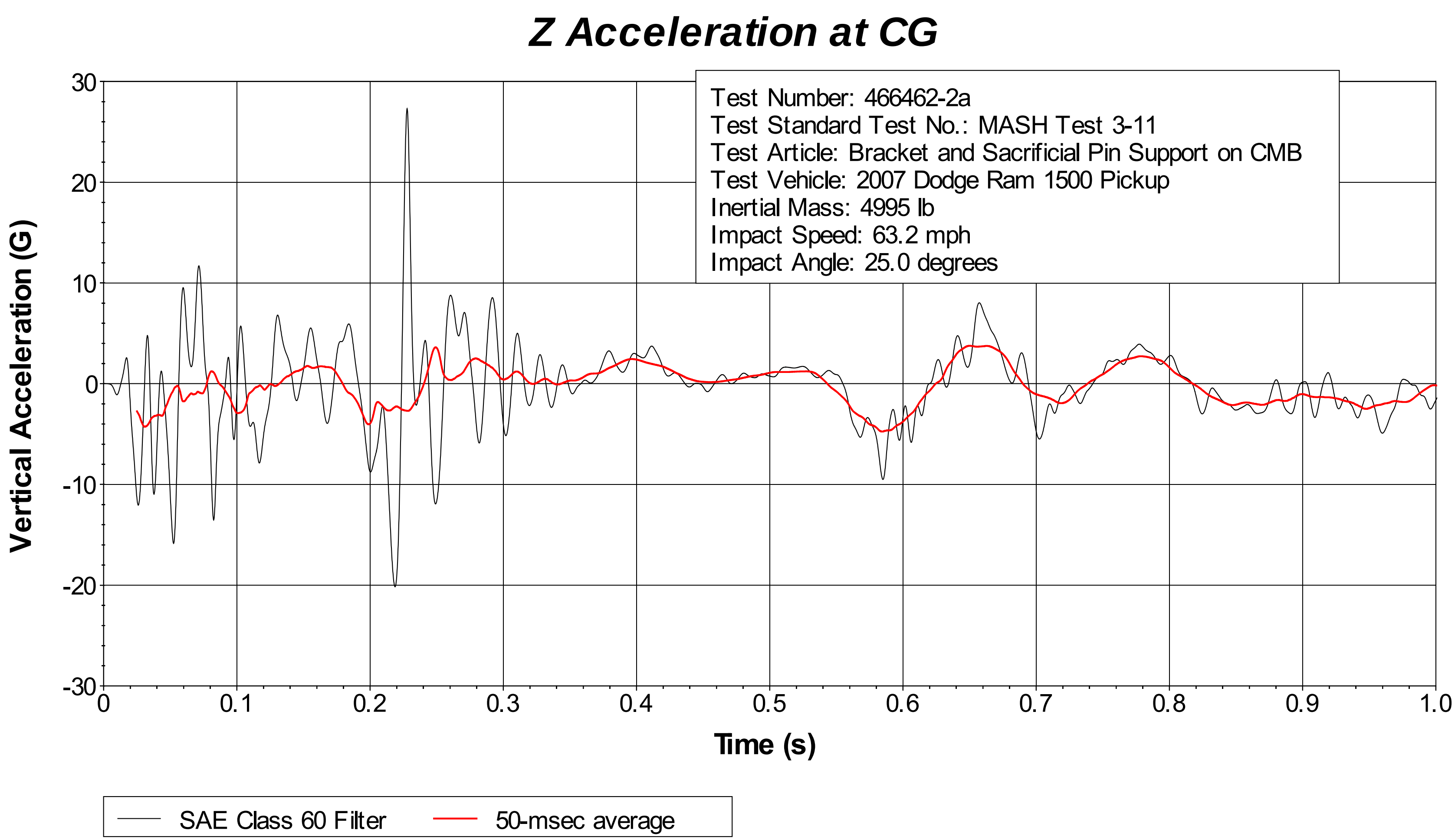


Figure D5. Vehicle Vertical Accelerometer Trace for Test No. 466462-2a (Accelerometer Located at Center of Gravity).

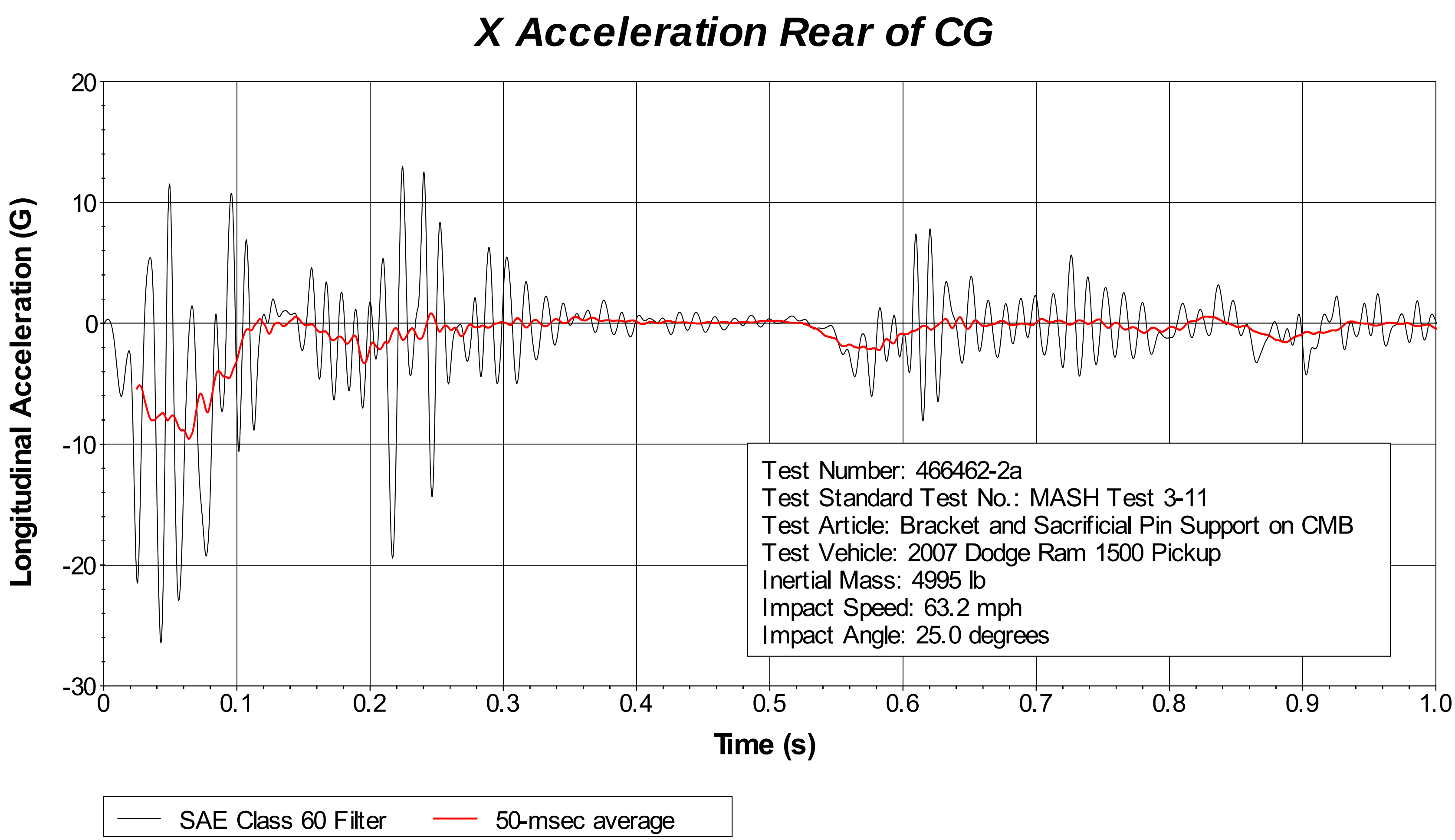


Figure D6. Vehicle Longitudinal Accelerometer Trace for Test No. 466462-2a (Accelerometer Located Rear of Center of Gravity).

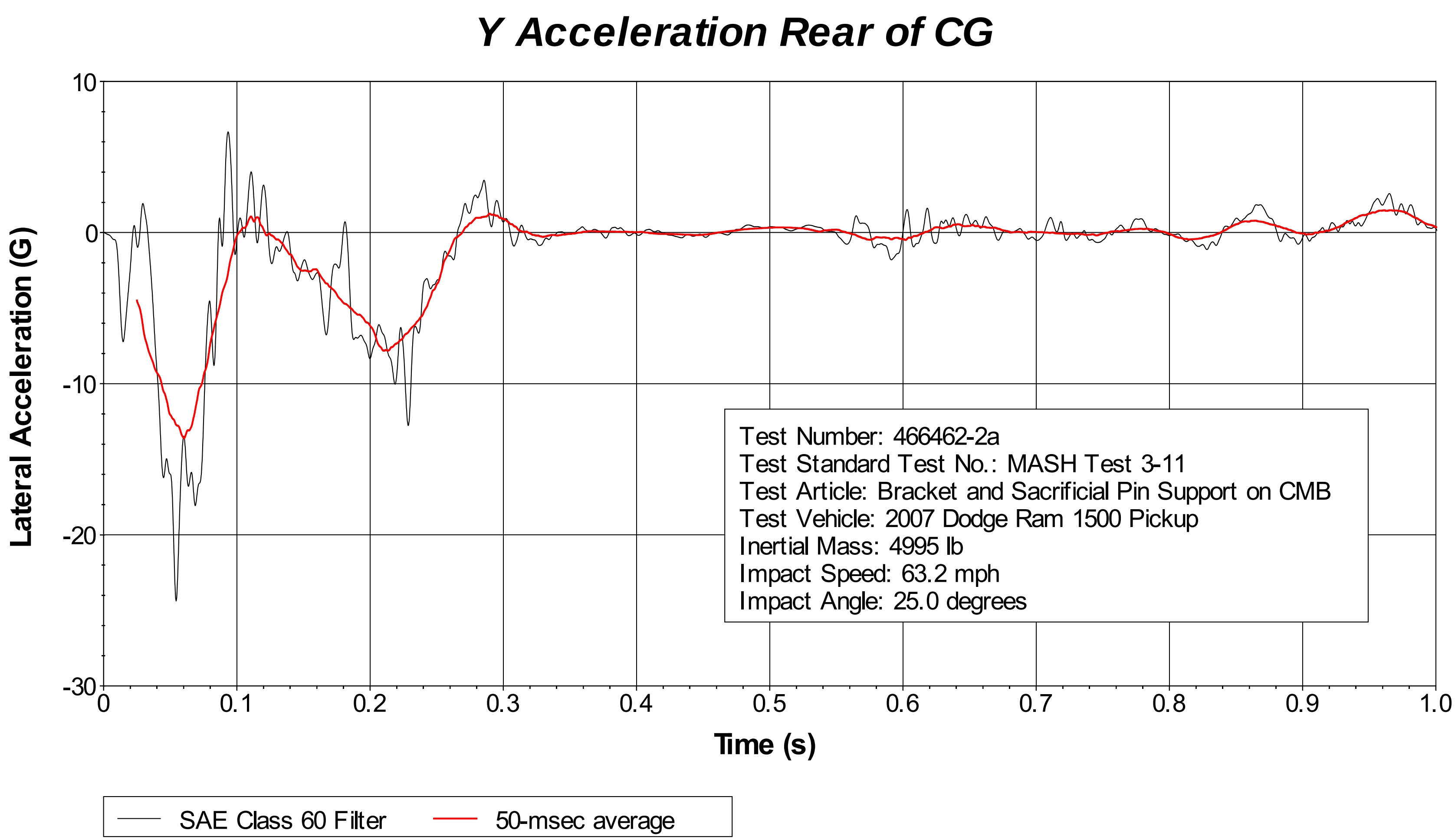


Figure D7. Vehicle Lateral Accelerometer Trace for Test No. 466462-2a (Accelerometer Located Rear of Center of Gravity).

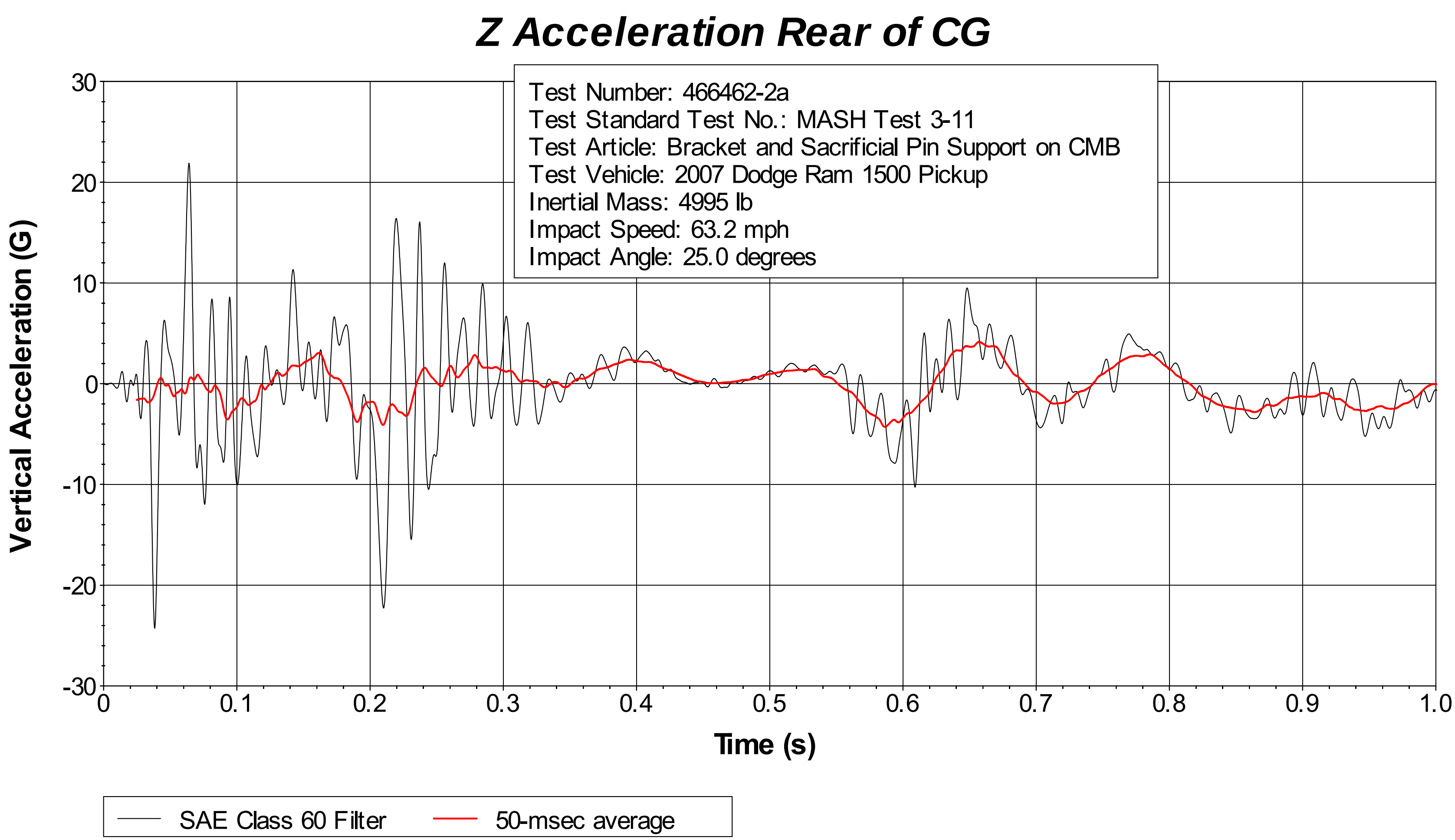
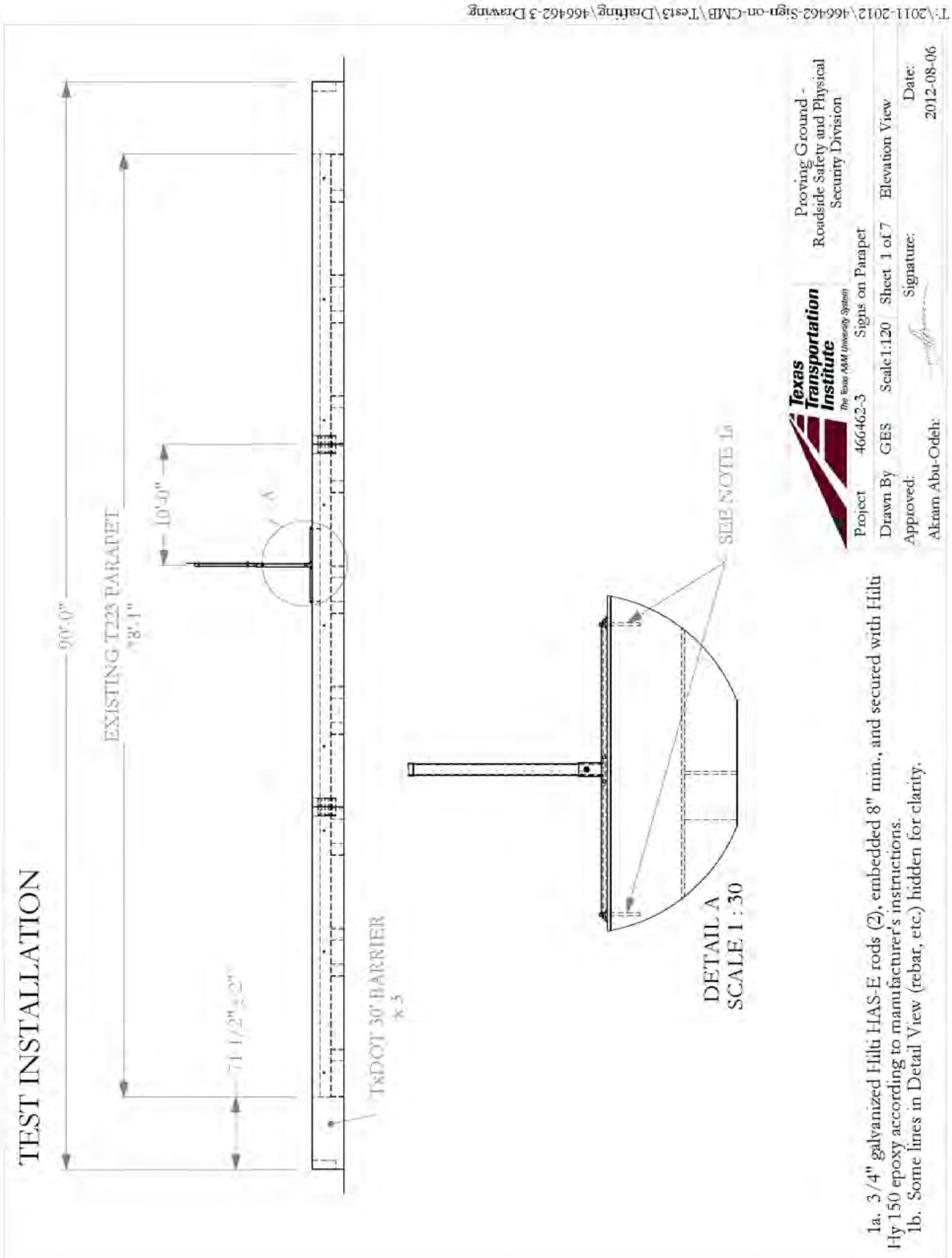
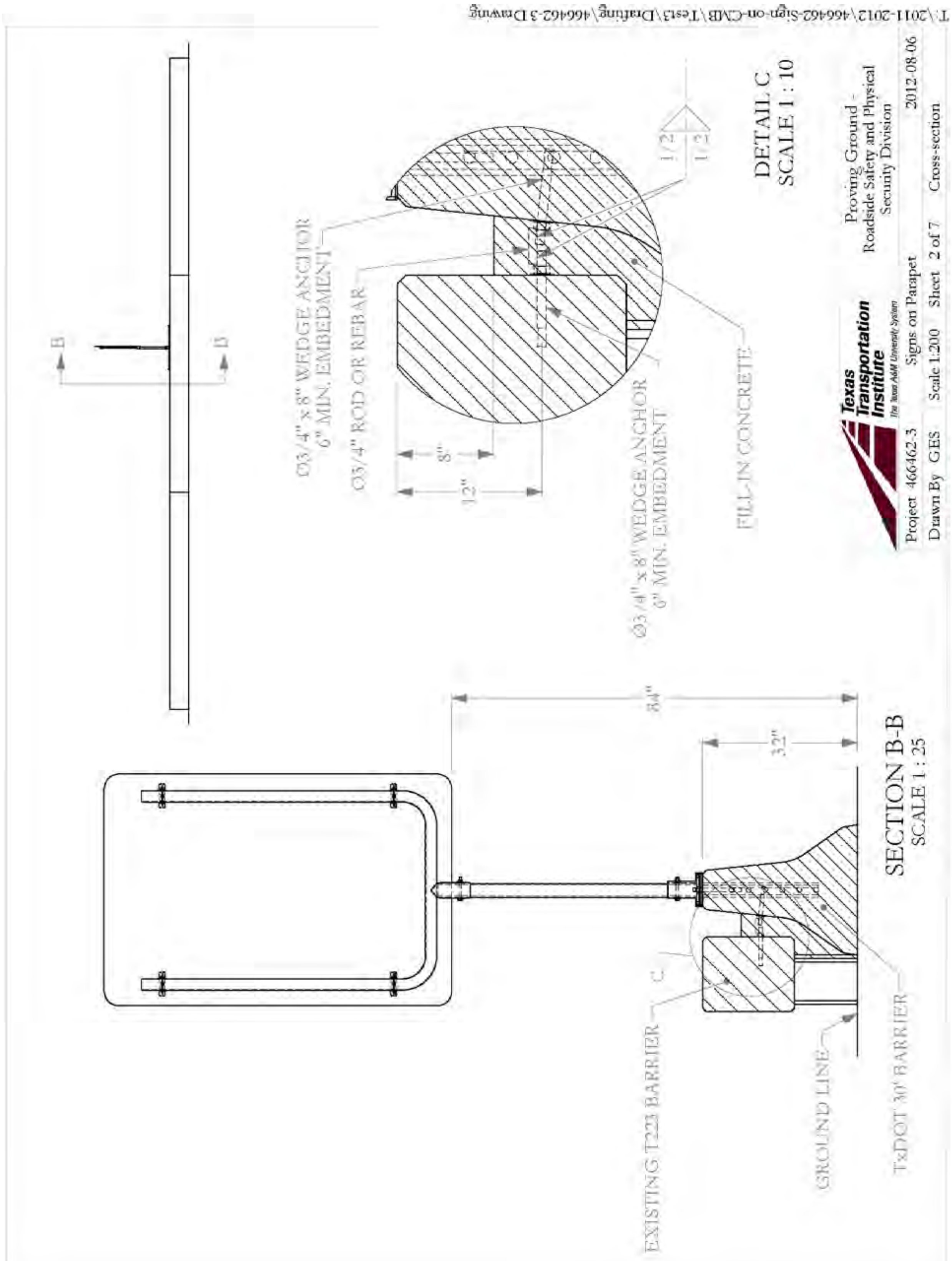


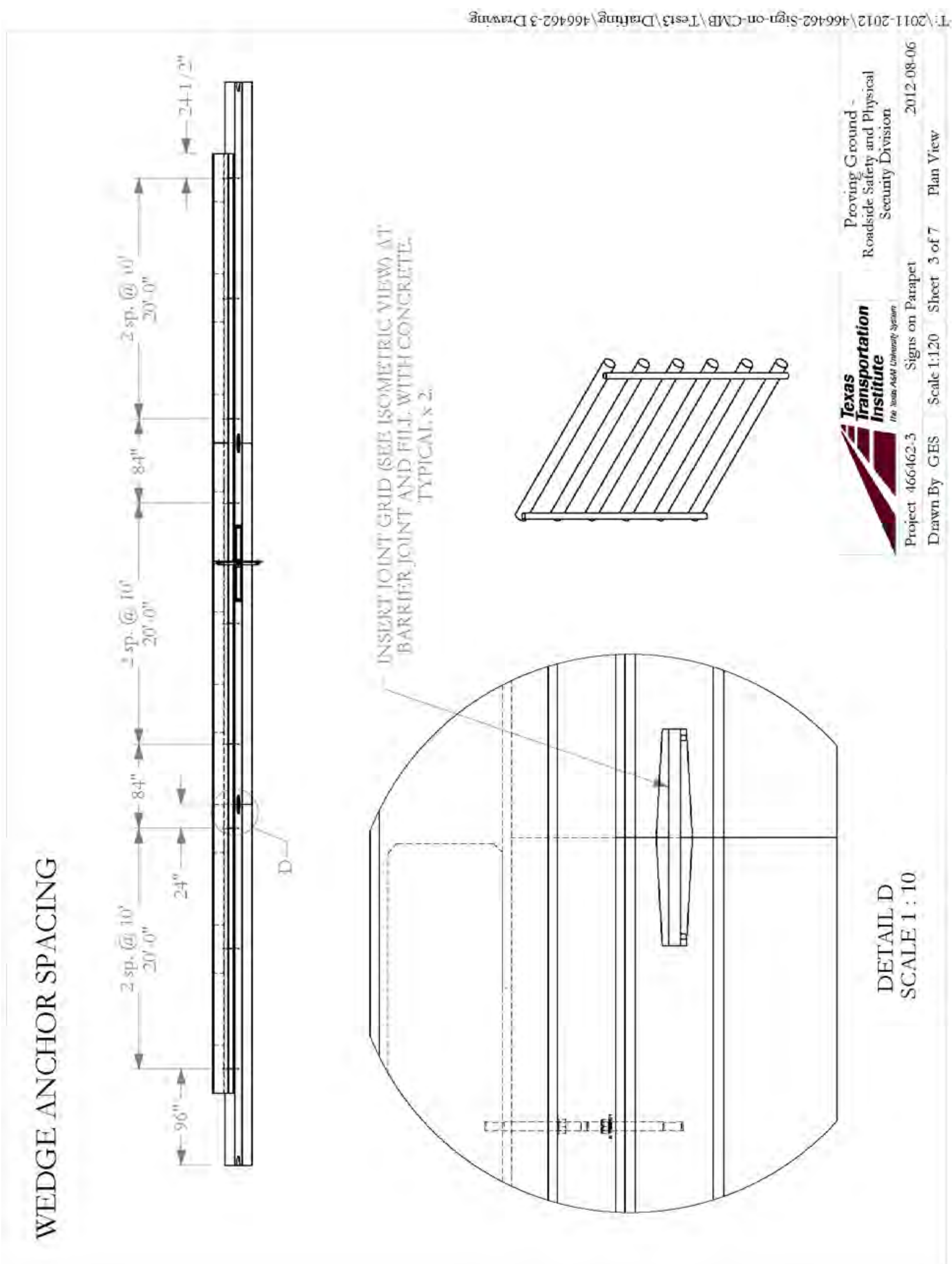
Figure D8. Vehicle Vertical Accelerometer Trace for Test No. 466462-2a (Accelerometer Located Rear of Center of Gravity).

APPENDIX E. CRASH TEST NO. 466462-3

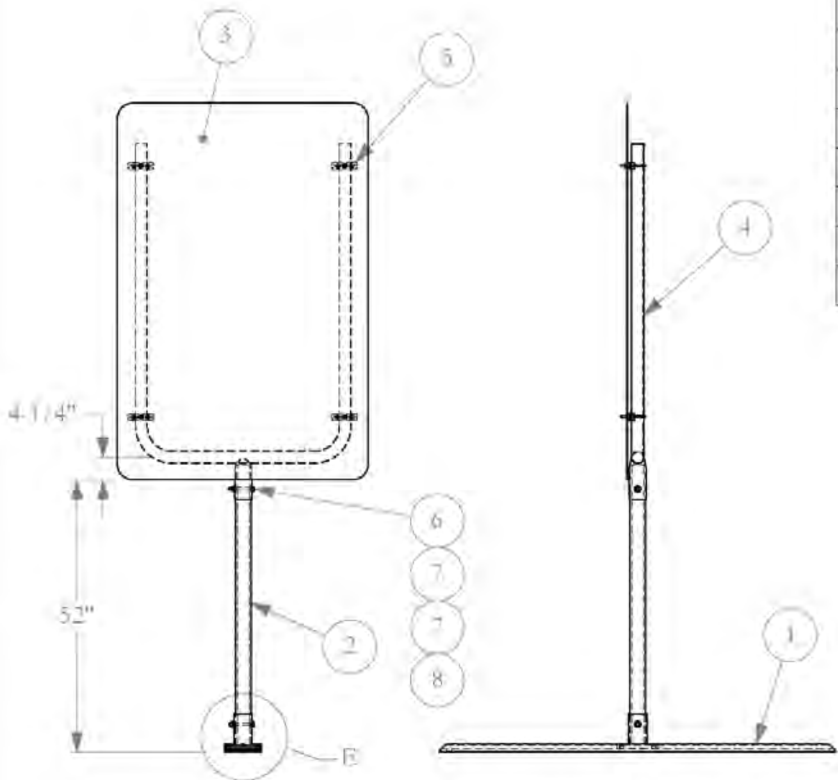
E1. DETAILS OF THE TEST ARTICLE




T:\2011-2012\466462-Sign-on-CMB\Test3\Drafting\466462-3 Drawing
B
B
Ø3/4" x 8" WEDGE ANCHOR
6" MIN. EMBEDMENT
Ø3/4" ROD OR REBAR
8"
12"
1/2
1/2
Ø3/4" x 8" WEDGE ANCHOR
6" MIN. EMBEDMENT
FILL-IN CONCRETE
DETAIL C
SCALE 1 : 10
84"
32"
C
SECTION B-B
SCALE 1 : 25
EXISTING T223 BARRIER
GROUND LINE
TxDOT 30' BARRIER
Texas Transportation Institute
The Texas A&M University System
Proving Ground -
Roadside Safety and Physical
Security Division
2012-08-06
Project 466462-3
Signs on Parapet
Drawn By GES
Scale 1:200
Sheet 2 of 7
Cross-section

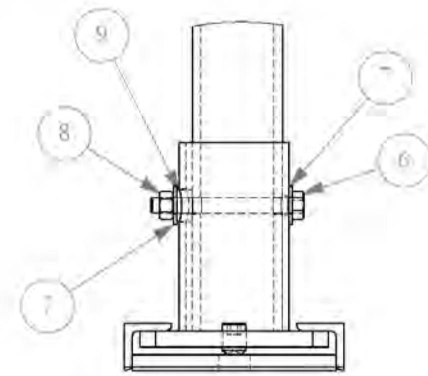

WEDGE ANCHOR SPACING
2 sp. @ 10'
20' 0"
96"
24"
84"
2 sp. @ 10'
20' 0"
84"
2 sp. @ 10'
20' 0"
24 1/2"
D
INSERT JOINT GRID (SEE ISOMETRIC VIEW) AT BARRIER JOINT AND FILL WITH CONCRETE. TYPICAL x 2.
DETAIL D
SCALE 1 : 10
Texas Transportation Institute
The Texas A&M University System
Proving Ground - Roadside Safety and Physical Security Division
Project 466462-3
Signs on Parapet
2012-08-06
Drawn By GES
Scale 1:120
Sheet 3 of 7
Plan View
T:\2011-2012\466462-Sign-on-CMB\Test3\Drafting\466462-3 Drawing

SIGNASSEMBLY



ELEVATION VIEWS

SIGN ASSEMBLY PARTS		
#	PART NAME	QTY.
1	Slide Assembly	1
2	Pipe, 2-1/2" sch. 80	1
3	Sign, 1/8" thick aluminum	1
4	U-Bracket	1
5	Sign Attachment Bracket	4
6	Bolt, 1/2 x 4-1/2 hex	2
7	Washer, 1/2 flat	4
8	Nut, 1/2 hex	2
9	Bushing, McMaster-Carr #92415A147	1



DETAIL E
SCALE 1 : 5

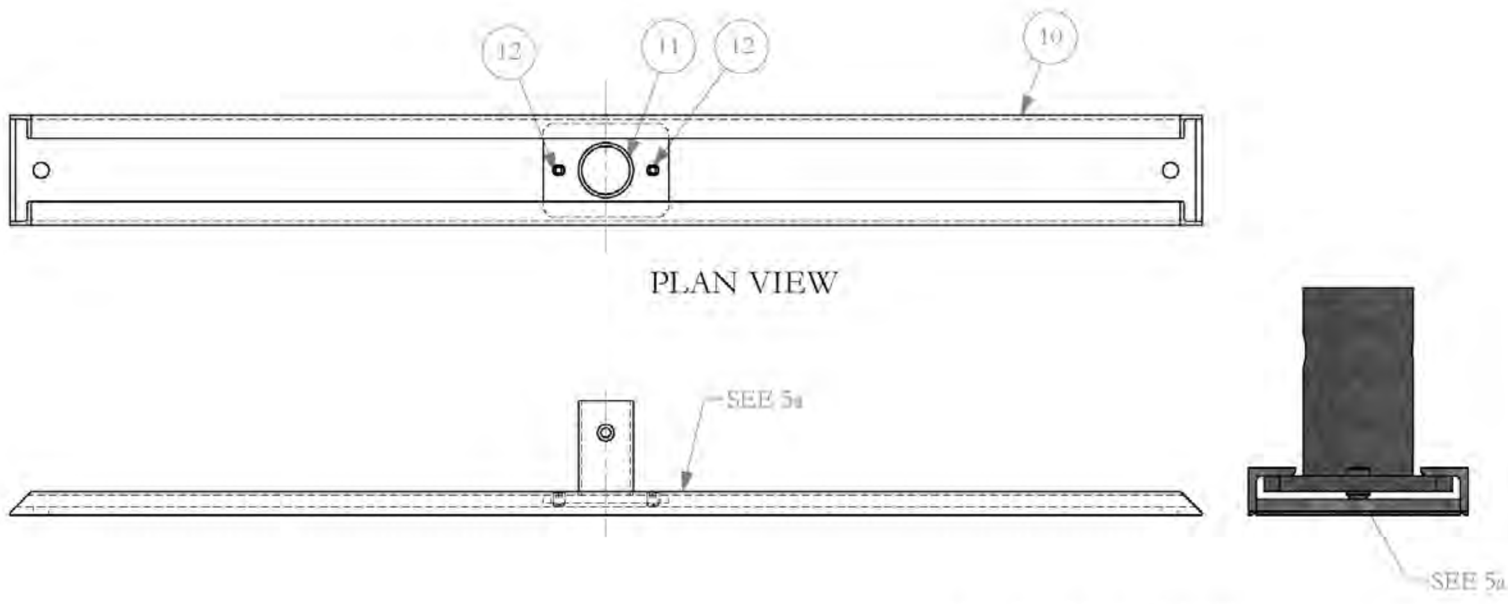
Texas Transportation Institute
The Texas A&M University System

Roadside Safety and Physical Security Division - Proving Ground

Project 466462-3 | Signs on Parapet | 2012-08-06
Drawn By GES | Scale 1:30 | Sheet 4 of 7 | Sign Assembly Details

T:\2011-2012\466462-Sign-on-CMB\Test3\Drafting\466462-3 Drawing

① SLIDE ASSEMBLY



SLIDE ASSEMBLY PARTS		
#	PART NAME	QTY.
10	Slide	1
11	Collar	1
12	Setscrew, Ø3/4 x 1" hex drive cup point	2

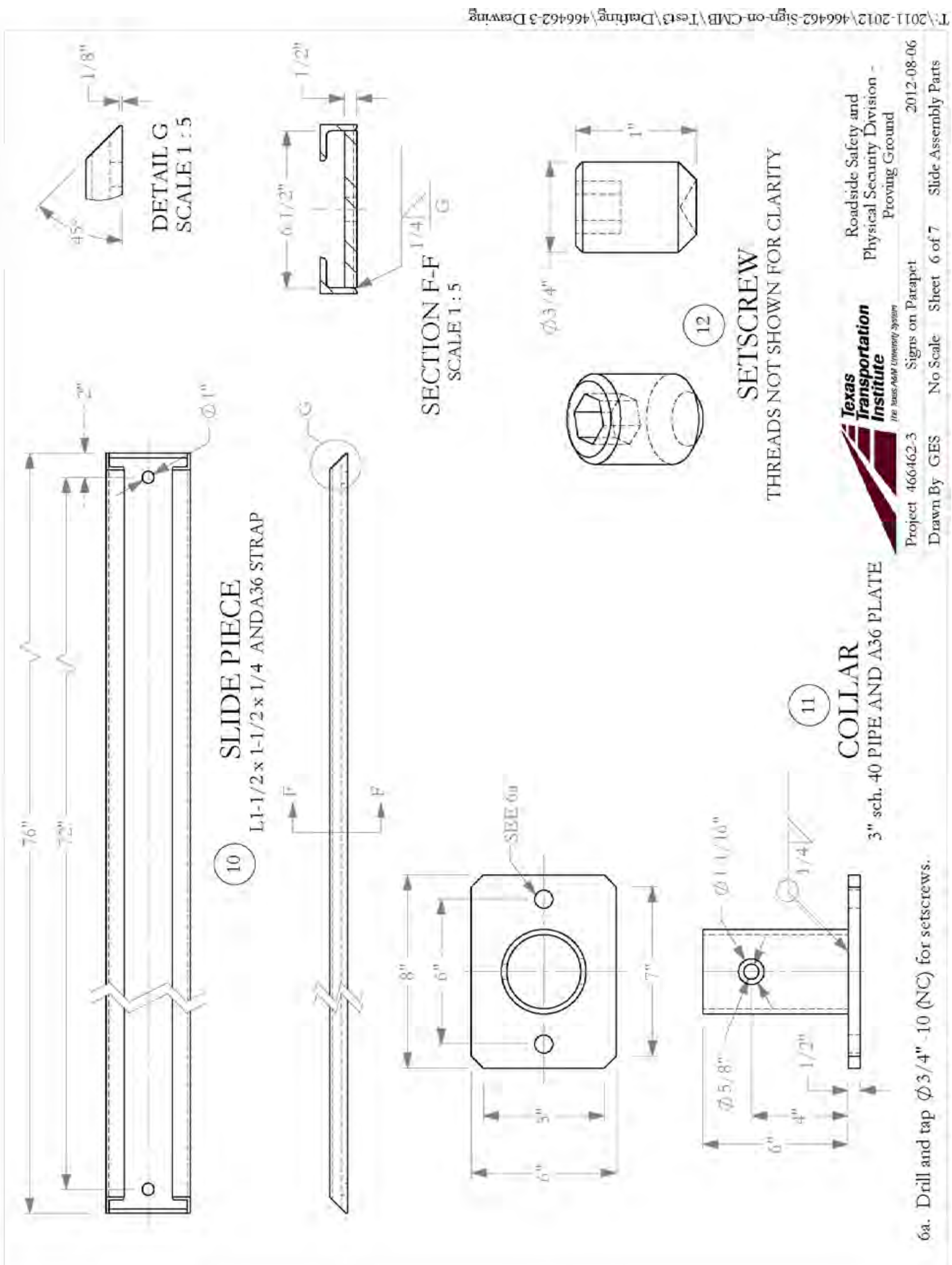
5a. Tighten setscrews (2) until Collar Plate touches top horizontal surface of angles, plus 1 turn (180°).

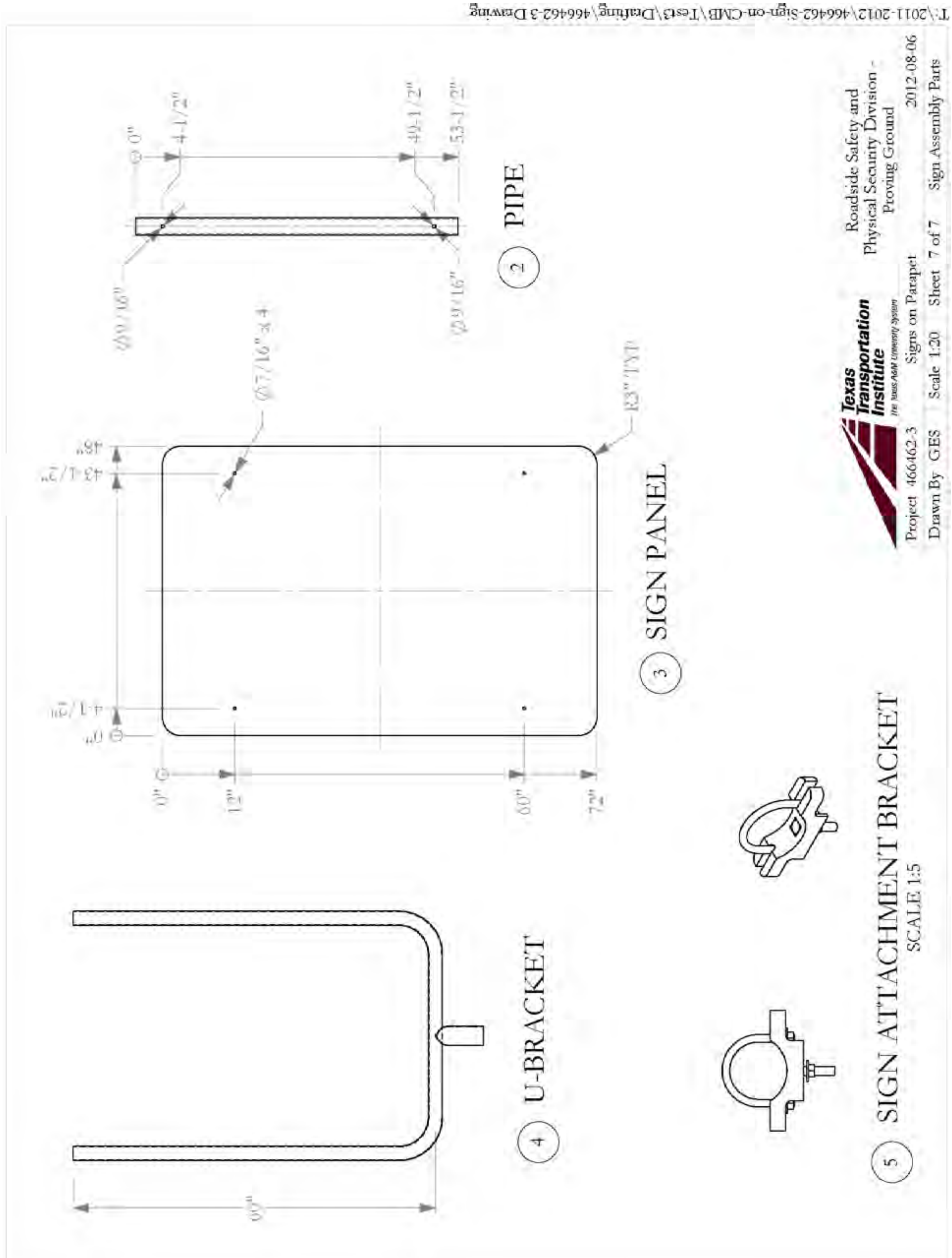
Texas Transportation Institute
The Texas A&M University System

Roadside Safety and Physical Security Division - Proving Ground

Project 466462-3	Signs on Parapet		2012-08-06
Drawn By GES	No Scale	Sheet 5 of 7	Slide Assembly

T:\2011-2012\466462-Sign-on-CMB\Test3\Drafting\466462-3 Drawing


T:\2011-2012\466462-Sign-on-CMB\Test3\Drafting\466462-3 Drawing
10
SLIDE PIECE
L1-1/2 x 1-1/2 x 1/4 AND A36 STRAP
DETAIL G
SCALE 1 : 5
SECTION F-F
SCALE 1 : 5
11
COLLAR
3" sch. 40 PIPE AND A36 PLATE
12
SETSCREW
THREADS NOT SHOWN FOR CLARITY
6a. Drill and tap Ø3/4" 10 (NC) for setscrews.
Texas Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project 466462-3
Signs on Parapet
2012-08-06
Drawn By GES
No Scale
Sheet 6 of 7
Slide Assembly Parts


T:\2011-2012\466462-Sign-on-CMB\Test3\Drafting\466462-3 Drawing
2 PIPE
0"
4-1/2"
49-1/2"
53-1/2"
Ø9/16"
3 SIGN PANEL
Ø7/16" x 4
R3" TYP
0"
12"
60"
72"
4-1/2"
43-1/2"
48"
4 U-BRACKET
60"
5 SIGN ATTACHMENT BRACKET
SCALE 1:5
Texas Transportation Institute
The Texas A&M University System
Roadside Safety and Physical Security Division - Proving Ground
Project 466462-3
Signs on Parapet
2012-08-06
Drawn By GES
Scale 1:20
Sheet 7 of 7
Sign Assembly Parts

E2. CERTIFICATION DOCUMENTATION

MATERIAL USED

TEST NUMBER	466462-3
TEST NAME	Sign on Barrier
DATE	2012-08-16

DATE RECEIVED	ITEM NUMBER	DESCRIPTION	SUPPLIER	HEAT #
2012-04-11	U-Bracket-1	2-7/8" OD sign bracket	Trinity	generic Trinity
2012-08-06	Angle 04	1-1/2 x 1-1/2 x 1-4	Mack Bolt & Steel	*
2012-08-06	Strap, 0.500-04	1/2 x 7 x 20' A36	Mack Bolt & Steel	*

E3. VEHICLE PROPERTIES AND INFORMATION

Table E1. Vehicle Properties for Test No. 466462-3.

Date: 2012-08-16 Test No.: 466462-3 VIN No.: 1D7HA18X6S635595

Year: 2006 Make: Dodge Model: Ram 1500

Tire Size: 265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 200203

Note any damage to the vehicle prior to test: ______

● Denotes accelerometer location.

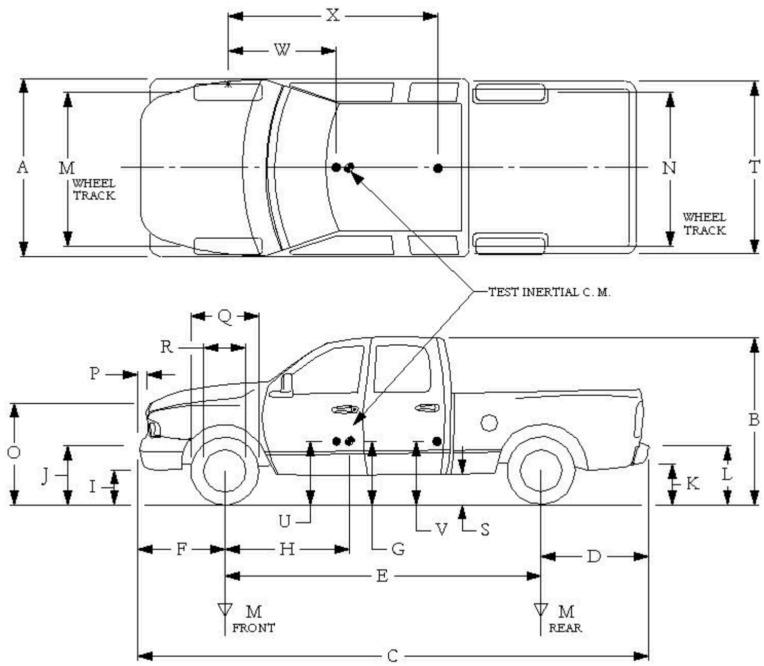
NOTES: ______

Engine Type: ______
Engine CID: ______

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

Optional Equipment: ______

Dummy Data:
Type: No dummy
Mass: ______
Seat Position: ______



Geometry: inches

A	78.25	F	36.00	K	20.50	P	2.88	U	28.50
B	75.00	G	28.19	L	29.12	Q	31.25	V	29.50
C	223.75	H	59.59	M	68.00	R	18.38	W	60.50
D	47.25	I	13.75	N	44.50	S	12.00	X	78.00
E	140.50	J	25.38	O		T	77.50		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	5.00	Bottom Frame Height - Front	17.125
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	10.25	Bottom Frame Height - Rear	24.75

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2979	2896	
Back	3900	M_{rear}	2139	2133	
Total	6700	M_{Total}	5118	5029	

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

Mass Distribution:
lb LF: 1482 RF: 1414 LR: 1045 RR: 1088

Table E2. Vehicle Parametric Measurements for Test No. 466462-3.

Date: 20.2-08-16 Test No.: 466462-3 VIN: 1D7HA18X6S635595

Year: 2006 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Pickup Mileage: 200203

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: None (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70R17

Measured Vehicle Weights: (lb)					
LF:	1482	RF:	1414	Front Axle:	2896
LR:	1045	RR:	1088	Rear Axle:	2133
Left:	2527	Right:	2502	Total:	5029
					5000 ±110 lb allowed
Wheel Base:	140.5 inches	Track: F:	68.5 inches	R:	68 inches
	148 ±12 inches allowed		Track = (F+R)/2 = 67 ±1.5 inches allowed		
Center of Gravity, SAE J874 Suspension Method					
X:	59.59 in	Rear of Front Axle		(63 ±4 inches allowed)	
Y:	-0.17 in	Left -	Right +	of Vehicle Centerline	
Z:	28.19 in	Above Ground		(minumum 28.0 inches allowed)	

Hood Height: 44.50 inches
43 ±4 inches allowed

Front Bumper Height: 25.675 inches

Front Overhang: 36.00 inches
39 ±3 inches allowed

Rear Bumper Height: 29.125 inches

Overall Length: 223.75 inches
237 ±13 inches allowed

Table E3. Exterior Crush Measurements for Test No. 466462-3.

Date: 2012-08-16 Test No.: 466462-3 VIN No.: 1D7HA18X6S635595

Year: 2006 Make: Dodge Model: Ram 1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	**Side Damage**
Undeformed end width ________	Bowing: B1 _____ X1 _____
Corner shift: A1 ________	B2 _____ X2 _____
A2 ________	
End shift at frame (CDC)	Bowing constant
(check one)	$\frac{X1+X2}{2}$ = _______
< 4 inches ________	
≥ 4 inches ________	

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bumper ht	16	9	28	9	5	3	2	1	0	+14
2	Side plane at bumper ht	16	14	40	0	3	7	10	12	14	+74
	Measurements recorded										
	in inches										

[1]Table taken from National Accident Sampling System (NASS).

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

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

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

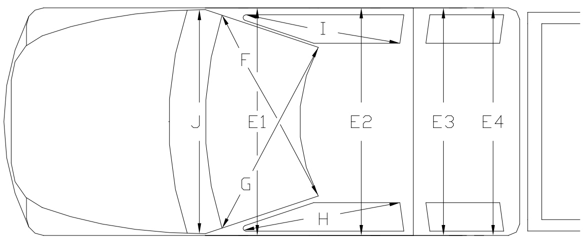
***Measure and document on the vehicle diagram the location of the maximum crush.

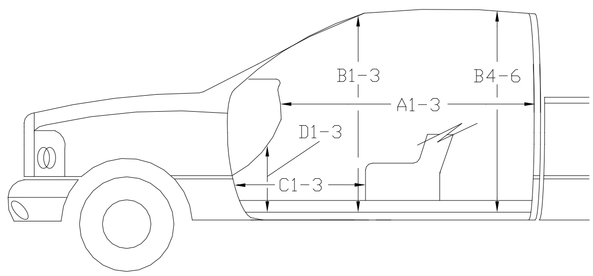
Note: Use as many lines/columns as necessary to describe each damage profile.

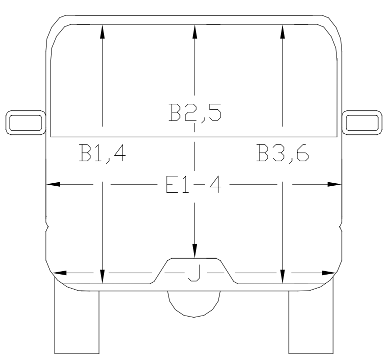
Table E4. Occupant Compartment Measurements for Test No. 466462-3.

Date: 2012-08-16 Test No.: 466462-3 VIN No.: 1D7HA18X6S635595

Year: 2006 Make: Dodge Model: Ram 1500







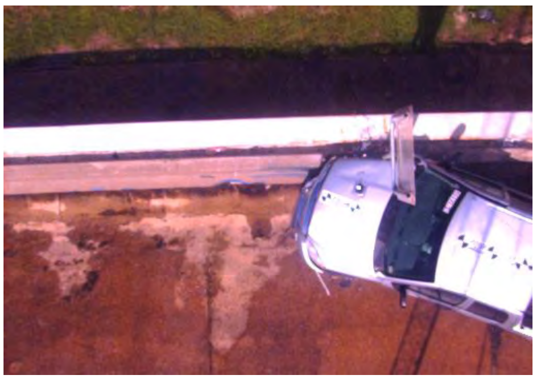
*Lateral area across the cab from
driver’s side kickpanel to passenger’s side kickpanel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

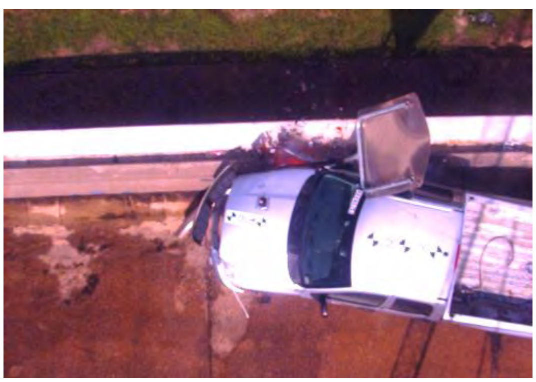
	Before (inches)	**After** (inches)
A1	64.50	64.50
A2	64.50	64.50
A3	64.50	64.50
B1	45.12	45.12
B2	42.50	42.25
B3	45.12	44.88
B4	42.12	42.12
B5	45.00	45.00
B6	42.12	42.12
C1	29.00	29.00
C2	----	----
C3	27.00	25.25
D1	12.50	----
D2	----	----
D3	11.50	12.00
E1	62.50	62.75
E2	64.50	66.00
E3	64.00	64.12
E4	64.12	64.12
F	60.00	60.00
G	60.00	60.00
H	39.00	39.00
I	39.00	39.00
J*	62.00	61.00

E4. SEQUENTIAL PHOTOGRAPHS

0.000 s



0.055 s



0.110 s

0.165 s

Figure E1. Sequential Photographs for Test No. 466462-3 (Overhead and Frontal Views).

Figure E1. Sequential Photographs for Test No. 466462-3 (Overhead and Frontal Views) (continued).

0.000 s

0.055 s

0.110 s

0.165 s

0.220 s

0.275 s

0.330 s

0.385 s

Figure E2. Sequential Photographs for Test No. 466462-3 (Rear View).

E5. VEHICLE ANGULAR DISPLACEMENTS

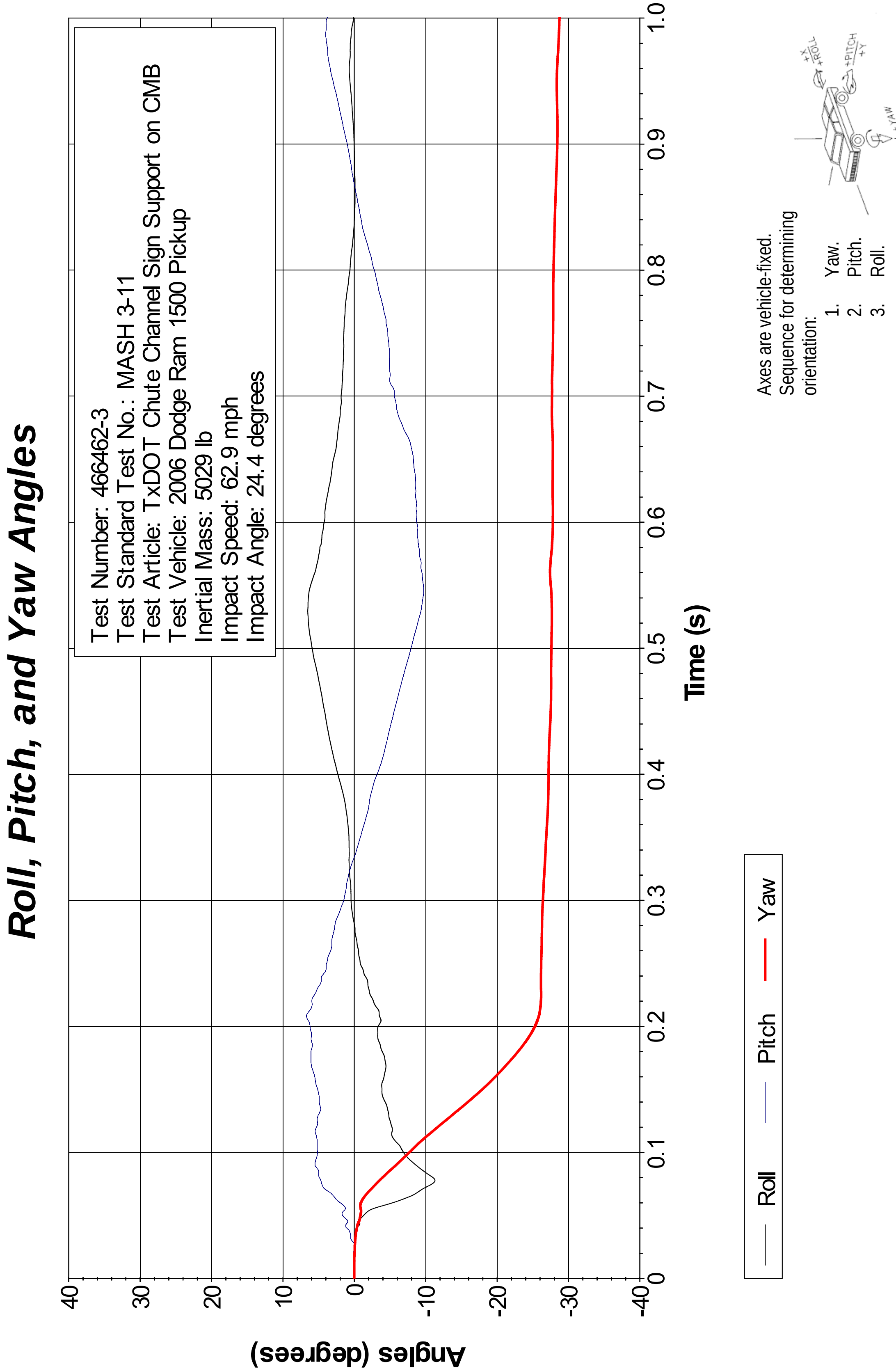


Figure E3. Vehicle Angular Displacements for Test No. 466462-3.

E6. VEHICLE ACCELERATIONS

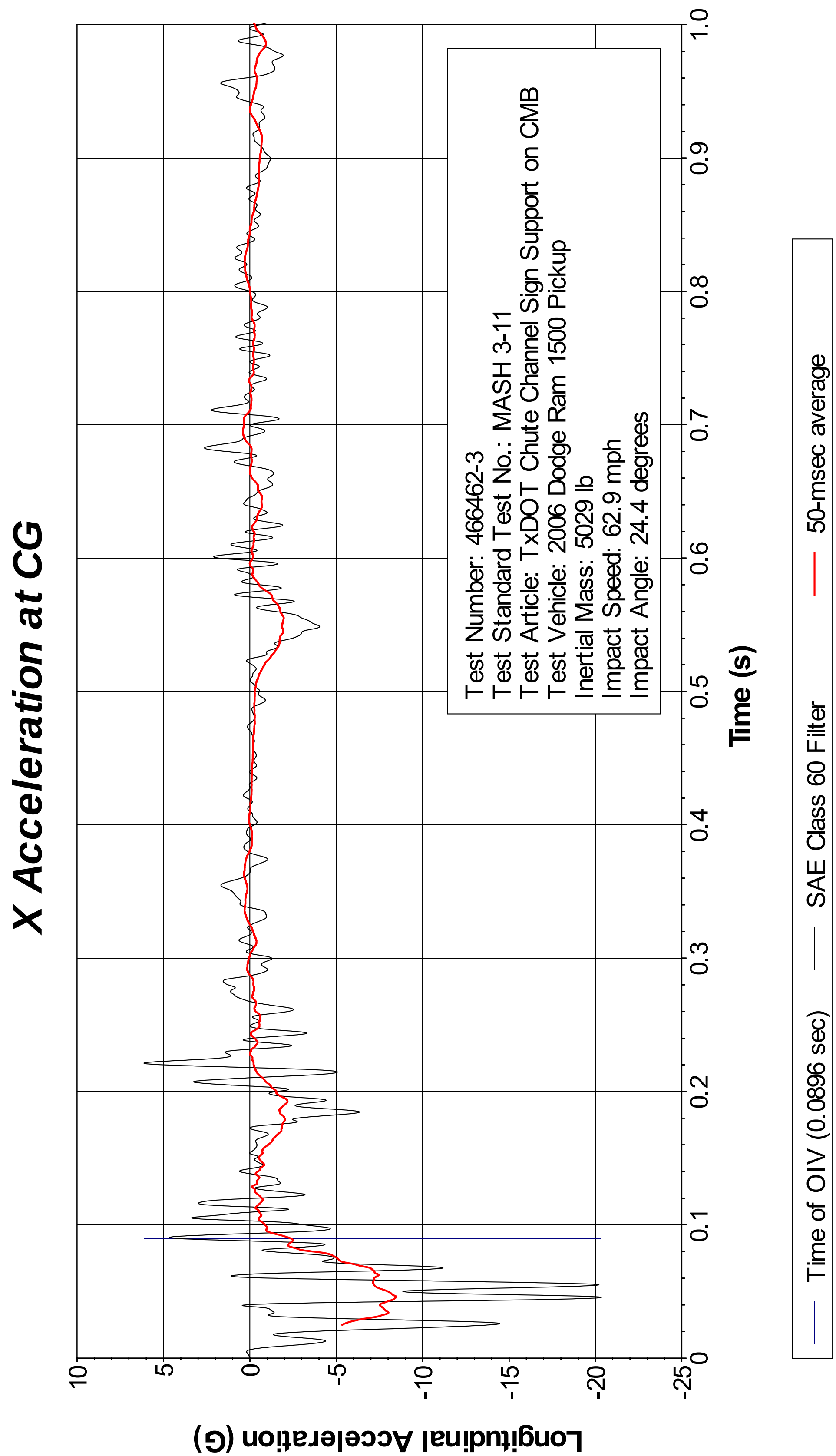


Figure E4. Vehicle Longitudinal Accelerometer Trace for Test No. 466462-3 (Accelerometer Located at Center of Gravity).

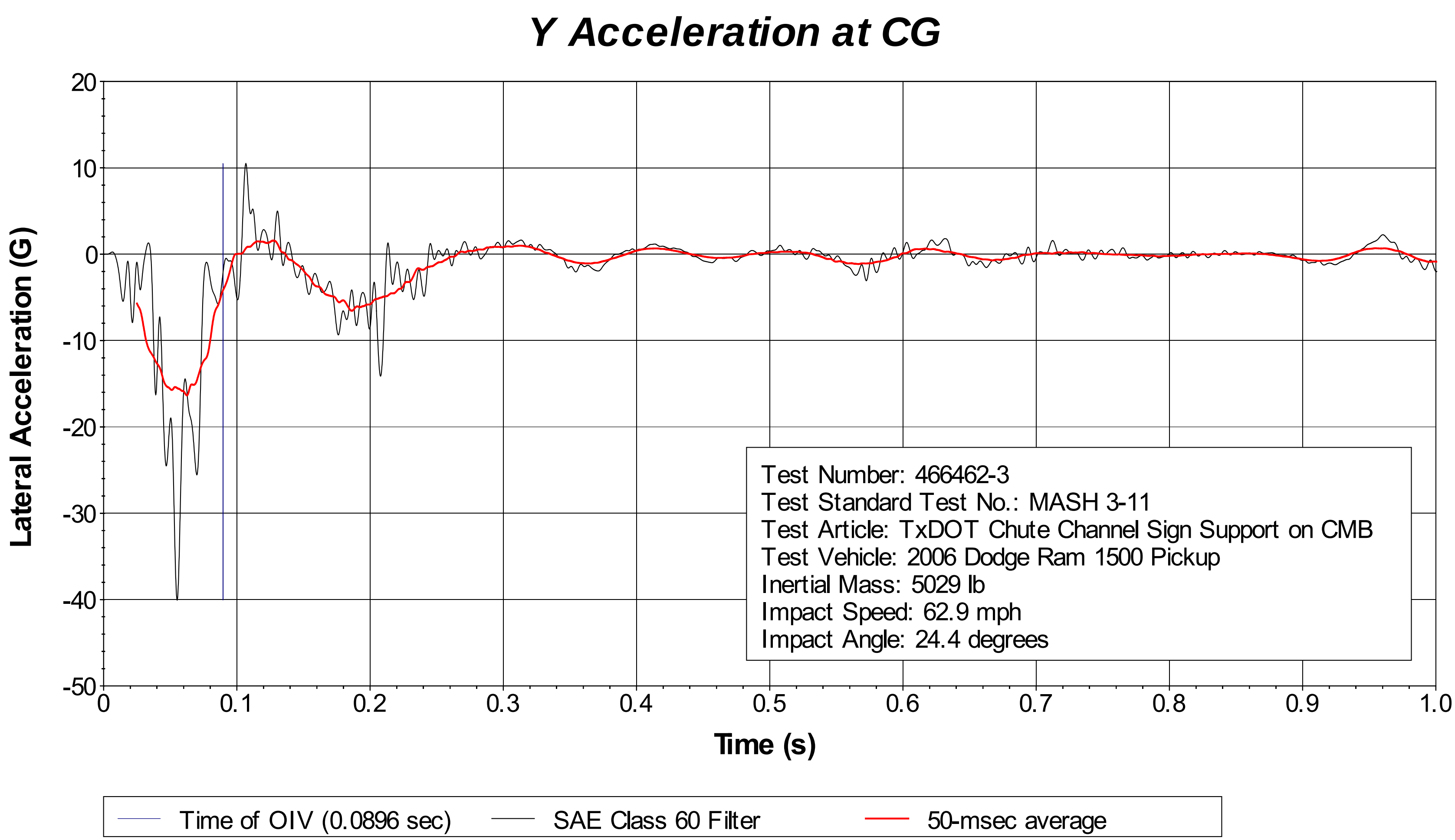


Figure E5. Vehicle Lateral Accelerometer Trace for Test No. 466462-3 (Accelerometer Located at Center of Gravity).

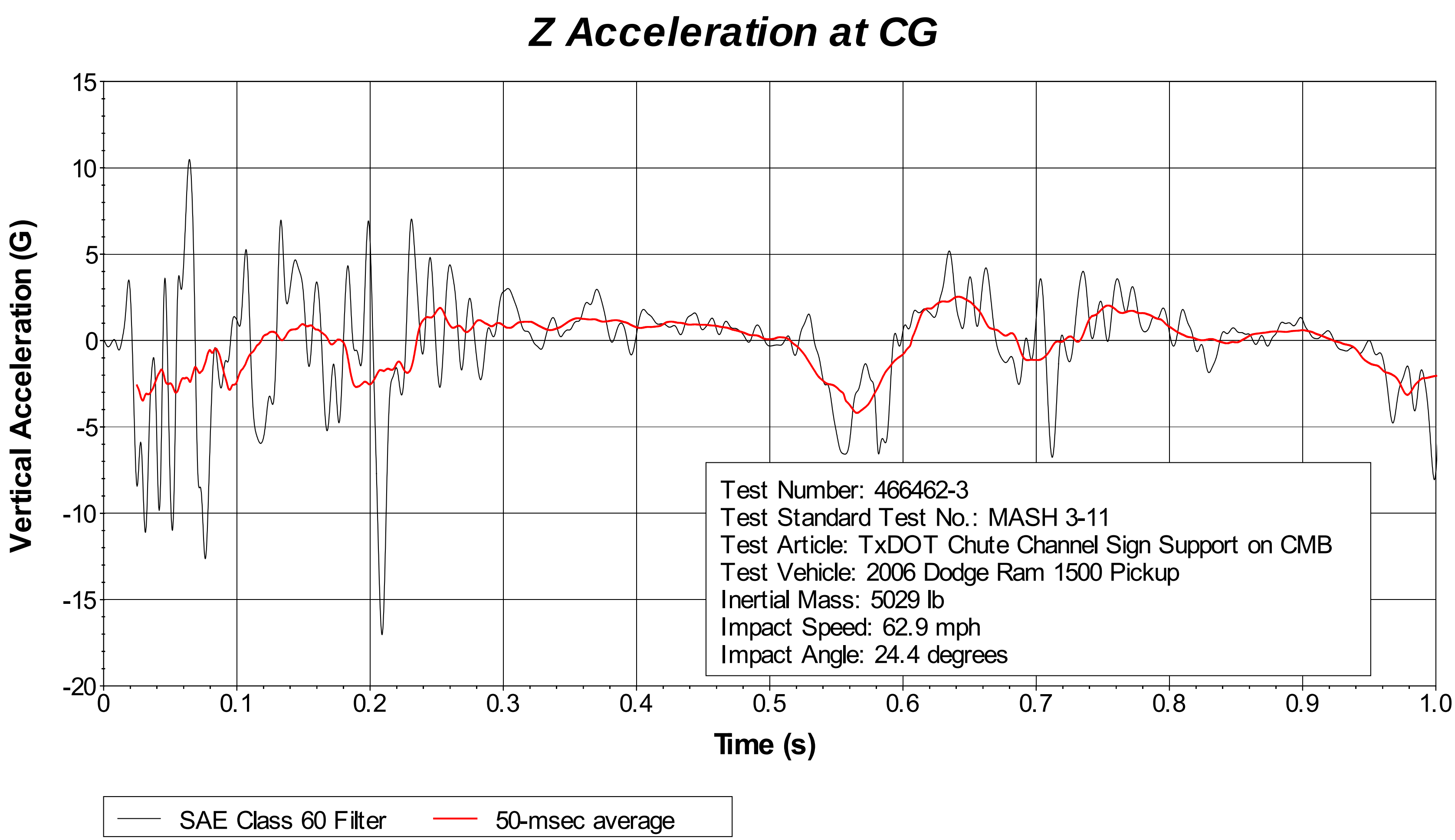


Figure E6. Vehicle Vertical Accelerometer Trace for Test No. 466462-3 (Accelerometer Located at Center of Gravity).

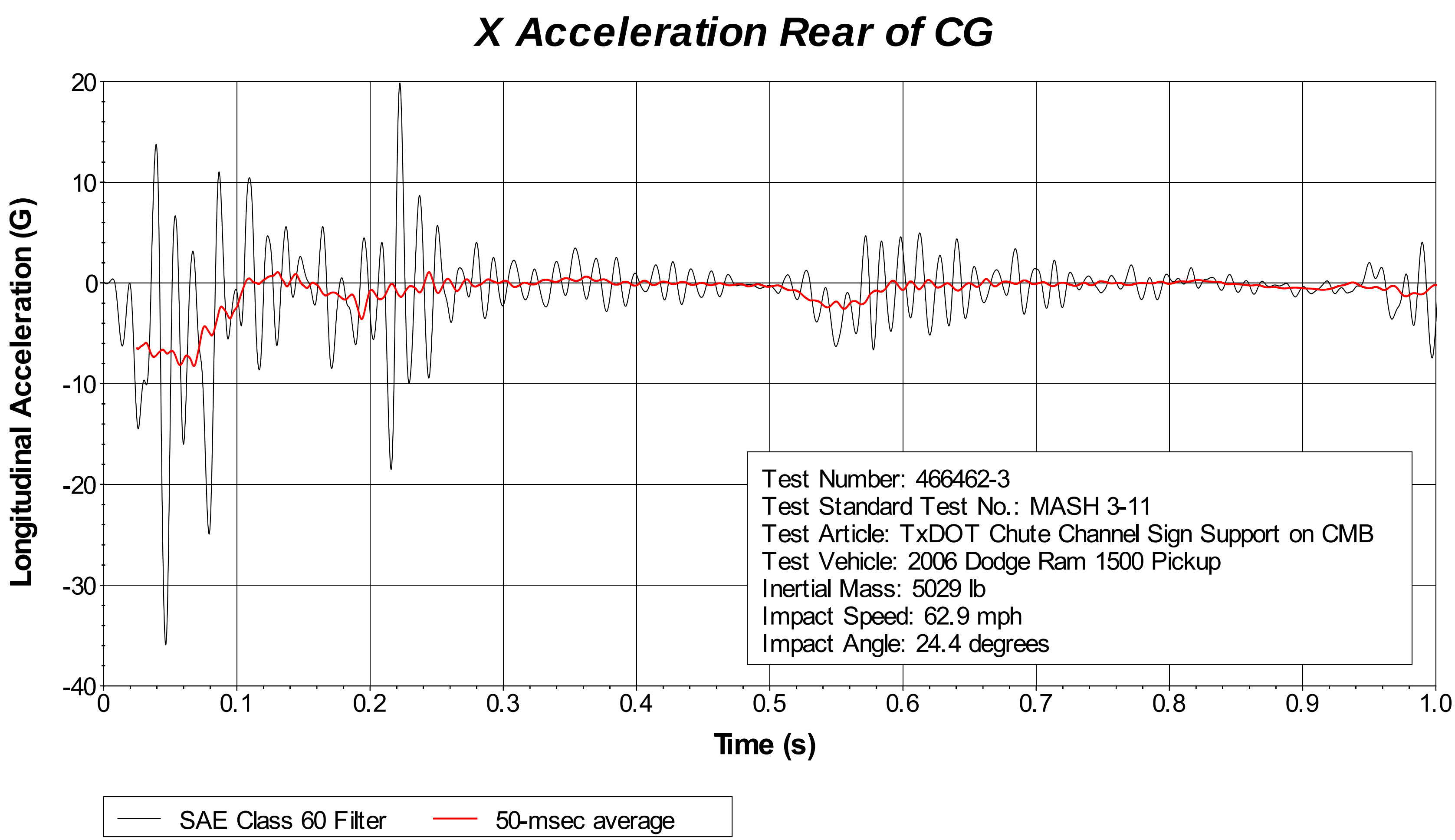


Figure E7. Vehicle Longitudinal Accelerometer Trace for Test No. 466462-3 (Accelerometer Located Rear of Center of Gravity).

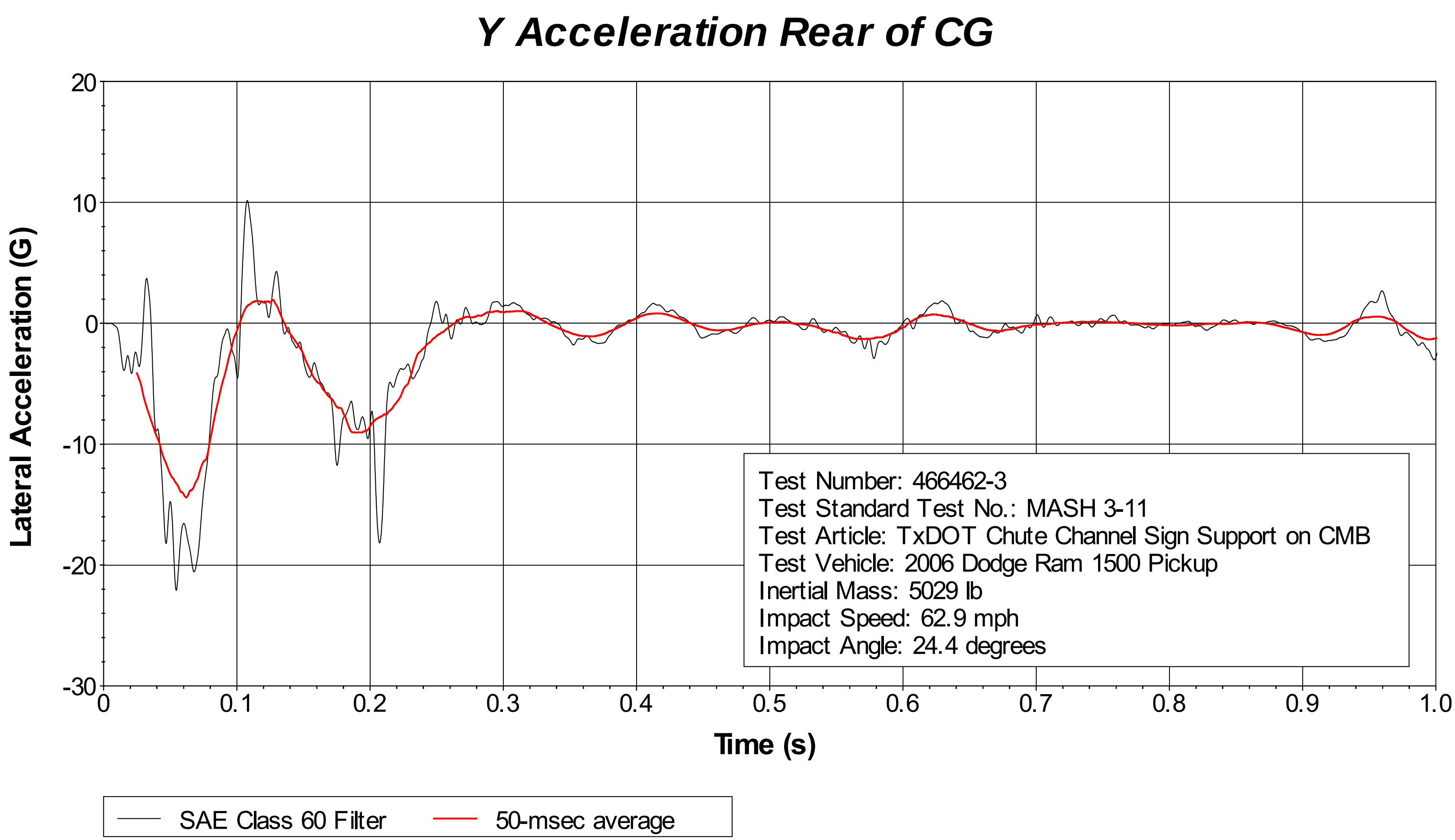


Figure E8. Vehicle Lateral Accelerometer Trace for Test No. 466462-3 (Accelerometer Located Rear of Center of Gravity).

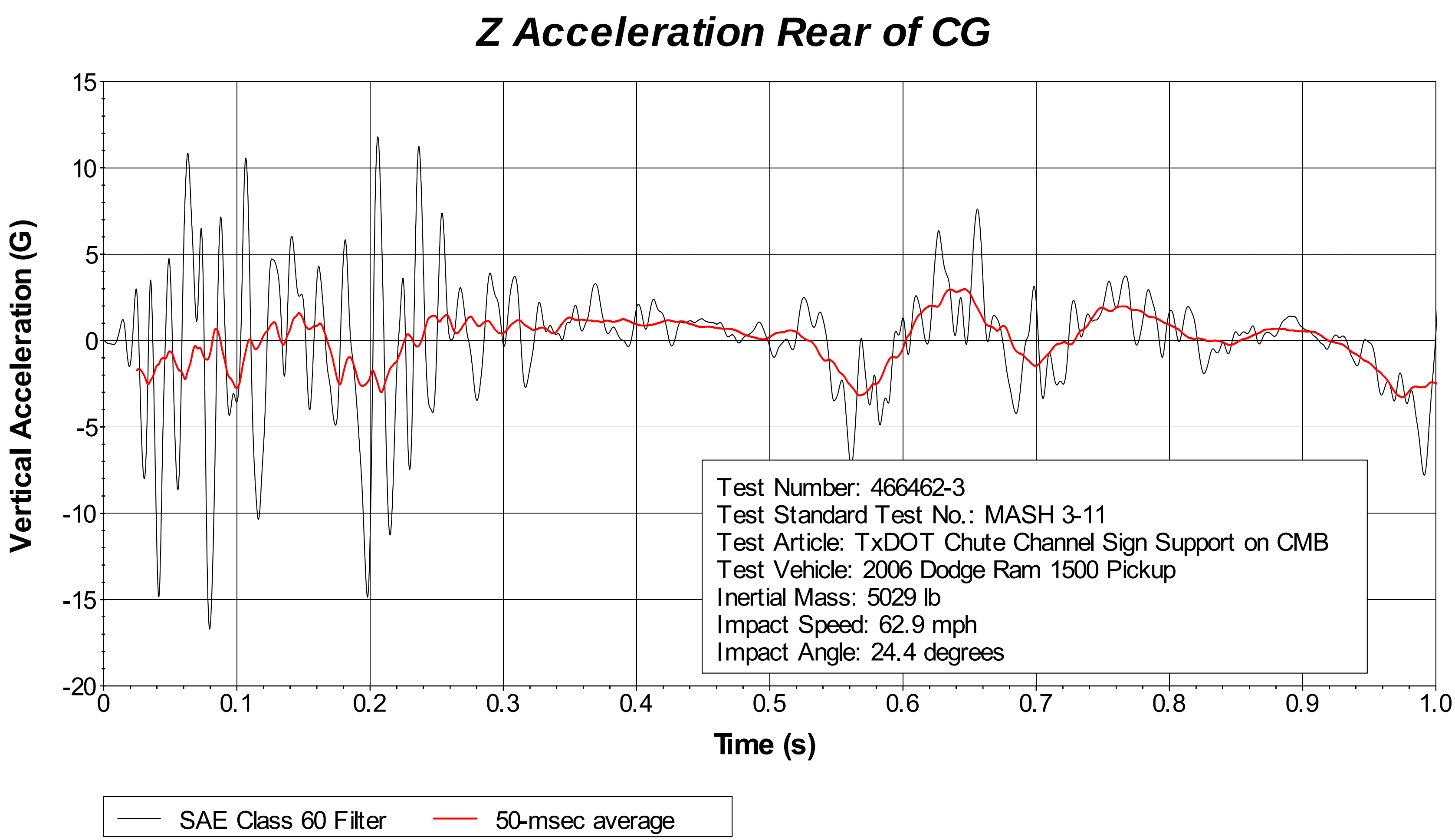
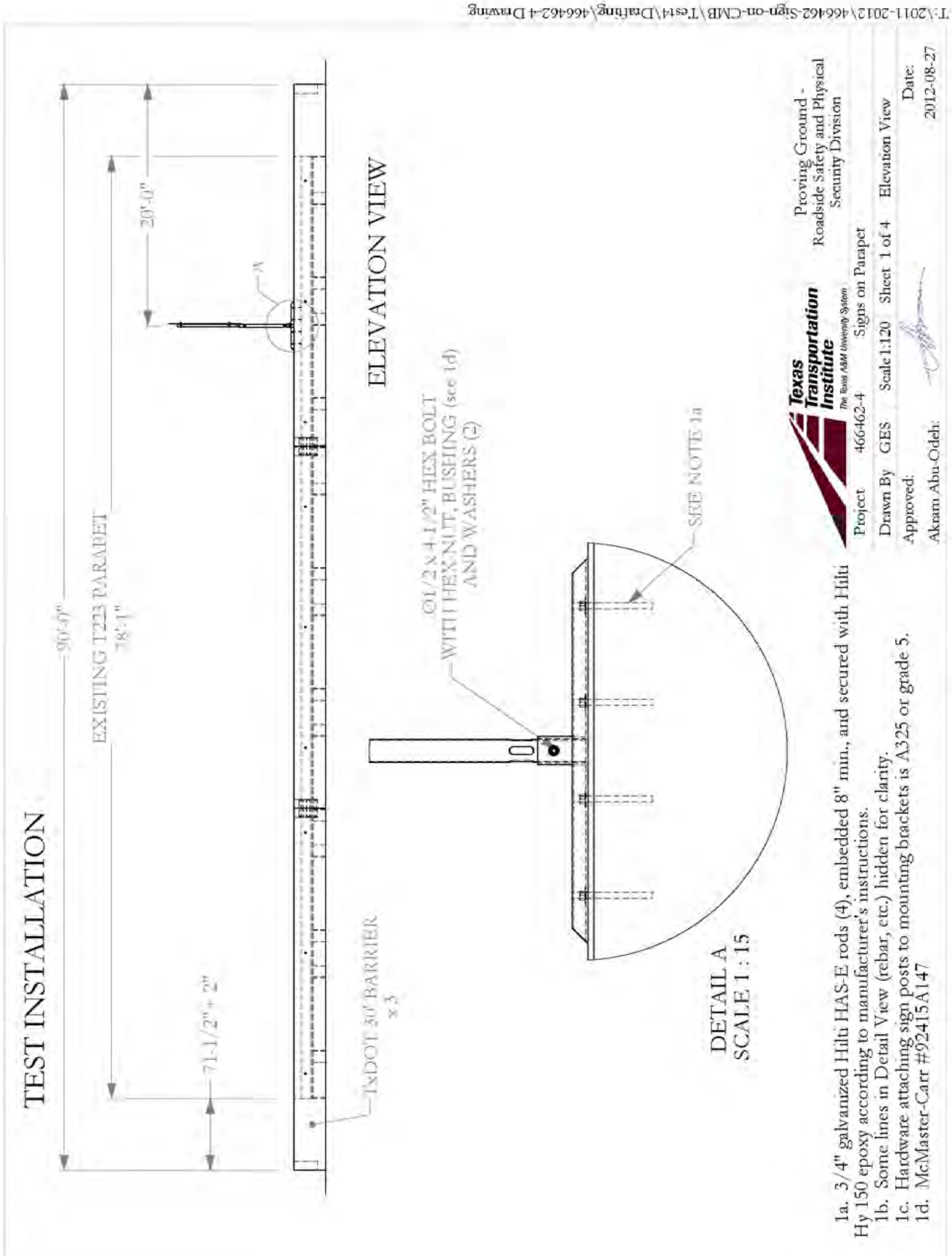
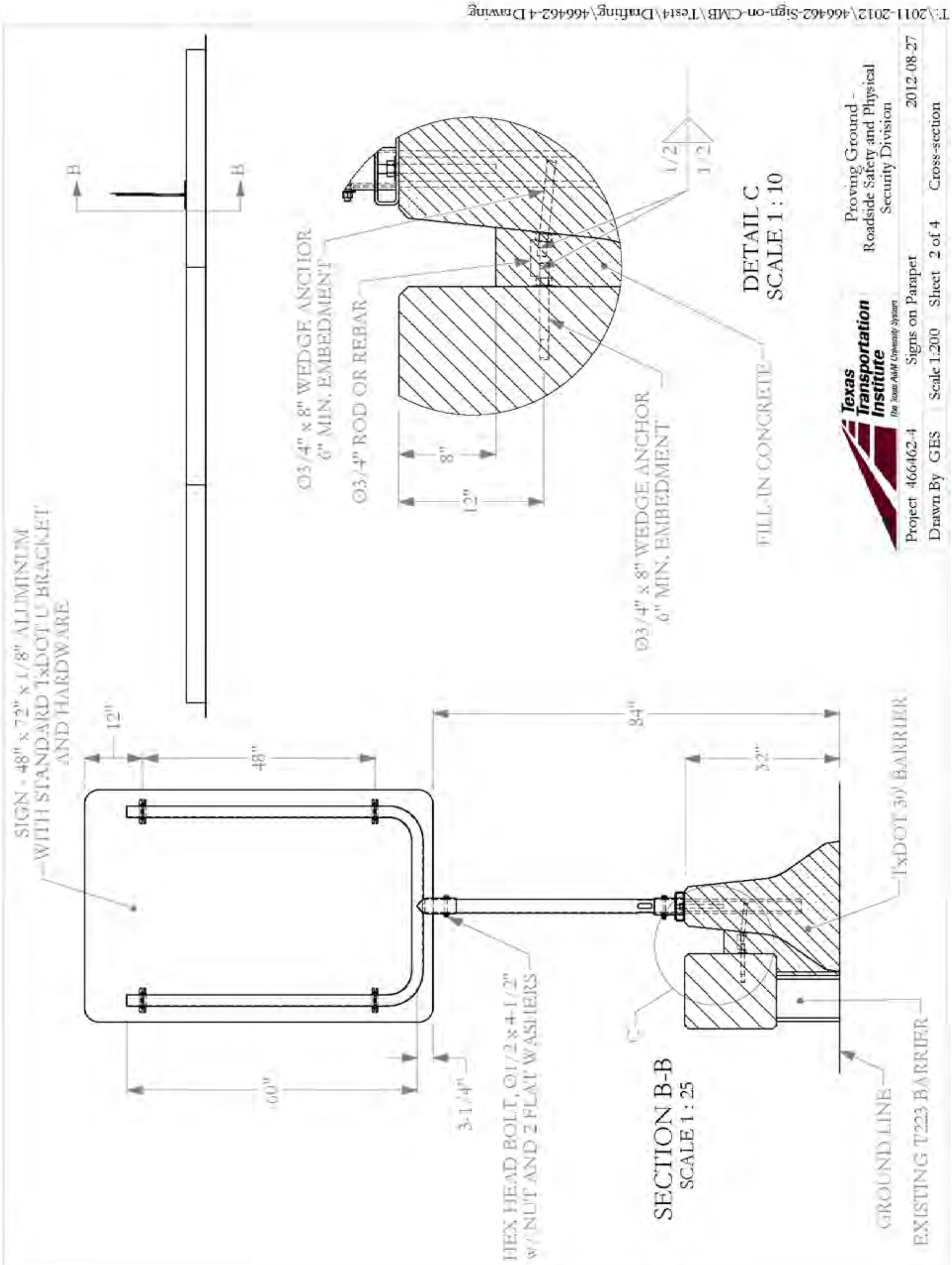


Figure E9. Vehicle Vertical Accelerometer Trace for Test No. 466462-3 (Accelerometer Located Rear of Center of Gravity).

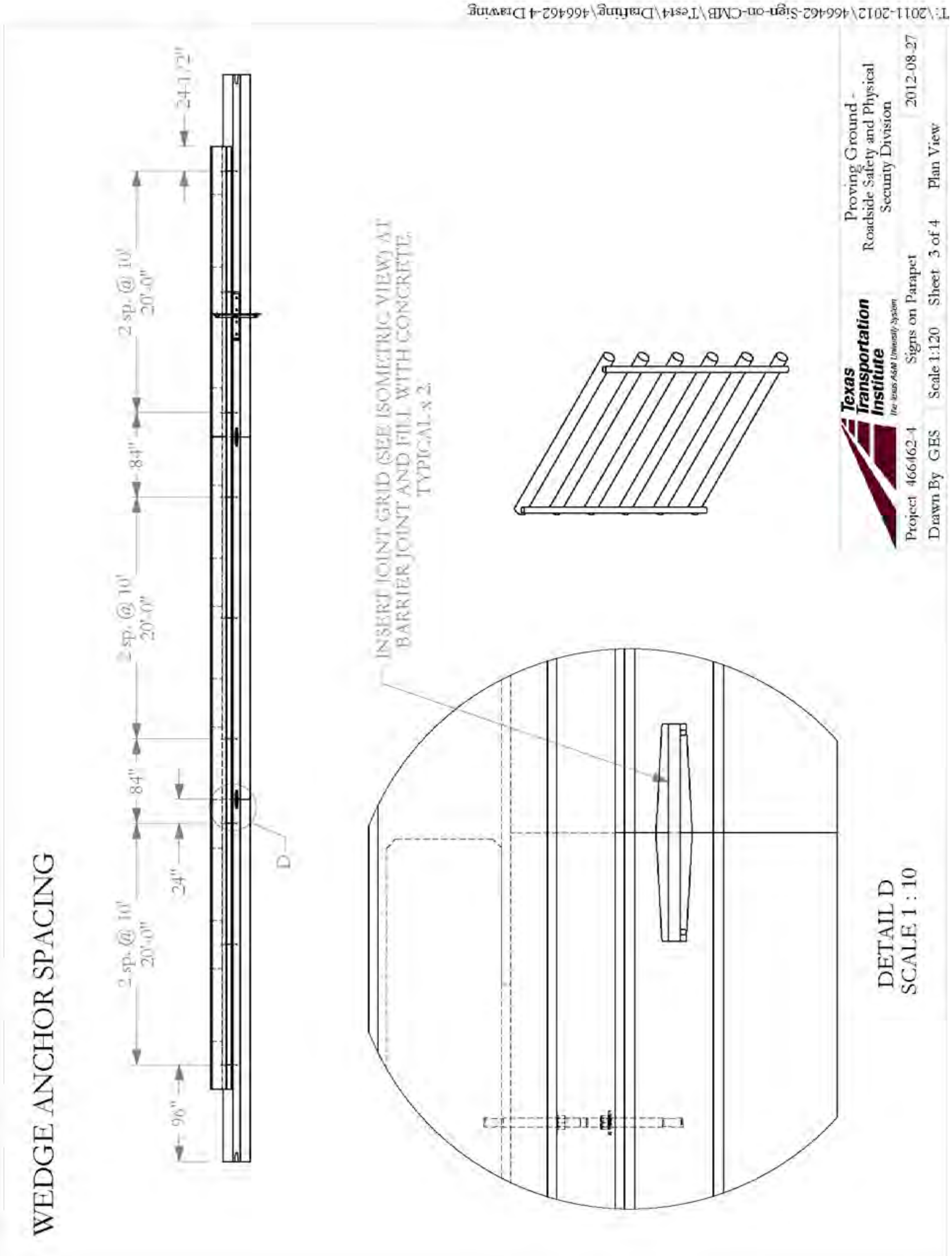
APPENDIX F. CRASH TEST NO. 466462-4

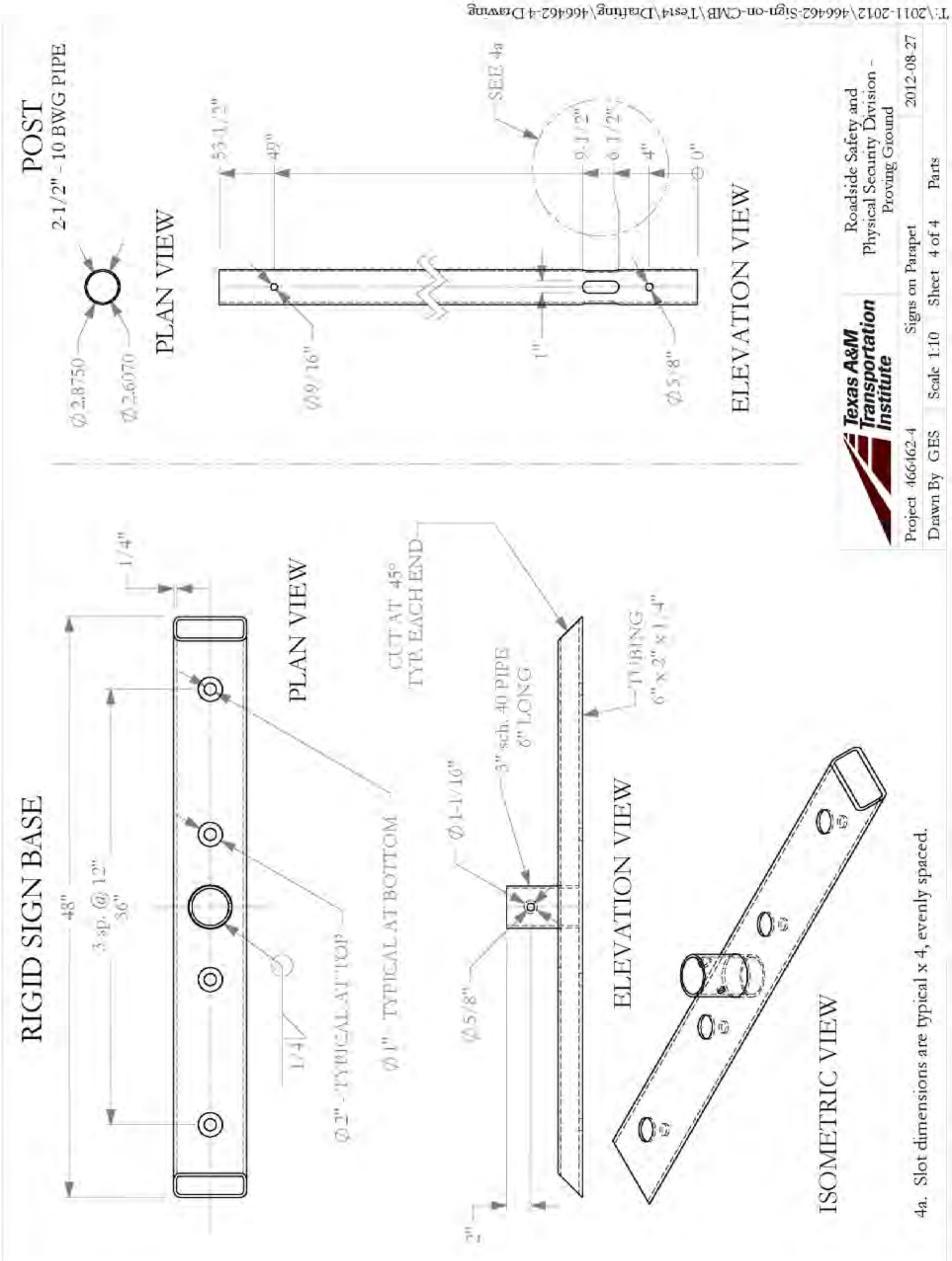
F1. DETAILS OF THE TEST ARTICLE





SIGN - 48" x 72" x 1/8" ALUMINUM
WITH STANDARD TxDOT U BRACKET
AND HARDWARE
12"
48"
60"
3-1/4"
84"
32"
HEX HEAD BOLT, Ø1/2 x 4-1/2"
W/ NUT AND 2 FLAT WASHERS
SECTION B-B
SCALE 1 : 25
C
TxDOT 30' BARRIER
GROUND LINE
EXISTING T223 BARRIER
B
B
Ø3/4" x 8" WEDGE ANCHOR
6" MIN. EMBEDMENT
Ø3/4" ROD OR REBAR
8"
12"
FILL-IN CONCRETE
Ø3/4" x 8" WEDGE ANCHOR
6" MIN. EMBEDMENT
1/2
1/2
DETAIL C
SCALE 1 : 10
Texas Transportation Institute
The Texas A&M University System
Proving Ground - Roadside Safety and Physical Security Division
Project 466462-4
Signs on Parapet
2012-08-27
Drawn By GES
Scale 1:200
Sheet 2 of 4
Cross-section
T:\2011-2012\466462-Sign-on-CMB\Test4\Drafting\466462-4 Drawing


WEDGE ANCHOR SPACING
96"
2 sp. @ 10'
20'-0"
24"
84"
2 sp. @ 10'
20'-0"
84"
2 sp. @ 10'
20'-0"
24-1/2"
D
DETAIL D
SCALE 1 : 10
INSERT JOINT GRID (SEE ISOMETRIC VIEW) AT BARRIER JOINT AND FILL WITH CONCRETE. TYPICAL x 2
Texas Transportation Institute
The Texas A&M University System
Proving Ground - Roadside Safety and Physical Security Division
Project 466462-4
Signs on Parapet
2012-08-27
Drawn By GES
Scale 1:120
Sheet 3 of 4
Plan View
T:\2011-2012\466462-Sign-on-CMB\Test4\Drafting\466462-4 Drawing


RIGID SIGN BASE
48"
3 sp. @ 12"
36"
1/4"
PLAN VIEW
1/4
Ø 2" TYPICAL AT TOP
Ø 1" TYPICAL AT BOTTOM
Ø 1-1/16"
3" sch. 40 PIPE
6" LONG
CUT AT 45°
TYP. EACH END
TUBING
6" x 2" x 1/4"
Ø 5/8"
2"
ELEVATION VIEW
ISOMETRIC VIEW
4a. Slot dimensions are typical x 4, evenly spaced.
POST
2-1/2" - 10 BWG PIPE
Ø 2.8750
Ø 2.6070
PLAN VIEW
53-1/2"
49"
9-1/2"
6-1/2"
4"
0"
SEE 4a
Ø 9/16"
1"
Ø 5/8"
ELEVATION VIEW
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project 466462-4
Signs on Parapet
2012-08-27
Drawn By GES
Scale 1:10
Sheet 4 of 4
Parts
T:\2011-2012\466462-Sign-on-CMB\Test4\Drafting\466462-4 Drawing

F2. CERTIFICATION DOCUMENTATION

MATERIAL USED

TEST NUMBER 466462-4

TEST NAME Sign on Barrier

DATE 2012-08-28

DATE RECEIVED	ITEM NUMBER	DESCRIPTION	SUPPLIER	HEAT #
2012-04-11	U-Bracket-1	2-7/8'' OD sign bracket	Trinity	generic Trinity
2010-05-11	Tubing 6x2-1	6x2x1/4 x 20' A500 gr. 5 ORA	Mack Bolt & Steel	921034
2012-01-18	Bolt 0.500-11	1/2 -13 x 4-1/2 gr. 5	Fastenal	1WG14
2011-06-28	Washer 0.5000-02	1/2 flat	Best Products Co.	
2011-06-28	Nut 0.5000-02	1/2 hex gr. 5	Best Products Co.	315702

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111

A

Customer:	SAMPLES,TESTING,TRAINING MTRLS 2525 STEMMONS FRWY DALLAS, TX 75207	Sales Order: 1151007 Customer PO: Samples BOL # 41575 Document # 1	Print Date: 4/10/12 Project: SAMPLES Shipped To: TX Use State: TX

Trinity Highway Products, LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SMALL SIGNS SUPPORT **

NCHRP Report 350 Compliant

Pieces	Description	Part No
9	1.500PS12@144	720018G
11	1.750PS12@144	720087G
1	2.000PS12@24 ANCH	720253G
2	2.875RD10 U BKT HDG	720852G
1	2.000PS14@24 ANCH	721116G

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

TL -3 or TL-4 COMPLIANT when installed according to manufactures specifications

Steel. The steel shall be in accordance with the standard specification for hot rolled carbon sheet steel, structural quality, ASTM A 1011, Grade 50. The average minimum yield strength after cold-forming shall be a minimum of 50,000 psi.

Coating. The posts shall be hot-dipped galvanized steel in accordance with ASTM A 653, G90, structural quality, Grade 50, Class 1. The corner weld shall be zinc coated after scarfing operation. The steel shall also be coated with a chromate conversion coating and a clear organic polymer topcoat. Both the interior and the exterior of the post shall be galvanized. Modifications made to the post after the initial fabrication, such as additional welding or other alterations shall be galvanized.

CERTIFICATION. The fabricator shall furnish to the engineer, a certification stating that the posts furnished comply with all requirements of this specification. The certification shall include or have attached specific results of tests of the mechanical and chemical properties of the steel conforming to section 2.1 and 2.2 of this specification. A certification shall be submitted with the bid

State of Texas, County of Tarrant. Sworn and Subscribed before me this 10th day of April, 2012

Notary Public:
Commission Expires:

/ JOMARY LUGINSLAND
MY COMMISSION EXPIRES
May 24, 2015

Trinity Highway Products, LLC
Certified By:
Quality Assurance

18Aug09 8:45 T E S T C E R T I F I C A T E No: CHI 614195

Sold By:
INDEPENDENCE TUBE CORPORATION
6226 W. 74TH STREET
CHICAGO, IL 60638
Tel: 708-496-0380 Fax: 708-563-1950

P/O No 6219002
Rel
S/O No CHI 162535-003
B/L No CHI 93892-002 Shp 19Aug09
Inv No Inv

Sold To: (144)
NAMASCO-EAST
500 COLONIAL PARKWAY
SUITE 500
ROSWELL, GA 30076

Ship To: (21)
NAMASCO-BUDA
2560 SOUTH LOOP 4
BUDA, TX

Tel: 678-259-8845 Fax: 571 323-0613

CERTIFICATE of ANALYSIS and TESTS Cert. No: CHI 614195
17Aug09

Part No 005
TUBING A500 GRADE B(C)
6" X 2" X 1/4" X 40'

	Pcs	Wgt
	54	26,373

Heat Number	Tag No	Pcs	Wgt
921034	533564	18	8,791
	YLD=54861/TEN=66278/ELG=36.41		
921034	533565	18	8,791
921034	533566	18	8,791

Heat Number	*** Chemical Analysis ***
921034	C=0.2100 Mn=0.8300 P=0.0110 S=0.0060 Si=0.0200 Al=0.0470 Cu=0.0200

T/R FAX

Test Report Clerk
MELTED IN U.S.A.

WE PROUDLY MANUFACTURE ALL OF OUR HSS IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED,
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.
****
CURRENT STANDARDS:
.... A500/A500M-07
.... A513-07
.... A252-98 (2002)

Page: 1 .... Last

Jinn Her Enterprise Co., Ltd.

No. 107, SHIN-LO ST, KANGSHAN, 820 KAOHSIUNG, TAIWAN R. O. C
TEL : +886 (07) 6228801 FAX : +886 (07) 6223750 - +886 (07) 6211505

CERTIFICATE OF INSPECTION

CUSTOMER NAME	: FASTENAL COMPANY PURCHASING-IMPORT TRAFFIC	REPORT NO	: JH11092918015
CUSTOMER'S ADDRESS	: 4730 SERVICE DRIVE, WINONA MN. 55987 U.S.A.,TEL : 507-453-8086 FAX: 507-494-7833	REPORT DATE	: 2011/10/19
		BOLT LOT NO	: B087766Y1
		BOLT MATERIAL	: SCR435
ORDER NUMBER	: 180050104	BOLT HEAT NO	: 1WG14
PART NUMBER	: 15221	NUT LOTNO	:
DESCRIPTION	: HEX CAP SCREW G8 HD MARK:6 RADIAL LINES & "FNL"	NUT MATERIAL	:
		NUT HEAT NO	:
		WASHER LOT NO	:
SIZE	: 1/2-13X4-1/2	WASHER MATERIAL	:
FINISH	: H.T. ZINC YELLOW 5 MICRON	WASHER HEAT NO	:
QUANTITY	: 1500.0	ASSEMBLY LOT NO	:
BOLT MFR.	: JINN HER ENTERPRISE CO.,LTD.	BOLT MFR. DATE	: 2011/9/2
NUT MFR.	:	NUT MFR. DATE	:
WASHER MFR.	:	WASHER MFR. DATE	:

BOLT DIMENSIONAL INSPECTION — INSPECTION : 2011/09/23
SPECIFICATION : ASME B18.2.1 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
WIDTH ACROSS CORNERS	JIS B1071	21.34-21.99	mm	21.46-21.53	8	8	0
WIDTH ACROSS FLATS	JIS B1071	18.70-19.05	mm	18.77-18.81	8	8	0
HEIGHT	JIS B1071	7.67-8.20	mm	7.83-7.87	8	8	0
BODY DIA.	JIS B1071	12.53-12.70	mm	12.54-12.56	8	8	0
BODY LENGTH	JIS B1071	MIN 72.65	mm	74.07-74.16	8	8	0
GRIP LENGTH	JIS B1071	MAX 82.55	mm	76.86-77.11	8	8	0
LENGTH	JIS B1071	111.76-114.30	mm	113.57-113.71	8	8	0
THREAD	ASME B1.3M	NONE	N/A	PASS	8	8	0

BOLT MECHANICAL INSPECTION — INSPECTION : 2011/09/15
SPECIFICATION : SAE J121 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
COMPLETELY DEC. DEPTH	SAE J121	MAX 0.015	mm	PASS	1	1	0
BASE METAL	SAE J121	MIN 0.813	mm	PASS	1	1	0

BOLT MECHANICAL INSPECTION — INSPECTION : 2011/09/15
SPECIFICATION : SAE J429 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
SURFACE HARDNESS	SAE J429	MAX 58.6	HR30N	55-56	8	8	0
CORE HARDNESS	SAE J429	33.0-39.0	HRC	38-38	8	8	0
TENSILE STRENGTH	SAE J429	MIN 150.0	ksi	170-172	4	4	0
PROOF LOAD	SAE J429	MIN 120.0	ksi	PASS	1	1	0

BOLT FINISH INSPECTION — INSPECTION : 2011/09/23
SPECIFICATION : ASTM F1941 — SAMPLING STANDARD : ASME B18.18.2M

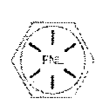
CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
THICKNESS OF COATING	ASTM A754/A754M	MIN 5.00000	um	8.14000-9.26000	4	4	0

BOLT APPEARANCE INSPECTION — INSPECTION : 2011/09/23
SPECIFICATION : SAE J1061 — SAMPLING STANDARD : ASME B18.18.2M

CHARACTERISTIC	TEST METHOD	STANDARD	UNIT	TEST VALUE	SAMPLE	ACC	REJ
GENERAL WORKMANSHIP	VISION	NONE	N/A	PASS	8	8	0

CHEMICAL ANALYSIS %

HEAT NO	C-x100	MN-x100	P-x1000	S-x1000	SI-x100	CU-x100	NI-x100	CR-x100	MO-x100	AL-x1000	B-x10000	V-x100
1WG14	36	72	14	9	20	1	3	102				



BOLT MARKING

Remark : 1.Lab is accredited according to ISO/IEC17025 requirements. This certificate is valid with signature of Yi-Sung Chen.

2.This test certificate is responsible for designated samples only. This test certificate only relates to the items listed and tested, it's not allowed to be partially used.

3.The above composition is quoted from original mill certs which is not in the scope of Lab Accreditation.

4.This test certificate in accordance with EN 10204 type 3.1.

5.Unless specified by the customer, the latest version of the testing specs was used.

6.Quality System conforms to ISO 9001 requirements and certified by TUV .

180050104

15221

B087766Y1

SUPER CHENG INDUSTRIAL CO.,LTD.

NO. 18 BEN-GONG 2nd ROAD., BEN CHOU INDUSTRIAL PARK, KAOHSIUNG COUNTY 820, TAIWAN R.O.C.
TEL：886-7-6225326-30(5 LINES) FAX：886-7-6215377/6212335/6235829

CERTIFICATE OF INSPECTION

CERT. #： S62-1010-03 ISSUED DATE： 2010/11/12 PAGE 1 OF 1

CLIENT：SUPER CHENG INDUSTRIAL CO., LTD.
ADDRESS：NO. 18 BEN-GONG 2nd ROAD., BEN CHOU INDUSTRIAL PARK, KAOHSIUNG COUNTY 820, TAIWAN R.O.C.

PURCHASER：FASTENAL COMPANY PURCHASING PO #：180038281
PART#1136310 QTY SHIPPED：112,500 PCS

COMMODITY：GRADE 5 FIN HEX NUT FINISH： TRIVALENT ZINC
SIZE： 1/2-13 LOT#： S62-1010-03 SAMPLING PLAN：ANSI/ASME B18.18.2M-93
QTY： 587270 PCS MATERIAL： SWRCH10A HEAT NO.： 315702
MANUFACTURER：SUPER CHENG IND. CO., LTD. MANU. DATE： 2010/10/27

DIMENSIONAL INSPECTION SPEC.：ANSI/ASME B18.2.2-87 SAMPLED BY： HUI HUA YU

ITEM	SAMPLE SIZE	SPECIFIED	ACTUAL RESULT	JUDGMENT
APPEARANCE	100	ASTM F812-07	GOOD	OK
W.A.F.	32	0.750 ~ 0.736 in.	0.743 ~ 0.741 in.	OK
W.A.C.	8	0.866 ~ 0.840 in.	0.852 ~ 0.848 in.	OK
THICKNESS	8	0.448 ~ 0.427 in.	0.447 ~ 0.439 in.	OK
THREAD	32	ANSI/ASME B1.1	PASS	OK

MECHANICAL PROPERTIES SPEC.：SAE J995-99 SAMPLED BY： HUI HUA YU

ITEM	SAMPLE SIZE	TEST METHOD	SPECIFIED	ACTUAL RESULT	JUDGMENT
HARDNESS	8	ASTM F606-09	MAX HRB107	98.0 ~ 94.0 HRBW	PASS
PROOF LOAD	4	ASTM F606-09	MIN 17000LB	17163 ~ 17152 LB	PASS

REMARK：1、THIS REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL WITHOUT WRITTEN APPROVAL OF THE LAB.
2、THIS INSPECTION CERTIFICATE IS FOR RESPONSIBILITY UNDER SAMPLE ONLY
3、ABOVE SAMPLES TESTED CONFORM TO THE FASTENER SPECIFICATION OR STANDARDS

LAB. DIRECTOR(SIGNATORY)：

表單編號：LQC 10E Rev.0

F3. VEHICLE PROPERTIES AND INFORMATION

Table F1. Vehicle Properties for Test No. 466462-4.

Date: 2012-08-28 Test No.: 466462-4 VIN No.: 1D7HA18N765711414

Year: 2006 Make: Dodge Model: Ram 1500

Tire Size: 265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 178125

Note any damage to the vehicle prior to test: ____

● Denotes accelerometer location.

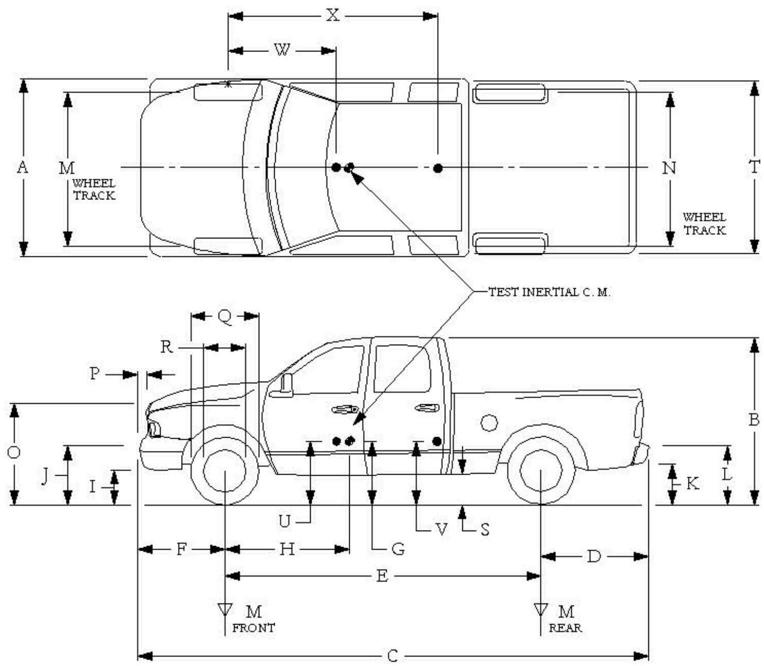
NOTES: ____

Engine Type: V-8
Engine CID: 4.7 liter

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

Optional Equipment: ____

Dummy Data:
Type: None
Mass: ____
Seat Position: ____



Geometry: inches

A	78.25	F	36.00	K	20.50	P	2.88	U	28.50
B	75.00	G	28.50	L	29.12	Q	31.25	V	29.50
C	223.75	H	62.08	M	68.50	R	18.38	W	60.50
D	47.25	I	13.75	N	68.00	S	12.00	X	78.00
E	140.50	J	25.38	O	44.50	T	77.50		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	5.00	Bottom Frame Height - Front	17.12
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	10.25	Bottom Frame Height - Rear	24.75

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2841	2797	
Back	3900	M_{rear}	2027	2214	
Total	6700	M_{Total}	4868	5011	

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

Mass Distribution:
lb LF: 1434 RF: 1363 LR: 1071 RR: 1143

Table F2. Vehicle Parametric Measurements for Test No. 466462-4.

Date: 2012-08-28 Test No.: 466462-4 VIN: 1D7HA18N765711414

Year: 2006 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 178125

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 176 lb weight at front of bed (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70R17

Measured Vehicle Weights: (lb)					
LF:	1434	RF:	1363	Front Axle:	2797
LR:	1071	RR:	1143	Rear Axle:	2214
Left:	2505	Right:	2506	Total:	5011
					5000 ±110 lb allowed
Wheel Base:	140.5 inches	Track: F:	68.5 inches	R:	68.0 inches
	148 ±12 inches allowed		Track = (F+R)/2 = 67 ±1.5 inches allowed		
Center of Gravity, SAE J874 Suspension Method					
X:	62.08 in	Rear of Front Axle		(63 ±4 inches allowed)	
Y:	0.01 in	Left -	Right +	of Vehicle Centerline	
Z:	28.5 in	Above Ground		(minumum 28.0 inches allowed)	

Hood Height: 44.5 inches
43 ±4 inches allowed

Front Bumper Height: 25.375 inches

Front Overhang: 36.0 inches
39 ±3 inches allowed

Rear Bumper Height: 29.125 inches

Overall Length: 223.75 inches
237 ±13 inches allowed

Table F3. Exterior Crush Measurements for Test No. 466462-4.

Date: 2012-08-28 Test No.: 466462-4 VIN No.: 1D7HA18N765711414

Year: 2006 Make: Dodge Model: Ram 1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________	Bowing: B1 _____ X1 _____
Corner shift: A1 ________	B2 _____ X2 _____
A2 ________	
End shift at frame (CDC)	Bowing constant
(check one)	$\frac{X1+X2}{2}$ = _______
< 4 inches ________	
≥ 4 inches ________	

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	14	14	24	0	4	8.5	10.5	12	14	+12
2	Side plane at bumper ht	14	18	32	0	3	9	12	15.5	18	+72
	Measurements recorded										
	in inches										

[1]Table taken from National Accident Sampling System (NASS).

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

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

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

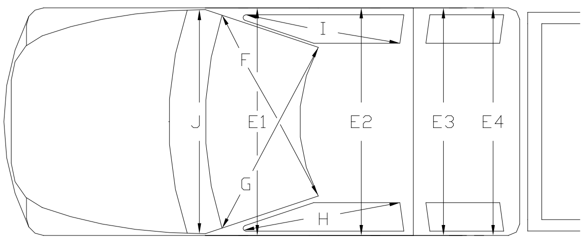
***Measure and document on the vehicle diagram the location of the maximum crush.

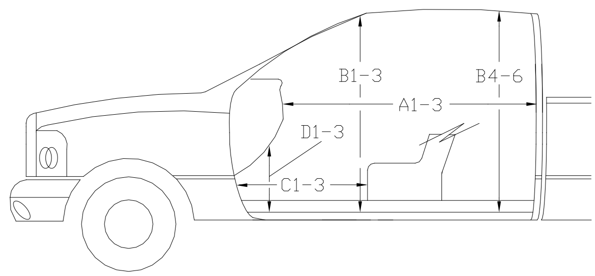
Note: Use as many lines/columns as necessary to describe each damage profile.

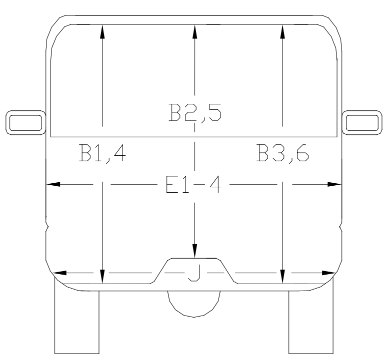
Table F4. Occupant Compartment Measurements for Test No. 466462-4.

Date: 2012-08-28 Test No.: 466462-4 VIN No.: 1D7HA18N765711414

Year: 2006 Make: Dodge Model: Ram 1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	**After** (inches)
A1	64.50	64.50
A2	64.50	64.50
A3	65.00	64.00
B1	45.25	45.25
B2	39.75	39.25
B3	45.25	45.75
B4	42.25	42.25
B5	45.00	45.00
B6	42.25	42.25
C1	29.50	29.50
C2	----	----
C3	27.00	24.00
D1	12.75	12.75
D2	----	----
D3	11.50	11.75
E1	62.75	63.75
E2	64.50	66.12
E3	64.00	64.12
E4	64.12	64.25
F	60.00	60.00
G	60.00	60.00
H	39.00	39.00
I	39.00	39.00
J*	62.12	60.25

F4. SEQUENTIAL PHOTOGRAPHS

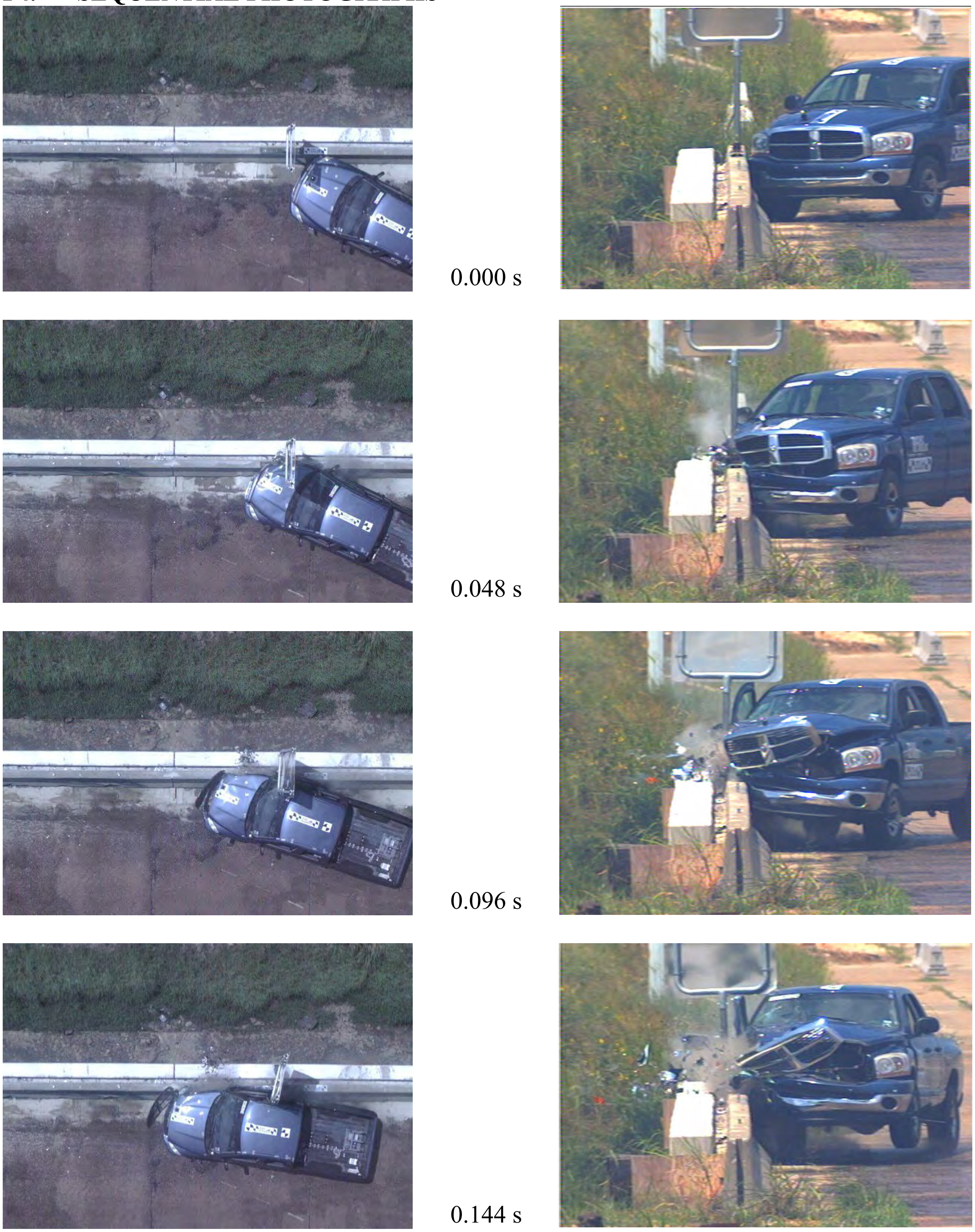
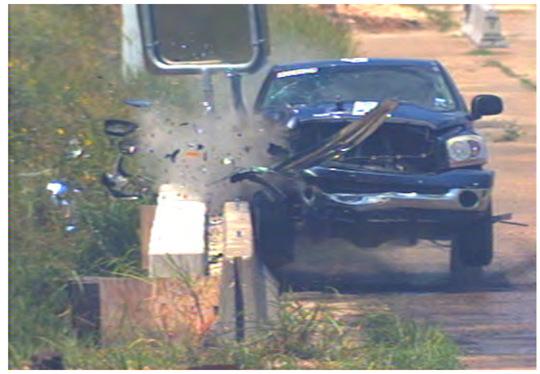
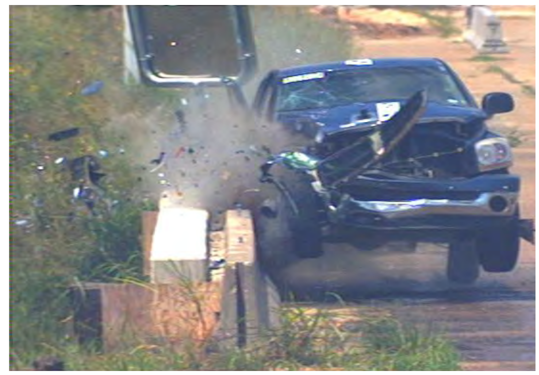


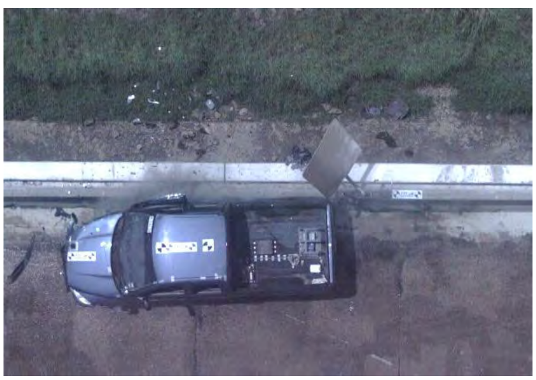
Figure F1. Sequential Photographs for Test No. 466462-4 (Overhead and Frontal Views).

0.192 s

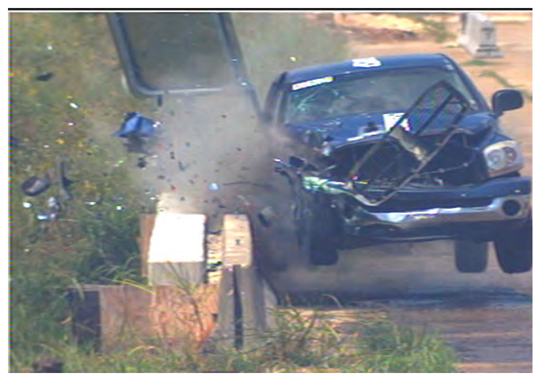


0.240 s





0.288 s



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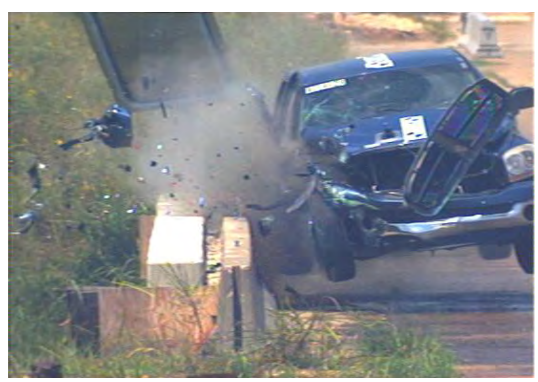
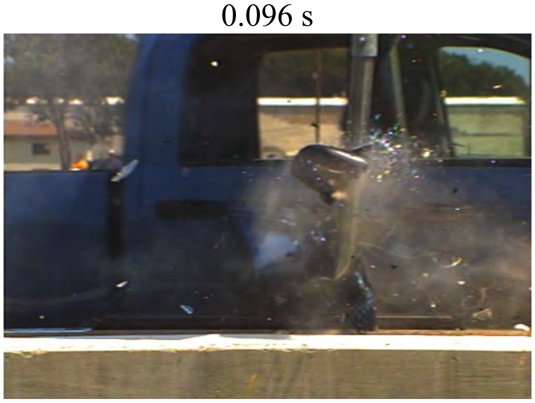


Figure F1. Sequential Photographs for Test No. 466462-4 (Overhead and Frontal Views) (continued).

0.000 s

0.048 s

0.096 s



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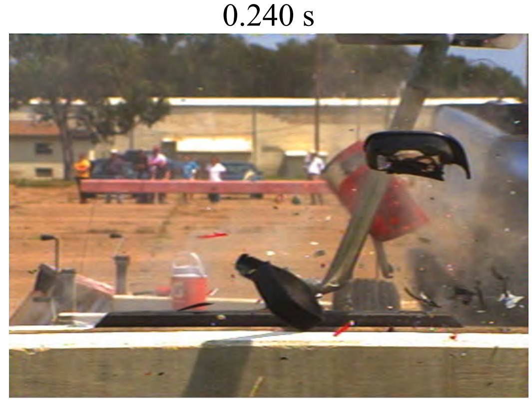
0.192 s

0.240 s



0.288 s

0.336 s

Figure F2. Sequential Photographs for Test No. 466462-4 (Rear View).

F5. VEHICLE ANGULAR DISPLACEMENTS

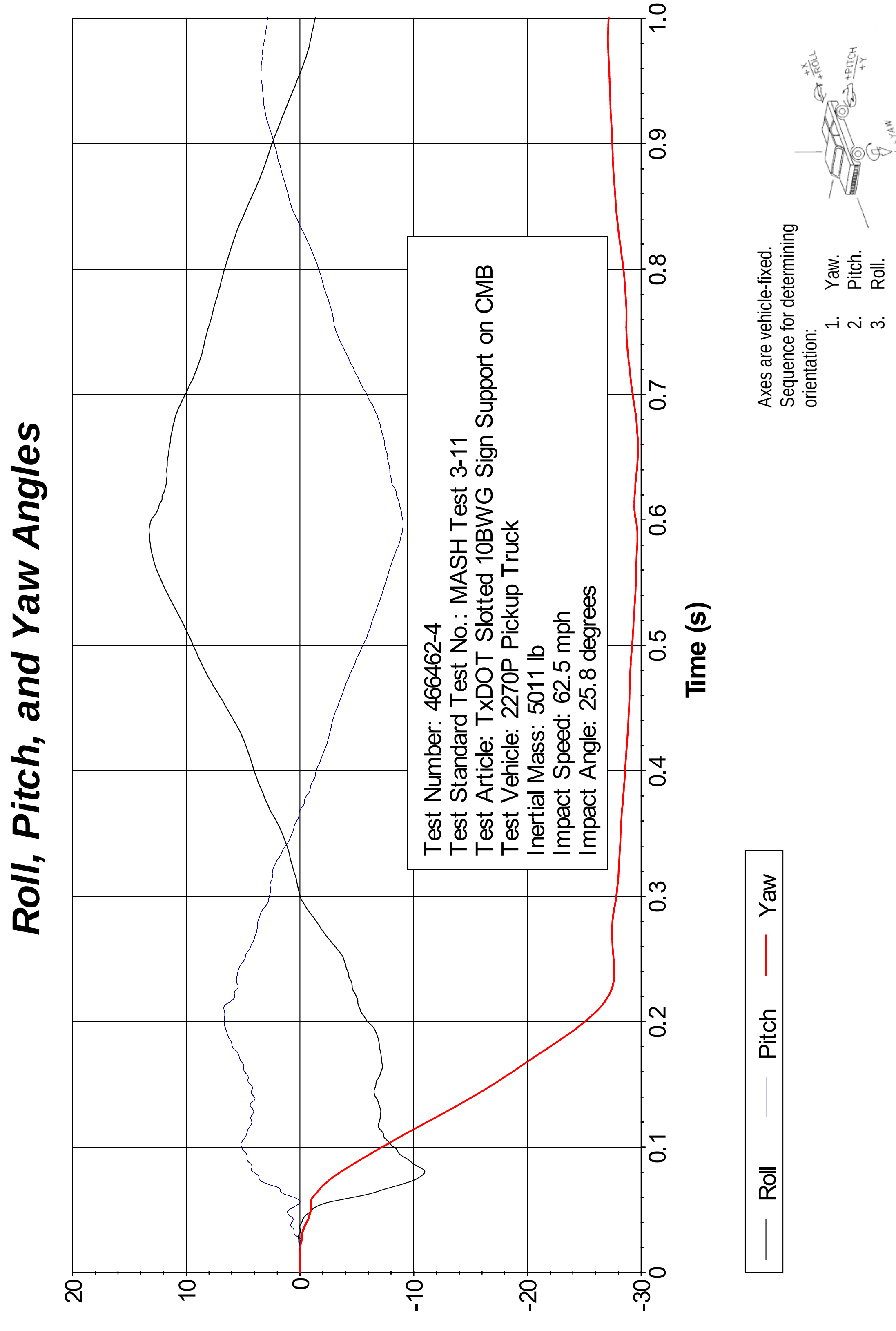


Figure F3. Vehicle Angular Displacements for Test No. 466462-4.

F6. VEHICLE ACCELERATIONS

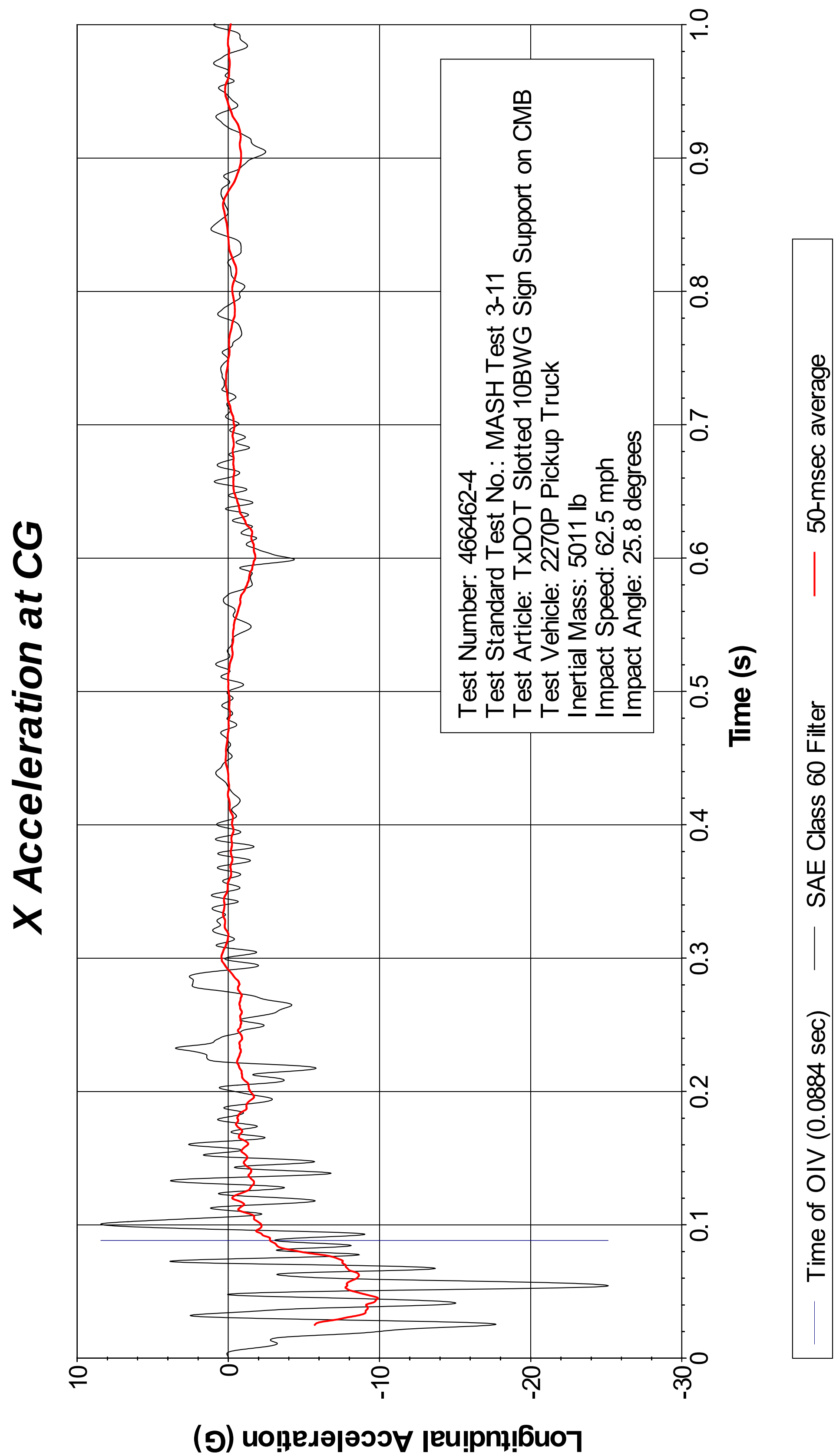


Figure F4. Vehicle Longitudinal Accelerometer Trace for Test No. 466462-4 (Accelerometer Located at Center of Gravity).

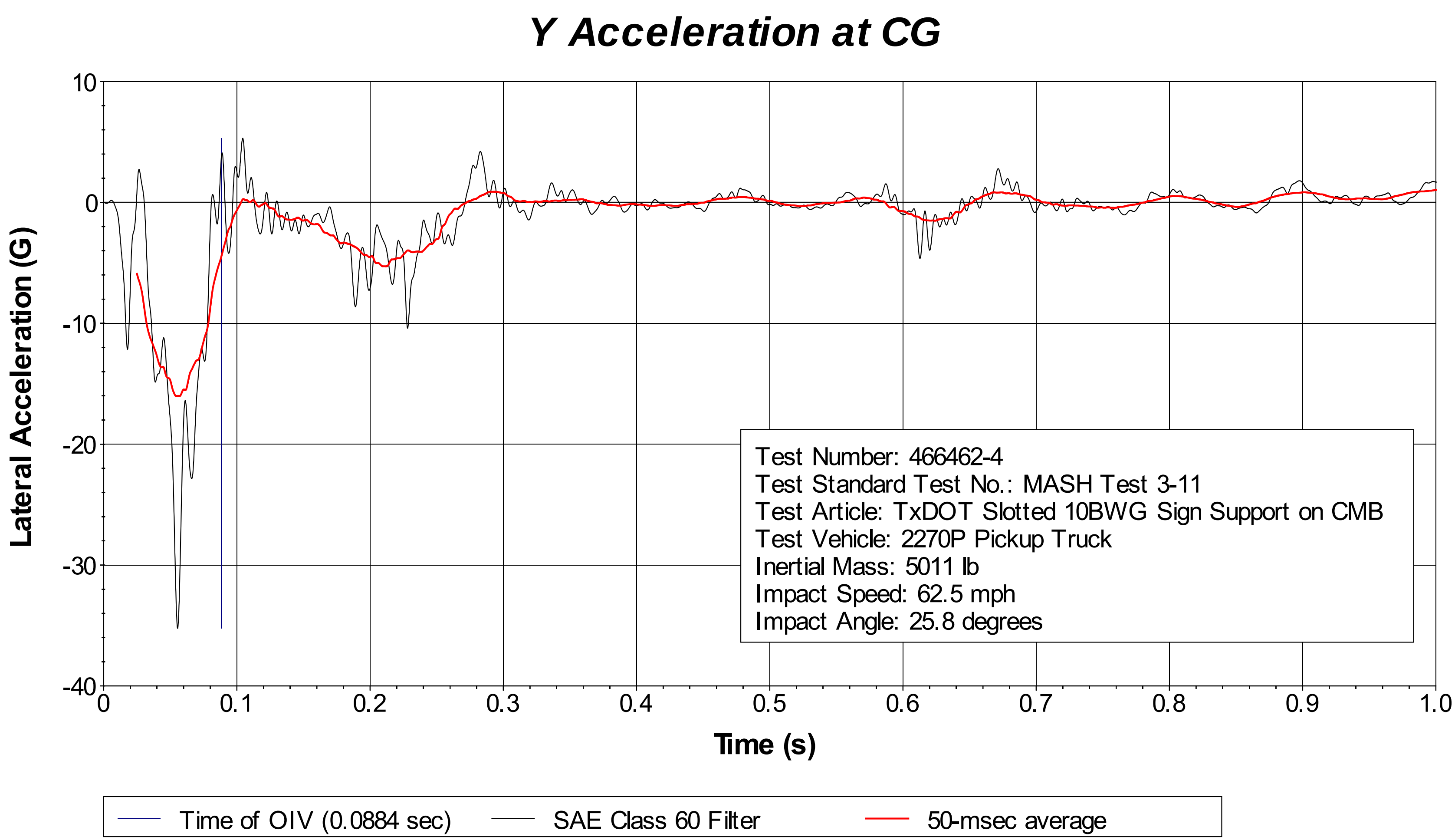


Figure F5. Vehicle Lateral Accelerometer Trace for Test No. 466462-4 (Accelerometer Located at Center of Gravity).

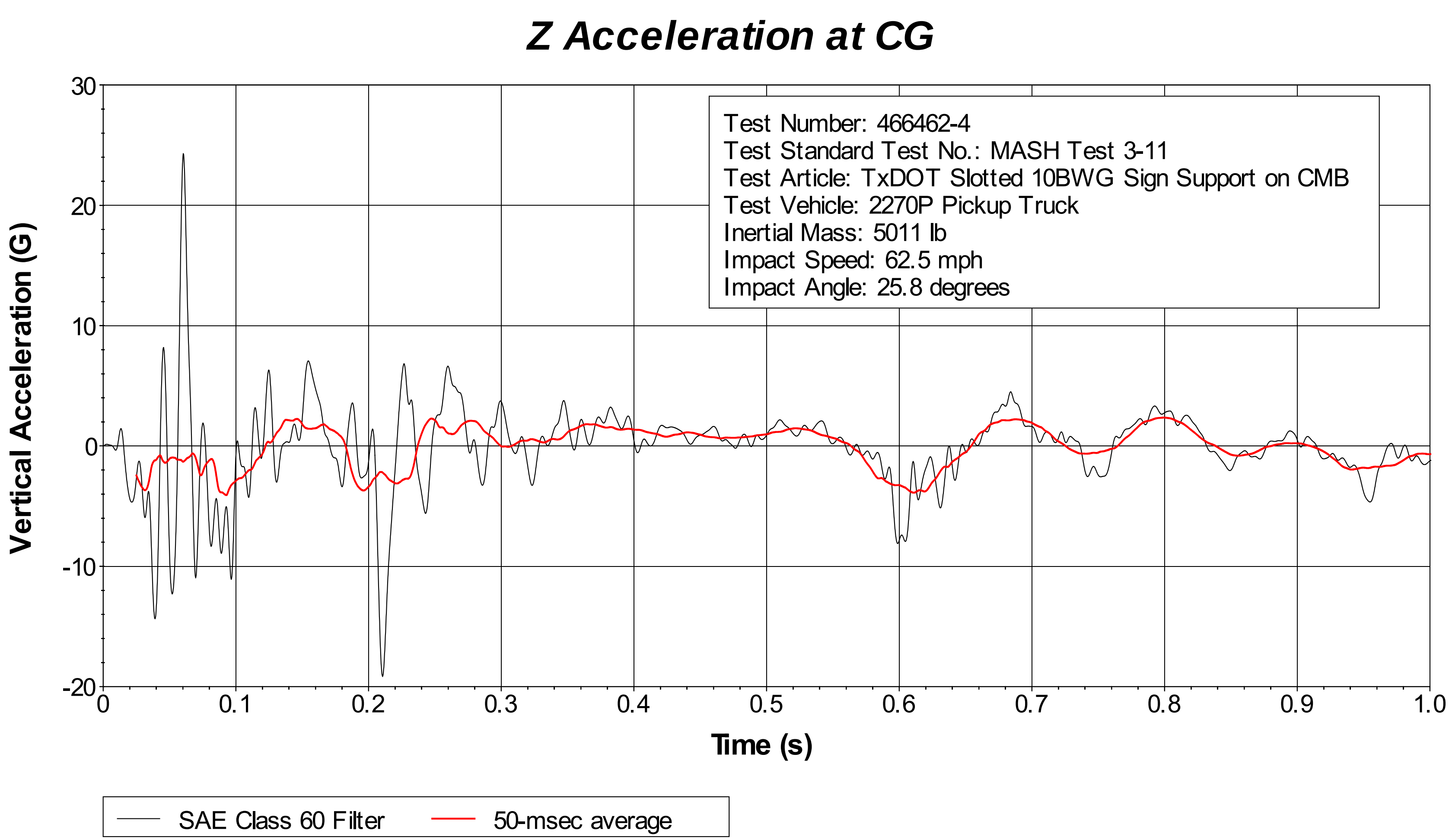


Figure F6. Vehicle Vertical Accelerometer Trace for Test No. 466462-4 (Accelerometer Located at Center of Gravity).

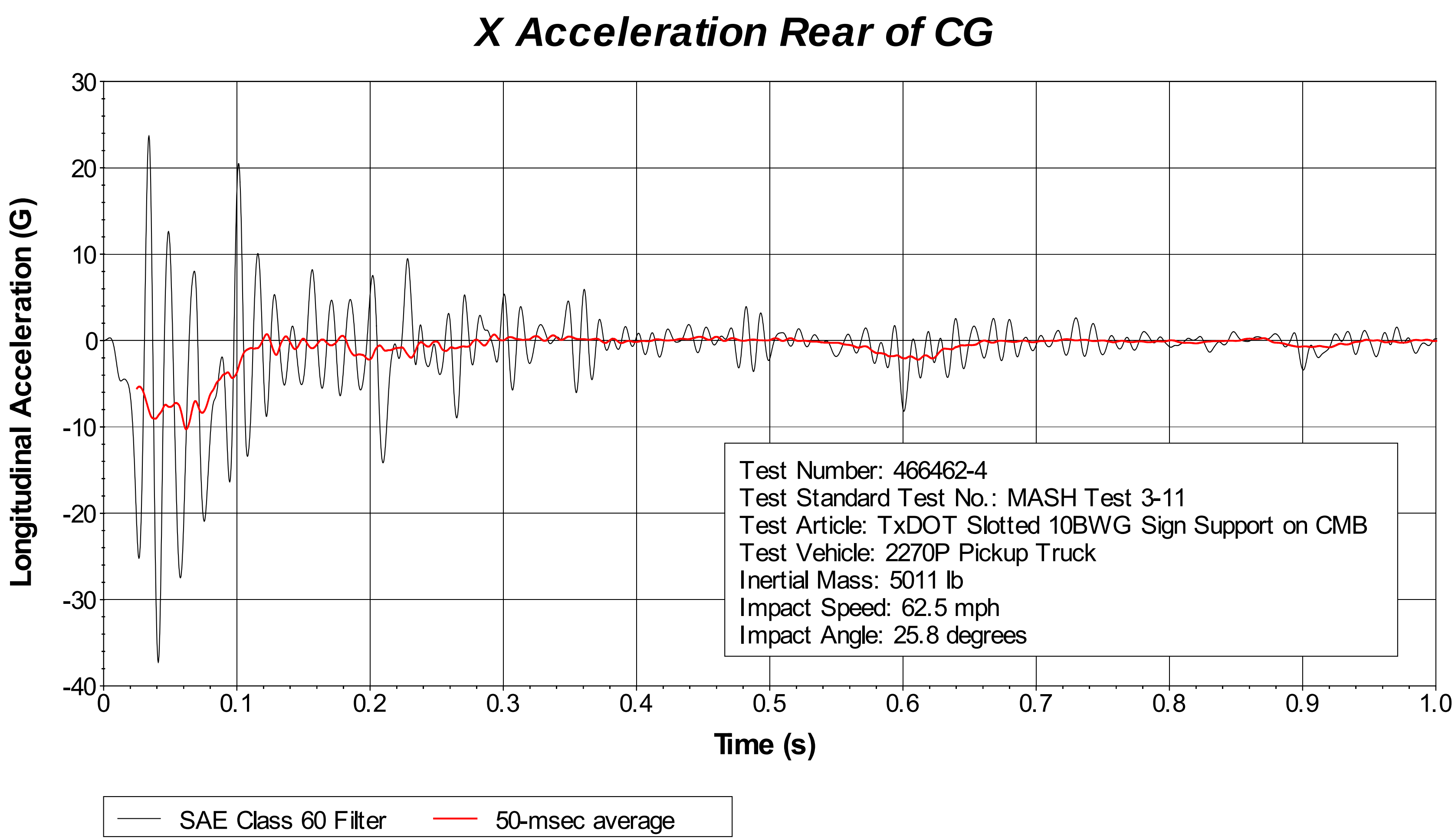


Figure F7. Vehicle Longitudinal Accelerometer Trace for Test No. 466462-4 (Accelerometer Located Rear of Center of Gravity).

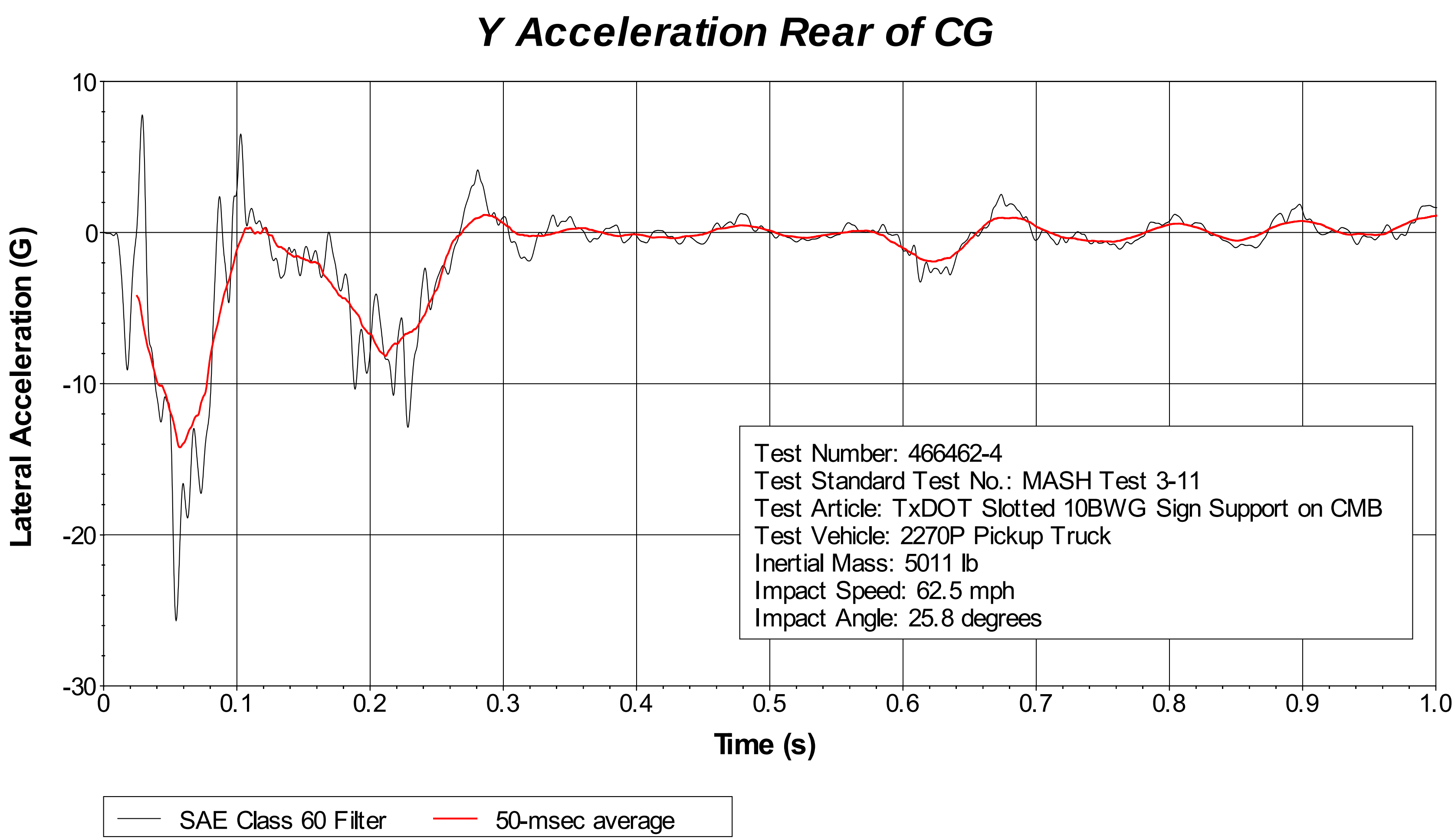


Figure F8. Vehicle Lateral Accelerometer Trace for Test No. 466462-4 (Accelerometer Located Rear of Center of Gravity).

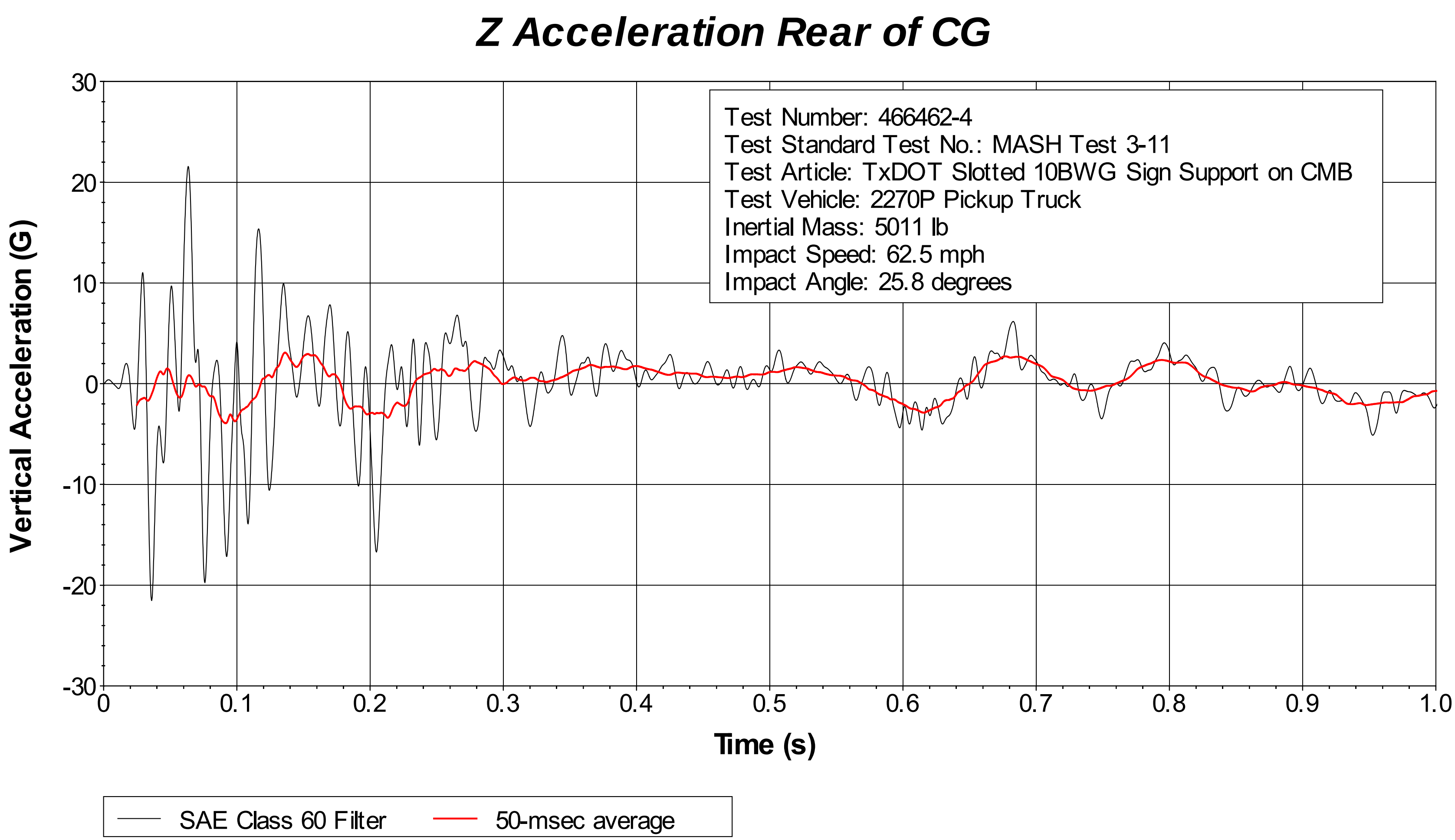


Figure F9. Vehicle Vertical Accelerometer Trace for Test No. 466462-4 (Accelerometer Located Rear of Center of Gravity).