TESTING AND EVALUATION OF MASH TL-3 TRANSITION BETWEEN GUARDRAIL AND PORTABLE CONCRETE BARRIERS

Submitted by

Robert W. Bielenberg, M.S.M.E., E.I.T.
Research Associate Engineer

Jessica L. Lingenfelter
Undergraduate Research Assistant

Justine E. Kohtz, B.S.M.E.
CAD Technician

Ronald K. Faller, Ph.D., P.E.
Research Associate Professor
MwRSF Director

John D. Reid, Ph.D.
Professor

MIDWEST ROADSIDE SAFETY FACILITY
Nebraska Transportation Center
University of Nebraska-Lincoln
130 Whittier Research Center
2200 Vine Street
Lincoln, Nebraska 68583-0853
(402) 472-0965

Submitted to

NEBRASKA DEPARTMENT OF ROADS
1500 Nebraska Highway 2
Lincoln, Nebraska 68502

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Iowa State University
2711 S. Loop Drive, Suite 4700
Ames, Iowa 50010-8664

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16. Abstract

Three full-scale vehicle crash tests were conducted according to the *Manual for Assessing Safety Hardware* (MASH) Test Level 3 (TL-3) safety performance criteria on a transition between the Midwest Guardrail System (MGS) and a portable concrete barrier (PCB) system. The transition system utilized for test nos. MGSPCB-1 through MGSPCB-3 consisted of a standard MGS that overlapped a series of F-shape PCB segments that approached the MGS at a 15H:1V flare. In the overlapped portion of the barrier systems, uniquely-designed blockout holders and a specialized W-beam end shoe mounting bracket were used to connect the systems.

In test no. MGSPCB-1, a 5,079-lb (2,304-kg) pickup truck impacted the barrier at 63.2 mph (101.8 km/h) and 25.3 degrees. The barrier captured and redirected the 2270P vehicle, and the vehicle decelerations were within the recommended occupant risk limits. In test no. MGSPCB-2, a 2,601-lb (1,180-kg) car impacted the barrier at 65.1 mph (104.8 km/h) and 24.0 degrees. The barrier captured and redirected the 1100C vehicle, and the vehicle decelerations were within the recommended occupant risk limits. In test no. MGSPCB-3, a 5,177-lb (2,348-kg) pickup truck impacted the barrier at 63.1 mph (101.5 km/h) and 24.6 degrees. For this test, the system was impacted in the reverse direction. The barrier captured and redirected the 2270P vehicle, and the vehicle decelerations were within the recommended occupant risk limits.

Based on the results of these successful crash tests, it is believed that the transition design detailed herein represents the first MASH TL-3 crashworthy transition between the MGS and PCBs.

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UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in standard full-scale crash testing and non-standard testing of roadside safety features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration.

ABOUT SWZDI

Iowa, Kansas, Missouri, and Nebraska created the Midwest States Smart Work-Zone Deployment Initiative in 1999, and Wisconsin joined in 2001. Through this pooled-fund study, researchers investigate better ways of controlling traffic through work zones. Their goal is to improve the safety and efficiency of traffic operations and highway work. The project is now administered by Iowa State University's Institute for Transportation.

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Ms. Karla Lechtenberg, Research Associate Engineer.

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- Iowa (lead state)
- Kansas
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J.C. Holloway, M.S.C.E., E.I.T., Test Site Manager
K.A. Lechtenberg, M.S.M.E., E.I.T., Research Associate Engineer
S.K. Rosenbaugh, M.S.C.E., E.I.T., Research Associate Engineer
J.D. Schmidt, Ph.D., P.E., Research Assistant Professor
C.S. Stolle, Ph.D., Research Assistant Professor
A.T. Russell, B.S.B.A., Shop Manager
S.M. Tighe, Laboratory Mechanic
D.S. Charroin, Laboratory Mechanic
M.A. Rasmussen, Laboratory Mechanic
E.W. Krier, Laboratory Mechanic
Undergraduate and Graduate Research Assistants

<u>Nebraska Department of Roads</u>

Phil TenHulzen, P.E., Design Standards Engineer
Jim Knott, P.E., State Roadway Design Engineer
Jodi Gibson, Research Coordinator
Anna Neben, Quality Management Project Coordinator

<u>Federal Highway Administration</u>

John Perry, P.E., Nebraska Division Office
Danny Briggs, Nebraska Division Office

<u>Iowa State University</u>

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EXECUTIVE SUMMARY

Often, road construction causes the need to create a work zone. In these scenarios, portable concrete barriers (PCBs) are typically installed to shield workers and equipment from errant vehicles as well as prevent motorists from striking other roadside hazards. For an existing W-beam guardrail system installed adjacent to the roadway and near the work zone, guardrail sections are removed in order to place the PCB system. The focus of this research study was to evaluate a previously-developed transition between W-beam guardrail and PCB to *Manual for Assessing Safety Hardware* (MASH) Test Level 3 (TL-3). A previous phase of this research program included the development of a guardrail and free-standing PCB transition using extensive LS-DYNA simulation as well as refinement of potential concepts. Concept refinement led to a transition system comprised of a tangent, nested- Midwest Guardrail System (MGS) that overlapped an adjacent, flared PCB system. LS-DYNA simulation was also used to identify critical impact points for use in full-scale vehicle crash testing.

Three full-scale vehicle crash tests were conducted according to the MASH TL-3 safety performance criteria on a MGS to PCB transition. These tests evaluated structural integrity, vehicle snag, vehicle instability, and vehicle capture. The transition system that was used in test nos. MGSPCB-1 through MGSPCB-3 consisted of a standard MGS that overlapped a series of F-shape, PCB segments that approached the MGS at a 15H:1V flare. In the overlapped portion of the barrier systems, uniquely-designed blockout holders and a specialized W-beam end shoe mounting bracket were used to connect the systems.

Test no. MGSPCB-1, which followed MASH test designation no. 3-21 criteria, involved a 5,079-lb (2,304-kg) pickup truck impacting the barrier at 63.2 mph (101.8 km/h) and 25.3 degrees. The barrier captured and redirected the 2270P vehicle, and the vehicle decelerations were within the recommended occupant risk limits. Test no. MGSPCB-2, which followed MASH test designation no. 3-20 criteria, involved a 2,601-lb (1,180-kg) car impacting the barrier at 65.1 mph (104.8 km/h) and 24.0 degrees. The barrier captured and redirected the 1100C vehicle, and the vehicle decelerations were within the recommended occupant risk limits. Test no. MGSPCB-3 was another MASH test designation no. 3-21 test, with a reverse-direction impact. A 5,177-lb (2,348-kg) pickup truck impacted the barrier at 63.1 mph (101.5 km/h) and 24.6 degrees. The barrier captured and redirected the 2270P vehicle, and the vehicle decelerations were within the recommended occupant risk limits.

Based on the results of these successful crash tests, it is believed that the transition design detailed herein represents the first MASH TL-3 crashworthy transition between the MGS and PCBs.

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

Acronym		Definition
AASHTO	-	American Association of State Highway and Transportation Officials
ACM	-	Airbag Control Module
AOS	-	AOS Technologies AG
ASI	-	Acceleration Severity Index
ASTM	-	American Society for Testing and Materials
B.S.B.A.	-	Bachelor of Science in Business Administration
BCT	-	Breakaway Cable Terminal
c.g.	-	center of gravity
CIP	-	Critical Impact Point
cm	-	centimeter
cyl	-	cylinder
deg	-	degree
dia.	-	diameter
DOT	-	Department of Transportation
DTS	-	Diversified Technical Systems, Incorporated
E.I.T.	-	Engineer in Training
FHWA	-	Federal Highway Administration
ft	-	foot
ft/s	-	feet per second
FWD	-	front-wheel drive
g's	-	g-force, acceleration due to gravity at the Earth's surface
GB	-	gigabyte
h	-	hour
H	-	Horizontal
Hz	-	Hertz
i.e.	-	id est (that is)
IAA	-	Independent Approving Authority
in.	-	inch
IS	-	impact severity
JVC	-	Victor Company of Japan, Limited
kg	-	kilogram
kip-in.	-	thousand pounds-force inches
kips	-	thousand pounds-force
kJ	-	kilojoules
km	-	kilometer
km/h	-	kilometers per hour
kN	-	kilonewton
L	-	liter

lb	-	pound(s)
LED	-	light-emitting diode
m	-	meter
m/s	-	meters per second
MASH	-	Manual for Assessing Safety Hardware
MGS	-	Midwest Guardrail System
mm	-	millimeter
mph	-	miles per hour
M.S.C.E.	-	Master of Science in Civil Engineering
M.S.M.E.	-	Master of Science in Mechanical Engineering
mV	-	millivolts
MwRSF	-	Midwest Roadside Safety Facility
N	-	Newton
NA	-	not applicable
NCHRP	-	National Cooperative Highway Research Program
NDOR	-	Nebraska Department of Roads
NHS	-	National Highway System
no.	-	number
nos.	-	numbers
OIV	-	occupant impact velocity
ORA	-	occupant ridedown acceleration
PCB	-	Portable Concrete Barrier
P.E.	-	Professional Engineer
Ph.D.	-	Doctor of Philosophy
PHD	-	Post-Impact Head Deceleration
p.m.	-	post meridiem
RWD	-	rear-wheel drive
s	-	second
SAE	-	Society of Automotive Engineers
sec	-	second
SYP	-	Southern Yellow Pine
THIV	-	Theoretical Head Impact Velocity
TL	-	Test Level
U.S.	-	United States
US	-	upstream
V	-	volts
V	-	Vertical
° F	-	degrees Fahrenheit
’	-	foot
”	-	inch
%	-	percent

$>$ - greater than
$\leq$ - less than or equal to
$\pm$ - plus or minus
σ_w - yield strength of W-beam rail
t_w - thickness of W-beam rail
D_b - bolt diameter
F_v - shear force

1 INTRODUCTION

1.1 Background

Work zones often require the use of portable concrete barriers (PCBs) within a limited area to provide protection for construction workers. In situations where an existing guardrail is immediately adjacent to the construction hazards that need to be shielded, highway designers must either connect the guardrail to the temporary barrier or replace it with PCB. Although interconnecting the two barrier systems represents the more convenient option, at present no suitable solutions have been made available. While a transition from guardrail to temporary barriers may not need to be nearly as stiff as a conventional approach transitions, it must provide sufficient stiffness and strength to prevent pocketing as well as to shield the end of the concrete barrier to prevent serious wheel snag. In addition, considerations must be made for attachment of the guardrail to the PCBs.

Nebraska Department of Roads (NDOR) and the Smart Work-Zone Deployment Initiative (SWZDI) have previously funded a project to develop a guardrail to PCB transition design capable of meeting the *Manual for Assessing Safety Hardware* (MASH) [1] Test Level 3 (TL-3) safety requirements. This research effort resulted in the development of a flared PCB to guardrail transition that utilized a tangent, nested Midwest Guardrail System (MGS) that overlapped a series of F-shape, PCB segments installed at a 15H:1V flare. Both the MGS and the F-shape PCB had previously been evaluated to MASH TL-3 [2-6]. During that research, computer simulation indicated a high likelihood that the proposed transition would meet MASH TL-3 and determined critical impact points for use in full-scale crash testing. In order to implement the proposed design, the transition details must be fully developed, fabricated, and then subjected to full-scale crash testing according to the MASH TL-3 safety requirements.

The new transition would eliminate the use of unproven connections between guardrail and PCBs. Further, limiting the use of PCBs strictly to the work zone area will also minimize the traffic disruption that these barriers can create to motorists passing in work zones.

1.2 Objective/Scope

The objective of this research study was to evaluate the safety performance of the MGS to PCB transition. The system was to be evaluated according to the TL-3 criteria of MASH. Two full-scale crash tests were conducted according to MASH test designation no. 3-21, and one full-scale crash test was conducted according to MASH test designation no. 3-20. Data obtained from these crash tests was analyzed, and the results were utilized to guide the project conclusions and recommendations. Additionally, implementation guidance for the new transition system was provided.

2 REFINEMENT OF TRANSITION CONCEPT

The Phase I research effort led to a basic design layout for the transition system based on extensive LS-DYNA simulations. This simulation effort provided general system behavior geometry for the transition design, but other design details were still needed prior to full-scale crash testing. These needs included final design of the connection hardware between the guardrail and the PCB and specification of the foundation system to support the PCBs. This chapter will review the preferred design concept and assumptions identified in Phase I and discuss the development of the connection hardware and foundation specification.

2.1 Phase I Preferred Transition Concept with Considerations

The Phase I research effort led to the development of a transition system comprised of a tangent, nested-MGS that overlapped an adjacent, flared PCB system, as shown in Figure 1. This schematic shows the configuration for the MGS to PCB transition based on the initial computer simulation analysis. It was found that:

1. The transition should consist of at least 137.5-ft (41.91-m) long MGS and an eleven segment PCB system installed at a 15H:1V flare. A minimum of eight PCBs should be placed downstream from the point where the MGS attaches to the PCBs. The portable barriers are 12.5-ft (3.81-m) long, F-shape PCBs, those previously developed through the Midwest States Pooled Fund Program [6]. The simulation analysis found that these system lengths were appropriate for development of both the guardrail and PCB systems. If shorter system lengths were desired for either barrier type, further full-scale crash testing would be required.

2. The transition required a minimum of three PCB segments extending behind the nested MGS at the 15H:1V flare. This finding pertained to guardrail attachment on the upstream end of the fourth PCB segment. Additional length of flared PCBs behind the MGS would not be an issue as the potential for vehicle and barrier interaction with the PCBs is maximized for the minimum overlap condition. Additional flared PCBs behind the MGS is likely given that field installations will not match up exactly with the minimum guardrail-to-PCB overlap.

3. Installation of standard MGS posts and blockouts was not recommended within the first two sections of guardrail upstream from the W-beam end shoe connection as the PCB would interfere with installation of those posts and prevent proper post rotation. Connection between the guardrail and the PCB on the first two PCB segments upstream from the end shoe was accomplished with specially-designed blockout holders, which are discussed later in this chapter.

4. A minimum of five 12-ft 6-in. (3,810-mm) long, nested W-beam sections must be utilized upstream from the end-shoe connection to the PCBs. For the minimum PCB overlap noted above, this corresponds to one complete 12.5-ft (3.81-m) long section of nested rail upstream from the end of the PCBs.

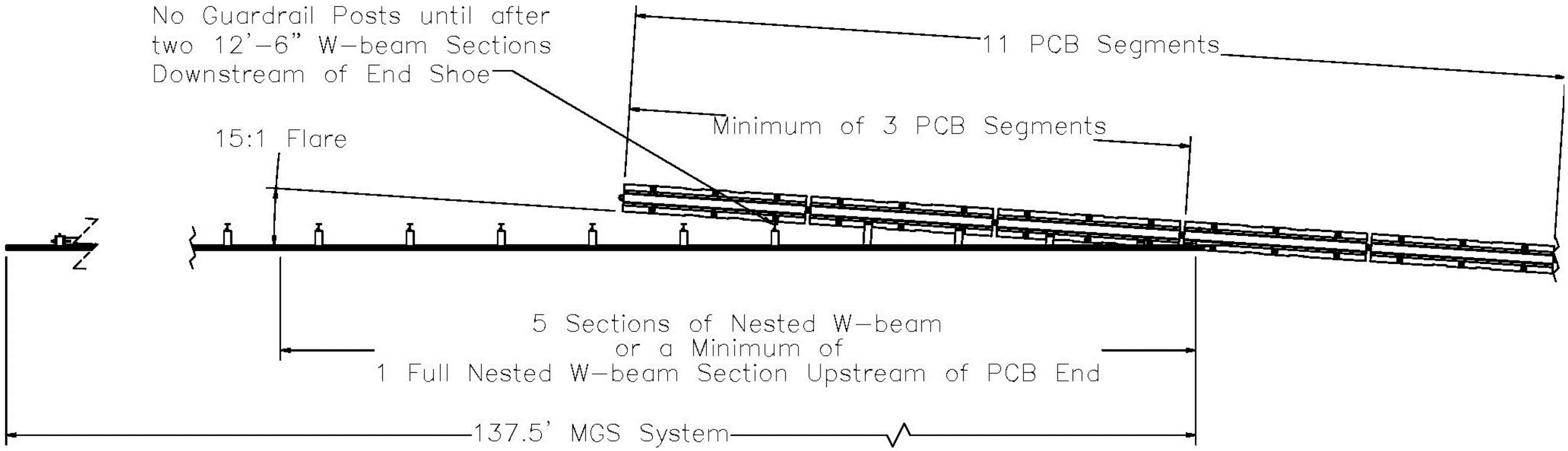


Figure 1. Phase I Nested MGS to Flared PCB Transition Concept

The system tested herein was developed based on these design assumptions. Further recommendations on system implementation are provided following the results of the full-scale crash testing and evaluation of the barrier system.

2.2 PCB Foundation

In the past, F-shape PCBs have been recommended for installation on paved road surfaces. This recommendation was made for several reasons. First, a paved surface provides a consistent pad for development of the sliding friction, which provides resistance to barrier motions and develops longitudinal tension in the barrier system. Second, there has been concern that placement of the barriers on a soil foundation may allow the barriers to gouge into the soil when displaced laterally. This gouging could allow the barrier to rotate backward and increases the vehicle climb of the sloped barrier face and vehicle instability. Neither of these behaviors are desirable. For this study, placement of the PCB segments outside of the paved road surface would likely be unavoidable due to the flaring of the PCB behind the guardrail system, which is typically installed in a soil foundation.

In order to alleviate these concerns, a recommended foundation specification was developed for the PCBs located within the transition system evaluated in this research. Thus, a well-compacted, crushed limestone base was required beneath the PCBs. The compacted, crushed limestone material must meet American Association of State Highway and Transportation Officials (AASHTO) Grade B soil specifications and should be installed to a depth of 6 in. (152 mm). The compacted base should be placed underneath all PCB segments installed on a paved road surface, and its dimensions should extend 1 ft (305 mm) in front of the barrier segments, underneath the barrier segments, and a minimum lateral width of 4 ft (1,219 mm) behind the barrier segments, which is nearly 6 ft (1,829 mm) wide. The compacted base should have a 10H:1V or flatter cross slope.

2.3 Guardrail to PCB Connection Hardware

After the first phase of the research project, where the overall layout of the transition system was developed, two attachment details between the guardrail and the PCB segments remained to be designed. These connections included the attachment of the end of the W-beam guardrail to the PCB segments as well as attachment of the W-beam rail and blockouts to the overlapped PCBs. These connections were needed to fasten the overlapped barrier systems to one another while remaining safe, being relatively easy to install, and remaining largely reusable.

2.3.1 W-Beam End Shoe to PCB Connection Hardware

The attachment of the end of the W-beam guardrail to the PCBs was designed using a steel mounting bracket, horizontal bolts, and a W-beam end shoe, as shown in Figure 2. The basic design was similar to previously-developed hardware that connects thrie beam approach guardrail transitions to sloped concrete end buttresses or parapets.

For this system, the mounting bracket needed to accommodate both the vertical taper of the barrier and the 15H:1V flare of the PCB segments. In addition, the interference caused by steel loop bars at the exterior ends of the PCB required separate attachment of the bracket to the PCB and the W-beam end shoe to the bracket. Thus, the mounting bracket attached to the PCB with four 1-in. (25-mm) diameter through-bolts, while the W-beam end shoe only bolted to the steel mounting bracket using nuts welded to the inside of the bracket for the five ⅞-in. (22-mm) diameter bolts. The bracket was sloped on its backside to allow the W-beam to meet the vertical taper of the PCB and the flare of the PCB segments. The downstream end of the bracket was tapered down to be flush with the PCB to prevent snag during reverse-direction impacts. The designers did weigh options to mount the guardrail end shoe directly to the barrier, but the through-bolt interference noted above and the difficultly of twisting the rail to meet the horizontal and vertical tapers seemed unacceptable. Full details on the connection design can be found in Chapter 5.

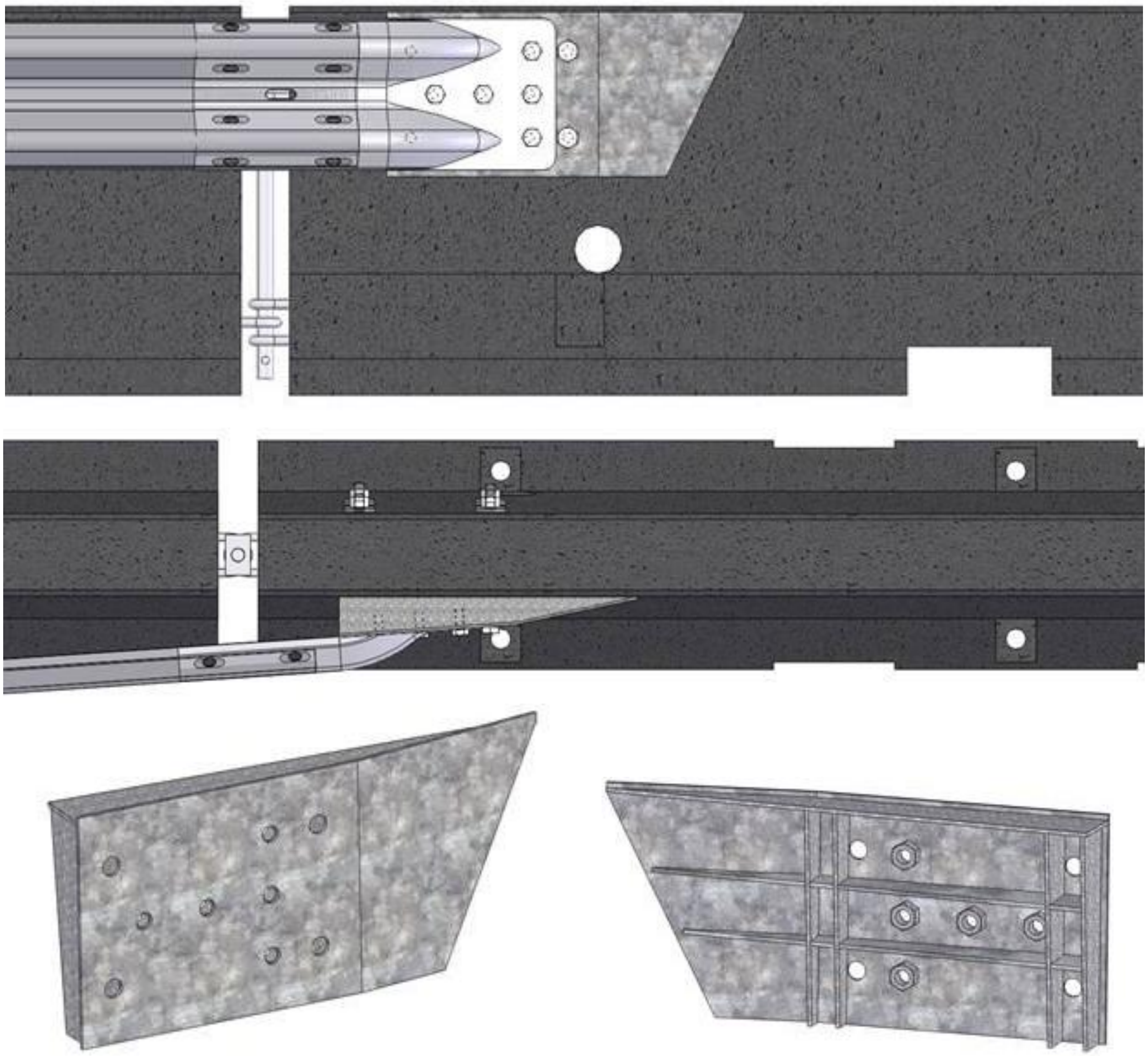


Figure 2. W-beam End Shoe Connection for MGS to PCB Transition

2.3.2 W-Beam Guardrail to PCB Connection Hardware

Installation of the guardrail on standard support posts in the overlapped barrier region was restricted due to interference with the PCB segments and concerns for limiting rotation of the support posts. Attachment of the remaining overlapped W-beam guardrail to the PCBs was critical in order to properly support the guardrail element and allow the two barrier systems to move and deflect simultaneously during vehicle impact. Thus, a guardrail blockout holder was developed to allow for attachment of the guardrail to the PCB segments using standard guardrail post bolts.

Several options were investigated for the blockout to PCB attachment. Issues with rebar interference and matching the vertical and horizontal tapers of the system were again a major consideration for the blockout attachment. It was also necessary to consider the attachment of the guardrail bolt from the blockout to the guardrail. Three basic options were developed to address these design considerations. All three options consisted of a steel mounting bracket that attached to the PCB using wedge-bolt mechanical anchors. Four mounting holes were included, but only two anchors were required. The additional holes allow for inadequate installation of the anchor or rebar interference. The brackets were designed to allow for bolting the blockout to both the guardrail and blockout holder using a guardrail bolt. Design variations were developed to provide options for matching the vertical and horizontal angles between the PCB and the guardrail as well as promote ease of fabrication and assembly.

The first concept considered was a double-taper blockout attachment, as shown in Figure 3. The double-taper blockout attachment consisted of welded steel plates that would be cut and assembled to transition between the vertical and horizontal angles of the PCB relative to the guardrail, which inherently made the geometry of the mounting bracket somewhat complex. The benefit of this configuration was that the attachment allowed for variable-depth, rectangular blockouts to be attached without flaring or angling the blockout to match the guardrail or PCB segments. The first blockout adjacent to the end shoe would consist only of the steel mount, while the other mounts would all require variable-depth blockouts. Drawbacks of this concept included its complex welded geometry and the fact that a mirrored design would be required for placement on the left- or right-hand side of the roadway.

The second option was based on a steel tube and base plate configuration, as shown in Figure 4. The steel tube and base plate attachment simplified the design of the mounting bracket by only accounting for the vertical flare of the PCB. The timber blockout was then cut on one face to match the 15H:1V flare of the PCB segments as shown below. This selection allowed for a simpler construction using a steel tube that is cut and welded to the face of a mounting plate. This design also allowed use on both sides of the roadway without the need for separate, mirrored components. However, blockouts would need to be cut to match the correct depth and 15H:1V angle. In addition, modified timber blocks were required at all four blockout mounts.

A final concept was considered that was similar to the steel tube and base plate concept but simplified to a single bent plate, as shown in Figure 5. The bent plate blockout attachment had all of the same advantages as the steel tube and base plate concept, but it was easier to construct from a single piece of steel and required no welding.

All of the blockout mounting bracket designs were presented to the project sponsor to seek feedback on their preferred design. The sponsor selected the bent plate blockout attachment based on its simpler construction. Full details on the bent plate blockout attachment are located in Chapter 5.

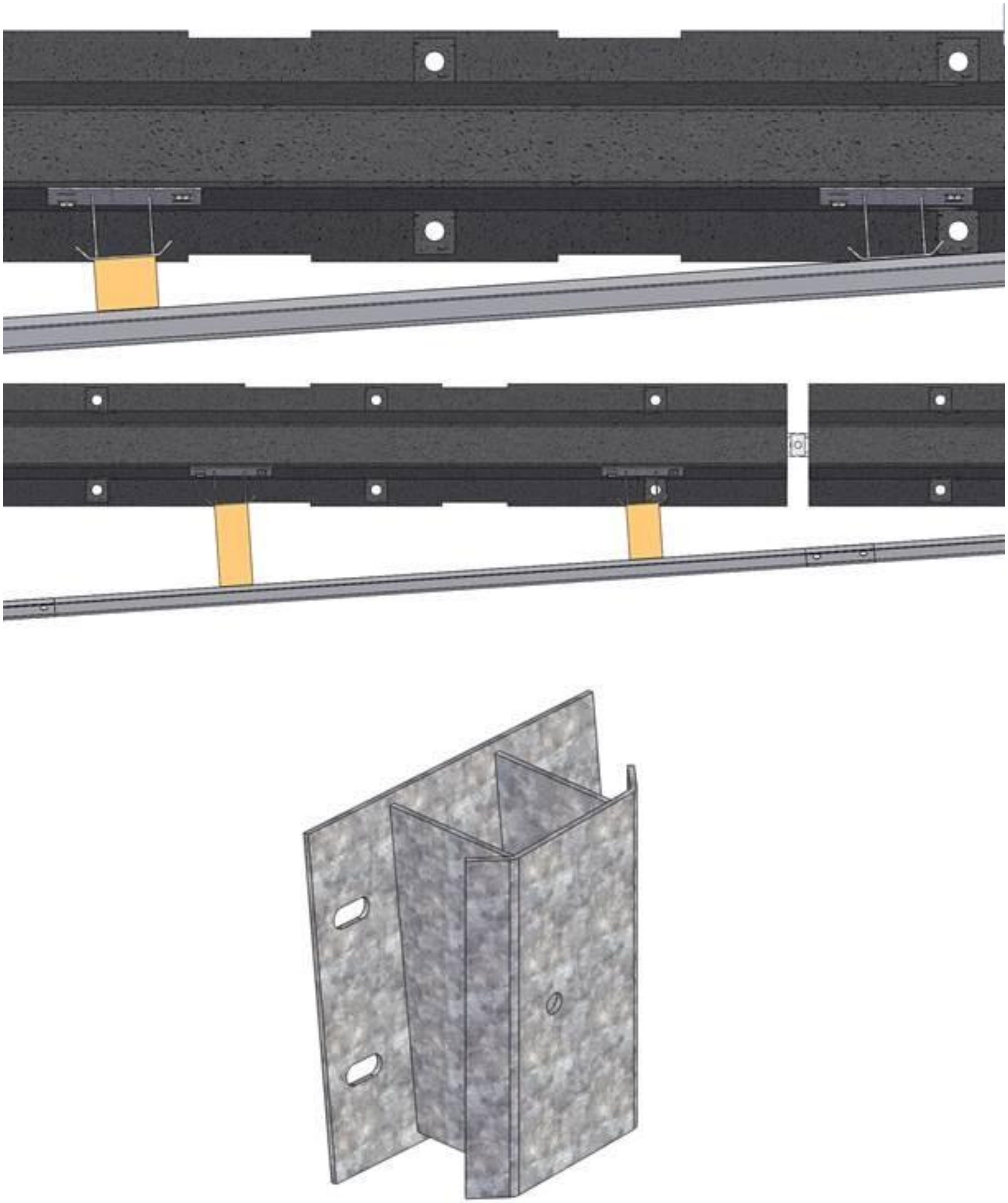


Figure 3. Double-Taper Blockout Attachment

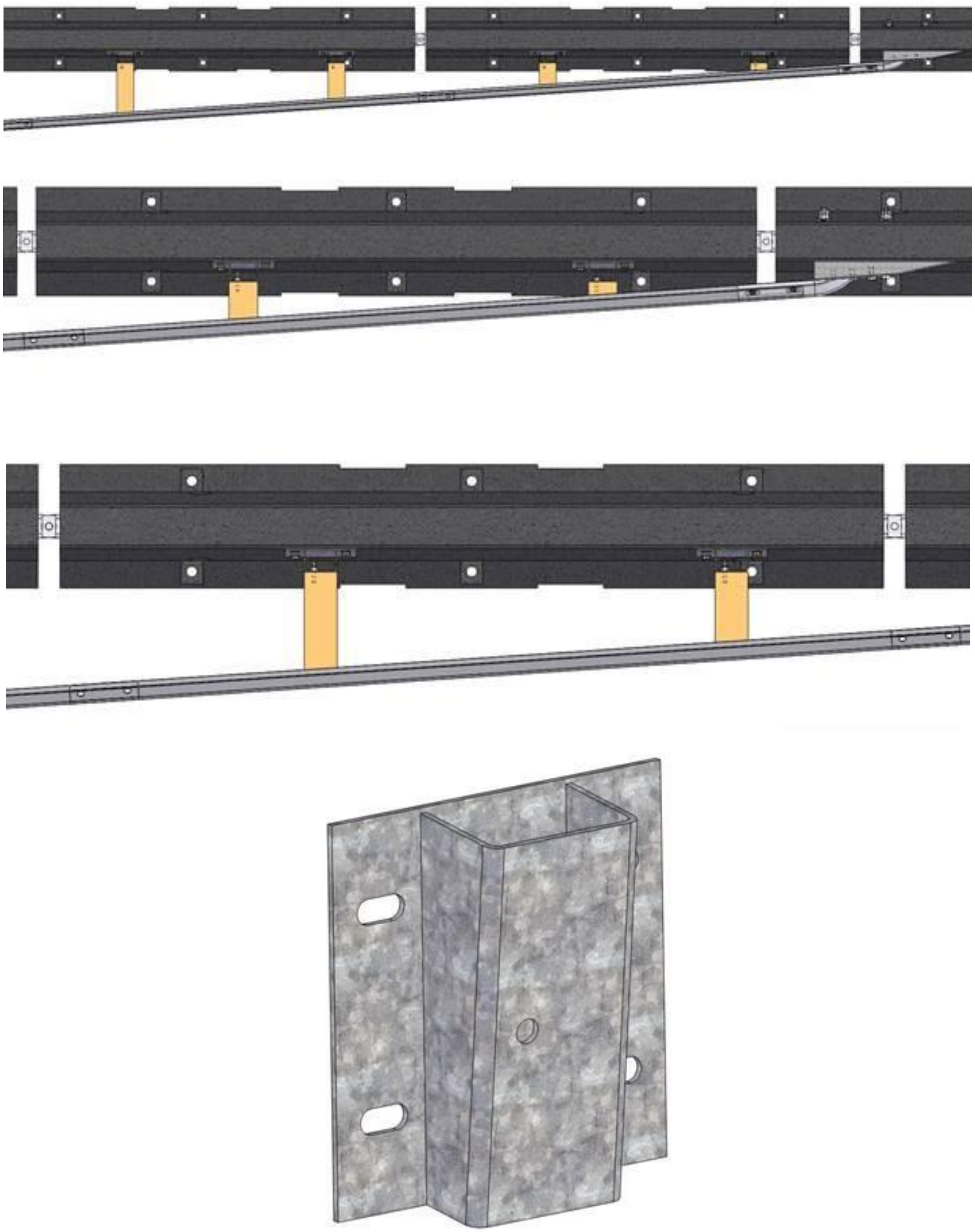


Figure 4. Steel Tube and Base Plate Blockout Attachment

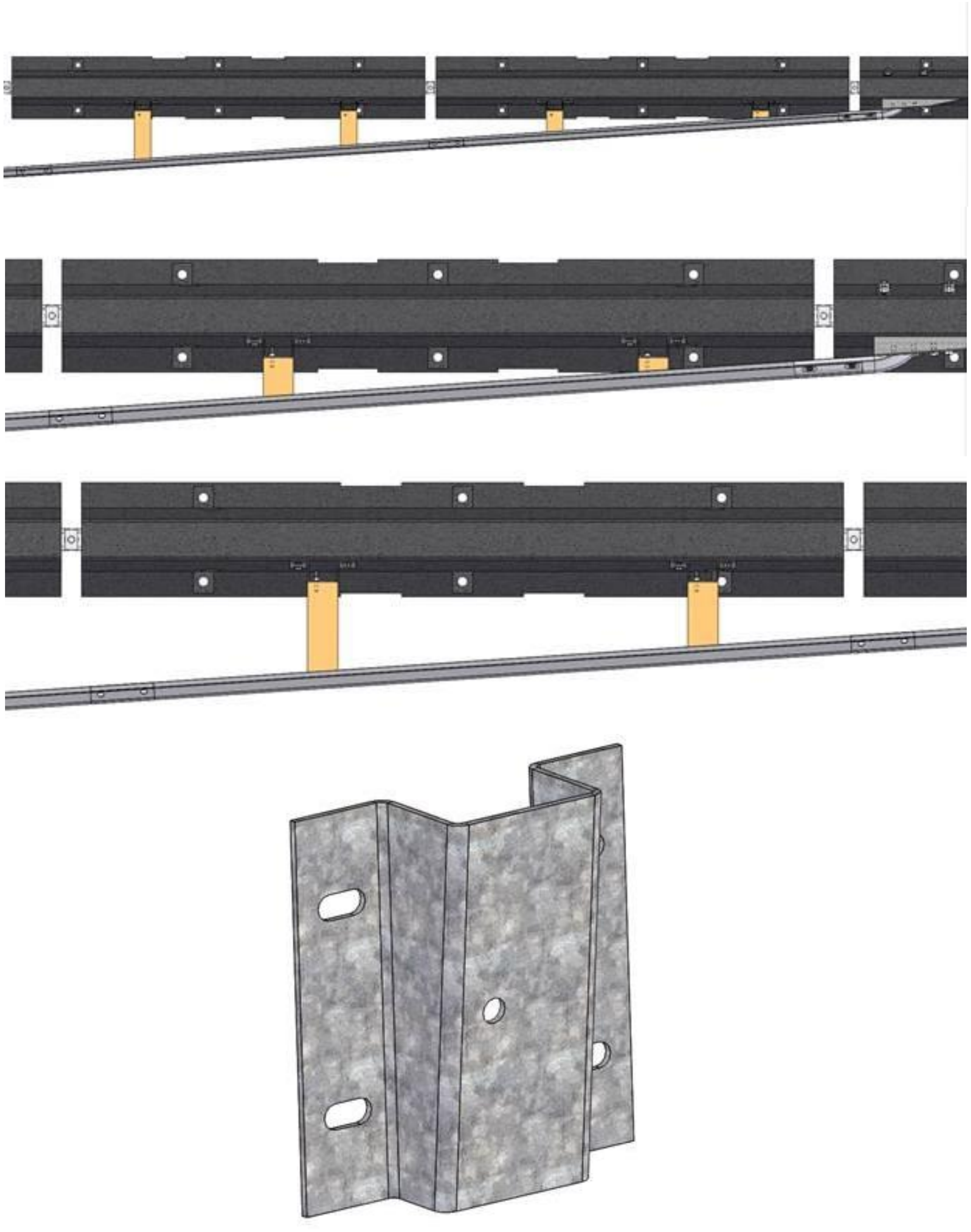


Figure 5. Bent Plate Blockout Attachment

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Longitudinal barrier transitions, such as transitions between W-beam guardrails and stiffer barriers, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH [1]. According to TL-3 of MASH, transitions must be subjected to two full-scale vehicle crash tests, as summarized in Table 1.

Table 1. MASH TL-3 Crash Test Conditions for Longitudinal Barriers - Transitions

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight, lb (kg)	Impact Conditions		Evaluation Criteria [1]
				Speed, mph (km/h)	Angle, deg.	
Longitudinal Barrier - Transition	3-20	1100C	2,425 (1,100)	62 (100)	25	A,D,F,H,I
	3-21	2270P	5,000 (2,270)	62 (100)	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2.

A review of the required MASH testing led to the recommendation for three crash tests to fully evaluate the transition. These tests would include MASH test designation nos. 3-20 and 3-21 which are tests to evaluate the transition with the 1100C small car and 2270P pickup truck vehicles. In addition, it was anticipated that a reverse-direction impact of test designation no. 3-21 with the 2270P vehicle would be required to evaluate the transition for installations that require two-way traffic adjacent to the barrier. MASH also requires that transitions be evaluated adjacent to their connection to rigid barriers and in the stiffness transition region. However, it was believed that the three tests noted above would be sufficient to evaluate the transition between two semi-rigid barrier systems where no significant stiffening exists.

Critical Impact Points (CIPs) were determined for each of the three full-scale vehicle crash tests. The Phase I research study contained a simulation effort that identified the CIPs for the 2270P tests in the full-scale crash testing program. Simulations were conducted throughout the length of the MGS to PCB transition in both the oncoming and reverse traffic directions. Critical parameters were monitored, including occupant risk measures, pocketing, vehicle snag, and vehicle stability. Full details of that analysis are provided in the Phase I report [2]. Based on the simulation results, the CIP for test no. 3-21 was determined to be the centerline of the fifth guardrail post upstream from the end-shoe attachment. For the reverse-direction test no. 3-21, the CIP was on the PCB system and 12 ft – 6 in. (3.81 m) upstream from the end-shoe attachment.

The Phase I effort did not consider the 1100C vehicle in the simulation of the MGS to PCB transition design. Additionally, the CIP selection charts in MASH are geared toward selection of CIP locations for beam and post systems (i.e., approach guardrail transitions) and were not relevant. However, engineering analysis and review of previous MASH testing with the 1100C vehicle was used to select a CIP for test no. 3-20. Potential transition CIPs for the 1100C vehicle should consider maximizing vehicle extension under the guardrail and simultaneous interactions with the PCB in order to promote wedging of the corner of the small car under the guardrail and between the two overlapped barrier systems. This type of behavior would tend to promote increased vehicle decelerations and instabilities as well as increased loading to the guardrail element. Previous testing of an MGS approach guardrail transition with a 4-in. (102-mm) tall, wedge-shaped curb has demonstrated rail rupture under combined loading when the front corner of the vehicle was wedged vertically between the curb and the guardrail [7]. Review of this approach guardrail transition and other full-scale crash tests indicated that an impact point 93¾ in. (2,381 mm) upstream from a splice tended to be critical. As such, the CIP selected for test no. 3-20 was located 93¾ in. (2,381 mm) upstream from the second guardrail splice away from the end shoe connection. The first guardrail splice in the system pertained to the connection of the W-beam end shoe to the nested W-beam guardrail. Location of the CIP at this point in the system would ensure that the vehicle critically loaded a splice while being engaged with both the W-beam guardrail and the PCB. Additionally, this CIP would allow for evaluation of the potential for vehicle interaction with the W-beam end shoe mounting bracket, if any existed.

It should be noted that the test matrix detailed herein represents the researchers' best engineering judgement with respect to the MASH safety requirements and their internal evaluation of critical tests necessary to evaluate the crashworthiness of the barrier system. However, the recent switch to new vehicle types as part of the implementation of the MASH criteria and the lack of experience and knowledge with certain barriers could result in unanticipated barrier performance. Thus, any tests within the evaluation matrix deemed non-critical may eventually need to be evaluated based on additional knowledge gained over time or revisions to the MASH criteria.

3.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the W-beam guardrail to concrete barrier transition system to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 2 and defined in greater detail in MASH [1]. The full-scale vehicle crash tests documented herein were conducted and reported in accordance with the procedures provided in MASH.

In addition to the standard occupant risk measures, the Post-Impact Head Deceleration (PHD), the Theoretical Head Impact Velocity (THIV), and the Acceleration Severity Index (ASI) were determined and reported. Additional discussion on PHD, THIV, and ASI is provided in MASH.

Table 2. MASH Evaluation Criteria for Longitudinal Barrier

<table>
<tr><td>Structural Adequacy</td><td colspan="4">A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="9">Occupant Risk</td><td colspan="4">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. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td></tr>
<tr><td colspan="4">F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td colspan="4">H. Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td rowspan="3"></td><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
<tr><td colspan="4">I. The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td rowspan="3"></td><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td></td><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

3.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH, foundation soil strength must be verified before any full-scale crash testing can occur. During the installation of a soil dependent system, additional W6x16 (W152x23.8) posts are installed near the impact region utilizing the same installation procedures as the system itself. Prior to full-scale testing, a dynamic impact test must be conducted to verify a minimum dynamic soil resistance of 7.5 kips (33.4 kN) at post deflections between 5 and 20 in. (127 and 508 mm) measured at a height of 25 in. (635 mm). If dynamic testing near the system is not desired, MASH permits a static test to be conducted instead and compared against the results of a previously established baseline test. In this situation, the soil must provide a resistance of at least 90% of the static baseline test at deflections of 5, 10, and 15 in. (127, 254, and 381 mm). Further details can be found in Appendix B of MASH.

4 TEST CONDITIONS

4.1 Test Facility

The testing facility is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 5 miles (8.0 km) northwest of the University of Nebraska-Lincoln.

4.2 Vehicle Tow and Guidance System

A reverse-direction, cable tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the barrier system. A digital speedometer on the tow vehicle increased the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch [8] was used to steer the test vehicle. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

4.3 Test Vehicles

For test no. MGSPCB-1, a 2008 Dodge Ram 1500 was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 4,977 lb (2,258 kg), 4,914 lb (2,229 kg), and 5,079 lb (2,304 kg), respectively. The test vehicle is shown in Figure 6, and vehicle dimensions are shown in Figure 7.

For test no. MGSPCB-2, a 2008 Kia Rio was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,434 lb (1,104 kg), 2,436 lb (1,105 kg), and 2,601 lb (1,180 kg), respectively. The test vehicle is shown in Figure 8, and vehicle dimensions are shown in Figure 9.

For test no. MGSPCB-3, a 2008 Dodge Ram 1500 was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,017 lb (2,276 kg), 5,012 lb (2,273 kg), and 5,177 lb (2,348 kg), respectively. The test vehicle is shown in Figure 10, and vehicle dimensions are shown in Figure 11.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [9] was used to determine the vertical component of the c.g. for the 2270P vehicle. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The vertical component of the c.g. for the 1100C vehicle was determined utilizing a procedure published by SAE [10].

The location of the final c.g. for test no. MGSPCB-1 is shown in Figures 7 and 12. The location of the final c.g. for test no. MGSPCB-2 is shown in Figures 9 and 13. The location of the final c.g. for test no. MGSPCB-3 is shown in Figures 11 and 14. Data used to calculate the location of the c.g. and ballast information are shown in Appendix B.

Square, black- and white-checkered targets were placed on the vehicles for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figures 12 through 14. Round, checkered targets were placed on the c.g. on the left-side door, the right-side door, and the roof of the each vehicle.

The front wheels of the each test vehicle were aligned to vehicle standards except the toe-in value was adjusted to zero so that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted under the vehicle's right-side windshield wiper and was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed digital videos. A remote-controlled brake system was installed in each test vehicle so the vehicles could be brought safely to a stop after the test.

4.4 Simulated Occupant

For test nos. MGSPCB-1 through MGSPCB-3, A Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the right-front seat of the test vehicle with the seat belt fastened. The dummy, which had a final weight of 165 lb (75 kg), was represented by model no. 572, serial no. 451, and was manufactured by Android Systems of Carson, California. As recommended by MASH, the dummy was not included in calculating the c.g. location.

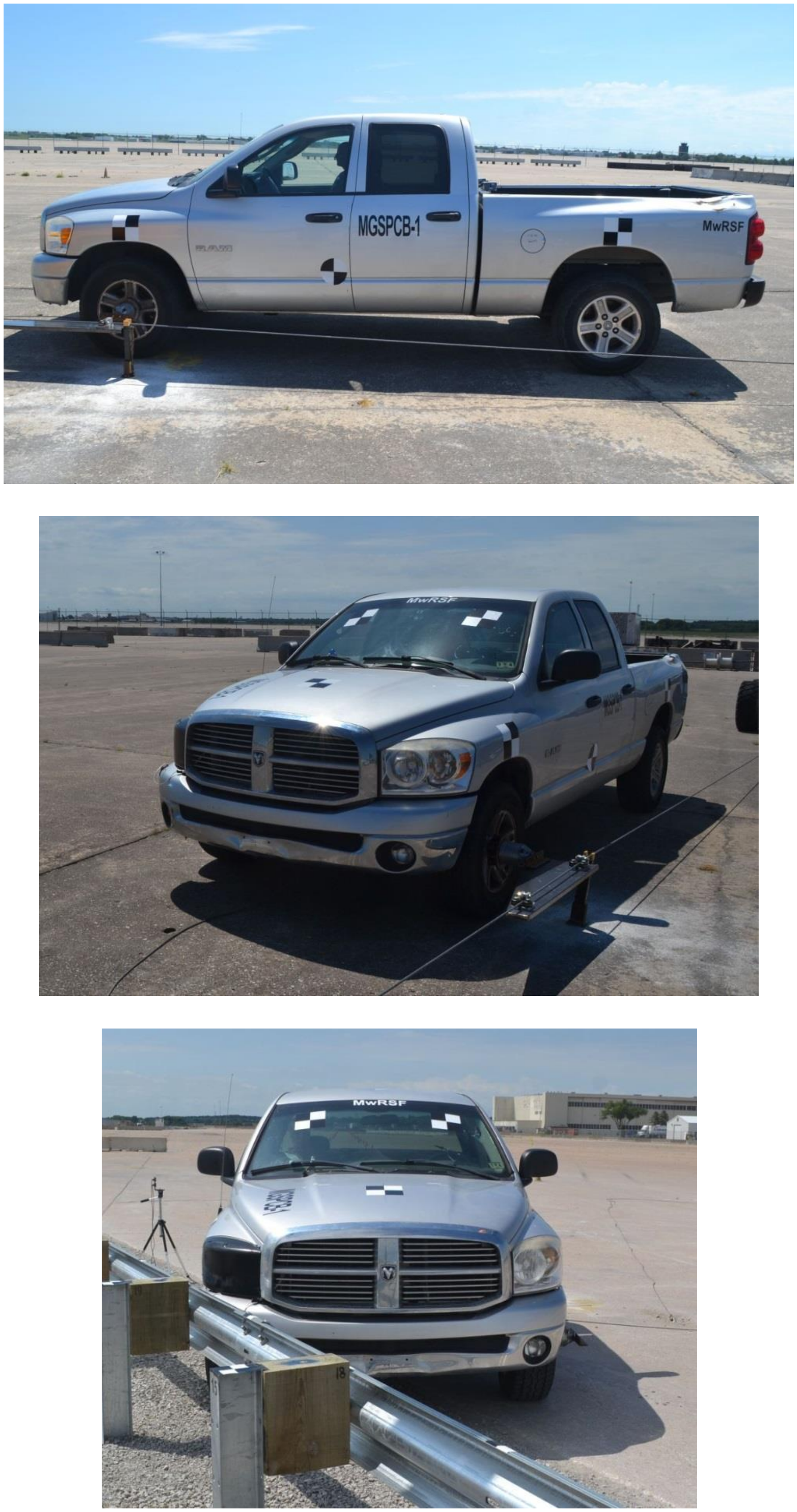
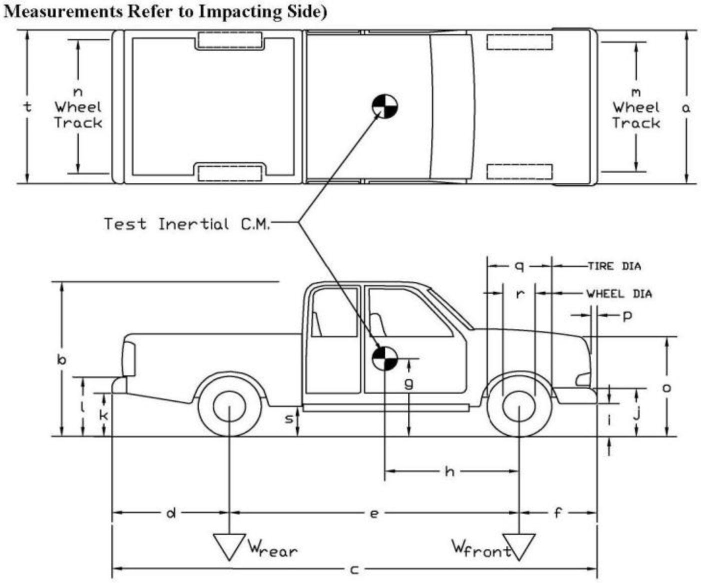


Figure 6. Test Vehicle, Test No. MGSPCB-1

Date:	7/20/2015	Test Number:	MGSPCB-1	Model:	RAM 1500
Make:	Dodge	Vehicle I.D.#:	1d7ha18n58s568126		
Tire Size:	LT265/70R17	Year:	2008	Odometer:	183761

Tire Inflation Pressure: 35

*(All Measurements Refer to Impacting Side)



Vehicle Geometry -- in. (mm)

a	78 1/2	(1994)	b	74 7/8	(1902)
c	227 1/2	(5779)	d	47	(1194)
e	140 1/4	(3562)	f	40 1/4	(1022)
g	28 1/2	(724)	h	60 1/2	(1538)
i	15	(381)	j	26	(660)
k	20 1/2	(521)	l	29	(737)
m	67 1/4	(1708)	n	67 1/2	(1715)
o	45	(1143)	p	2 1/2	(64)
q	31 1/4	(794)	r	18 1/2	(470)
s	15	(381)	t	75 1/4	(1911)

Wheel Center Height Front	14 5/8	(371)
Wheel Center Height Rear	14 5/8	(371)
Wheel Well Clearance (F)	34 1/2	(876)
Wheel Well Clearance (R)	37 3/4	(959)
Frame Height (F)	18 1/4	(464)
Frame Height (R)	25	(635)
Engine Type	Gasoline	
Engine Size	4.7L V8	
Transmission Type:	Automatic	
Drive Type:	RWD	

Mass Distribution lb (kg)

Gross Static	LF	1453	(659)	RF	1445	(655)
	LR	1081	(490)	RR	1100	(499)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2829 (1283)	2793 (1267)	2898 (1315)
W-rear	2148 (974)	2121 (962)	2181 (989)
W-total	4977 (2258)	4914 (2229)	5079 (2304)

GVWR Ratings

Front	3700 lb
Rear	3900 lb
Total	6700 lb

Dummy Data

Type:	Hybrid II
Mass:	165 lb
Seat Position:	Passenger

Note any damage prior to test: Driver side box side top crushed.

Figure 7. Vehicle Dimensions, Test No. MGSPCB-1

Figure 8. Test Vehicle, Test No. MGSPCB-2

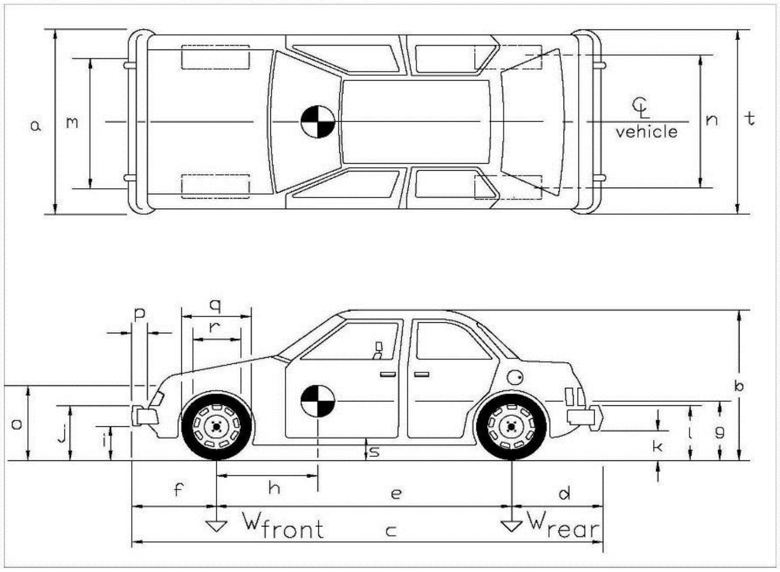
Date: 7/30/2015 | Test Number: MGSPCB-2 | Model: Rio

Make: Kia | Vehicle I.D.#: knadc123586430239

Tire Size: 185/65R14 | Year: 2008 | Odometer: 168978

Tire Inflation Pressure: 32

*(All Measurements Refer to Impacting Side)



Vehicle Geometry -- in. (mm)

a	61 3/4	(1568)	b	57 1/2	(1461)
c	167 1/2	(4255)	d	36 3/4	(933)
e	98 5/8	(2505)	f	32 1/8	(816)
g	22 3/8	(570)	h	36	(915)
i	8 3/4	(222)	j	22	(559)
k	12 1/2	(318)	l	25	(635)
m	56 3/8	(1432)	n	57 3/8	(1457)
o	28 1/2	(724)	p	2	(51)
q	23 3/8	(594)	r	15 3/8	(391)
s	11 3/4	(298)	t	63 1/4	(1607)

Wheel Center Height Front	10 5/8	(270)
Wheel Center Height Rear	11 1/8	(283)
Wheel Well Clearance (F)	25 1/8	(638)
Wheel Well Clearance (R)	25	(635)
Frame Height (F)	6 1/4	(159)
Frame Height (R)	15 3/4	(400)
Engine Type	Gasoline	
Engine Size	4 Cyl 1.6L	
Transmition Type:	Automatic	
Drive Axle:	FWD	

Mass Distribution lb (kg)

Gross Static				
	LF	804 (365)	RF	829 (376)
	LR	489 (222)	RR	479 (217)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	1571 (713)	1546 (701)	1633 (741)
W-rear	863 (391)	890 (404)	968 (439)
W-total	2434 (1104)	2436 (1105)	2601 (1180)

GVWR Ratings

Front	1918 lb
Rear	1874 lb
Total	3638 lb

Dummy Data

Type: Hybrid II

Mass: 165 lb

Seat Position: Passenger

Note any damage prior to test: Missing front air dam trim section.

Figure 9. Vehicle Dimensions, Test No. MGSPCB-2

Figure 10. Test Vehicle, Test No. MGSPCB-3

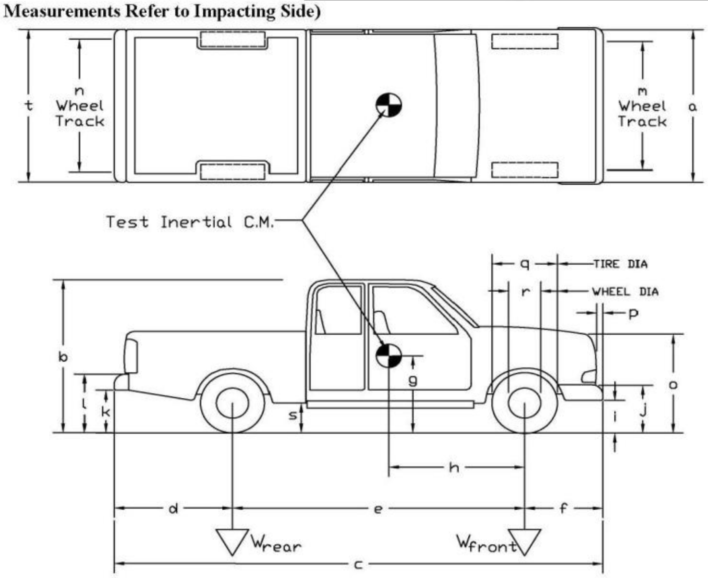
Date: 8/25/2015 **Test Number:** MGSPCB-3 **Model:** RAM 1500

Make: Dodge **Vehicle I.D.#:** 1d7ha18n88s553166

Tire Size: 265/70R17 **Year:** 2008 **Odometer:** 108813

Tire Inflation Pressure: 35

***(All Measurements Refer to Impacting Side)**



Vehicle Geometry -- in. (mm)

a	78	(1981)	b	75	(1905)
c	227 1/2	(5779)	d	47	(1194)
e	140 1/2	(3569)	f	40	(1016)
g	28 3/4	(729)	h	62 3/8	(1586)
i	15 1/2	(394)	j	26 3/4	(679)
k	21 1/2	(546)	l	29 3/4	(756)
m	67 3/4	(1721)	n	67 1/2	(1715)
o	45 1/8	(1146)	p	3	(76)
q	31	(787)	r	18 1/2	(470)
s	15 5/8	(397)	t	75 1/4	(1911)

Wheel Center Height Front	15	(381)
Wheel Center Height Rear	15 1/8	(384)
Wheel Well Clearance (F)	35 3/8	(899)
Wheel Well Clearance (R)	38 7/8	(987)
Frame Height (F)	18 1/4	(464)
Frame Height (R)	26	(660)
Engine Type	Gasoline	
Engine Size	4.7L V8	
Transmission Type:	Automatic	
Drive Type:	RWD	

Mass Distribution lb (kg)

Gross Static	LF	1471 (667)	RF	1419 (644)	
	LR	1133 (514)	RR	1154 (523)	

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2839 (1288)	2785 (1263)	2890 (1311)
W-rear	2178 (988)	2227 (1010)	2287 (1037)
W-total	5017 (2276)	5012 (2273)	5177 (2348)

GVWR Ratings

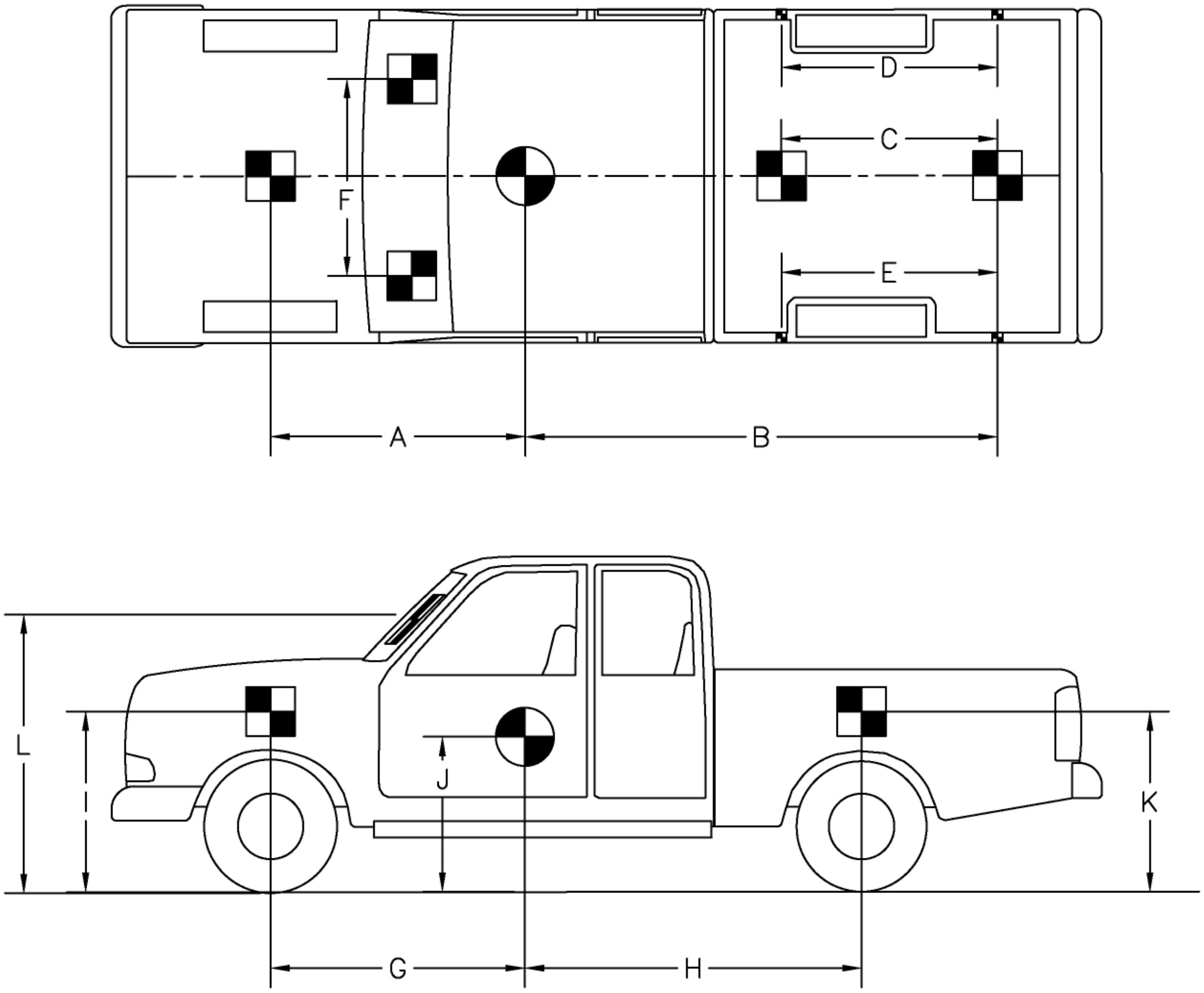
Front	3700
Rear	3900
Total	6700

Dummy Data

Type:	Hybrid II
Mass:	165 lb
Seat Position:	Passenger

Note any damage prior to test: Dents in the rear bumper.

Figure 11. Vehicle Dimensions, Test No. MGSPCB-3

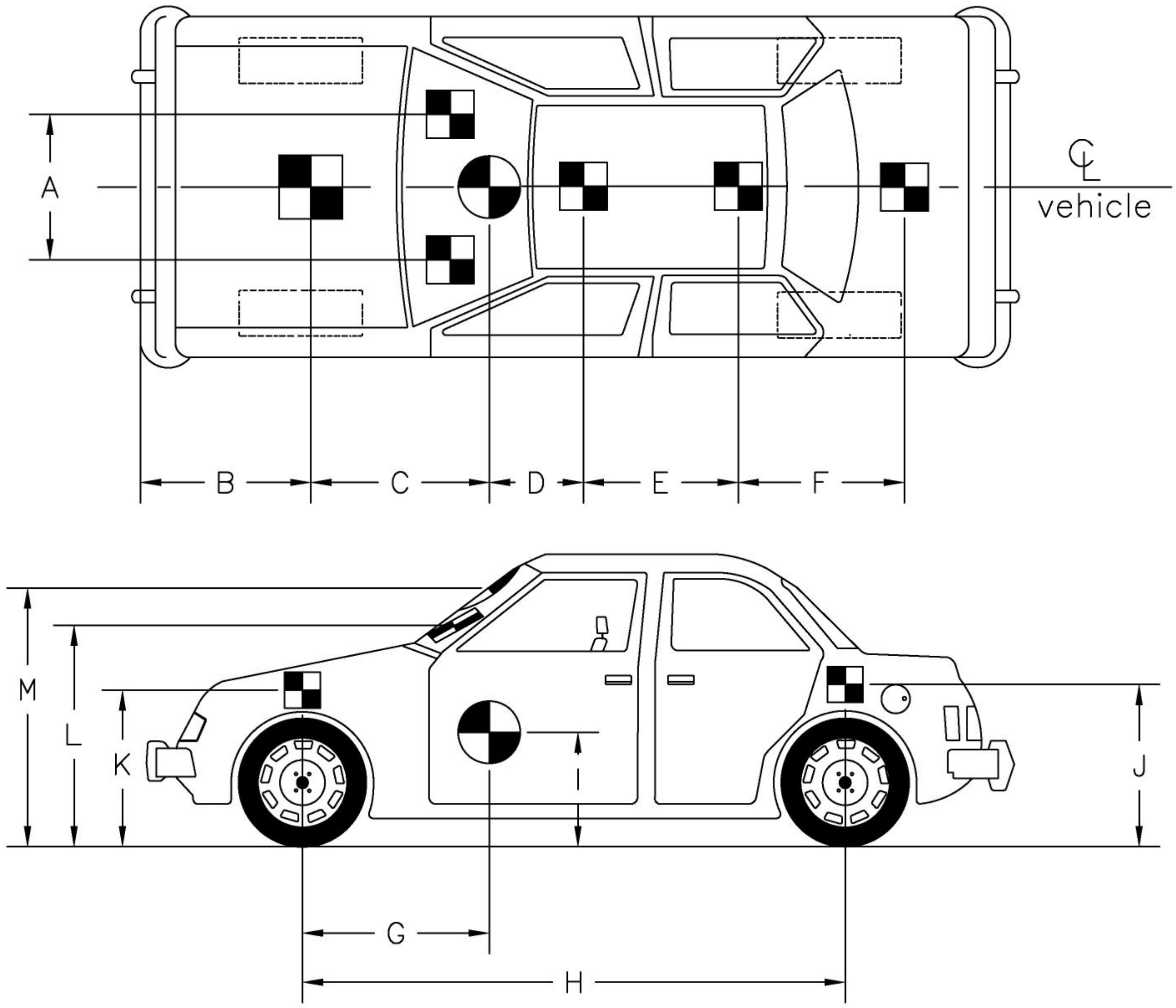


TEST #: MGSPCB-1

TARGET GEOMETRY-- in. (mm)

A	**74 7/8**	**(1902)**	**E**	**63 7/8**	**(1622)**	**I**	**38 3/4**	**(984)**
B	**103 1/2**	**(2629)**	**F**	**35 3/4**	**(908)**	**J**	**28 1/2**	**(724)**
C	**44**	**(1118)**	**G**	**60 1/2**	**(1537)**	**K**	**42**	**(1067)**
D	**64**	**(1626)**	**H**	**79 3/4**	**(2026)**	**L**	**65 1/4**	**(1657)**

Figure 12. Target Geometry, Test No. MGSPCB-1

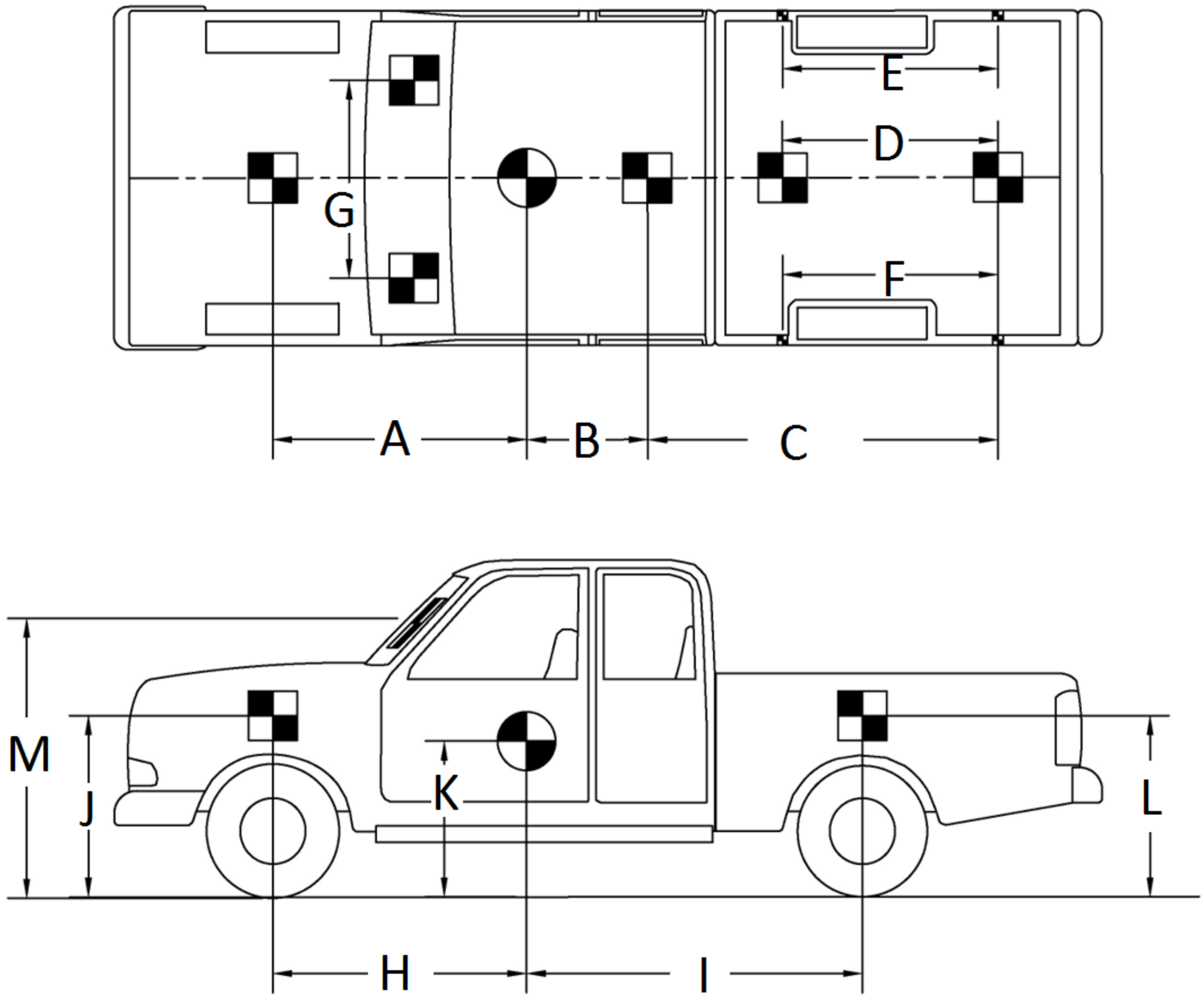


TEST #: MGSPCB-2 Vehicle: Kia Rio

TARGET GEOMETRY-- in. (mm)

A	**24 1/8**	**(613)**	**E**	**43 3/4**	**(1111)**	**I**	**22 1/4**	**(565)**
B	**21 1/4**	**(540)**	**F**	**33 1/2**	**(851)**	**J**	**29**	**(737)**
C	**46**	**(1168)**	**G**	**36**	**(914)**	**K**	**29 1/4**	**(743)**
D	**7 3/4**	**(197)**	**H**	**98 3/4**	**(2508)**	**L**	**48 1/2**	**(1232)**
						M	**52**	**(1321)**

Figure 13. Target Geometry, Test No. MGSPCB-2



TEST #: MGSPCB-3

TARGET GEOMETRY-- in. (mm)

A	78 1/2	(1994)	F	64	(1626)	K	28 3/4	(730)
B	31 3/4	(806)	G	35 1/8	(892)	L	43	(1092)
C	75 1/2	(1918)	H	62 1/2	(1588)	M	64 1/4	(1632)
D	48 1/4	(1226)	I	78 1/4	(1988)			
E	64	(1626)	J	39 7/8	(1013)			

Figure 14. Target Geometry, Test No. MGSPCB-3

4.5 Data Acquisition Systems

4.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions for test nos. MGSPCB-1 through MGSPCB-3. All of the accelerometers were mounted near the center of gravity of the test vehicles. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [11].

The two systems used in all three tests, the SLICE-1 and SLICE-2 units, were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The acceleration sensors were mounted inside the bodies of custom built SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessor. Each SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.5.2 Rate Transducers

Two identical angle rate sensor systems mounted inside the bodies of the SLICE-1 and SLICE-2 event data recorders were used to measure the rates of rotation of the test vehicles in test nos. MGSPCB-1 through MGSPCB-3. Each SLICE MICRO Triax ARS had a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) and recorded data at 10,000 Hz to the onboard microprocessors. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

4.5.3 Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the test vehicles before impact. Five retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the side of each vehicle. When the emitted beam of light was reflected by the targets and returned to the Emitter/Receiver, a signal was sent to the data acquisition computer, recording at 10,000 Hz, as well as the external LED box activating the LED flashes. The speed was then calculated using the spacing between the retroreflective targets and the time between the signals. LED lights and high-speed digital video analysis are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

4.5.4 Load Cells and String Potentiometers

Load cells were installed on the upstream anchor for test no. MGSPCB-1. The load cells were Transducer Techniques model no. TLL-50K with a load range up to 50 kips (222 kN). String potentiometers were also attached to the system at the upstream anchor. The string potentiometers were Unimeasure model no. PA-50-70124 with a displacement range up to 50 in. (127 cm). During testing, output voltage signals were sent from the transducers to a National Instruments PCI-6071E data acquisition board, acquired with LabView software, and stored on a personal computer at a sample rate of 10,000 Hz. The positioning and set up of the transducers are shown in Figure 15.

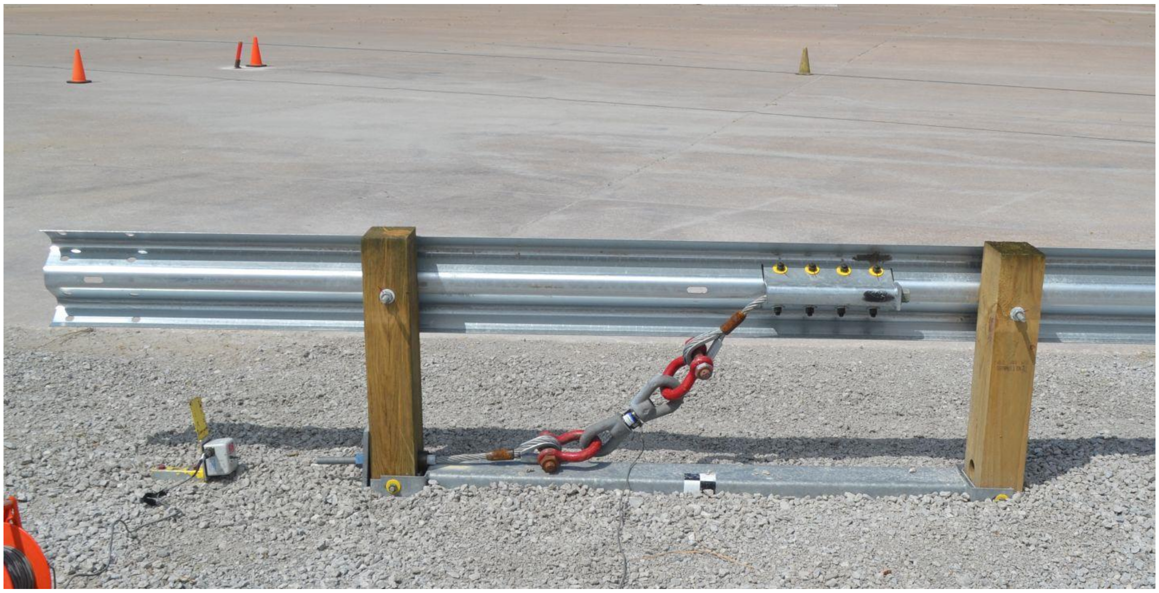
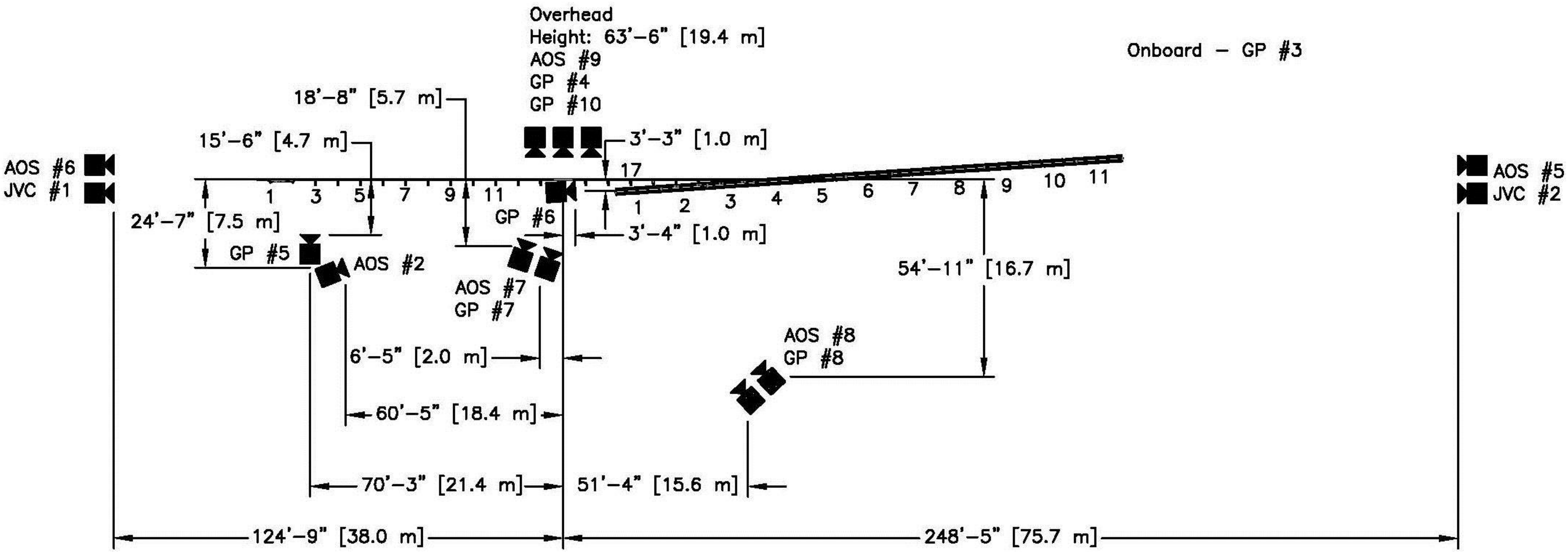


Figure 15. Location of Load Cells and String Potentiometers

4.5.5 Digital Photography

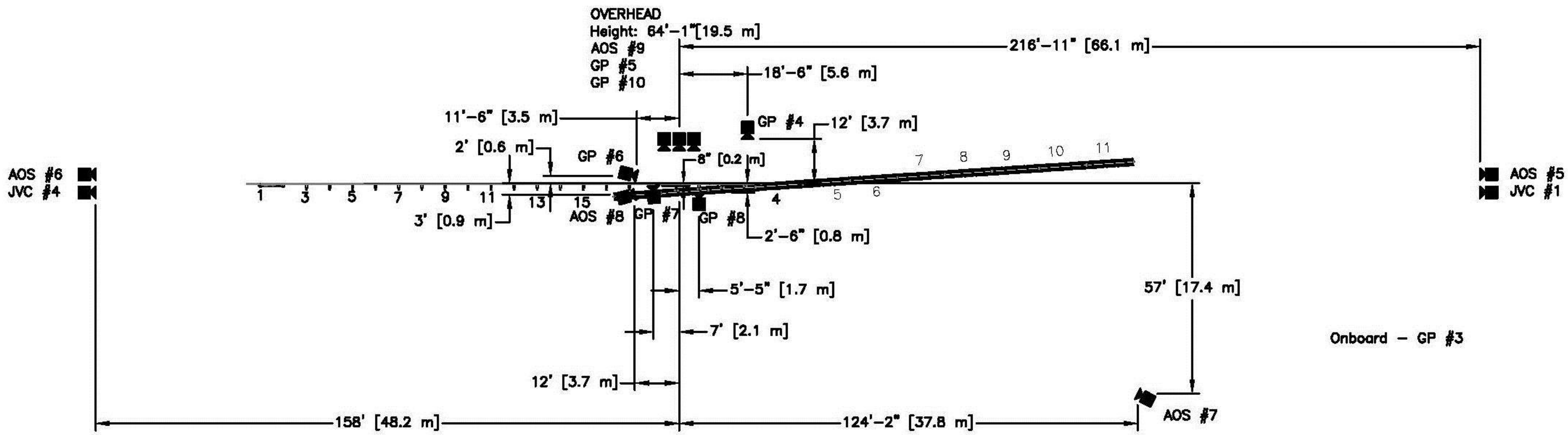
Six AOS high-speed digital video cameras, seven GoPro digital video cameras, and four JVC digital video cameras were utilized to film test no. MGSPCB-1. Five AOS high-speed digital video cameras, seven GoPro digital video cameras, and four JVC digital video cameras were utilized to film test no. MGSPCB-2. Five AOS high-speed digital video cameras, eight GoPro digital video cameras, and three JVC digital video cameras were utilized to film test no. MGSPCB-3. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system for each test are shown in Figures 16 through 18.

The high-speed videos were analyzed using ImageExpress MotionPlus and RedLake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos. A Nikon D3200 digital still camera was also used to document pre- and post-test conditions for all tests.



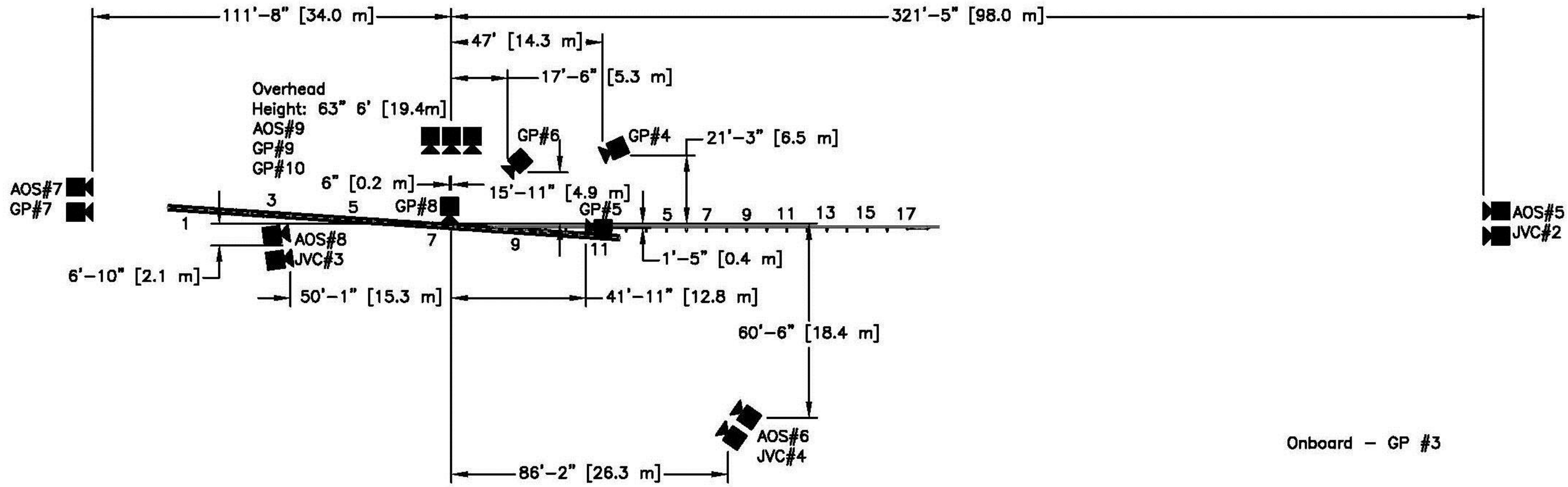
No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-2	AOS Vitcam CTM	500	Cosmicar 50 mm Fixed	-
AOS-5	AOS X-PRI Gigabit	500	Vivitar 135 mm Fixed	-
AOS-6	AOS X-PRI Gigabit	500	Sigma 28-70 DG	50
AOS-7	AOS X-PRI Gigabit	500	Nikon 20 mm Fixed	-
AOS-8	AOS S-VIT 1531	500	Sigma 24-70	28
AOS-9	AOS TRI-VIT 2236	1000	Kowa 12 mm Fixed	-
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	240		
GP-8	GoPro Hero 4	240		
GP-10	GoPro Hero 4	240		
JVC-1	JVC – GZ-MC500 (Everio)	29.97		
JVC-2	JVC – GZ-MG27u (Everio)	29.97		

Figure 16. Camera Locations, Speeds, and Lens Settings, Test No. MGSPCB-1



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-5	AOS X-PRI Gigabit	500	Vivitar 135 mm Fixed	-
AOS-6	AOS X-PRI Gigabit	500	Sigma 24-70 DG	70
AOS-7	AOS X-PRI Gigabit	500	Canon 17-102	50
AOS-8	AOS S-VIT 1531	1000	Sigma 24-70	70
AOS-9	AOS TRI-VIT 2236	500	Kowa 12 mm Fixed	-
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	240		
GP-8	GoPro Hero 4	120		
GP-10	GoPro Hero 4	240		
JVC-1	JVC – GZ-MC500 (Everio)	29.97		
JVC-4	JVC – GZ-MG27u (Everio)	29.97		

Figure 17. Camera Locations, Speeds, and Lens Settings, Test No. MGSPCB-2



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-5	AOS X-PRI Gigabit	500	Vivitar 135 mm Fixed	-
AOS-6	AOS X-PRI Gigabit	500	Sigma 28-70 DG	28
AOS-7	AOS X-PRI Gigabit	500	Fujinon 50 mm Fixed	-
AOS-8	AOS S-VIT 1531	500	Sigma 28-70	70
AOS-9	AOS TRI-VIT 2236	500	Kowa 12 mm Fixed	-
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	240		
GP-8	GoPro Hero 4	240		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	240		
JVC-2	JVC – GZ-MG27u (Everio)	29.97		
JVC-3	JVC – GZ-MG27u (Everio)	29.97		
JVC-4	JVC – GZ-MG27u (Everio)	29.97		

Figure 18. Camera Locations, Speeds, and Lens Settings, Test No. MGSPCB-3

5 DESIGN DETAILS, TEST NO. MGSPCB-1

The test installation was comprised of 138.5 ft (42.2 m) of MGS with an end anchorage, a stiffness transition, and 140.8 ft (42.9 m) of F-shaped PCB at a 15H:1V flare, as shown in Figures 19 through 54. The guardrail transition began 10 in. (254 mm) downstream from the upstream end of the fourth PCB, with three full PCB behind the guardrail system. Photographs of the test installation are shown in Figures 55 through 58. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The system was constructed with sixteen steel posts spaced at 75 in. (1,905 mm) on center. Post nos. 3 through 18 were standard 72-in. (1,829-mm) steel posts with a soil embedment depth of 40 in. (1,016 mm). A 6-in. wide x 12-in. deep x 14¼-in. long (152-mm x 305-mm x 362-mm) blockout was used to block the rail away from the front face of each steel post. A 16D double head nail was also driven through a hole in the front flange of the post into the top of the blockout assembly to prevent rotation of the blockout.

Post nos. 1 and 2 were breakaway cable terminal (BCT) timber posts measuring 5½ in. wide x 7½ in. deep x 46 in. long (140 mm x 191 mm x 1,168 mm) and were placed in 6-ft (1.8-m) long foundation tubes, as shown in Figure 23. The upstream and downstream ends of the guardrail installation were configured with a trailing-end anchorage system. The guardrail anchorage system was utilized to simulate the strength of other crashworthy end terminals. The anchorage system consisted of timber posts, foundation tubes, anchor cables, bearing plates, rail brackets, and channel struts, which closely resembled the hardware used in the Modified BCT system and is now part of a crashworthy, downstream trailing end terminal [12-15]. The 12-gauge (2.66-mm thick) W-beam was mounted at a height of 31 in. (787 mm) and nested from the midspan between post nos. 12 and 13 to the W-beam end shoe.

Eleven 150-in. (3,810-mm) long F-shape PCBs with a target 5,000 psi (34.5 MPa) 28-day compressive strength were connected to the MGS. The concrete barriers were 22½ in. (572 mm) wide at the base and 8 in. (203 mm) wide at the top. PCB details are shown in Figures 46 and 47. Each of the barrier segments were connected by 1¼ in. (32 mm) diameter A36 steel connection pins and connector plates placed between ¾-in. (19-mm) diameter reinforcing bar loops extending from the end of the barrier sections. The connection loop bar material was A709 Grade 70 or A706 Grade 60 steel. The connection pin details are shown in Figure 49. Mounting plates and blockouts were attached to concrete barriers no. 2 and 3. All PCB segments were set on top of 6-in. (152-mm) deep compacted crushed limestone meeting AASHTO Grade B soil specifications or on the concrete tarmac at the MwRSF outdoor test facility.

The overlapped portion of the transition from MGS to PCB incorporated four blockouts between the guardrail and concrete barriers. The blockouts varied in size depending on the distance between the guardrail and PCB and were mounted on blockout mounting plates. The mounting plates were 13 in. (330 mm) wide and $13^{5}/_{16}$ in. (338 mm) tall. The depth of the plate at the top was 4¼ in. (107 mm) and 2⅞ (73 mm) at the bottom. Although the mounting plate has four holes, it was secured to the PCB by two ¾-in. diameter x 6-in. long (M20x152) Power Wedge Bolts. On the downstream end of the mounting plate, the plate was secured by the upper hole, and on the upstream side by the lower hole. Transition blockout details are shown in Figure 42, and mounting plate details are shown in Figures 34 through 37.

The guardrail was connected and transitioned to the concrete barrier at an angle of 3.8 degrees by a steel mounting bracket and W-beam end shoe. The W-beam end shoe mounting bracket was connected to the impact side of concrete barrier no. 4 with four 1-in. (25-mm) diameter A325 Grade A bolts through 1⅛-in. (29-mm) diameter bolt holes, which were measured and drilled in the field. The W-beam end shoe mounting bracket was $13^9/_{16}$ in. (344 mm) tall and $23^3/_{16}$ in. (589 mm) wide along the bottom edge. The downstream end was angled 8.0 degrees to be flush against the concrete barrier. A W-beam end shoe was attached to the front side of the mounting bracket with five ⅞-in. (22-mm) diameter A325 bolts secured by A563 nuts welded to the interior of the mounting bracket.

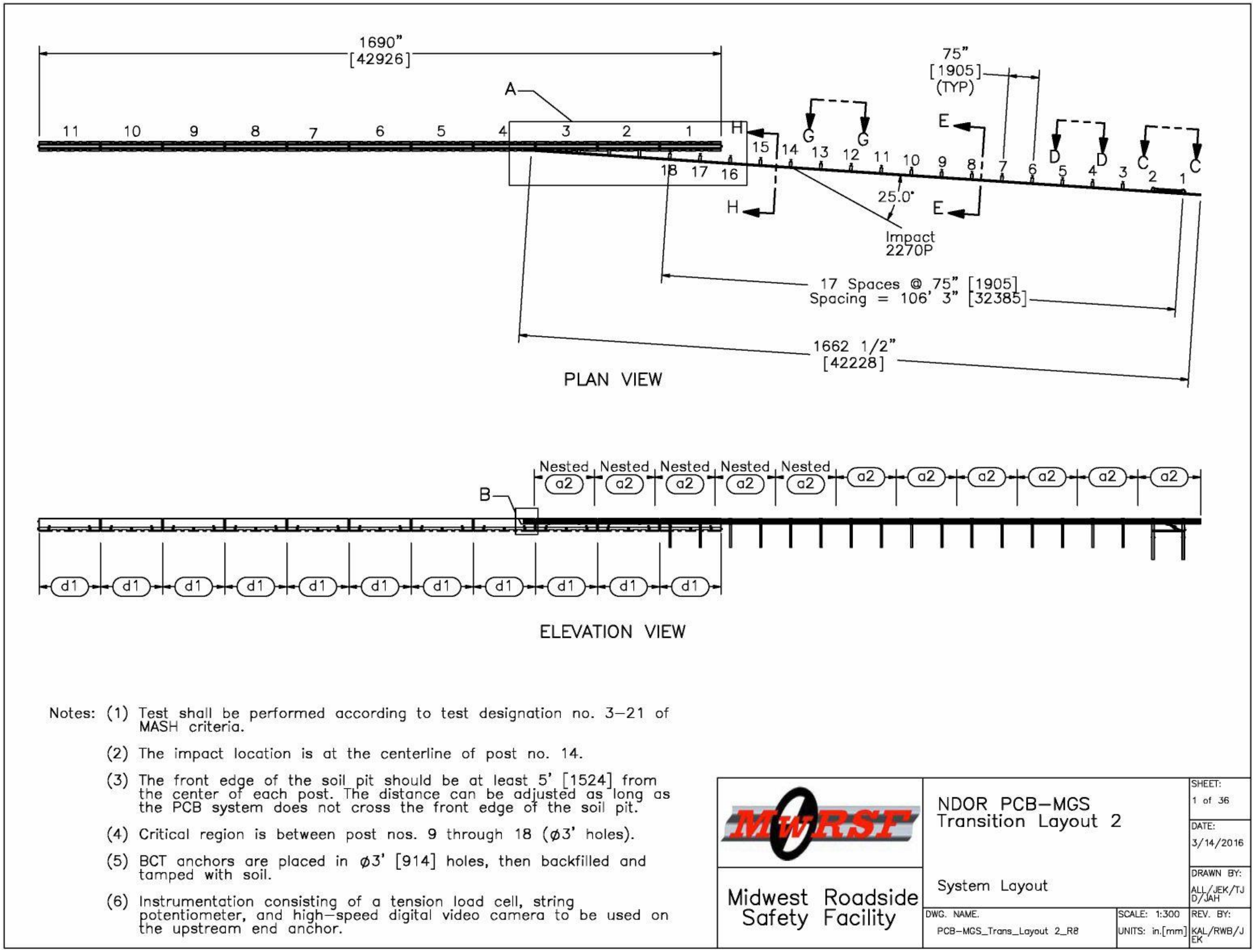
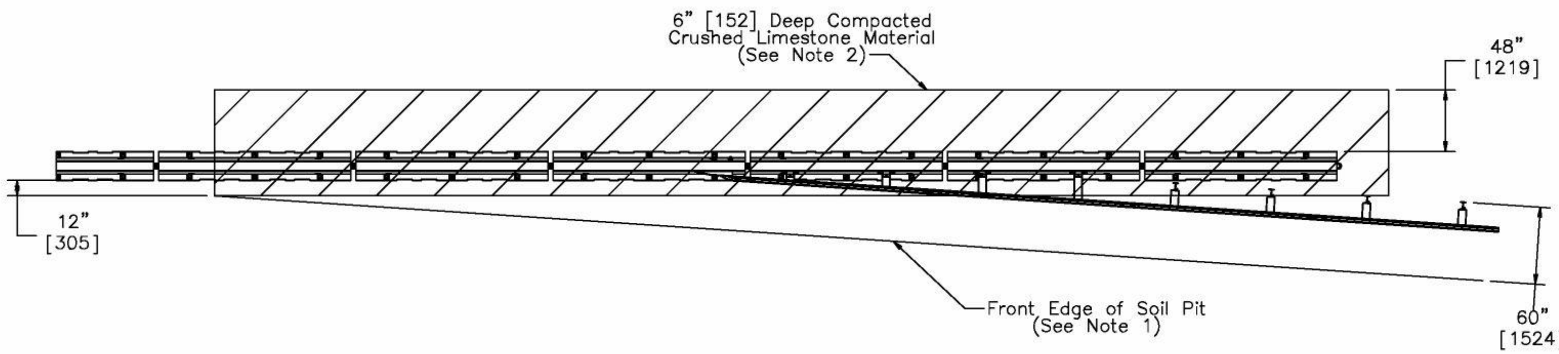


Figure 19. Test Installation Layout, Test No. MGSPCB-1



Notes: (1) The front edge of the soil pit should be at least 5' [1524] from the center of each post. The distance can be adjusted as long as the PCB system does not cross the front edge of the soil pit.

(2) The compacted crushed limestone material must meet AASHTO Grade B soil specifications. The length of this limestone material pit is up to the discretion of the test site manager.

Midwest Roadside Safety Facility	NDOR PCB–MGS Transition Layout 2		SHEET: 2 of 36
			DATE: 3/14/2016
	Soil Pit Detail		DRAWN BY: ALL/JEK/TJD/JAH
	DWG. NAME. PCB–MGS_Trans_Layout 2_R8	SCALE: 1:120 UNITS: in.[mm]	REV. BY: KAL/RWB/JEK

Figure 20. Soil Pit Detail, Test No. MGSPCB-1

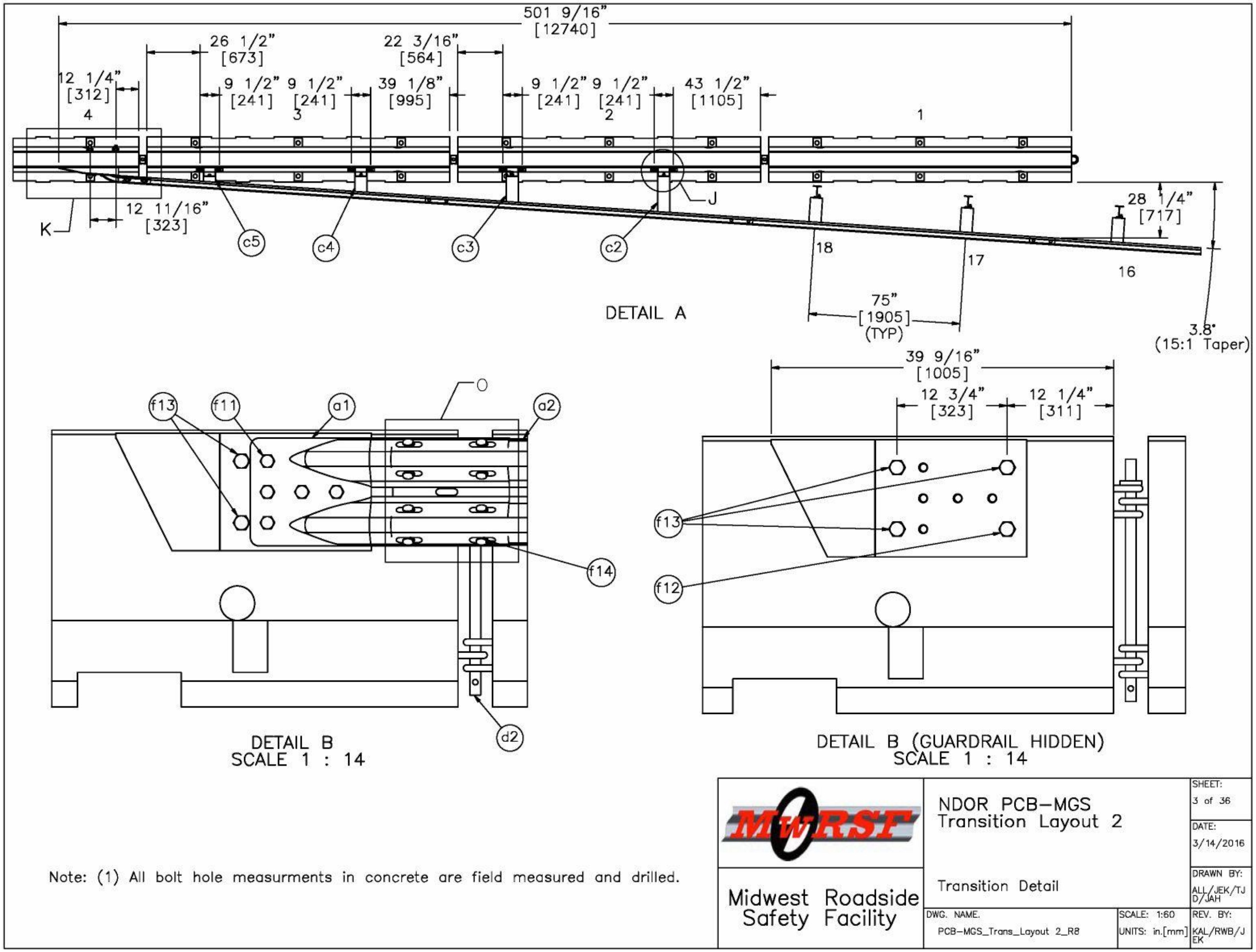


Figure 21. Transition Detail, Test No. MGSPCB-1

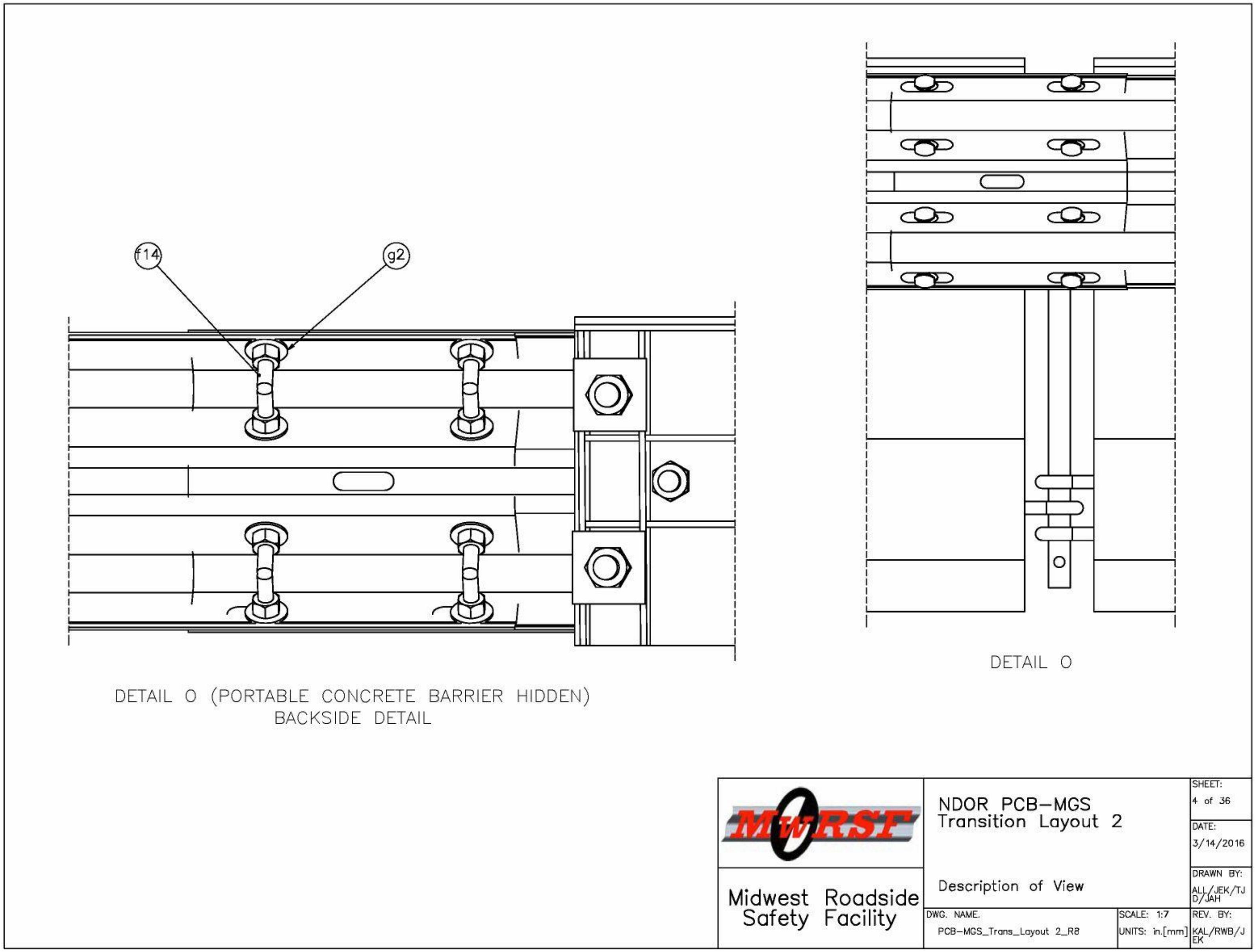


Figure 22. Description of View, Test No. MGSPCB-1

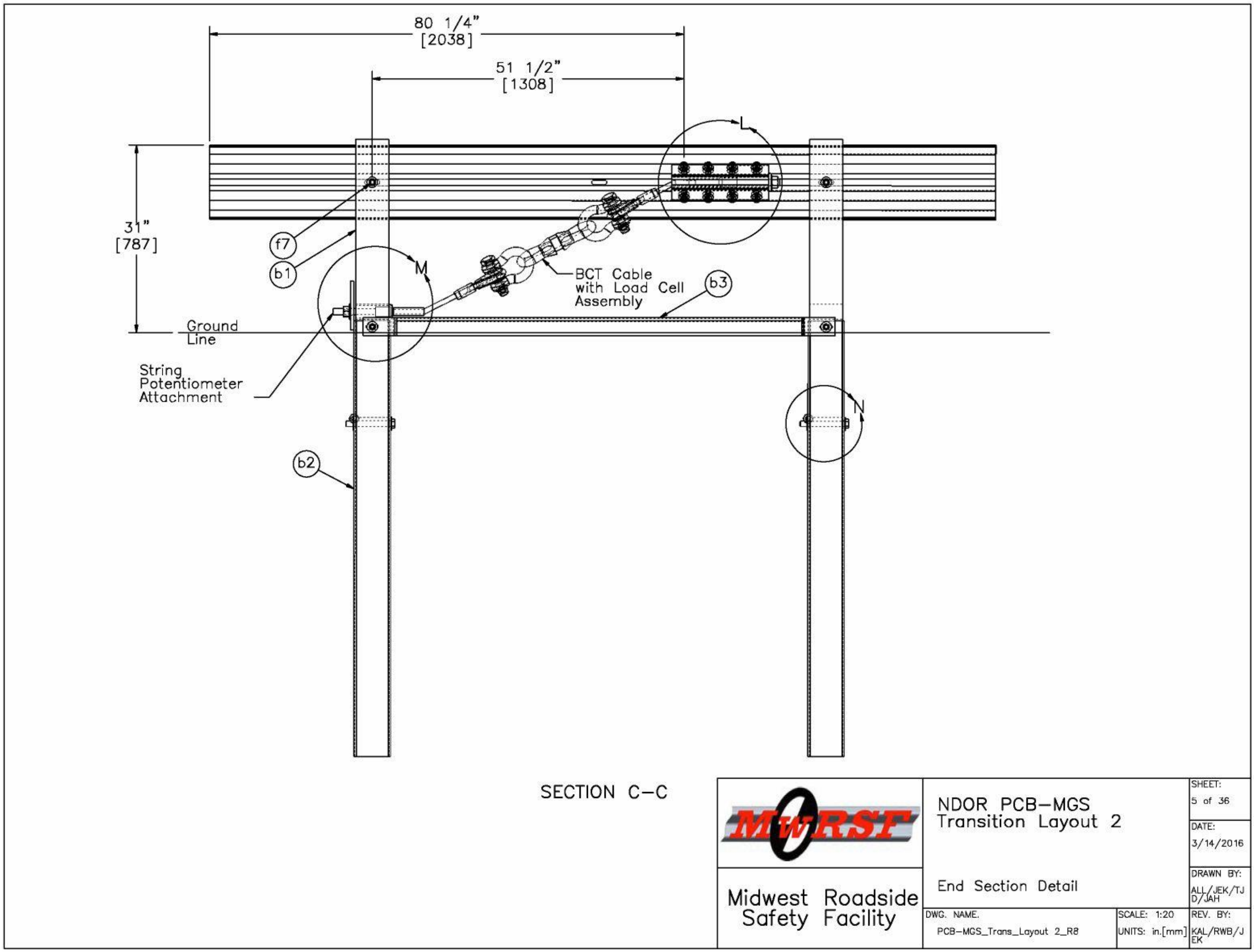


Figure 23. End Section Detail, Test No. MGSPCB-1

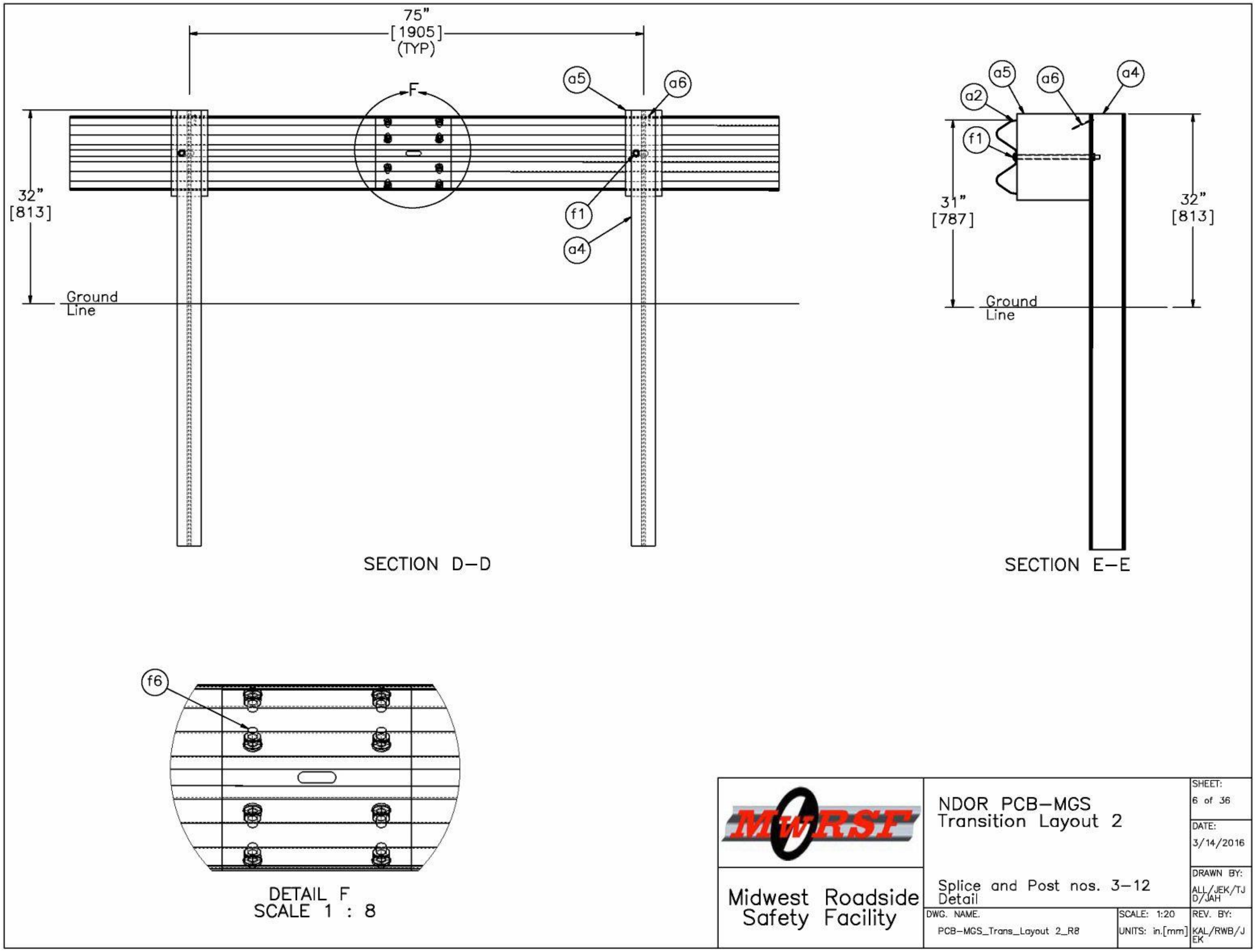


Figure 24. Splice and Post Nos. 3-12 Detail, Test No. MGSPCB-1

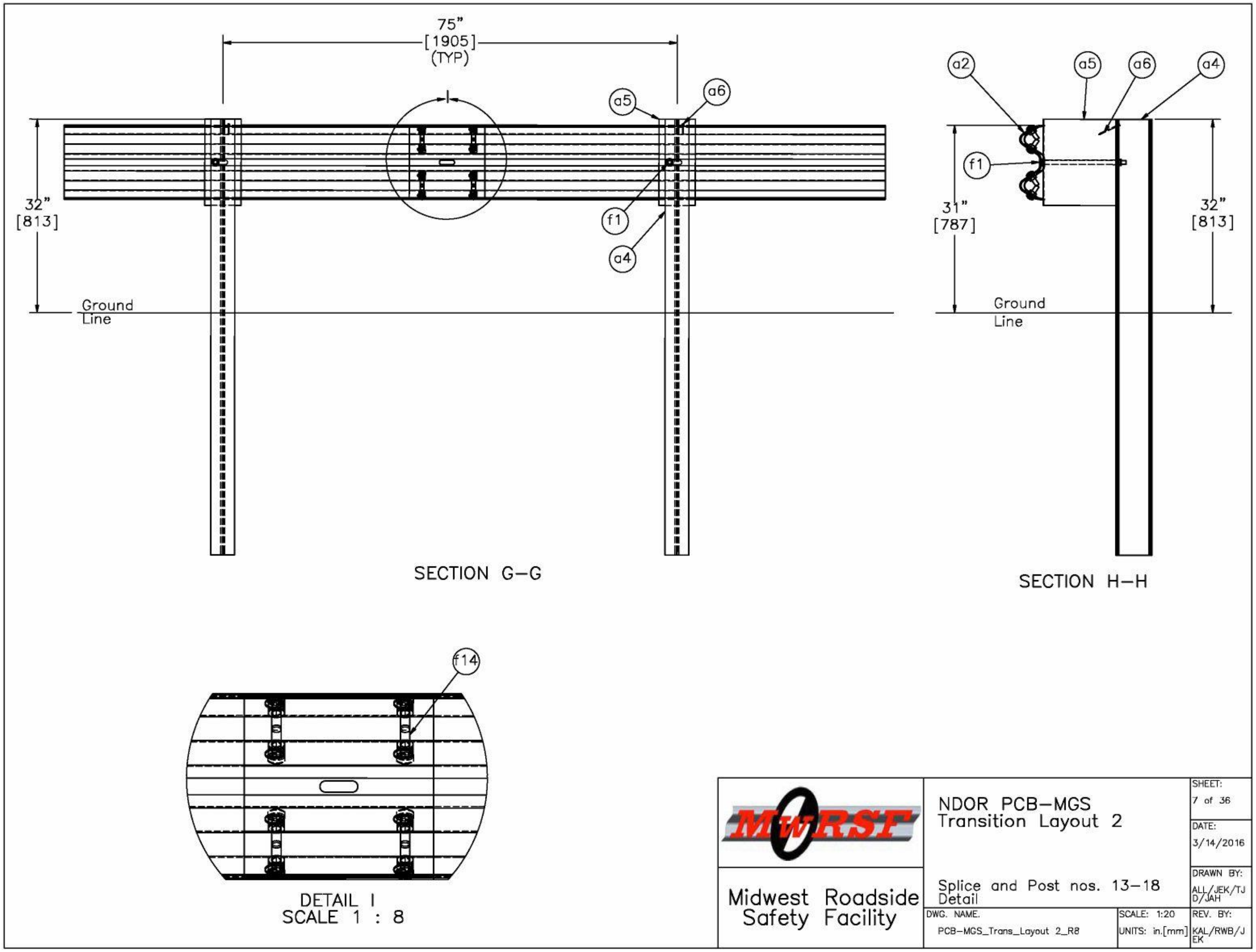


Figure 25. Splice and Post Nos. 13-18 Detail, Test No. MGSPCB-1

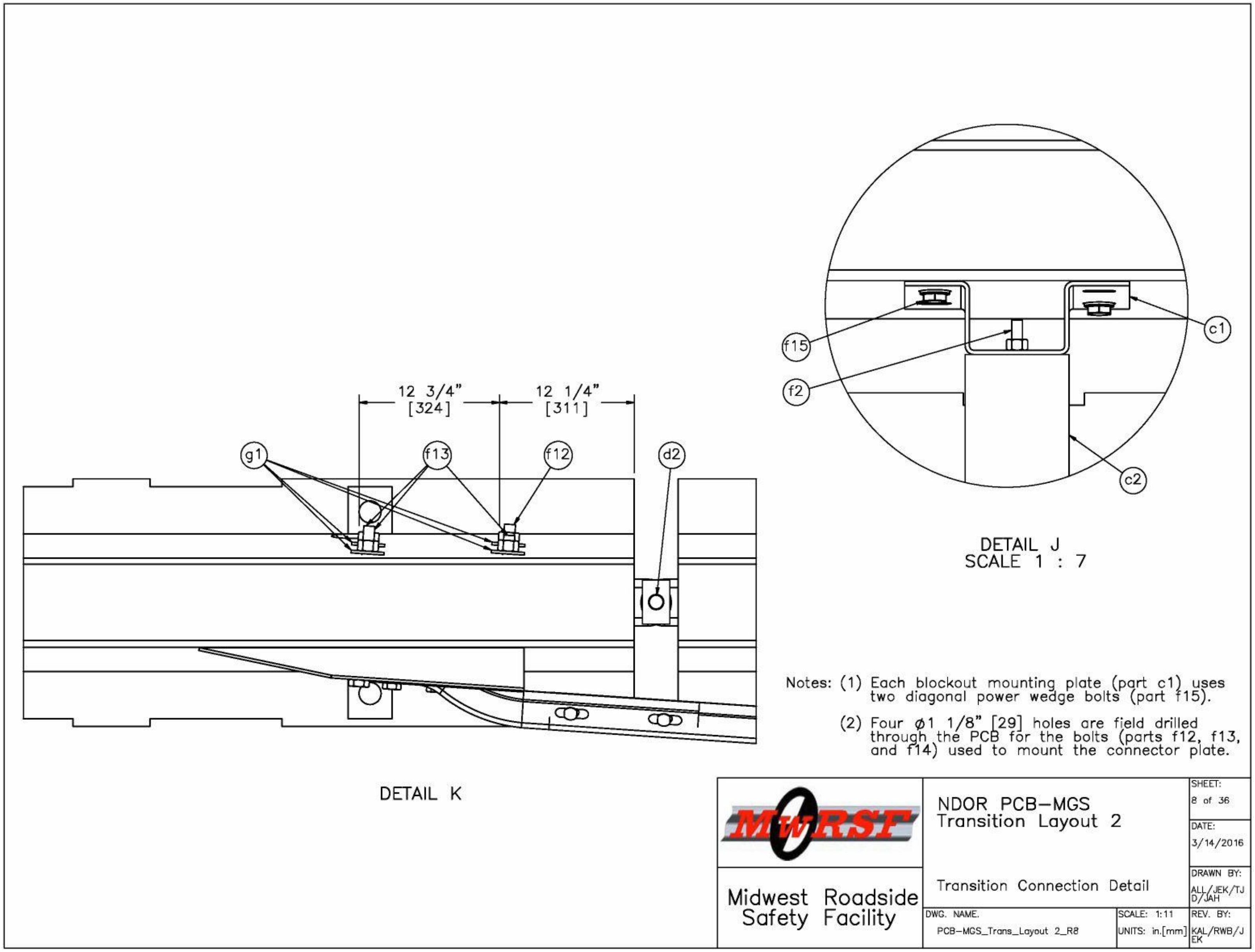


Figure 26. Transition Connection Detail, Test No. MGSPCB-1

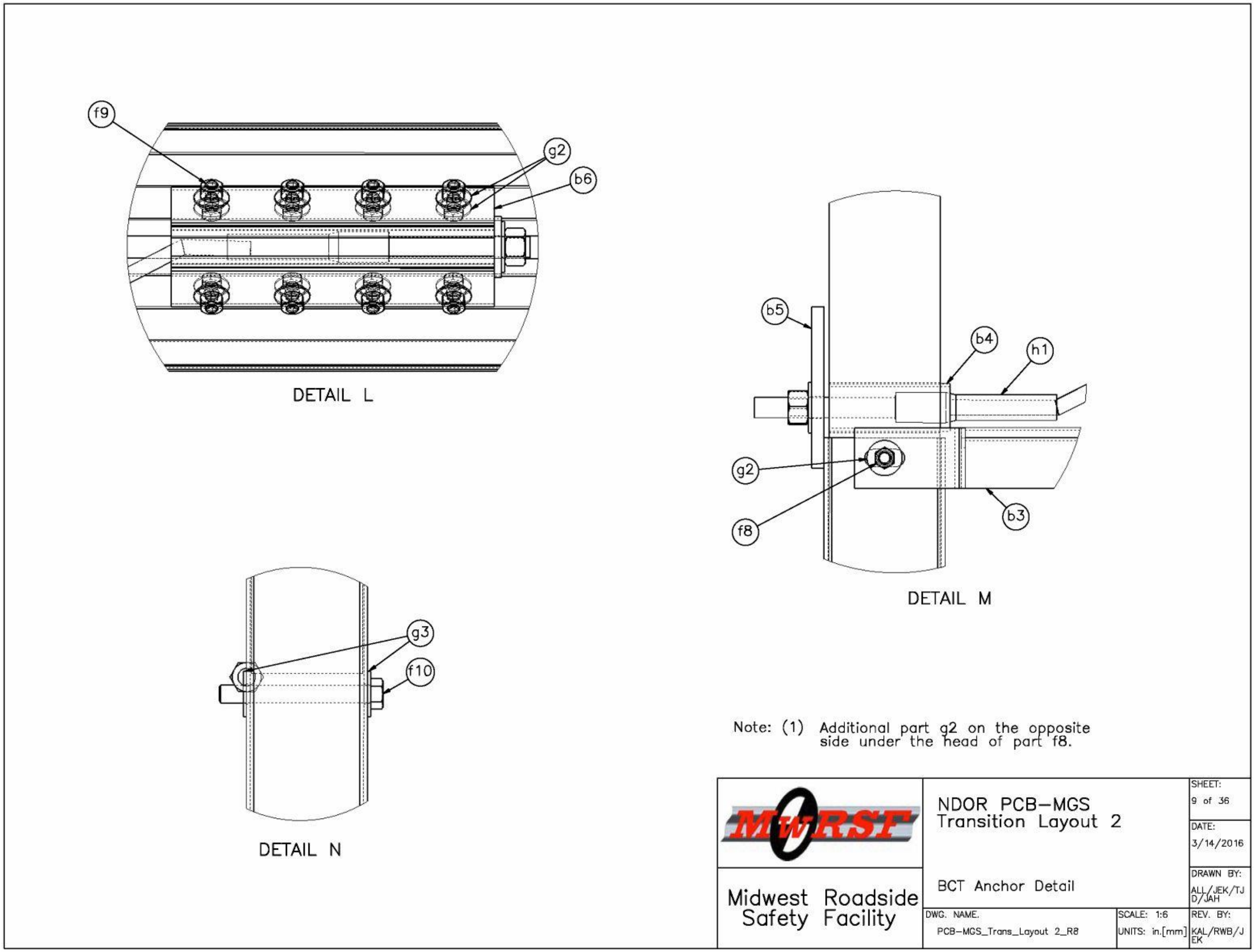


Figure 27. BCT Anchor Detail, Test No. MGSPCB-1

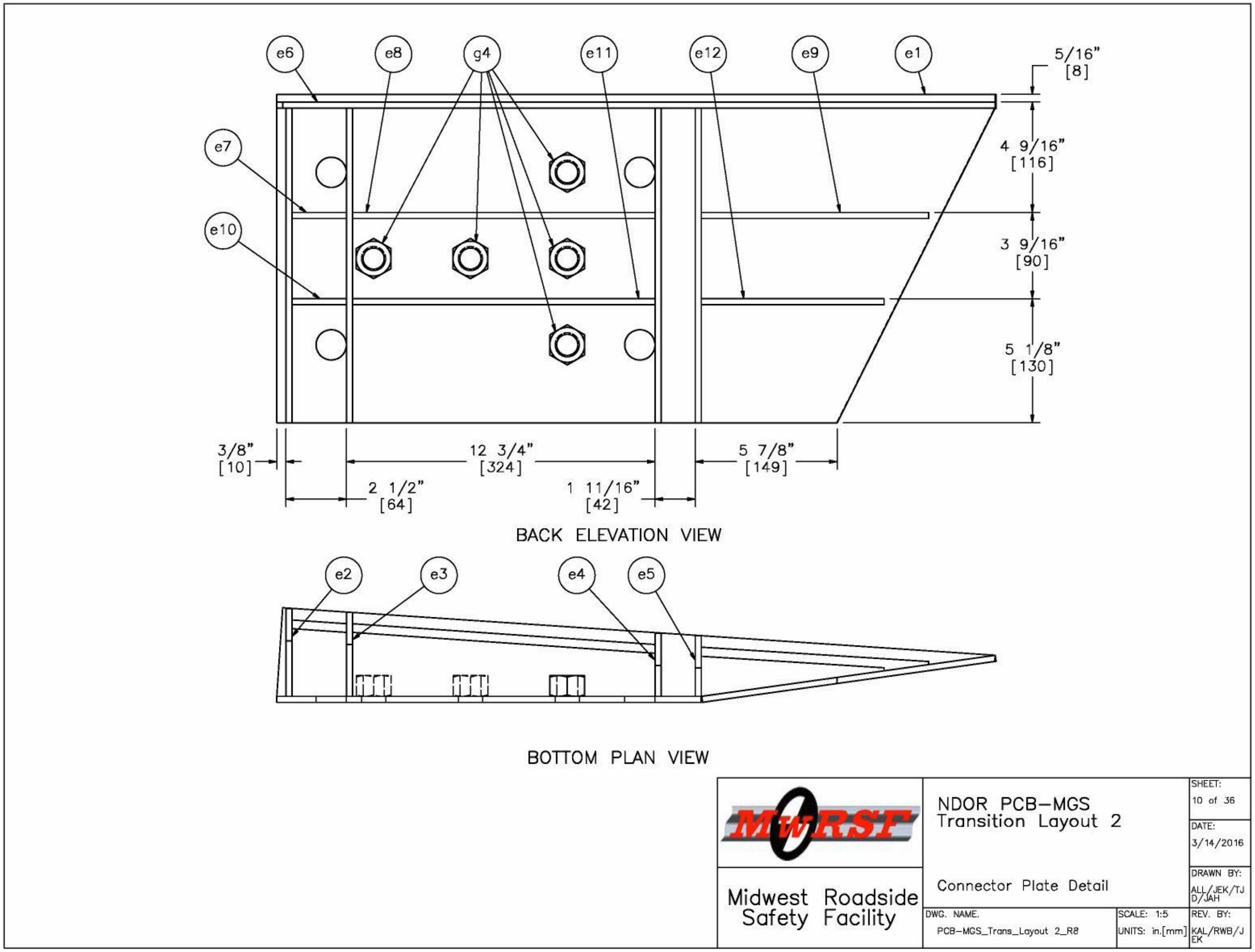


Figure 28. Connector Plate Detail, Test No. MGSPCB-1

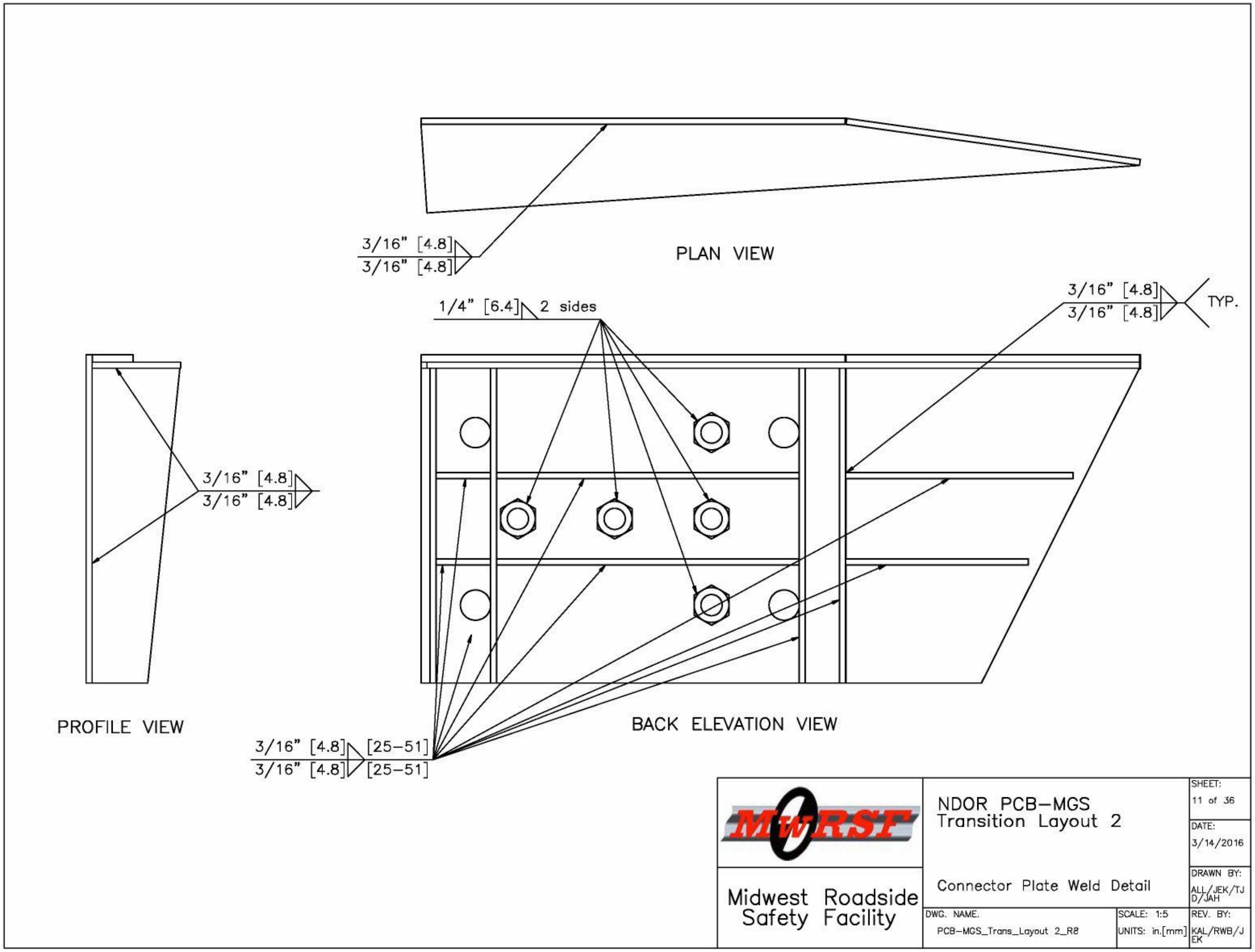
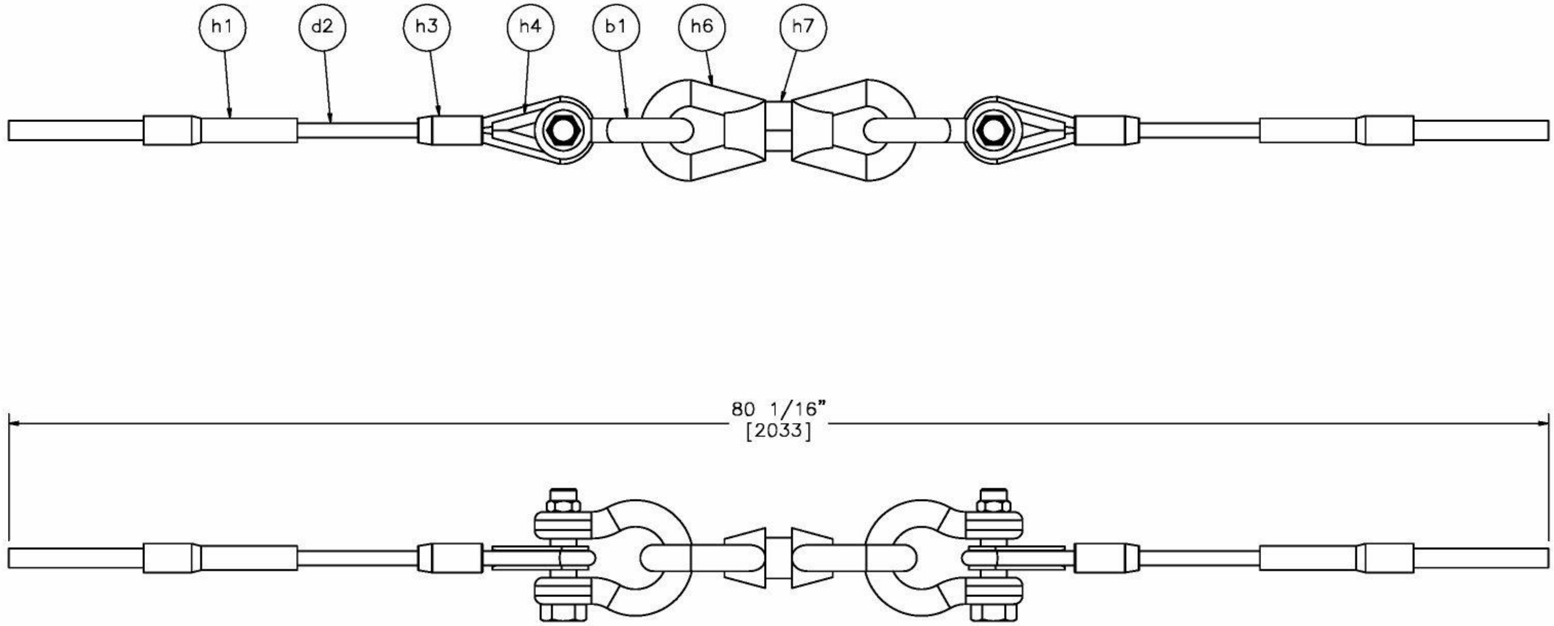


Figure 29. Connector Plate Weld Detail, Test No. MGSPCB-1



Note: (1) 6x25 IWRC IPS cables meet the minimum breaking strength of 42.7 kips [190 kN] and may be substituted for the 6x19 IWRC IPS cables.

MwRSF	NDOR PCB–MGS Transition Layout 2	SHEET: 12 of 36
		DATE: 3/14/2016
Midwest Roadside Safety Facility	BCT Anchor Cable and Load Cell Detail	DRAWN BY: ALL/JEK/TJD/JAH
	DWG. NAME. PCB–MGS_Trans_Layout 2_R8	SCALE: 1:8 / UNITS: in.[mm] / REV. BY: KAL/RWB/JEK

Figure 30. BCT Anchor Cable and Load Cell Detail, Test No. MGSPCB-1

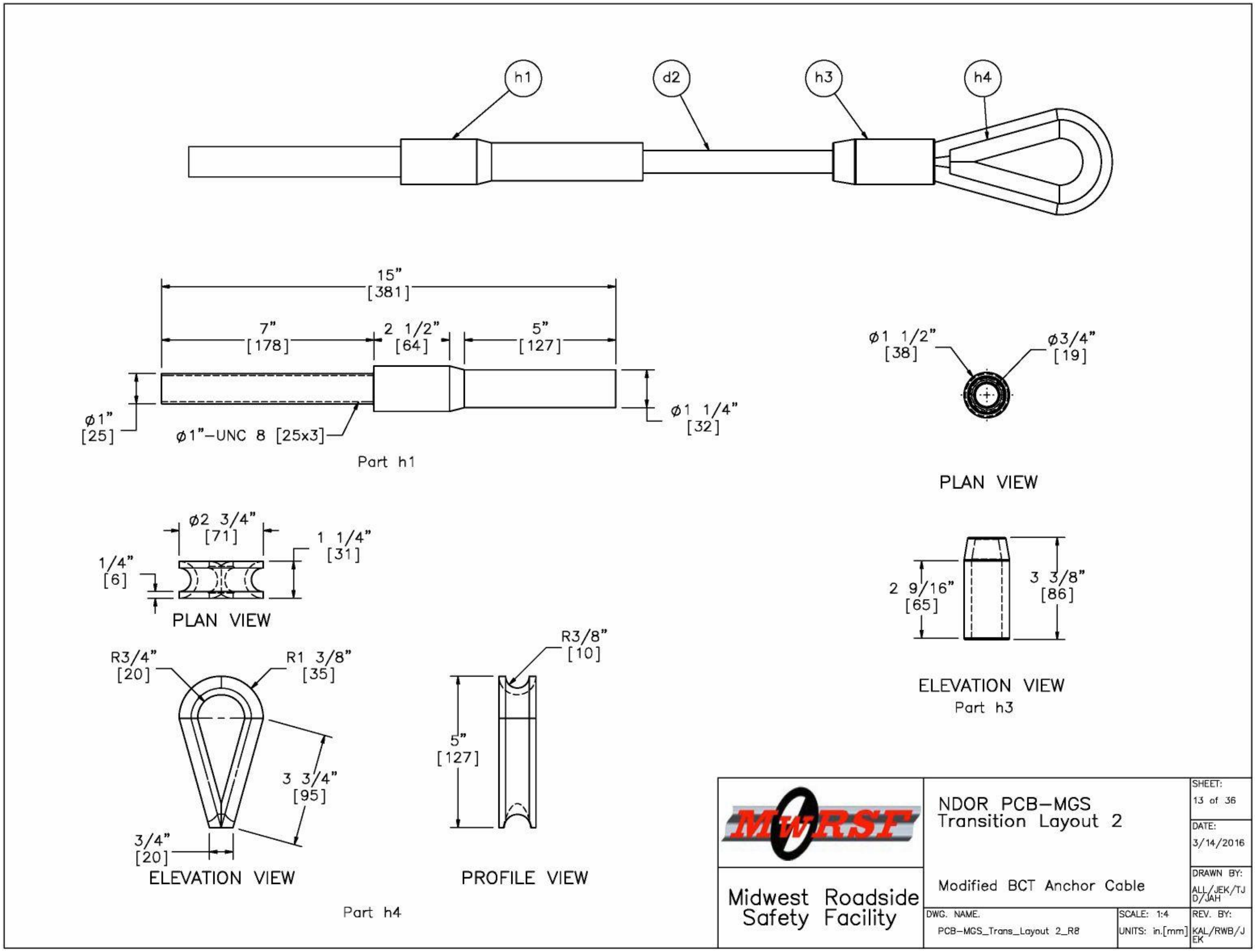


Figure 31. Modified BCT Anchor Cable, Test No. MGSPCB-1

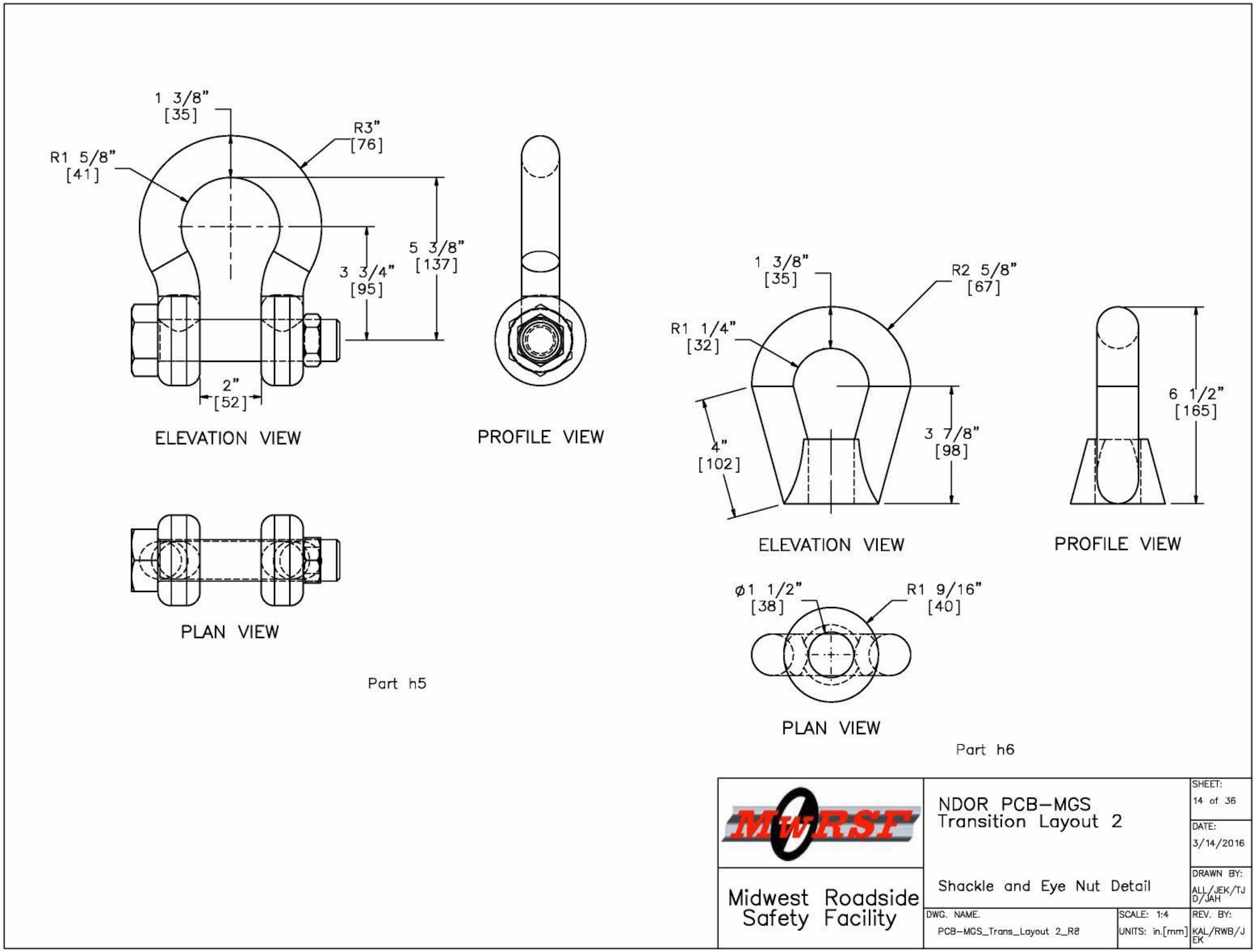


Figure 32. Shackle and Eye Nut Detail, Test No. MGSPCB-1

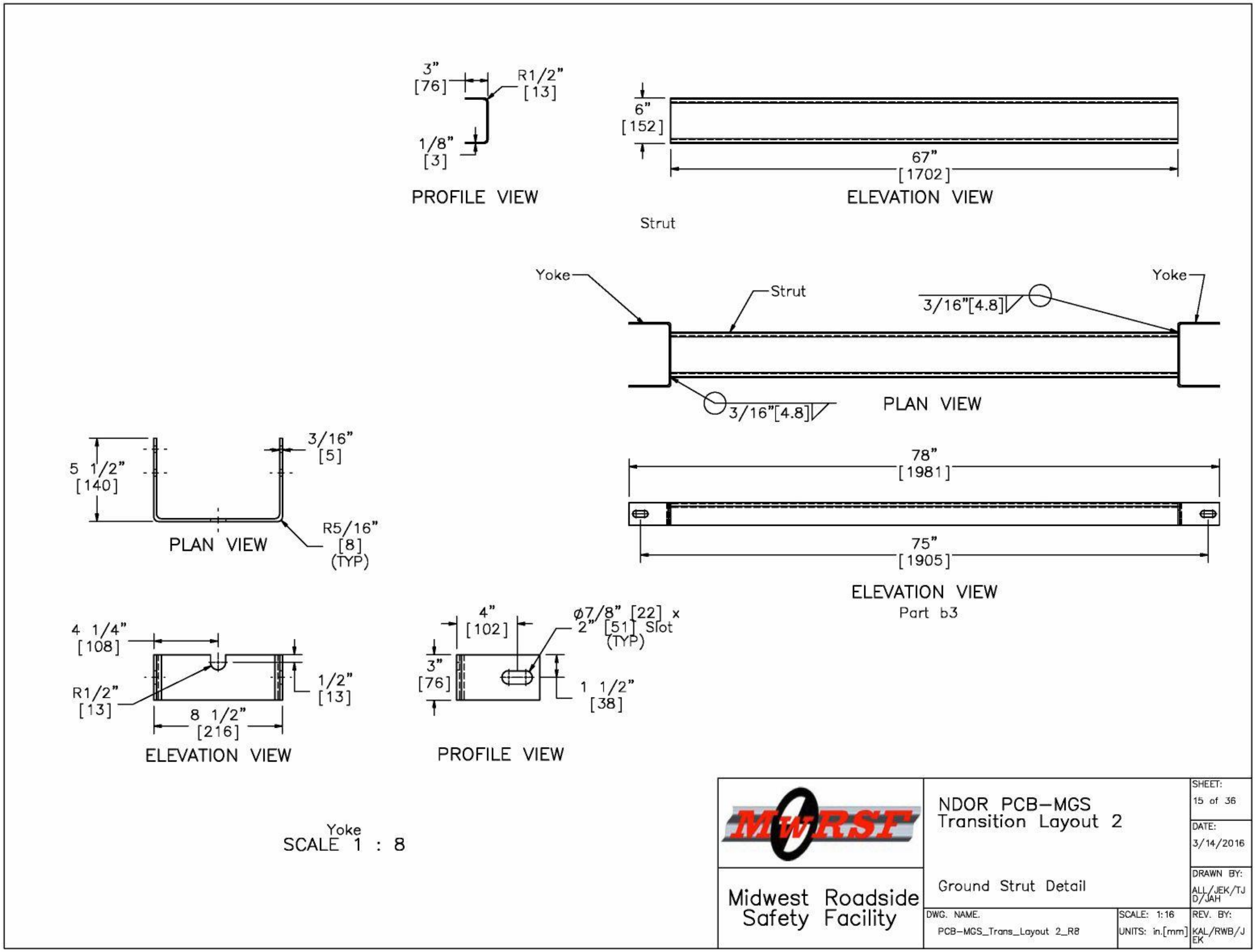


Figure 33. Ground Strut Detail, Test No. MGSPCB-1

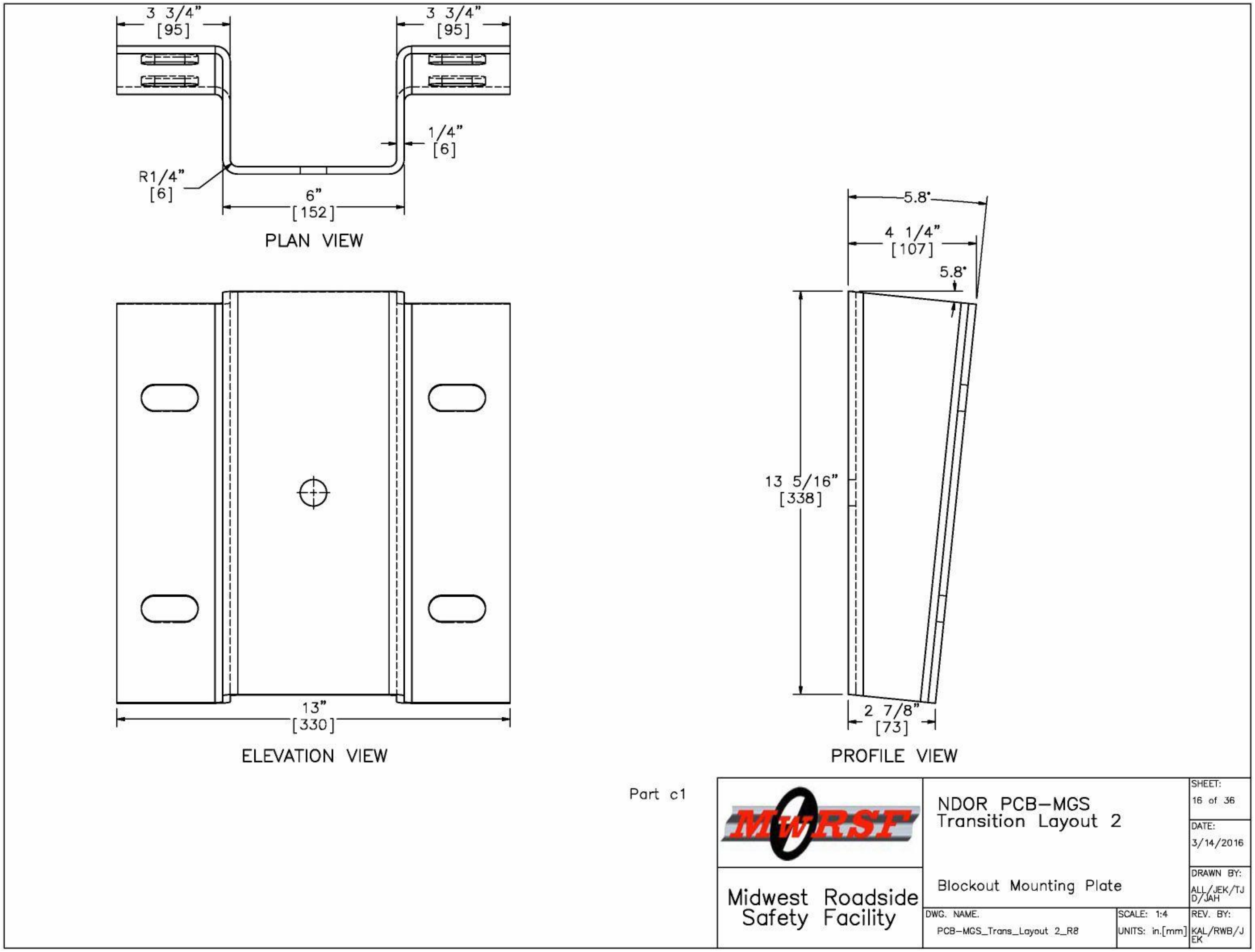


Figure 34. Blockout Mounting Plate, Test No. MGSPCB-1

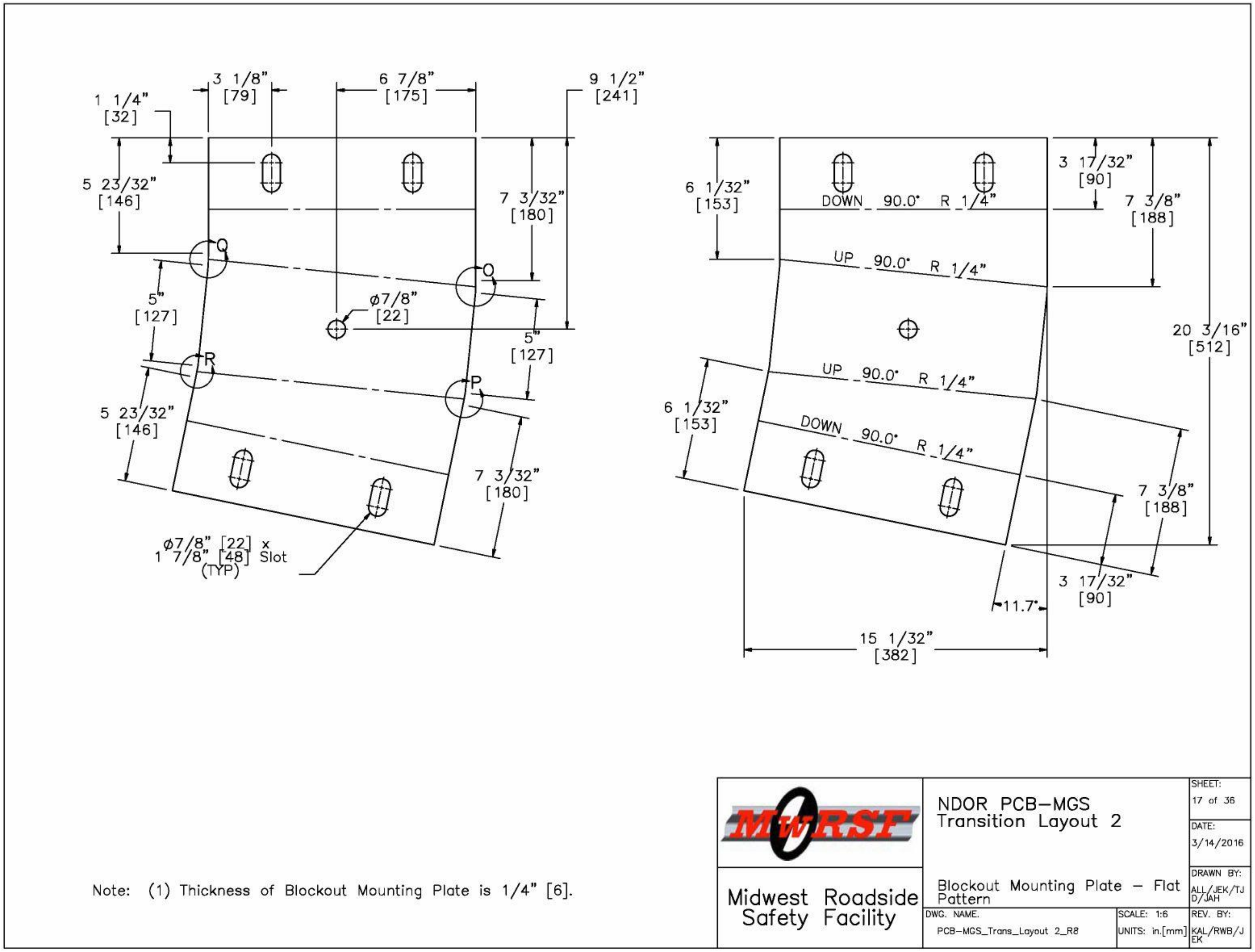


Figure 35. Blockout Mounting Plate, Flat Pattern, Test No. MGSPCB-1

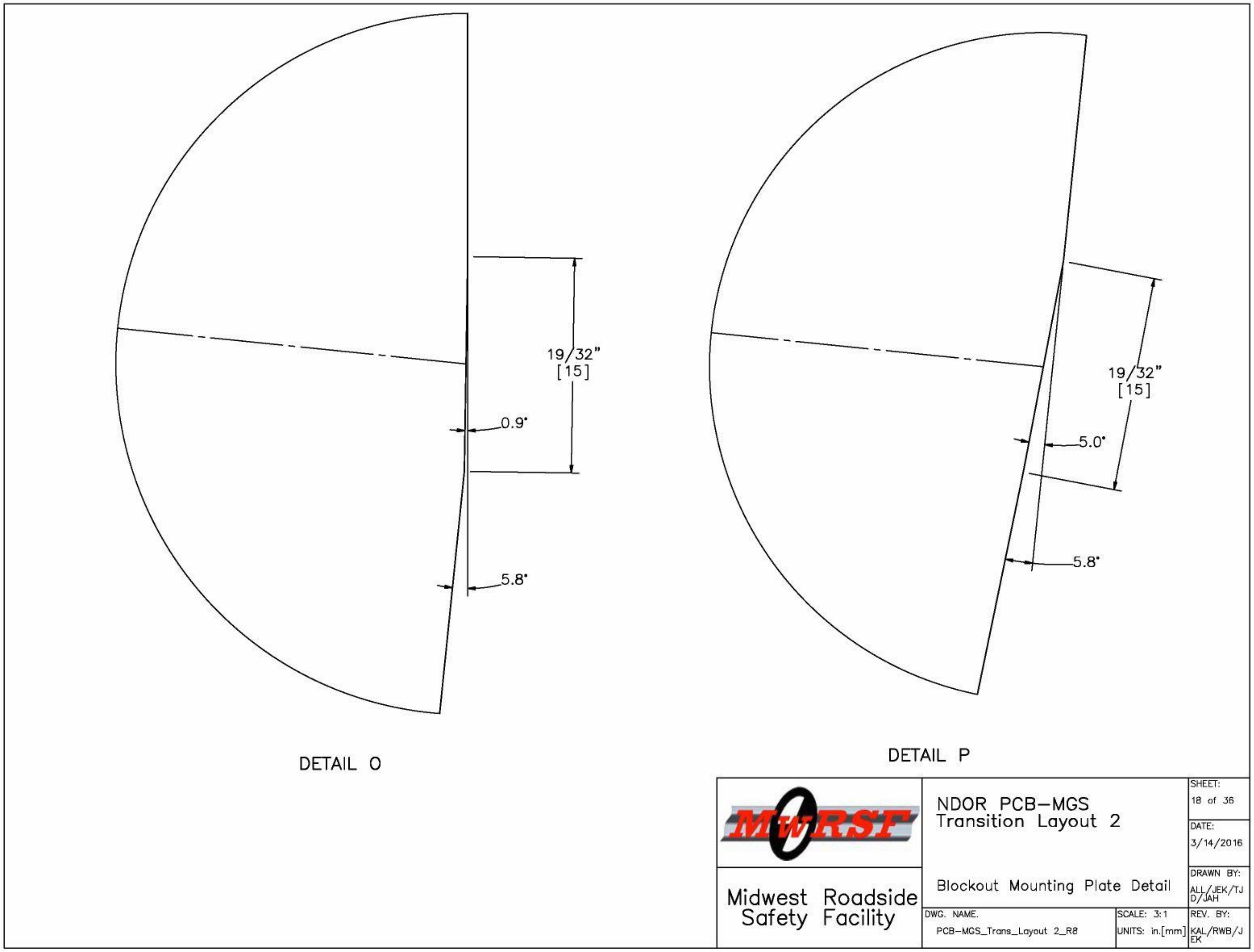


Figure 36. Blockout Mounting Plate Detail, Test No. MGSPCB-1

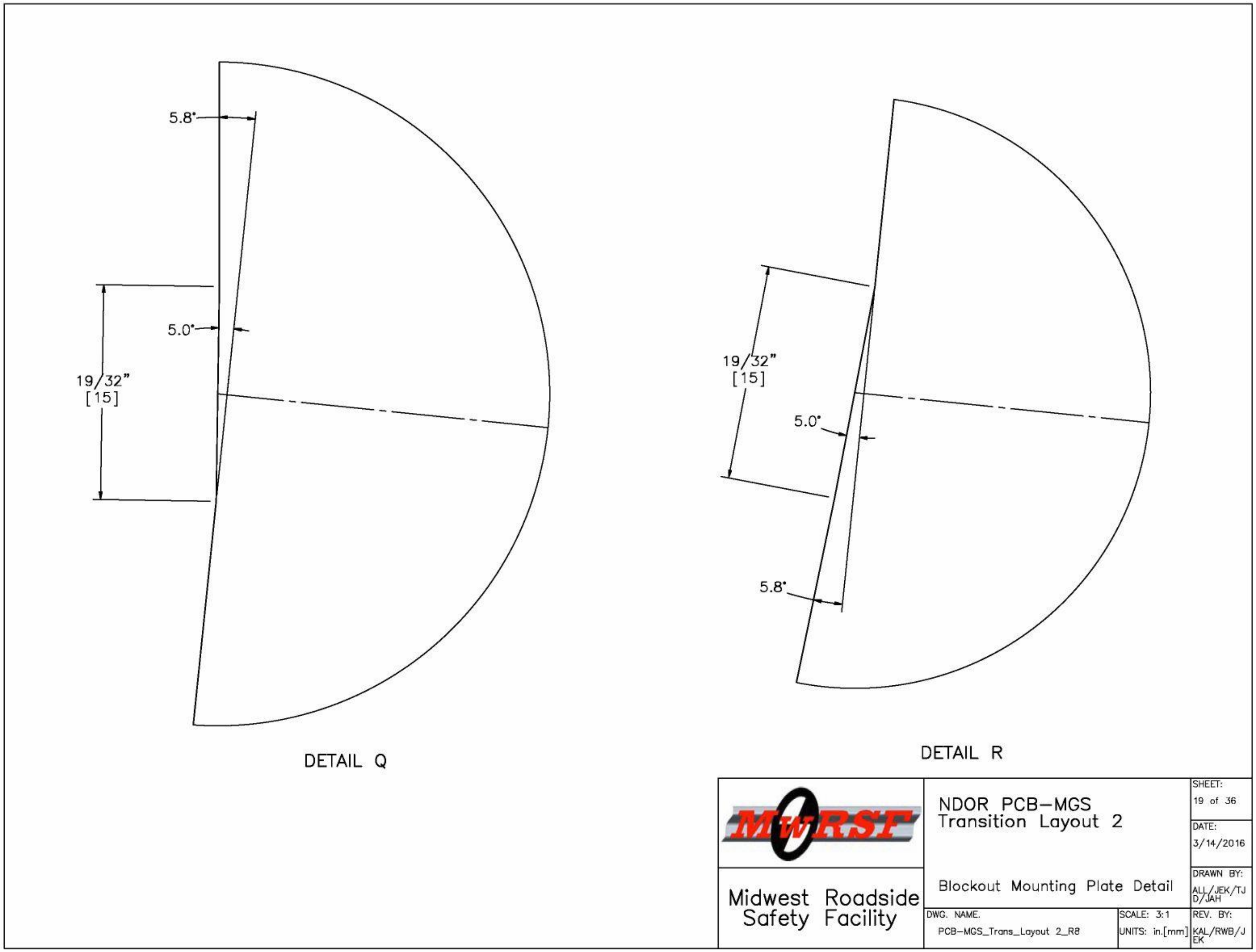


Figure 37. Blockout Mounting Plate Detail, Test No. MGSPCB-1

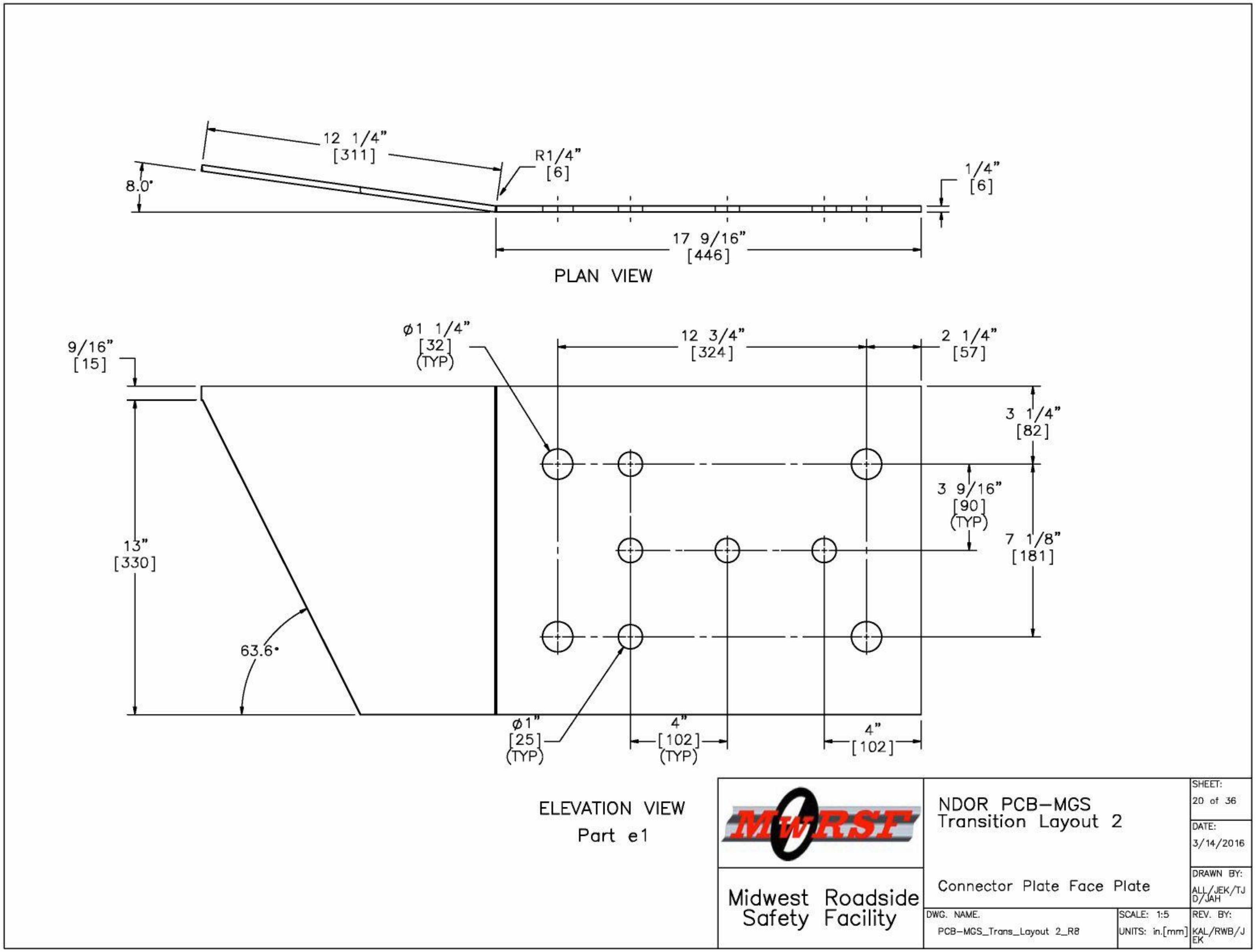


Figure 38. Connector Plate Face Plate, Test No. MGSPCB-1

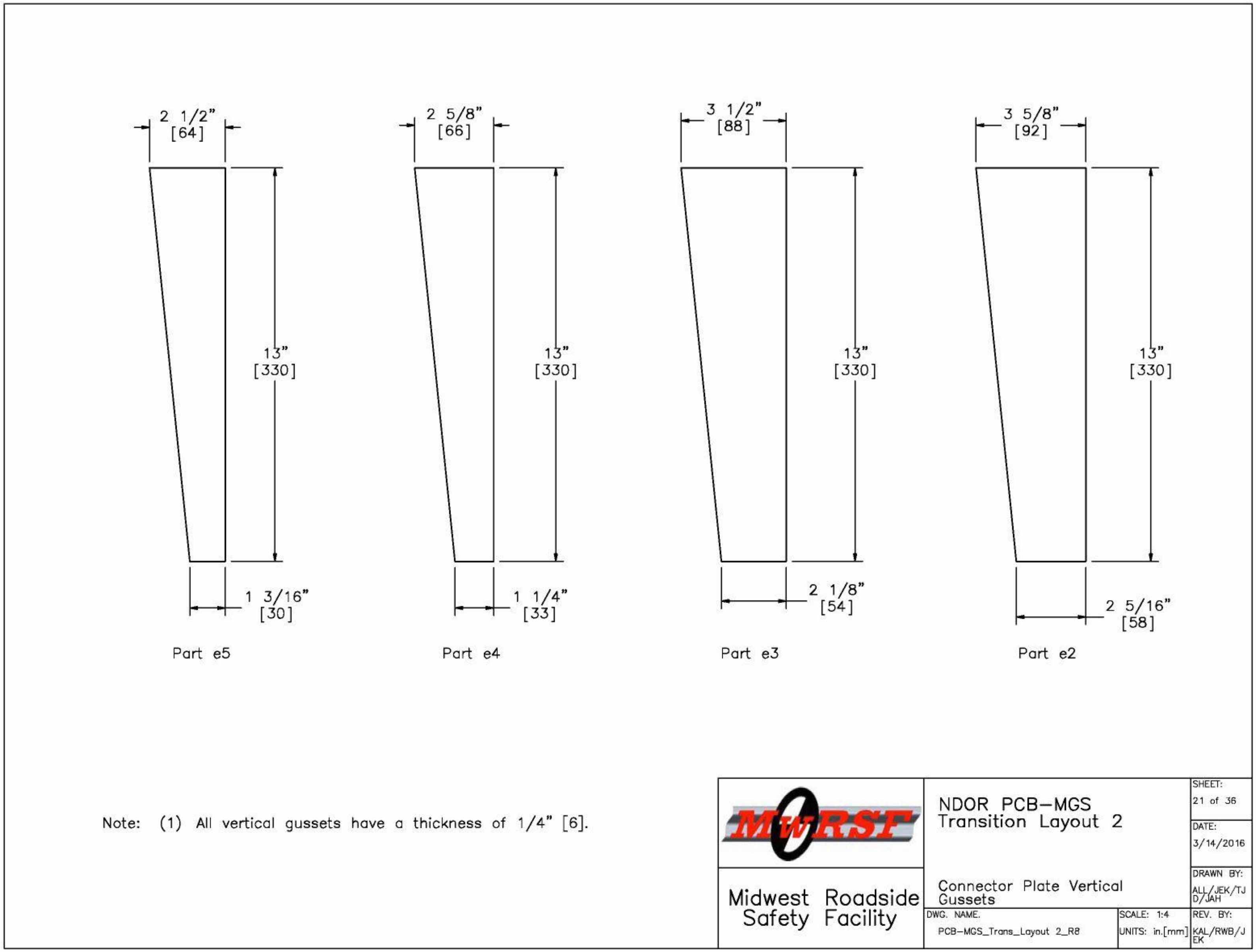


Figure 39. Connector Plate Vertical Gussets, Test No. MGSPCB-1

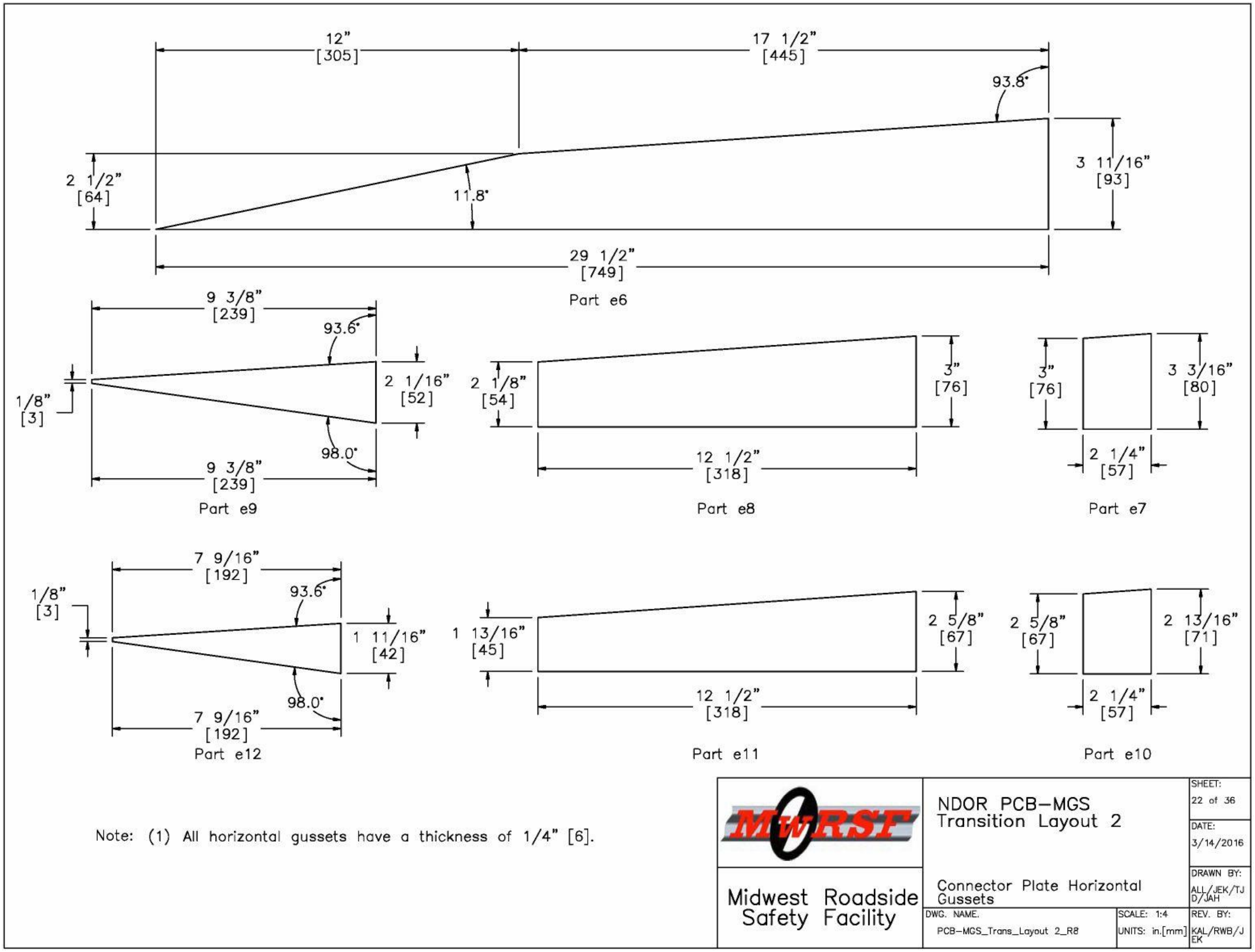


Figure 40. Connector Plate Horizontal Gussets, Test No. MGSPCB-1

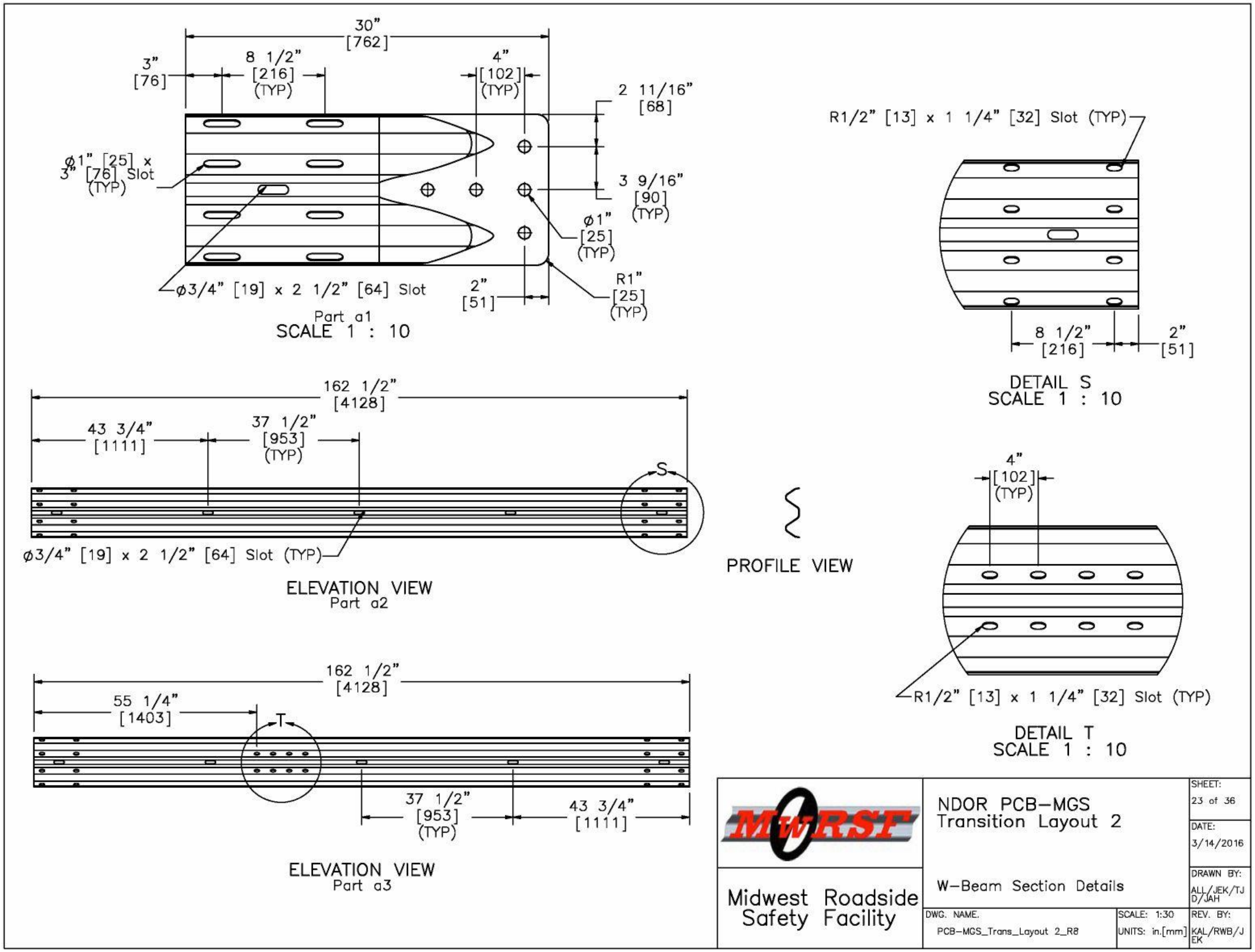


Figure 41. W-Beam Section Detail, Test No. MGSPCB-1

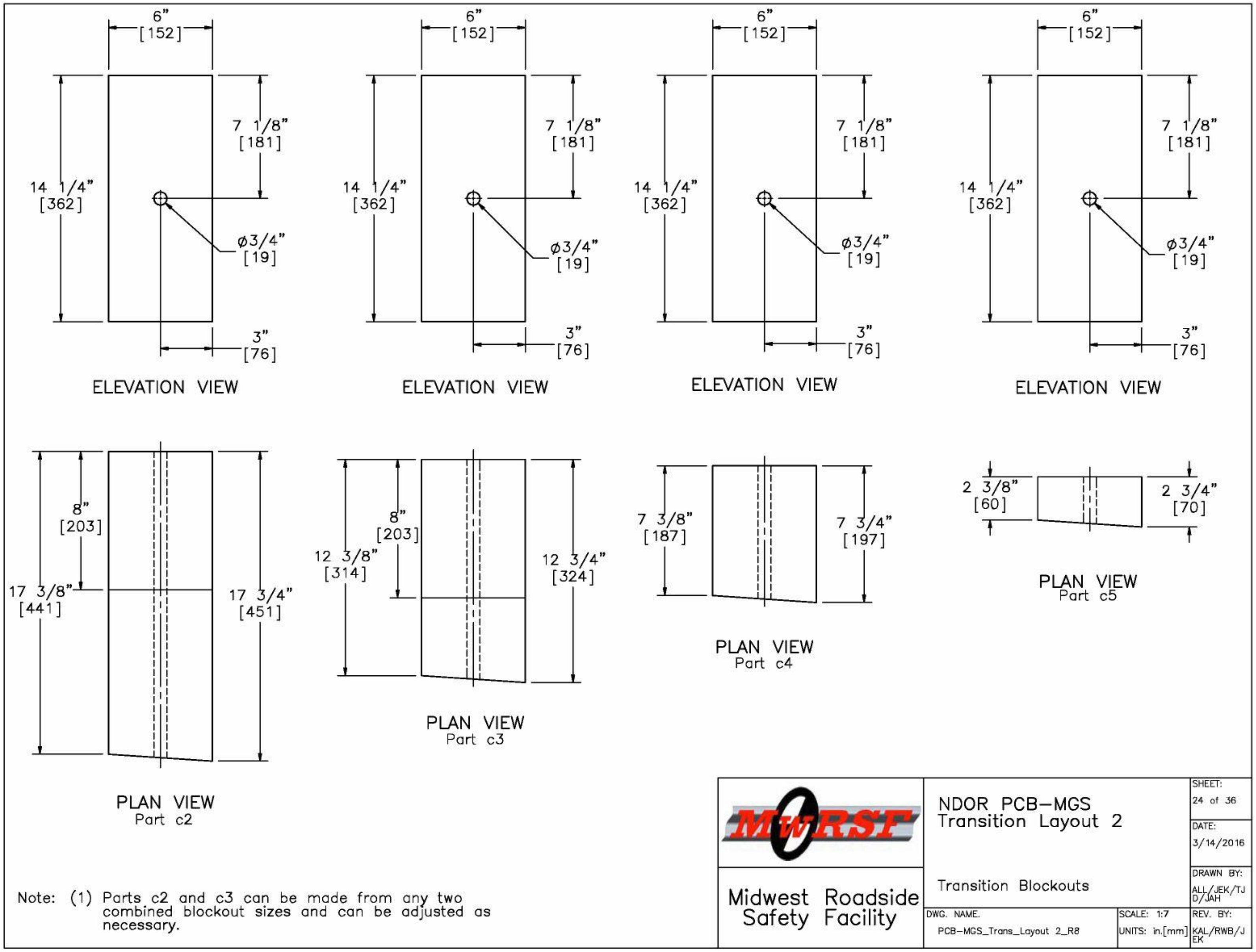


Figure 42. Transition Blockouts, Test No. MGSPCB-1

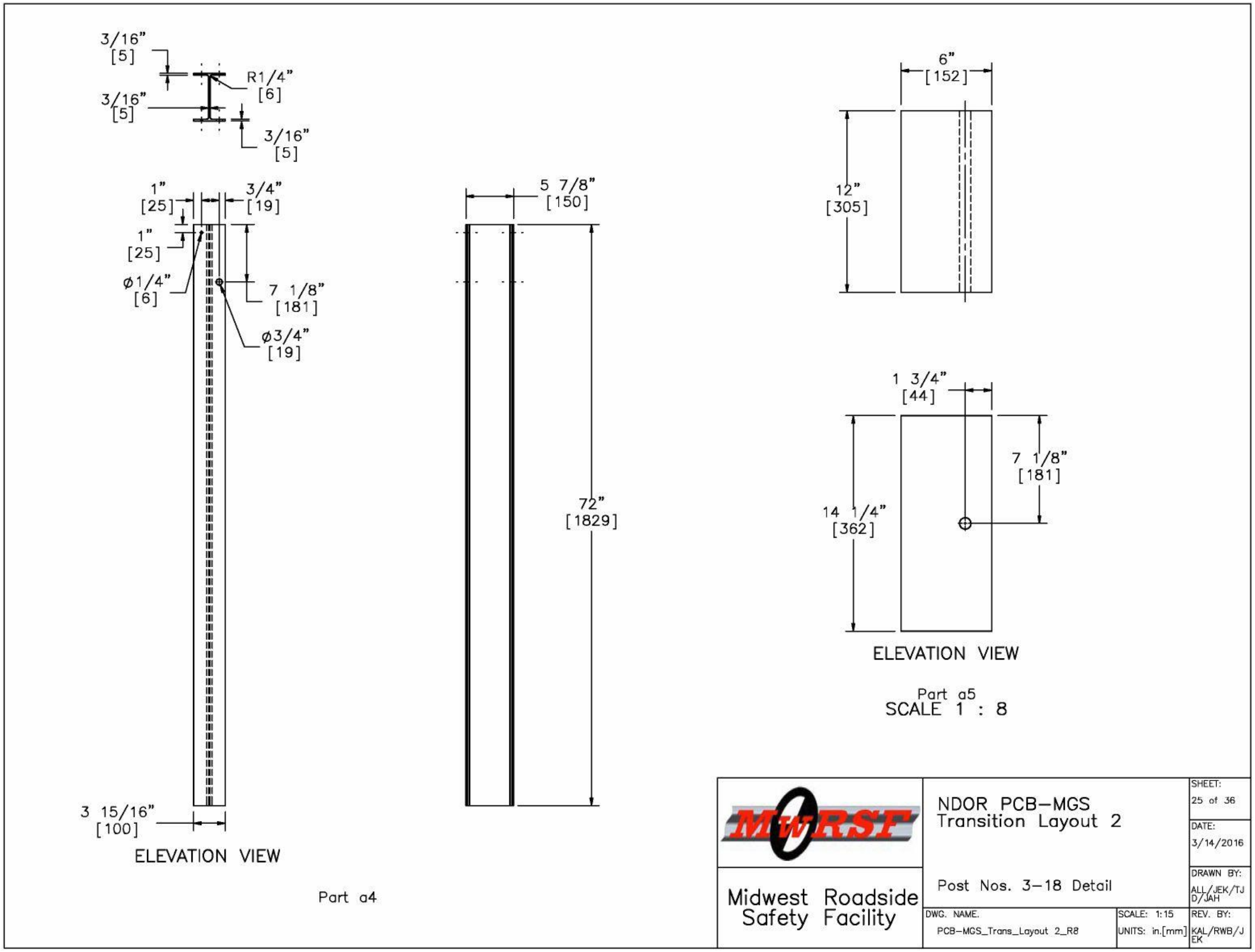


Figure 43. Post nos. 3-18 Detail, Test No. MGSPCB-1

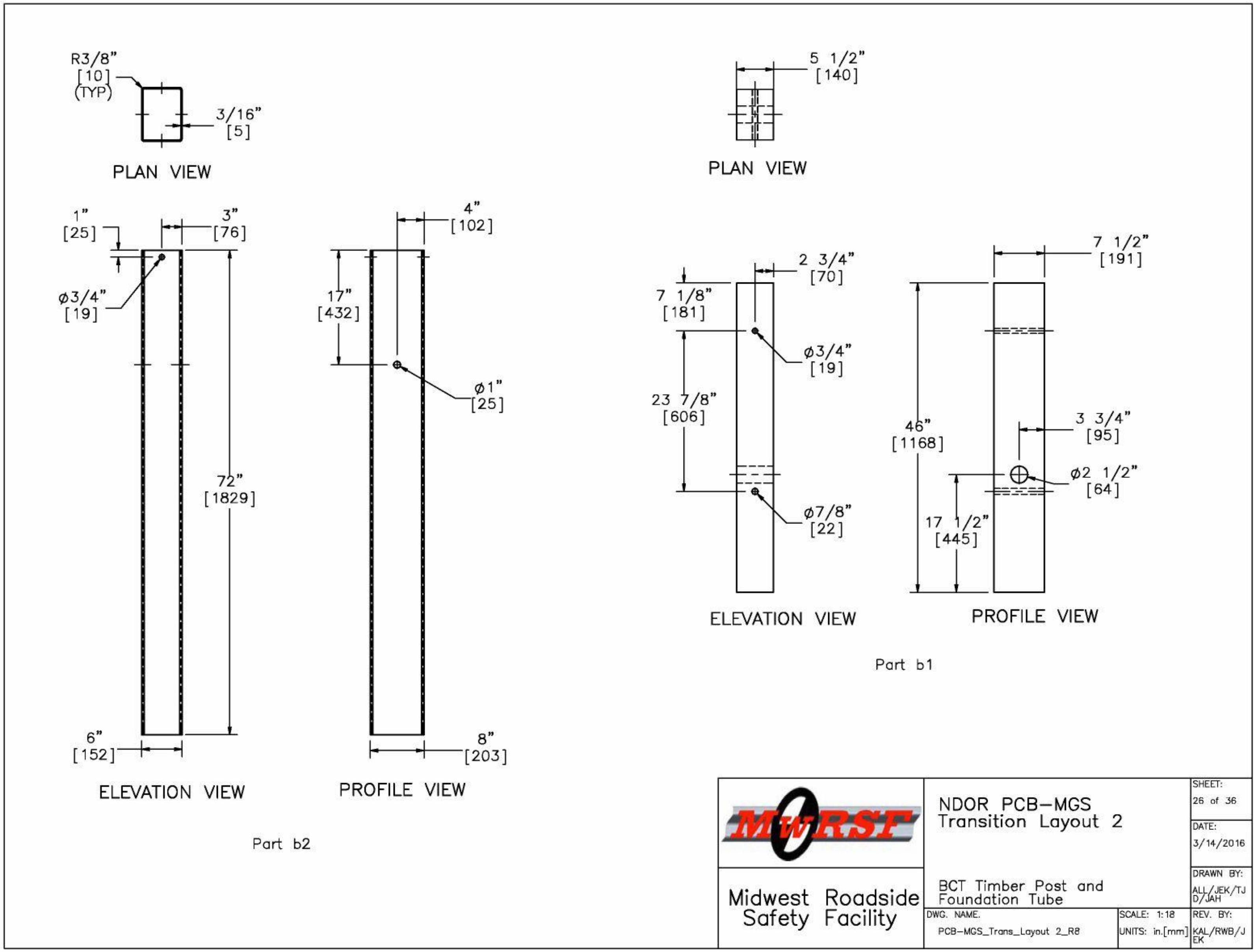


Figure 44. BCT Timber Post and Foundation Tube, Test No. MGSPCB-1

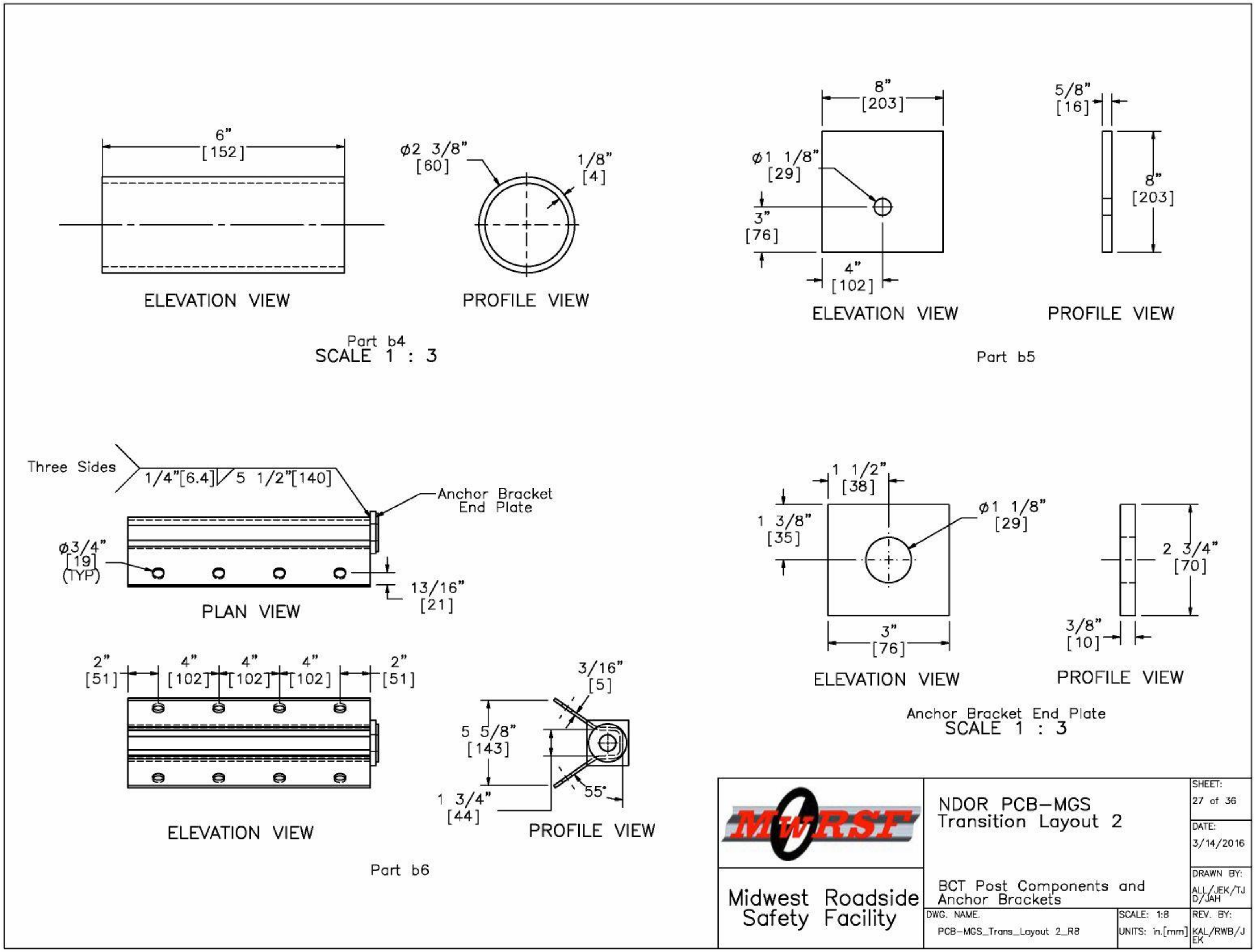


Figure 45. BCT Post Components and Anchor Brackets, Test No. MGSPCB-1

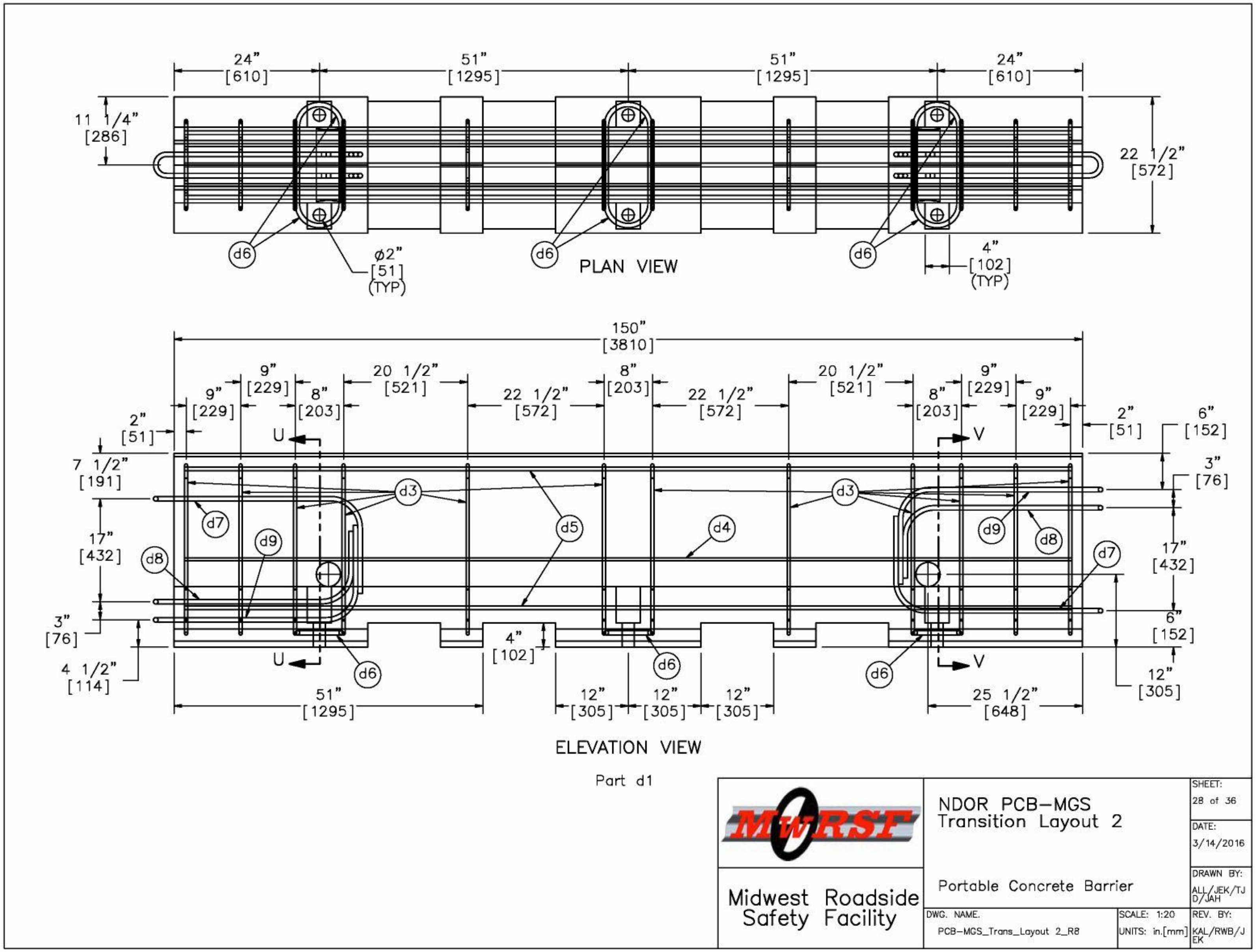


Figure 46. Portable Concrete Barrier, Test No. MGSPCB-1

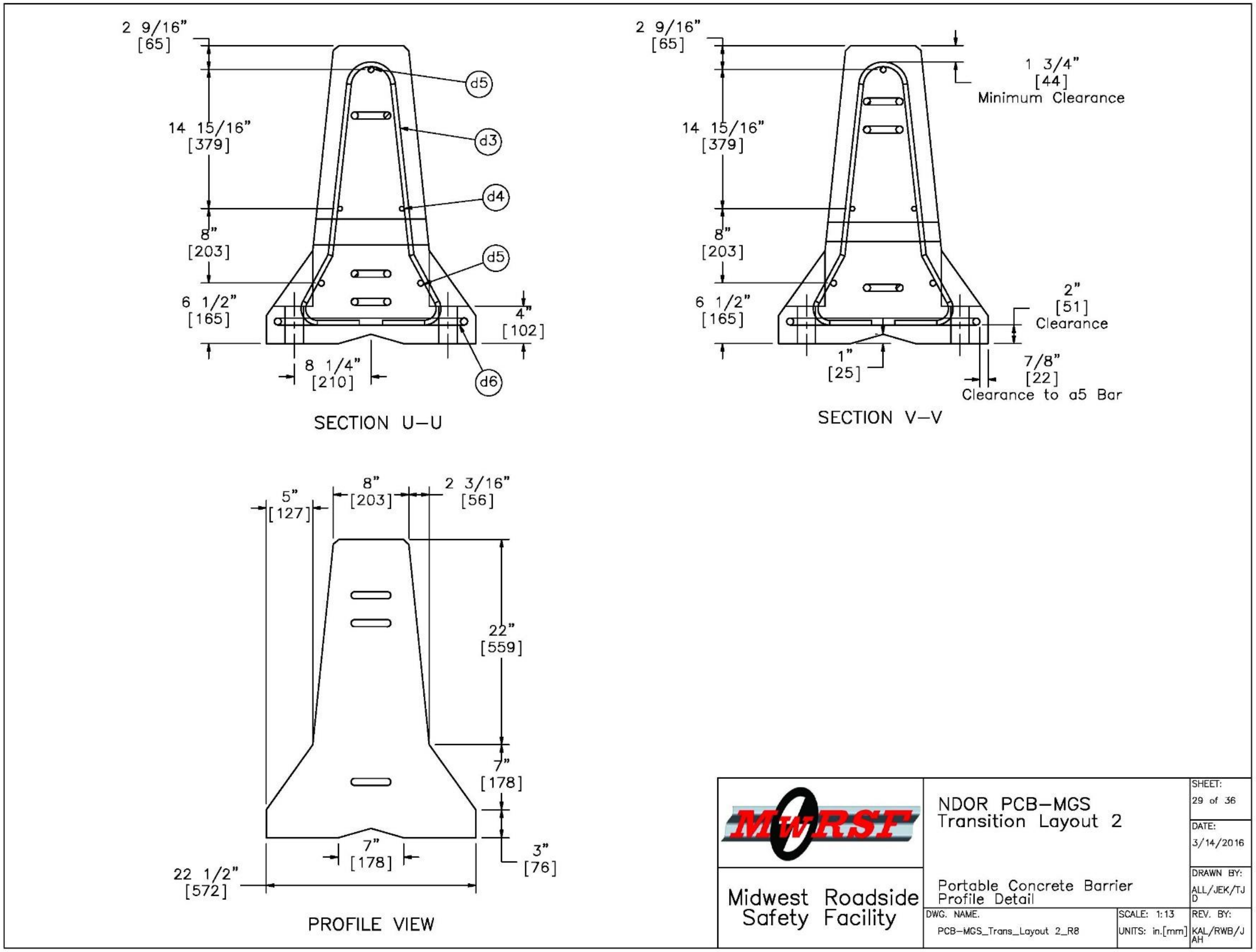


Figure 47. Portable Concrete Barrier Profile Detail, Test No. MGSPCB-1

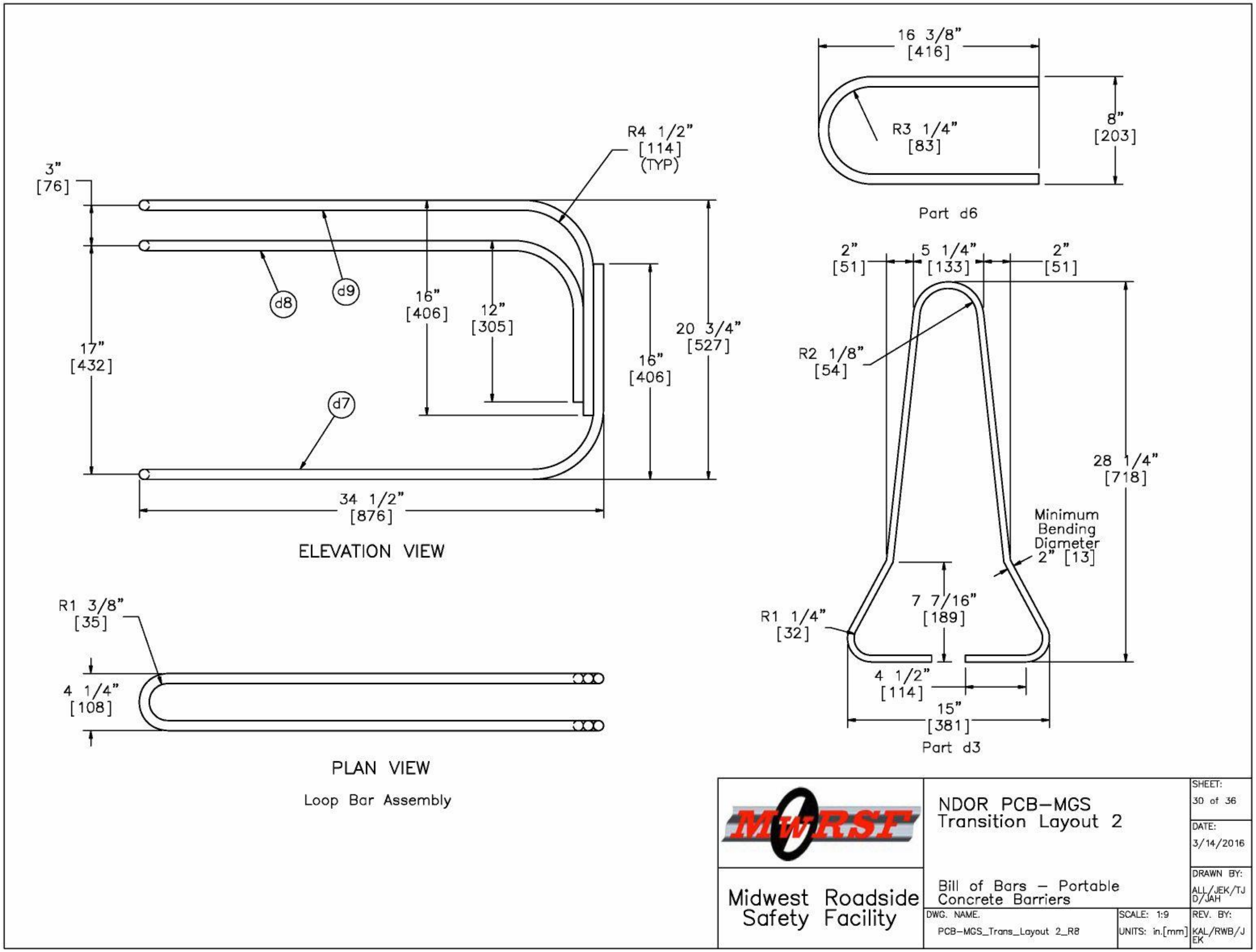


Figure 48. Bill of Bars – Portable Concrete Barriers, Test No. MGSPCB-1

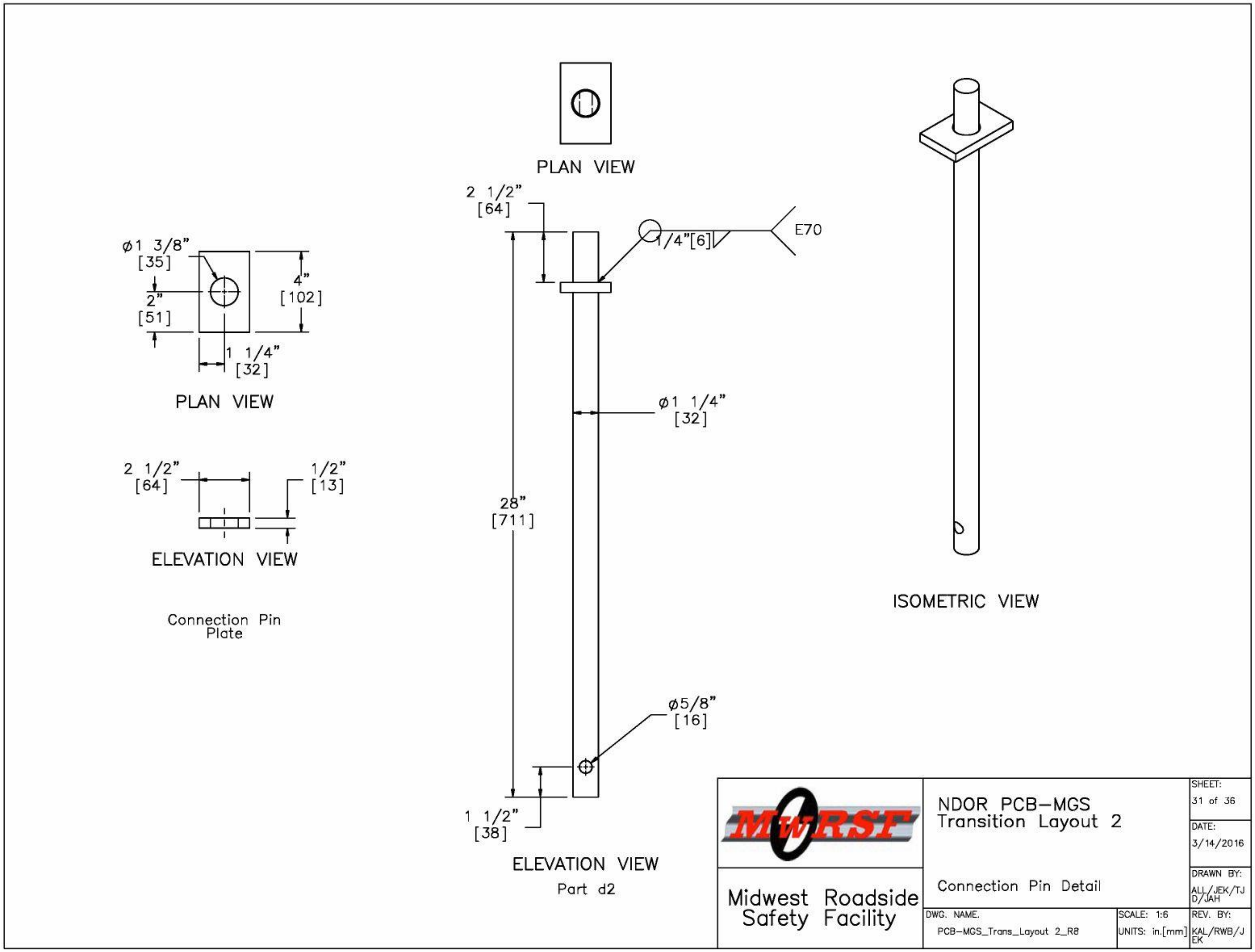


Figure 49. Connection Pin Detail, Test No. MGSPCB-1

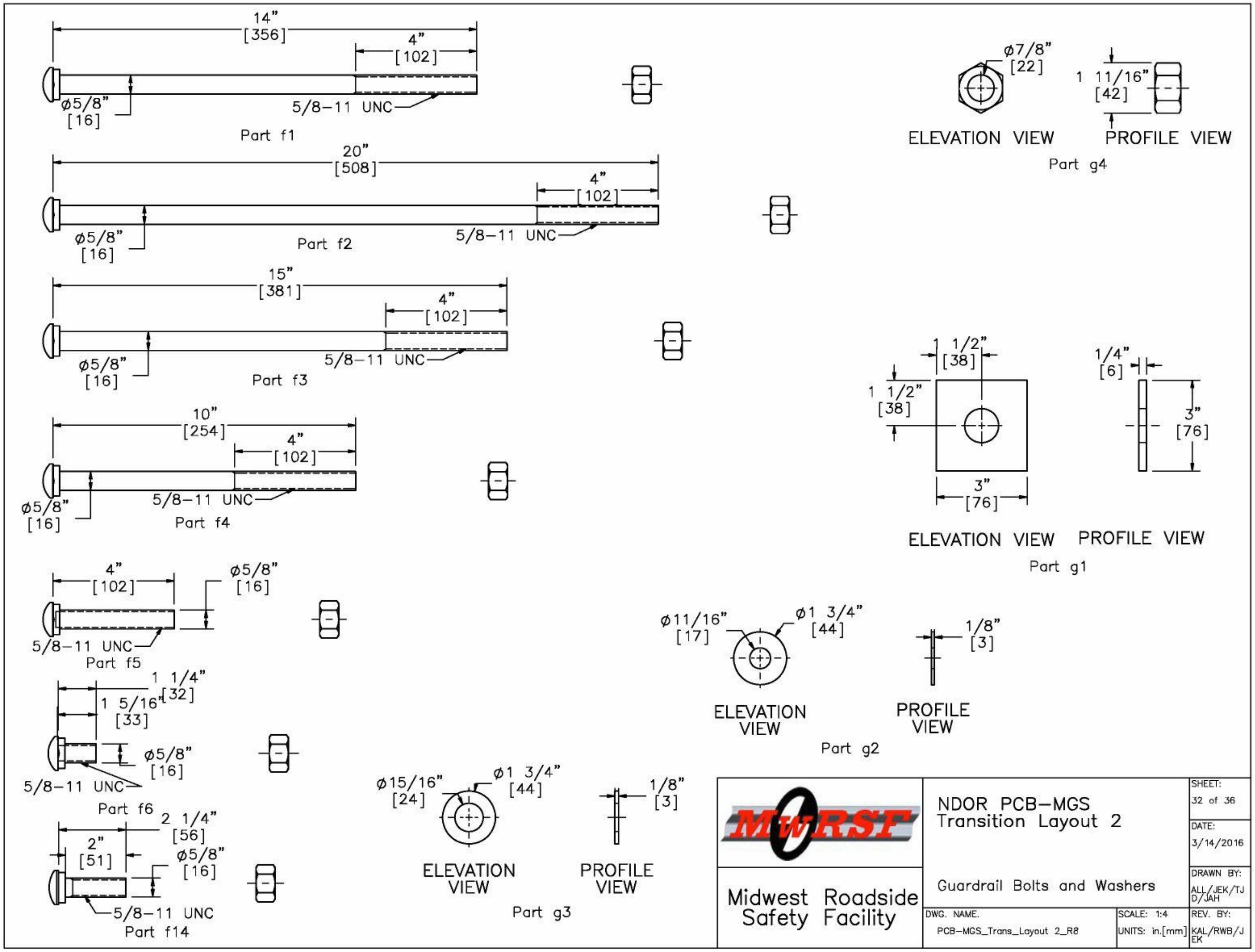


Figure 50. Guardrail Bolts and Washers, Test No. MGSPCB-1

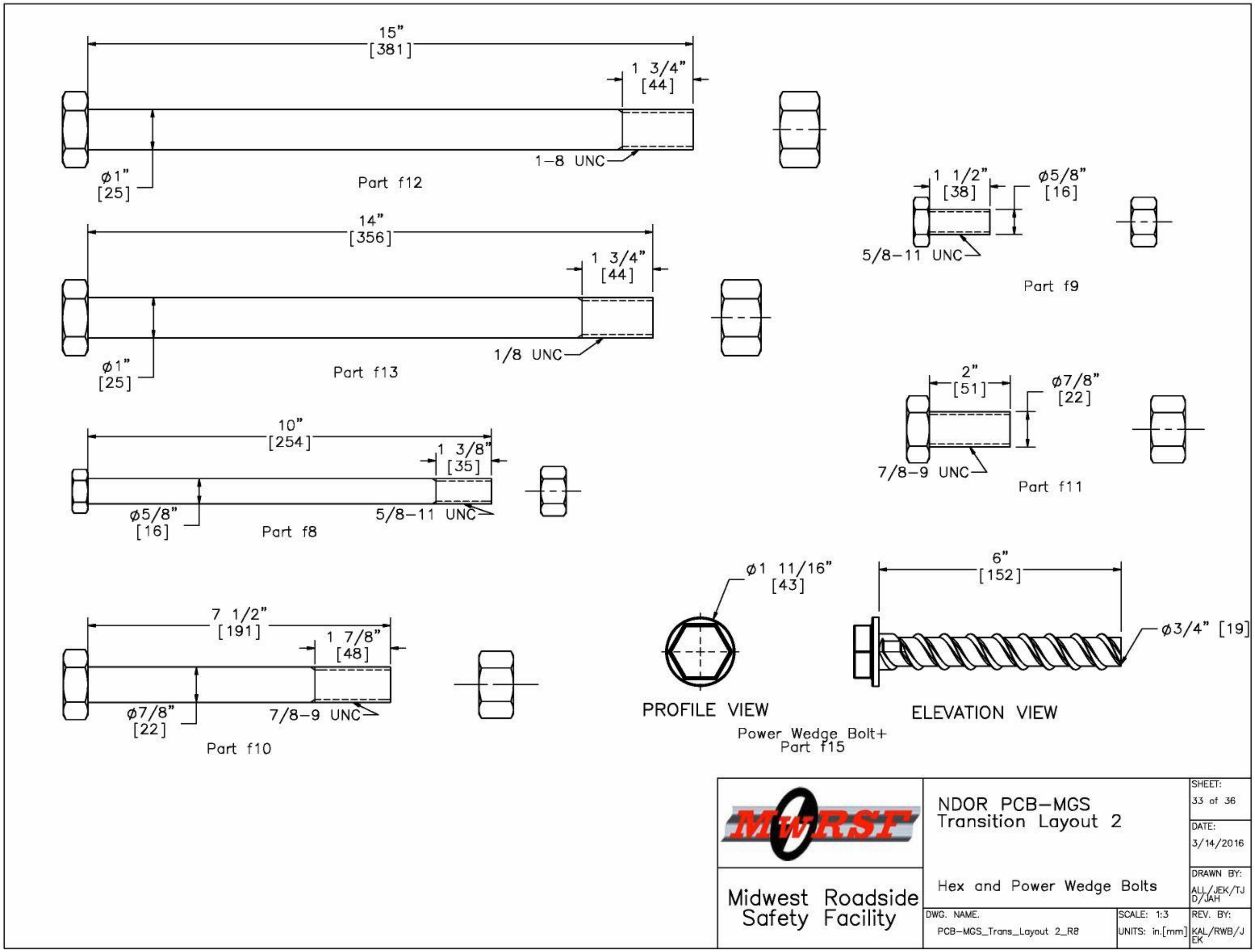


Figure 51. Hex and Power Wedge Bolts, Test No. MGSPCB-1

Item No.	QTY.	Description	Material Spec	Hardware Guide
a1	1	W–Beam End Shoe Section	10 gauge [3.4] AASHTO M180 Galv.	RWE02a
a2	15	12'–6" [3810] W–Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv.	RWM04a
a3	1	12'–6" [3810] W–Beam MGS End Section	12 gauge [2.7] AASHTO M180 Galv.	RWM14a
a4	16	W6"x8.5" [W152x12.6], 72" Long [1829] Steel Post	ASTM A992 Min. 50 ksi [345 MPa] Steel Galv. or W6x9 [W152x13.4] ASTM A36 Min. 36 ksi [248 MPa] Steel Galv.	PWE06
a5	16	6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	PDB10a
a6	16	16D Double Head Nail	–	–
b1	2	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots 18" [457] above or below ground tension face)	PDF01
b2	2	72" [1829] Long Foundation Tube	ASTM A500 Grade B Galv.	PTE06
b3	1	Ground Strut Assembly	ASTM A36 Steel Galv.	PFP02
b4	1	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Grade B Schedule 40 Galv.	FMM02
b5	1	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel Galv.	FPB01
b6	1	Anchor Bracket Assembly	ASTM A36 Steel Galv.	FPA01
c1	4	Blockout Mounting Plate	ASTM A36 Steel Galv.	–
c2	1	6"x17 3/4"x14 1/4" [152x451x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	–
c3	1	6"x12 3/4"x14 1/4" [152x324x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	–
c4	1	6"x7 3/4"x14 1/4" [152x197x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	–
c5	1	6"x2 3/4"x14 1/4" [152x70x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	–
d1	11	Portable Concrete Barrier	min f'c=5000 psi [34.5 MPa]	–
d2	10	1 1/4" [32] Dia., 28" [711] Long Connector Pin	ASTM A36	FMW02
d3	132	1/2" [13] Dia., 72" [1829] Long Form Bar	ASTM A615 Grade 60	–
d4	22	1/2" [13] Dia., 146" [3708] Long Longitudinal Bar	ASTM A615 Grade 60	–
d5	33	5/8" [16] Dia., 146" [3708] Long Longitudinal Bar	ASTM A615 Grade 60	–
d6	66	3/4" [19] Dia., 36" [914] Long Anchor Loop Bar	ASTM A615 Grade 60	–
d7	22	3/4" [19] Dia., 102" [2591] Long Connection Loop Bar	ASTM A709 Grade 70 or A706 Grade 60	–
d8	22	3/4" [19] Dia., 91" [2311] Long Connection Loop Bar	ASTM A709 Grade 70 or A706 Grade 60	–

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NDOR PCB–MGS Transition Layout 2

Bill of Materials

SHEET: 34 of 36
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DWG. NAME. PCB–MGS_Trans_Layout 2_R8
SCALE: 1:768
UNITS: in.[mm]
REV. BY: KAL/RWB/JEK

Figure 52. Bill of Materials, Test No. MGSPCB-1

Item No.	QTY.	Description	Material Spec	Hardware Guide
d9	22	3/4" [19] Dia., 101" [2565] Long Connection Loop Bar	ASTM A709 Grade 70 or A706 Grade 60	–
e1	1	Connector Plate Face Plate	ASTM A36 Steel Galv.	–
e2	1	3 5/8" [92] Connector Plate Vertical Gusset	ASTM A36 Steel Galv.	–
e3	1	3 1/2" [88] Connector Plate Vertical Gusset	ASTM A36 Steel Galv.	–
e4	1	2 5/8" [66] Connector Plate Vertical Gusset	ASTM A36 Steel Galv.	–
e5	1	2 1/2" [64] Connector Plate Vertical Gusset	ASTM A36 Steel Galv.	–
e6	1	29 1/2" [749] Long Connector Plate Horizontal Gusset	ASTM A36 Steel Galv.	–
e7	1	2 1/4" [57] x 3 3/16" [80] Connector Plate Horizontal Gusset	ASTM A36 Steel Galv.	–
e8	1	12 1/2" [318] x 3" [76] Connector Plate Horizontal Gusset	ASTM A36 Steel Galv.	–
e9	1	9 3/8" [239] Long Connector Plate Horizontal Gusset	ASTM A36 Steel Galv.	–
e10	1	2 1/4" [57] x 2 13/16" [71] Connector Plate Horizontal Gusset	ASTM A36 Steel Galv.	–
e11	1	12 1/2" [318] x 2 5/8" [67] Connector Plate Horizontal Gusset	ASTM A36 Steel Galv.	–
e12	1	7 9/16" [192] Long Connector Plate Horizontal Gusset	ASTM A36 Steel Galv.	–
f1	16	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBB06
f2	1	5/8" [16] Dia. UNC, 20" [508] Long Guardrail Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBB07
f3	1	5/8" [16] Dia. UNC, 15" [381] Long Guardrail Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBB07
f10	2	7/8" Dia. [22] UNC, 7 1/2" [191] Long Hex Head Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBX22a
f11	5	7/8" [22] Dia. UNC, 2" [51] Long Heavy Hex Bolt	Bolt ASTM A325 Galv.	FBX22b
f12	1	1" [25] Dia. UNC, 15" [381] Long Heavy Hex Bolt and Nut	Bolt ASTM A325 Galv., Nut ASTM A563 A Galv.	FBX27b
f13	3	1" [25] Dia., UNC, 14" [356] Long Heavy Hex Bolt and Nut	Bolt ASTM A325 Galv., Nut ASTM A563 A Galv.	FBX27b
f14	48	5/8" [16] Dia. UNC, 2" [51] Long Guardrail Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563A Galv.	FBB02
f15	8	ϕ3/4" x 6" [M20x152] Power Wedge Bolt+	Galvanized	FWR01

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NDOR PCB–MGS Transition Layout 2

Bill of Materials Continued

SHEET: 35 of 36
DATE: 3/14/2016
DRAWN BY: ALL/JEK/TJD/JAH
DWG. NAME. PCB–MGS_Trans_Layout 2_R8
SCALE: 1:8
UNITS: in.[mm]
REV. BY: KAL/RWB/JEK

Figure 53. Bill of Materials Continued, Test No. MGSPCB-1

Item No.	QTY.	Description	Material Spec	Hardware Guide
f4	1	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBB06
f5	1	5/8" [16] Dia. UNC, 4" [102] Long Guardrail Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBB01
f6	40	5/8" [16] Dia. UNC, 1 1/4" [32] Long Guardrail Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBB01
f7	2	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBB03
f8	2	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBX16a
f9	8	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt ASTM A307 Grade A Galv., Nut ASTM A563 A Galv.	FBX16a
g1	4	3"x3"x1/4" [76x76x6] Square Washer	A572 Grade 50 Galvanized	FWR01
g2	27	5/8" [16] Dia. Plain Round Washer	ASTM F844 Galv.	FWC16a
g3	4	7/8" [22] Dia. Plain Round Washer	ASTM F844 Galv.	FWC22a
g4	5	7/8" [22] Dia. UNC Heavy Hex Nut	ASTM A563 DH Galv.	FBX14b
h1	2	BCT Anchor Cable End Swaged Fitting	Grade 5 – Galv.	–
h2	2	3/4" [190] Dia. 6x19 IWRC IPS Wire Rope	IPS Galv.	–
h3	2	115–HT Mechanical Splice – 3/4" [19] Dia.	As Supplied	–
h4	2	Crosby Heavy Duty HT – 3/4" [19] Dia. Cable Thimble	Stock No. 1037773 – Galv.	–
h5	2	Crosby G2130 or S2130 Bolt Type Shackle – 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3	Stock Nos. 1019597 and 1019604 – As Supplied	–
h6	2	Chicago Hardware Drop Forged Heavy Duty Eye Nut – Drilled and Tapped 1 1/2" [38] Dia. – UNF 12 [M36	Stock No. 107 – As Supplied	–
h7	1	TLL–50K–PTB Load Cell	–	–

Midwest Roadside Safety Facility

NDOR PCB–MGS Transition Layout 2

Bill of Materials Continued

SHEET: 36 of 36

DATE: 3/14/2016

DRAWN BY: ALL/JEK/TJD/JAH

DWG. NAME. PCB–MGS_Trans_Layout 2_R8

SCALE: 1:8

UNITS: in.[mm]

REV. BY: KAL/RWB/JEK

Figure 54. Bill of Materials Continued, Test No. MGSPCB-1

Figure 55. Test Installation, Test No. MGSPCB-1

Figure 56. Test Installation, Test No. MGSPCB-1

Figure 57. Test Installation, Test No. MGSPCB-1

Figure 58. Test Installation, Test No. MGSPCB-1

6 FULL-SCALE CRASH TEST NO. MGSPCB-1

6.1 Static Soil Test

Before full-scale crash test no. MGSPCB-1 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

6.2 Weather Conditions

Test no. MGSPCB-1 was conducted on July 20, 2015 at approximately 12:30 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 3.

Table 3. Weather Conditions, Test No. MGSPCB-1

Temperature	86° F
Humidity	53%
Wind Speed	6 mph
Wind Direction	310° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.03 in.
Previous 7-Day Precipitation	0.64 in.

6.3 Test Description

The 4,914-lb (2,229-kg) pickup truck impacted the MGS to PCB transition at a speed of 63.2 mph (101.8 km/h) and at an angle of 25.3 degrees. Initial vehicle impact was to occur at the centerline of post no. 14, as shown in Figure 63, which was selected using LS-DYNA analysis to maximize pocketing and the probability of wheel snag. The actual point of impact was 2½ in. (64 mm) downstream from the intended impact point. A sequential description of the impact events is contained in Table 4. A summary of the test results and sequential photographs are shown in Figure 59. Additional sequential photographs are shown in Figures 60 and 61. Documentary photographs of the crash test are shown in Figure 62. The vehicle came to rest 234 ft – 1 in. (71.3 m) downstream from impact and 21 ft – 11 in. (6.7 m) in front of the barrier oriented downstream. The vehicle trajectory and final position are shown in Figures 59 and 64.

Table 4. Sequential Description of Impact Events, Test No. MGSPCB-1

TIME (sec)	EVENT
0.000	The vehicle impacted the barrier 2½ in. (64 mm) downstream from post no. 14.
0.006	Vehicle's right-front bumper deformed.
0.008	Vehicle's right headlight and right fender deformed.
0.018	Vehicle's right-front tire contacted rail downstream from post no. 14, and post no. 14 deflected backward.
0.022	Post no. 16 twisted counterclockwise.
0.026	Post no. 10 rotated backward, and post no. 15 twisted clockwise and deflected downstream.
0.030	Post no. 14 twisted clockwise, vehicle's right-front door deformed, and post nos. 9 and 11 twisted clockwise.
0.034	Post nos. 5, 6, 7, 8, and 12 began to twist clockwise.
0.036	Post no. 13 twisted clockwise, and post no. 15 twisted counterclockwise.
0.040	Vehicle hood deformed, post no. 15 rotated backward, and post no. 4 twisted clockwise.
0.046	Post no. 3 twisted clockwise, and post no. 15 deflected downstream.
0.052	Vehicle's right-rear door deformed, and post no. 13 deflected backward.
0.054	Post no. 16 deflected backward, vehicle yawed away from barrier, and post no. 15 bent downstream.
0.060	Rail detached from post bolt at post no. 15.
0.064	Post no. 16 deflected downstream.
0.072	Blockout no. 15 twisted counterclockwise, and post no. 15 twisted clockwise.
0.082	Post no. 17 deflected backward.
0.088	Vehicle's right-front tire contacted post no. 15.
0.110	Top of vehicle's right-front door pulled away from frame.
0.114	Post no. 16 bent downstream.
0.120	Rail detached from post bolt at post no. 16, and post no. 18 deflected backward.
0.134	Post no. 17 twisted counterclockwise.
0.138	Post no. 18 twisted counterclockwise.
0.144	Post no. 16 contacted concrete barrier no. 1 and became wedged against it.
0.146	Concrete barrier no. 1 rotated counterclockwise, and post no. 17 bent backward.
0.156	Vehicle's right front tire contacted post no. 16.
0.180	Vehicle's right quarter panel contacted rail at post no. 14.
0.182	Post no. 14 bent upstream, vehicle's tailgate deformed, upstream end of concrete barrier no. 1 deflected backward, and post no. 17 contacted concrete barrier no. 1.
0.186	Vehicle's left-front tire became airborne, and right taillight deformed.

0.194	Rail detached from post bolt at post no. 17.
0.198	Vehicle rolled toward barrier.
0.203	Post no. 18 contacted concrete barrier no. 1.
0.224	Rail between post nos. 16 and 17 contacted concrete barrier no. 1.
0.243	Vehicle was parallel to system at a speed of 48.3 mph (77.7 km/h).
0.252	Vehicle pitched downward, and blockout no. 15 detached from post no. 15.
0.282	Concrete barrier no. 2 rotated counterclockwise.
0.284	Concrete barrier no. 2 deflected backward.
0.290	Vehicle’s left-rear tire became airborne.
0.298	Vehicle’s right taillight detached.
0.312	Vehicle pitched upward, and concrete barrier no. 1 rolled away from traffic side of system.
0.362	Vehicle’s right headlight detached.
0.402	Vehicle’s right-front tire was detached.
0.408	Vehicle rolled away from barrier.
0.412	Vehicle pitched downward.
0.448	Concrete barrier no. 1 rolled toward traffic side of system.
0.520	Vehicle exited system at a speed of 38.6 mph (62.1 km/h) and at an angle of 21.0 degrees.
0.610	Vehicle’s left-front tire regained contact with ground.
0.730	Vehicle rolled toward barrier.
0.746	Vehicle pitched upward.
0.780	Vehicle’s left-rear tire regained contact with ground.
0.826	Vehicle’s right-rear tire regained contact with ground.
0.978	Vehicle rolled away from barrier.
0.984	Vehicle pitched downward.

6.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 65 through 70. Barrier damage consisted of rail deformation, bending of the steel posts, contact marks on the front face of the concrete segments, and spalling of the concrete. The length of vehicle contact along the barrier was approximately 37 ft – 8½ in. (11.5 m), which spanned from 14¾ in. (375 mm) upstream from post no. 14 to 12 in. (305 mm) upstream from blockout no. 20.

Post no. 1 had vertical cracking at the middle of the front face along the entire length, and post no. 2 had cracking on the upstream side extending outward from the BCT hole. Post nos. 3 through 13 twisted downstream, and the front face of their blockouts had dents and gouging from the guardrail. The front flange of post no. 14 partially twisted clockwise along the length of the blockout, and blockout no. 14 had cracking on the bottom front upstream corner. Contact marks began 14¾ in. (375 mm) upstream of post no. 14 and were due to the right-rear corner of the vehicle slapping the guardrail after the initial impact. The bottom corrugation of the guardrail flattened from 13 in. (330 mm) upstream of post no. 15 to post no. 17. Post no. 15 had a dent in the front flange 17 in. (432 mm) from the top, and blockout no. 15 disengaged from the rail due to bolt shear. Post no. 16 twisted and bent downstream with the downstream side of the post against the upstream face of concrete barrier no. 1. The downstream flanges of post no. 16 were bent outward, and the steel fractured at the downstream bottom blockout holes. Blockout no. 16 was partially fractured, and the post bolt was bent 90 degrees. Post no. 17 bent downstream, and the blockout was partially fractured. The top back upstream flange of post no. 17 was bent inward. Post no. 18 had a dent located 2 in. (51 mm) above the ground line on the back downstream flange. A kink formed on the top corrugation, extending from 11½ in. (292 mm) upstream of post no. 18 to 17 in. (432 mm) downstream of post no. 18. The blockout mounts that connected the rail to the PCB, and the mount for the end shoe transition were undamaged.

Contact marks on concrete barrier no. 1 extended 17 in. (432 mm) up the front face of the barrier and ran diagonally to the first anchor hole, and contact marks from the tire started 24 in. (610 mm) upstream of the midpoint on the bottom tapper. An indented contact mark extended upward 28 in. (711 mm) on the front face of concrete barrier no. 1 and stopped 6 in. (152 mm) downstream of the midpoint. Concrete barrier no. 1 also had spalling on the upstream corner located 8 in. (203 mm) and 12 in. (305 mm) from the ground line. Concrete barrier no. 2 had contact marks 6 in. (152 mm) upstream from blockout no. 19 and 12 in. (305 mm) upstream from blockout no. 20.

The maximum permanent set of the rail, posts, and concrete barriers for the system was 26¾ in. (679 mm) at the rail at post no. 16, 22½ (572 mm) at post no. 16, and 5⅝ in. (168 mm) at the downstream target on concrete barrier no. 1, as measured in the field. The maximum lateral dynamic deflection of the rail, posts, and concrete barriers was 36.1 in. (917 mm) at the rail at post no. 16, 27.7 in. (704 mm) at post no. 15, and 6.7 in. (170 mm) at the downstream end of concrete barrier no. 1, as determined from high-speed digital video analysis. The working width of the system was found to be 58.7 in. (1,491 mm), also determined from high-speed digital video analysis.

6.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 71 through 73. The maximum occupant compartment deformations are listed in Table 5 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH-established deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

The majority of the damage was concentrated on the right-front corner and right side of the vehicle where the impact occurred. The right headlight and fog light disengaged. The right side of the front bumper was crushed inward and back. The right-front wheel detached. The right-front fender had a 14-in. (356-mm) long by 2-in. (51-mm) deep dent located above the wheel well. The right-front door had a 14-in. (356-mm) long dent along the bottom and was separated 1¼ in. (32 mm) from the door frame. Contact marks ran along the right side of the vehicle, starting at the front fender and extending 67 in. (1,702 mm) to the rear door.

The front of the right quarter panel had an 11-in. (279-mm) scrape approximately 14 in. (356 mm) from the bottom. The right quarter panel had contact marks starting behind the wheel well and extending 11 in. (279 mm) toward the rear of the vehicle and a 15-in. (381-mm) by 17-in. (432-mm) dent located behind the wheel well. The right-rear tire deflated due to a 2-in. (51-mm) cut at the outer edge, and the right-rear wheel had a 1-in. (25-mm) fracture on the outer wheel rim. The right taillight disengaged, and the right-rear bumper and tailgate partially disengaged.

The vehicle grill was partially disengaged, and the windshield had a 26-in. (660-mm) diameter crack with spidering. The airbags deployed due to impact with a secondary concrete barrier system that was set up to stop the vehicle after exiting the system and not due to impact with the MGS to PCB transition system. Although some front-end damage may be associated with this secondary impact, it is indistinguishable from the primary system impact damage.

Table 5. Maximum Occupant Compartment Deformations by Location, Test No. MGSPCB-1

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	0.36 (9)	≤ 9 (229)
Floor Pan & Transmission Tunnel	0.24 (6)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	0.78 (20)	≤ 12 (305)
Side Door (Above Seat)	0.56 (14)	≤ 9 (229)
Side Door (Below Seat)	0.87 (22)	≤ 12 (305)
Roof	0	≤ 4 (102)
Windshield	0	≤ 3 (76)

6.6 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 6. Note that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 6. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 59. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

The vehicle airbag system was activated prior to test no. MGSPCB-1, and data was recorded in the Airbag Control Module (ACM) if the airbags fired. In this test, the impact with the barrier system was not sufficient to fire the airbags, but a secondary impact with downstream protection PCBs did cause the airbags to fire. The ACM acceleration and velocity data are compared to the standard acceleration transducers in Appendix E.

Table 6. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MGSPCB-1

Evaluation Criteria		Transducer		MASH Limits
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-12.63 (-3.85)	-12.80 (-3.90)	±40 (12.2)
	Lateral	-16.60 (-5.06)	-15.72 (-4.79)	±40 (12.2)
ORA g's	Longitudinal	19.77	20.34	±20.49
	Lateral	-11.03	-12.47	±20.49
MAX. ANGULAR DISPL. deg.	Roll	14.35	10.20	±75
	Pitch	-5.13	-6.15	±75
	Yaw	-39.86	-40.19	not required
THIV ft/s (m/s)		19.62 (5.98)	20.05 (6.11)	not required
PHD g's		20.60	20.64	not required
ASI		0.82	0.85	not required

6.7 Load Cells and String Potentiometers

The pertinent data from the load cells and string potentiometers was extracted from the bulk signal and analyzed using the transducer's calibration factor. The recorded data and analyzed results are detailed in Appendix F. The exact moment of impact could not be determined from the transducer data as impact may have occurred a few milliseconds prior to a measurable signal increase in the data. Thus, the extracted data curves should not be taken as precise time after impact, but rather a general time line between events within the data curve itself.

6.8 Discussion

The analysis of the test results for test no. MGSPCB-1 showed that the MGS to PCB transition system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix E, were deemed acceptable, because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle exited the barrier at an angle of 21.0 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. MGSPCB-1, conducted on the MGS to PCB transition system, was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-21.

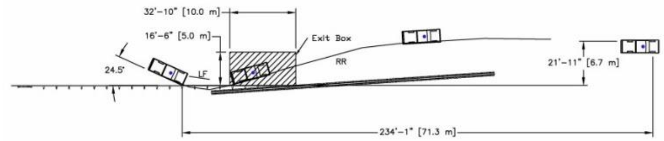
0.000 sec

0.056 sec

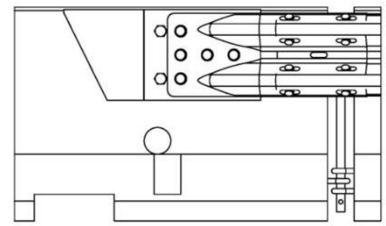
0.146 sec

0.243 sec

0.554 sec



- Test Agency .... MwRSF
- Test Number MGSPCB-1
- Date 7/20/2015
- MASH Test Designation 3-21
- Test Article .... MGS to PCB Transition
- Total Length .... 240.1 ft (73.2 m)
- Key Component – W-beam Guardrail
  - Thickness .... 12 ga. (2.66 mm)
  - Mounting Height .... 31 in. (787 mm)
- Key Component – ASTM 992 Steel Post
  - Length .... 72 in. (1,829 mm)
  - Embedment Depth .... 40 in. (1,016 mm)
  - Spacing .... 75 in. (1,905 mm)
- Key Component – 5,000 psi PCB
  - Length .... 150 in. (3,810 mm)
  - Width .... 22½ in. (572 mm)
  - Height .... 32 in. (813 mm)
- Soil Type .... Coarse Crushed Limestone
- Vehicle Make /Model .... 2008 Dodge Ram 1500
  - Curb .... 4,977 lb (2,258 kg)
  - Test Inertial .... 4,914 lb (2,229 kg)
  - Gross Static .... 5,079 lb (2,304 kg)
- Impact Conditions
  - Speed .... 63.2 mph (101.8 km/h)
  - Angle .... 25.3 deg
  - Impact Location .... 2½ in. (64 mm) downstream from post no. 14
- Impact Severity (IS) .... 119.6 kip-ft (162.2 kJ) > 106 kip-ft (144 kJ) limit from MASH
- Exit Conditions
  - Speed .... 38.6 mph (62.1 km/h)
  - Angle .... 21.0 deg
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory



- Vehicle Stopping Distance .... 234 ft – 1 in. (71.3 m) downstream
  - Lateral .... 21 ft – 11 in. (6.7 m) in front
- Vehicle Damage .... Moderate
  - VDS [16] 01-RFQ-4
  - CDC [17] 01-RDEW-4
  - Maximum Interior Deformation .... 0.87 in. (22 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 26¾ in. (679 mm)
  - Dynamic .... 36.1 in. (917 mm)
  - Working Width .... 58.7 in. (1,491 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH Limit
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-12.63 (-3.85)	-12.80 (-3.90)	±40 (12.2)
	Lateral	-16.60 (-5.06)	-15.72 (-4.79)	±40 (12.2)
ORA g's	Longitudinal	19.77	20.34	±20.49
	Lateral	-11.03	-12.47	±20.49
MAX ANGULAR DISP. deg.	Roll	14.35	10.20	±75
	Pitch	-5.13	-6.15	±75
	Yaw	-39.86	-40.19	not required
THIV – ft/s (m/s)		19.62 (5.98)	20.05 (6.11)	not required
PHD – g's		20.60	20.64	not required
ASI		0.82	0.85	not required

Figure 59. Summary of Test Results and Sequential Photographs, Test No. MGSPCB-1

0.000 sec

0.000 sec

0.060 sec

0.062 sec

0.134 sec

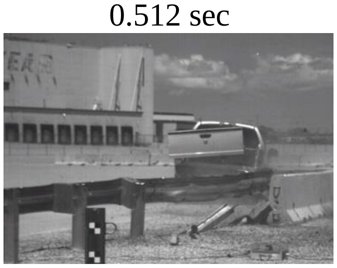
0.138

0.252 sec

0.188 sec

0.512 sec

0.290 sec



0.846 sec

0.448 sec

Figure 60. Additional Sequential Photographs, Test No. MGSPCB-1

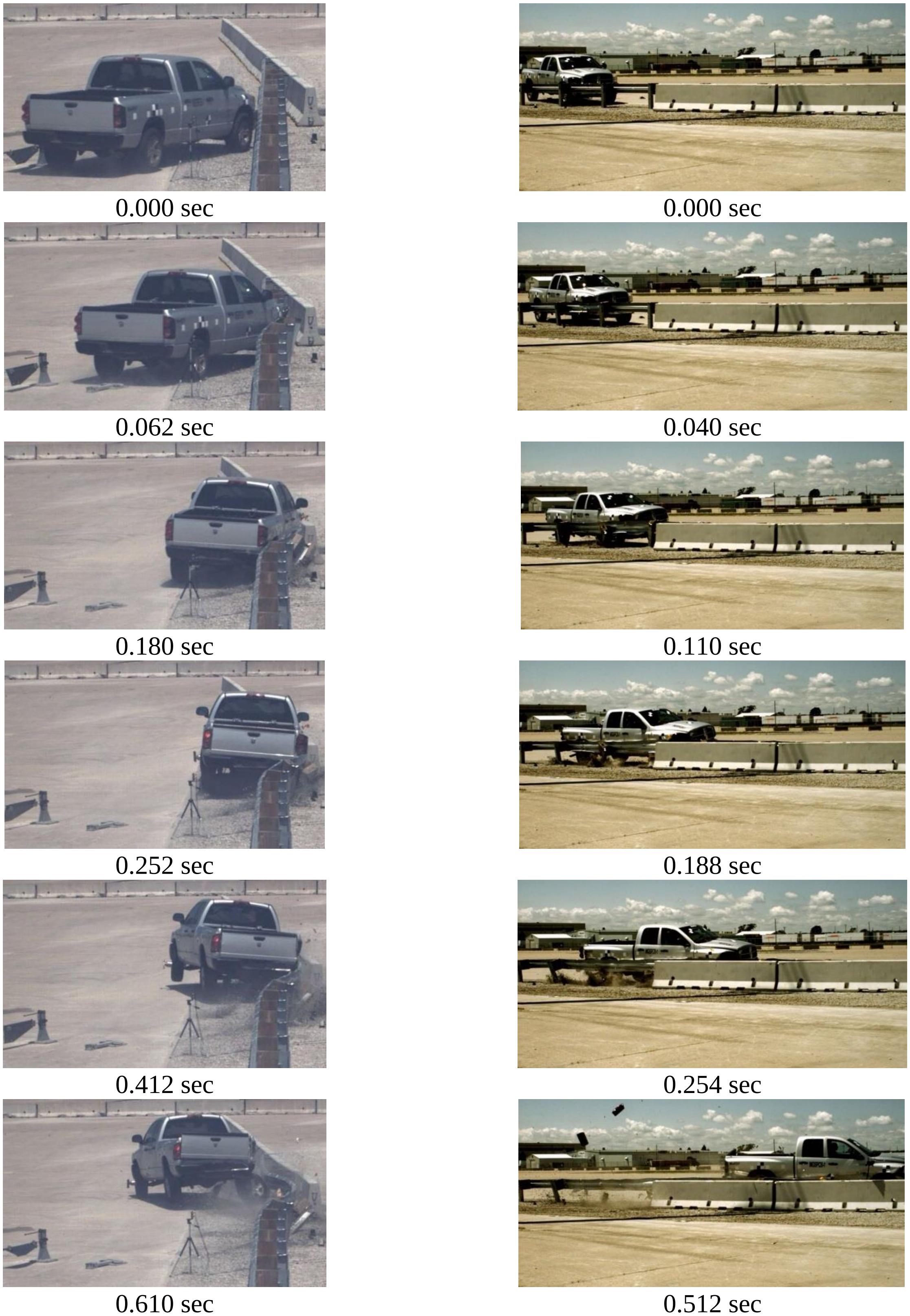


Figure 61. Additional Sequential Photographs, Test No. MGSPCB-1

Figure 62. Documentary Photographs, Test No. MGSPCB-1

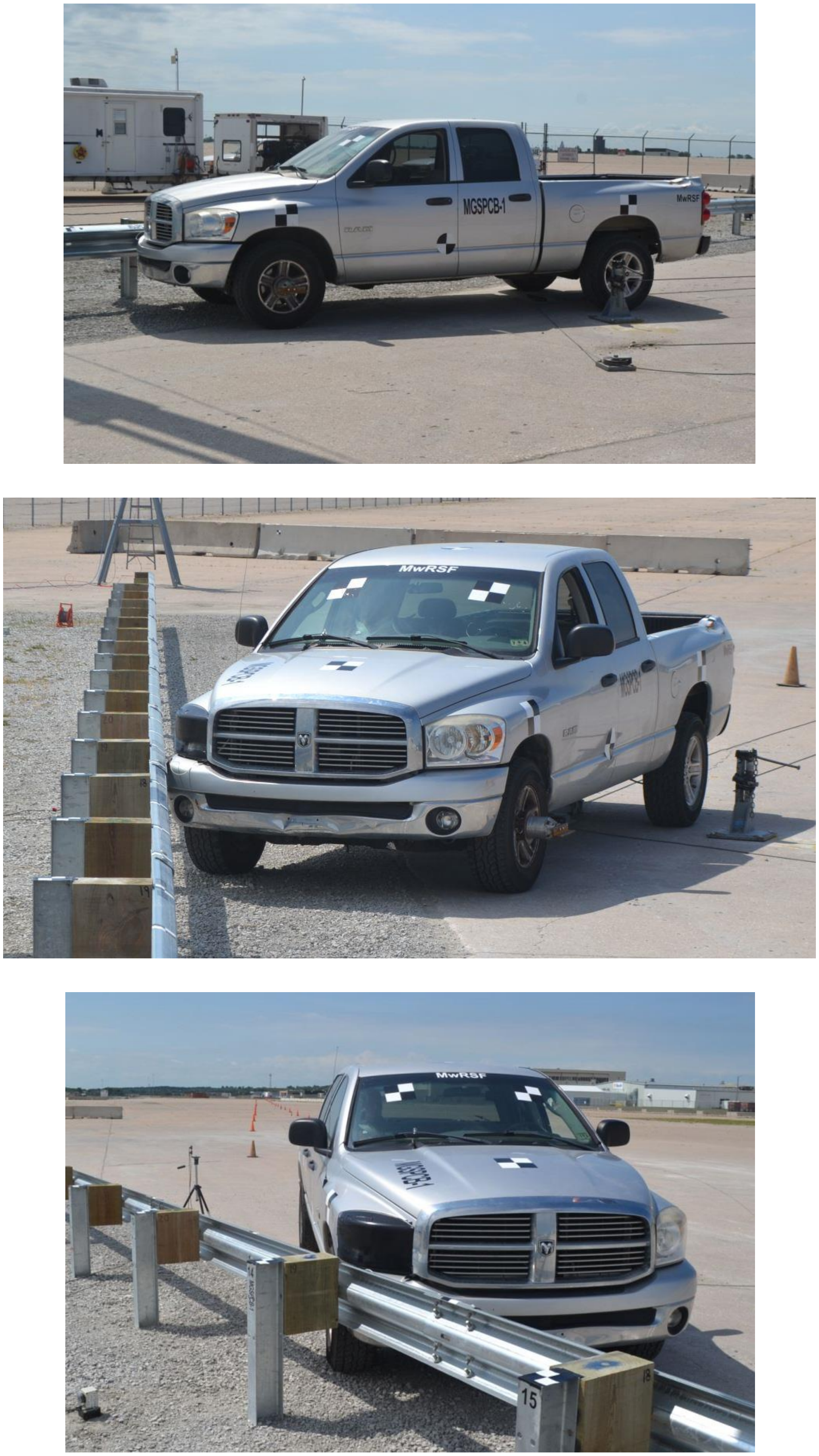


Figure 63. Impact Location, Test No. MGSPCB-1

Figure 64. Vehicle Final Position, Test No. MGSPCB-1

Figure 65. System Damage, Test No. MGSPCB-1

Figure 66. System Damage Between Post Nos. 12 and 15, Test No. MGSPCB-1

Figure 67. System Damage Between Post Nos. 14 and 18, Test No. MGSPCB-1

Figure 68. Post Nos. 16 and 17 Damage, Test No. MGSPCB-1

Figure 69. Transition Damage, Test No. MGSPCB-1

Figure 70. Damage at Non-Post Locations Nos. 30 through 23, Test No. MGSPCB-1

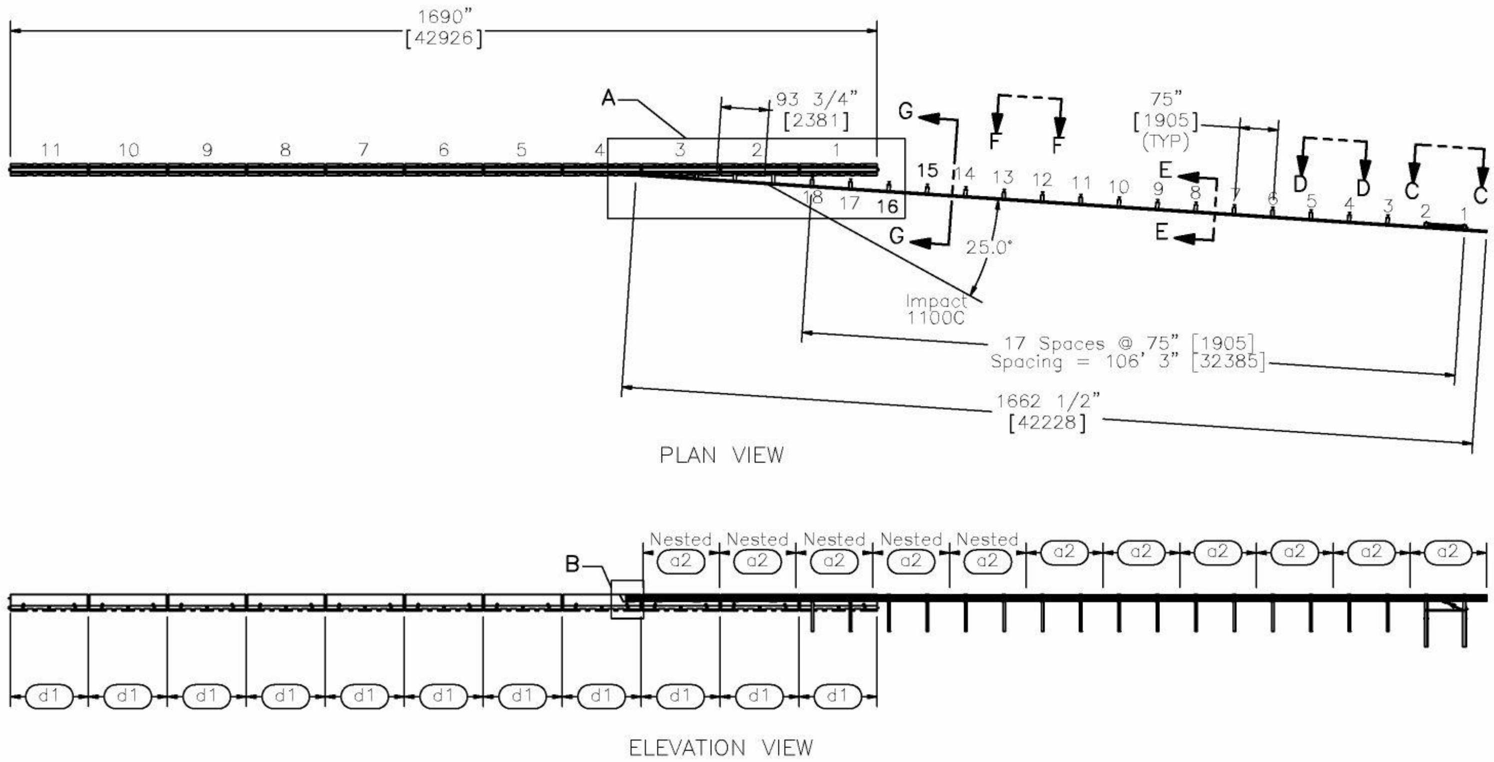
Figure 71. Vehicle Damage, Test No. MGSPCB-1

Figure 72. Windshield Damage and Occupant Compartment Deformation, Test No. MGSPCB-1

Figure 73. Undercarriage Damage, Test No. MGSPCB-1

7 DESIGN DETAILS, TEST NO. MGSPCB-2

The MGS to PCB transition test installation for test no. MGSPCB-2 was identical to that used in test no. MGSPCB-1, as shown in Figure 74. Photographs of the test installation are shown in Figures 75 through 77. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.



Notes: (1) Test shall be performed according to test designation no. 3–20 of MASH criteria.

(2) The impact location is 93.75" [2381] upstream from the centerline of the second splice upsrtream from the end shoe.

(3) The front edge of the soil pit should be at least 5' [1524] from the center of each post. The distance can be adjusted as long as the PCB system does not cross the front edge of the soil pit.

(4) Critical region is between post nos. 12 through 18 (ø3' holes).

(5) BCT anchors are placed in ø3' [914] holes, then backfilled and tamped with soil.

Midwest Roadside Safety Facility	NDOR PCB–MGS Transition MGSPCB–2	SHEET: 1 of 36
		DATE: 3/15/2016
	System Layout	DRAWN BY: JEK/TJD/JAH
	DWG. NAME. MGSPCB–2_R4	SCALE: 1:300 UNITS: in.[mm]	REV. BY: KAL/RWB/JEK

Figure 74. Test Installation Layout, Test No. MGSPCB-2

Figure 75. Test Installation, Test No. MGSPCB-2

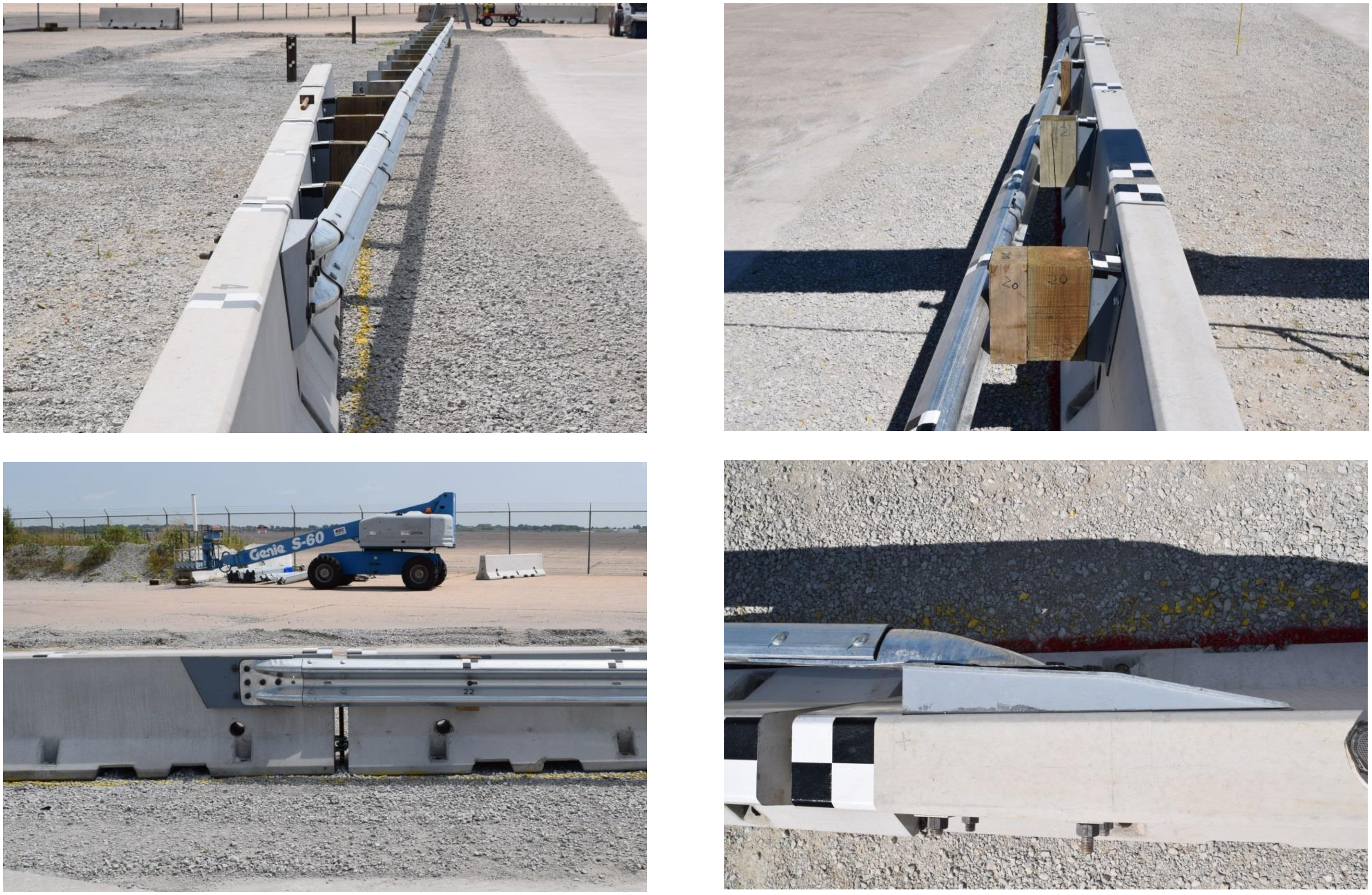


Figure 76. Test Installation, Test No. MGSPCB-2

Figure 77. Test Installation, Test No. MGSPCB-2

8 FULL-SCALE CRASH TEST NO. MGSPCB-2

8.1 Static Soil Test

Before full-scale crash test no. MGSPCB-2 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

8.2 Weather Conditions

Test no. MGSPCB-2 was conducted on July 30, 2015 at approximately 12:15 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 7.

Table 7. Weather Conditions, Test No. MGSPCB-2

Temperature	89° F
Humidity	31%
Wind Speed	14 mph
Wind Direction	220° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.02 in.
Previous 7-Day Precipitation	0.51 in.

8.3 Test Description

The 2,436-lb (1,105-kg) car impacted the MGS to PCB transition at a speed of 65.1 mph (104.8 km/h) and at an angle of 24.0 degrees. Initial vehicle impact was to occur 93.75 in. (2,381 mm) upstream from the centerline of the second splice upstream from the end shoe, as shown in Figure 83. This impact point was selected to maximize loading of the W-beam rail element and evaluate the propensity for the small car to snag on the tapered W-beam and the end shoe connection bracket as noted in Chapter 3. The actual point of impact was 5¾ in. (146 mm) upstream from the intended impact point. A sequential description of the impact events is contained in Table 8. A summary of the test results and sequential photographs are shown in Figure 78. Additional sequential photographs are shown in Figures 79 and 80. Documentary photographs of the crash test are shown in Figures 81 and 82. The vehicle came to rest 157 ft – 5 in. (48.0 m) downstream of impact and 22 ft (6.7 m) in front of the barrier oriented downstream. The vehicle trajectory and final position are shown in Figures 78 and 84.

Table 8. Sequential Description of Impact Events, Test No. MGSPCB-2

TIME (sec)	EVENT
0.000	Vehicle impacted barrier 99½ in. (2527 mm) upstream from centerline of the second splice upstream from end shoe.
0.002	Vehicle’s right headlight contacted rail between blockout nos. 19 and 20 and deformed.
0.006	Blockout nos. 19 and 20 rotated backward, and vehicle’s right side mirror deformed.
0.010	Concrete barrier no. 2 rolled away from traffic side of system.
0.014	Vehicle hood deformed and overrode rail between blockout nos. 19 and 20.
0.024	Vehicle’s left headlight deformed, blockout nos. 19 and 20 deflected backward, and vehicle’s left fender deformed.
0.030	Vehicle yawed away from barrier.
0.032	Post no. 18 rotated clockwise, vehicle pitched downward, and post nos. 3 and 4 rotated clockwise.
0.036	Left-front side of roof deformed, and post no. 18 began to deflect backward.
0.040	Post no. 5 rotated clockwise, post no 2 deflected backward, and vehicle’s right-front tire contacted concrete barrier no. 2.
0.044	Concrete barrier no. 2 rotated counterclockwise, blockout no. 21 deflected backward, concrete barrier no. 3 rolled away from traffic side of system and rotated counterclockwise, post nos. 6, 7, 9, and 10 rotated clockwise, and post nos. 8, 16, and 17 rotated clockwise.
0.048	Post nos. 11 and 14 rotated clockwise.
0.050	Blockout no. 22 deflect backward, concrete barrier no. 1 rolled away from the traffic side of system, concrete barrier no. 2 rotated clockwise, post no. 12 rotated clockwise, vehicle’s right airbag deployed, vehicle’s left-front door deformed, post no. 13 rotated clockwise, and the upstream end of concrete barrier no. 3 fractured.
0.054	Vehicle’s windshield deformed due to airbag contact, and concrete barrier no. 1 rotated clockwise.
0.060	Vehicle’s right-front door deformed and vehicle rolled away from barrier.
0.074	Concrete barrier no. 4 rotated clockwise.
0.076	Concrete barrier no. 2 deflected backward and vehicle’s right-front window shattered.
0.080	Post no. 17 deflected backward.
0.084	Blockout no. 19 rotated forward and counterclockwise.
0.108	Concrete barrier no. 4 rolled away from traffic side of system.
0.112	Concrete barrier no. 5 rolled away from traffic side of system.
0.134	Blockout no. 20 rotated forward.
0.136	Concrete barrier no. 3 rolled toward traffic side of system.

0.146	Concrete barrier no. 4 rotated counterclockwise.
0.150	Vehicle rolled toward barrier.
0.154	Vehicle pitched upward and concrete barrier no. 6 rotated counterclockwise.
0.162	Concrete barrier no. 5 rotated clockwise and concrete barrier no. 6 deflected backward.
0.232	Vehicle was parallel to barrier at a speed of 43.6 mph (70.2 km/h).
0.240	Rail detached from post bolt at blockout no. 19.
0.244	Vehicle hood was jarred open.
0.264	Vehicle pitched downward.
0.290	Blockout no. 19 rotated clockwise.
0.354	Vehicle rolled away from barrier.
0.437	Vehicle exited system at a speed of 41.2 mph (66.3 km/h) and an angle of 13.6 degrees.

8.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 85 through 89. Barrier damage consisted of rail deformation, contact marks on the front face of the concrete segments, and spalling of the concrete. The length of vehicle contact along the barrier was approximately 33 ft – 8¾ in. (10.3 m), which spanned from 5¾ in. (146 mm) upstream of the intended impact point to 8½ in. (216 mm) downstream of the upstream end of concrete barrier no. 5.

Post nos. 1 and 2 rotated downstream and blockout nos. 3 through 18 twisted downstream. Post no. 18 deflected backward. The rail disengaged from the bolt at blockout no. 19 and the blockout mounting plate translated ⅝ in. (16 mm) upstream. The rail kinked at the bottom of the rail at blockout no. 19 and at the top of the rail 3¾ in. (95mm) upstream of blockout no. 19. Blockout no. 20 twisted upstream and had a vertical crack at the bolt hole. The blockout mounting plate translated ⅜ in. (10 mm) upstream, and the rail flattened at the bottom corrugation at blockout no. 20. Blockout no. 21 rotated upstream, and the mounting plate translated ¾ in. (19 mm) upstream. Blockout no. 22 rotated upstream, and the mounting plate translated ⅝ in. (16 mm) upstream. The blockout mounts that connected the rail to the PCB and the mount for the end shoe transition were undamaged.

Concrete barrier no. 2 had a 14-in. (356-mm) tall by 4¾-in. (121-mm) long by 2½-in. (64-mm) deep spall located on the upstream front corner 7 in. (178 mm) from the top. Tire marks began 54¼ in. (1,378 mm) upstream from the downstream end and traveled upward to a maximum height of 19 in. (483 mm). The tire marks continued onto concrete barrier no. 3 and extended across the entire front face. Concrete barrier no. 3 had spalling on the upstream back corner of the barrier extending laterally from the slope break point to the top. The reinforcement and loop bar were exposed. Tire marks extended along the entire bottom front face of concrete barrier no. 4 with a maximum contact height of 7 in. (178 mm) from the bottom.

The maximum permanent set of the rail, posts, and concrete barriers for the system was 23½ in. (597 mm) at the rail at the midspan between blockout nos. 20 and 21, 4⅛ in. (105 mm) at post no. 18, and 25⅞ in. (657 mm) at the downstream target on concrete barrier no. 2, as measured in the field. The maximum lateral dynamic deflection of the rail, posts, and concrete barriers for the system was 26.3 in. (667 mm) at the rail at blockout no. 20, 3.1 in. (78 mm) at post no. 18, and 28.1 in. (714 mm) at the downstream target of concrete barrier no. 2, as determined from high-speed digital video analysis. The working width of the system was found to be 61.4 in. (1,560 mm), also determined from high-speed digital video analysis.

8.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 90 through 92. The maximum occupant compartment deformations are listed in Table 9 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH occupant compartment deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

The majority of the damage was concentrated on the right-front corner and right side of the vehicle where the impact occurred. The right-front fender was displaced back 5½ in. (140 mm) and left 7 in. (178 mm). The right headlight disengaged. The right-front wheel cover was bent, and the right-front tire was partially disengaged from the wheel. Crush began at the front fender extending back 45 in. (1,143 mm) and upward 4 in. (102 mm). Additional crush started 15 in. (381 mm) up from the bottom of the right-front wheel well and extended back 28 in. (711 mm) and up 4 in. (102 mm).

The right A-Pillar buckled at 9 in. (229 mm) and 22 in. (559 mm) from the bottom. The right-front door was ajar 3 in. (76 mm) at the top, and the right-front window was shattered. The right-front door had 3-in. (76-mm) tall contact marks starting 21 in. (533 mm) from the bottom. The roof had two depressions starting at the right edge. A 2-in. (51-mm) by 2-in. (51-mm) depression was located 2 in. (51 mm) from the front edge and the other was a 10-in. (254-mm) by 10-in. (254-mm) depression located 16 in. (406 mm) from the front edge. Contact marks started 15 in. (381 mm) and 23 in. (584 mm) from the bottom of the right-rear door and extended to the rear of the car. An 11-in. (279-mm) tall by ¾-in. (19-mm) deep dent started at the right taillight and extended 26 in. (660 mm) forward.

The left-front door was ajar ⅜ in. (10 mm) at the top. The left-front tire separated from the wheel. The left headlight partially disengaged, but the cables were still attached. The windshield deformed and shattered due to airbag deployment, not from interaction with the barrier, which can be seen in the high-speed video. Because the windshield shatter was not due to vehicle interaction or direct contact with the barrier system, it was not considered in the test evaluation. The windshield also had a 23-in. (584-mm) long tear at the top located 10 in. (254 mm) from the left A-Pillar also caused by the airbag deployment.

The front bumper separated from the left-front fender and the right-front bumper was torn away 19 in. (483 mm) from the center. The hood had two dents on the front edge, a 2½-in. (64-mm) deep dent and a 1¾-in. (44-mm) deep dent, located 8 in. (203 mm) and 14 in. (356 mm) right of center, respectively. The hood also had a 7-in. (178-mm) long by 1-in. (25-mm) deep dent on the underside located 14 in. (356 mm) right of center at the front edge of the hood. The hood latch had disengaged, and the hood was open.

Table 9. Maximum Occupant Compartment Deformations by Location, Test No. MGSPCB-2

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	1.08 (28)	≤ 9 (229)
Floor Pan & Transmission Tunnel	0.27 (7)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	0.82 (21)	≤ 12 (305)
Side Door (Above Seat)	2.83 (72)	≤ 9 (229)
Side Door (Below Seat)	1.70 (43)	≤ 12 (305)
Roof	0.87 (22)	≤ 4 (102)
Windshield	N/A	≤ 3 (76)

8.6 Occupant Risk

The calculated OIVs and maximum 0.010-sec ORAs in both the longitudinal and lateral directions are shown in Table 10. Note that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 10. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 78. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix G.

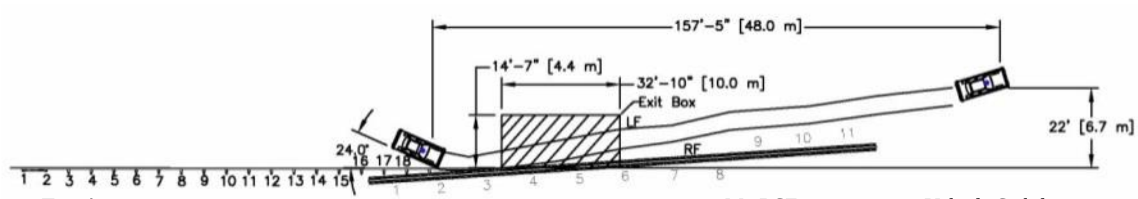
8.7 Discussion

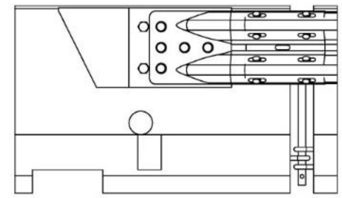
The analysis of the test results for test no. MGSPCB-2 showed that the MGS to PCB transition system adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix G, were deemed acceptable, because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle exited the barrier at an angle of 13.6 degrees and its trajectory did not violate the bounds of the exit box. Therefore, test no. MGSPCB-2, conducted on the MGS to PCB transition system, was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-20.

Table 10. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MGSPCB-2

Evaluation Criteria		**Transducer**		**MASH Limits**
		SLICE-1 (primary)	**SLICE-2**	
OIV ft/s (m/s)	Longitudinal	-23.82 (-7.26)	-22.86 (-6.97)	±40 (12.2)
	Lateral	-22.38 (-6.82)	-22.03 (-6.71)	±40 (12.2)
ORA g's	Longitudinal	-6.14	-5.79	±20.49
	Lateral	-6.85	-7.20	±20.49
MAX. ANGULAR DISPL. deg.	Roll	-9.62	-10.49	±75
	Pitch	-5.92	-6.46	±75
	Yaw	-43.56	-43.68	not required
THIV ft/s (m/s)		29.54 (9.00)	29.38 (8.95)	not required
PHD g's		9.01	8.86	not required
ASI		1.72	1.71	not required

0.000 sec | 0.048 sec | 0.150 sec | 0.232 sec | 0.422 sec

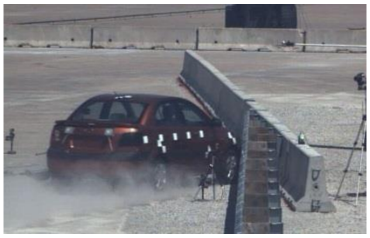




- Test Agency .... MwRSF
- Test Number MGSPCB-2
- Date 7/30/2015
- MASH Test Designation 3-20
- Test Article .... MGS to PCB Transition
- Total Length .... 240.1 ft (73.2 m)
- Key Component – W-beam Guardrail
  - Thickness .... 12 ga. (2.66 mm)
  - Mounting Height .... 31 in. (787 mm)
- Key Component – ASTM 992 Steel Post
  - Length .... 72 in. (1,829 mm)
  - Embedment Depth .... 40 in. (1,016 mm)
  - Spacing .... 75 in. (1,905 mm)
- Key Component – 5,000 psi PCB
  - Length .... 150 in. (3,810 mm)
  - Width .... 22½ in. (572 mm)
  - Height .... 32 in. (813 mm)
- Soil Type .... Coarse Crushed Limestone
- Vehicle Make /Model .... 2008 Kia Rio
  - Curb .... 2,434 lb (1,104 kg)
  - Test Inertial .... 2,436 lb (1,105 kg)
  - Gross Static .... 2,601 lb (1,180 kg)
- Impact Conditions
  - Speed .... 65.1 mph (104.8 km/h)
  - Angle .... 24.0 deg
  - Impact Location ....
  - .... 99½ in. (2,527 mm) U.S. from centerline of 2nd splice U.S. from end shoe
- Impact Severity (IS) .... 57.2 kip-ft (77.6 kJ) > 51 kip-ft (69.7 kJ) limit from MASH
- Exit Conditions
  - Speed .... 41.2 mph (66.3 km/h)
  - Angle .... 13.6 deg
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 157 ft – 5 in. (48.0 m) downstream
  - Lateral .... 22 ft (6.7 m) in front
- Vehicle Damage .... Moderate
  - VDS [16] 01-RFQ-6
  - CDC [17] 01-FRAW-6
  - Maximum Interior Deformation .... 2.83 in. (72 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 25⅞ in. (657 mm)
  - Dynamic .... 28.1 in. (714 mm)
  - Working Width .... 61.4 in. (1,560 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH Limit
		SLICE-1 (primary)	SLICE-2	
OIV ft/s (m/s)	Longitudinal	-23.82 (-7.26)	-22.86 (-6.97)	±40 (12.2)
	Lateral	-22.38 (-6.82)	-22.03 (-6.71)	±40 (12.2)
ORA g's	Longitudinal	-6.14	-5.79	±20.49
	Lateral	-6.85	-7.20	±20.49
MAX ANGULAR DISP. deg.	Roll	-9.62	-10.49	±75
	Pitch	-5.92	-6.46	±75
	Yaw	-43.56	-43.68	Not required
THIV – ft/s (m/s)		29.54 (9.00)	29.38 (8.95)	Not required
PHD – g's		9.01	8.86	Not required
ASI		1.72	1.71	Not required

Figure 78. Summary of Test Results and Sequential Photographs, Test No. MGSPCB-2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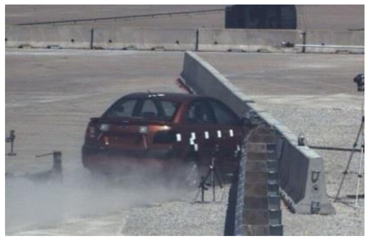
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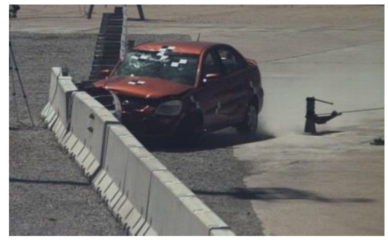
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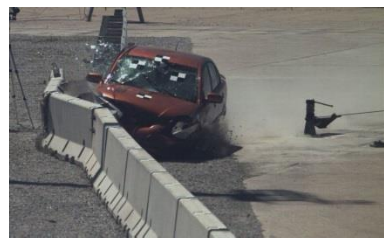
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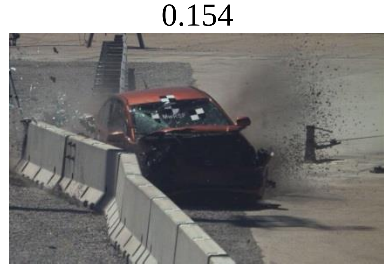
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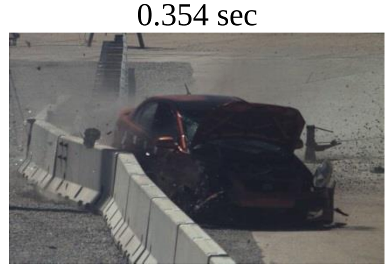
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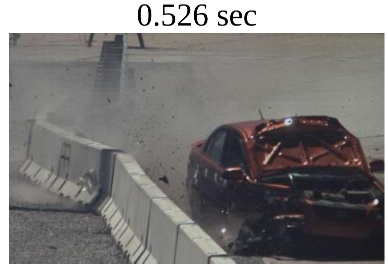
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Figure 79. Additional Sequential Photographs, Test No. MGSPCB-2


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0.014 sec


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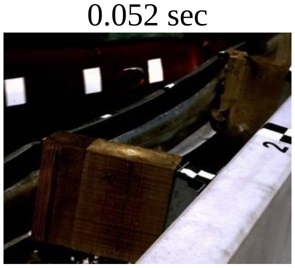
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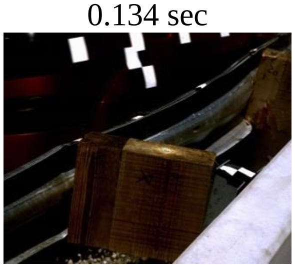
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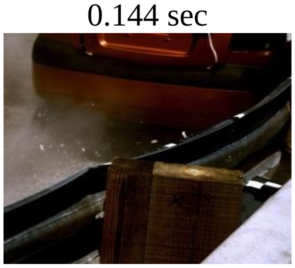
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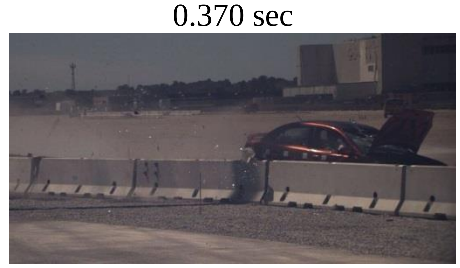
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Figure 80. Additional Sequential Photographs, Test No. MGSPCB-2

Figure 81. Documentary Photographs, Test No. MGSPCB-2

Figure 82. Documentary Photographs, Test No. MGSPCB-2

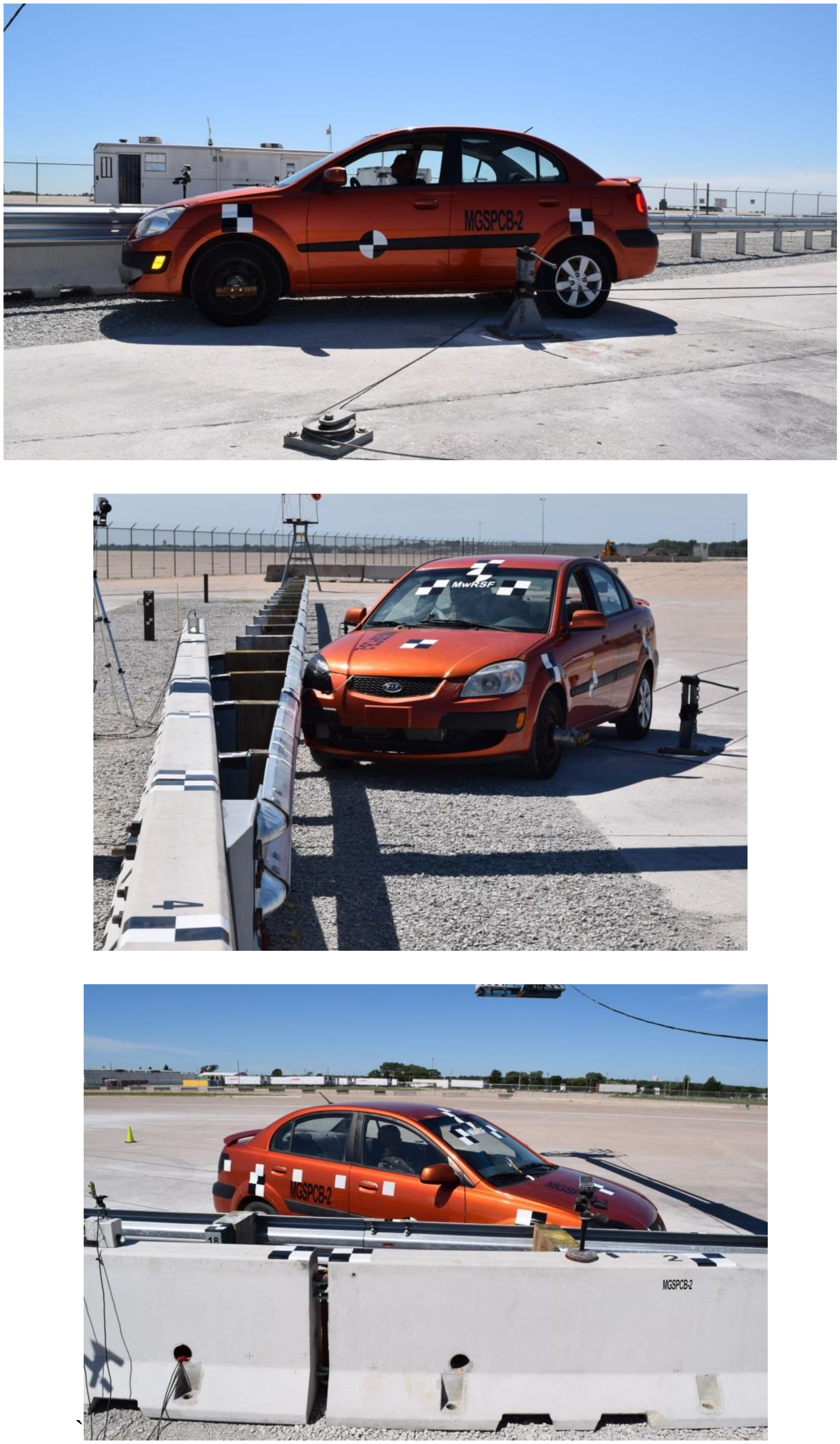


Figure 83. Impact Location, Test No. MGSPCB-2

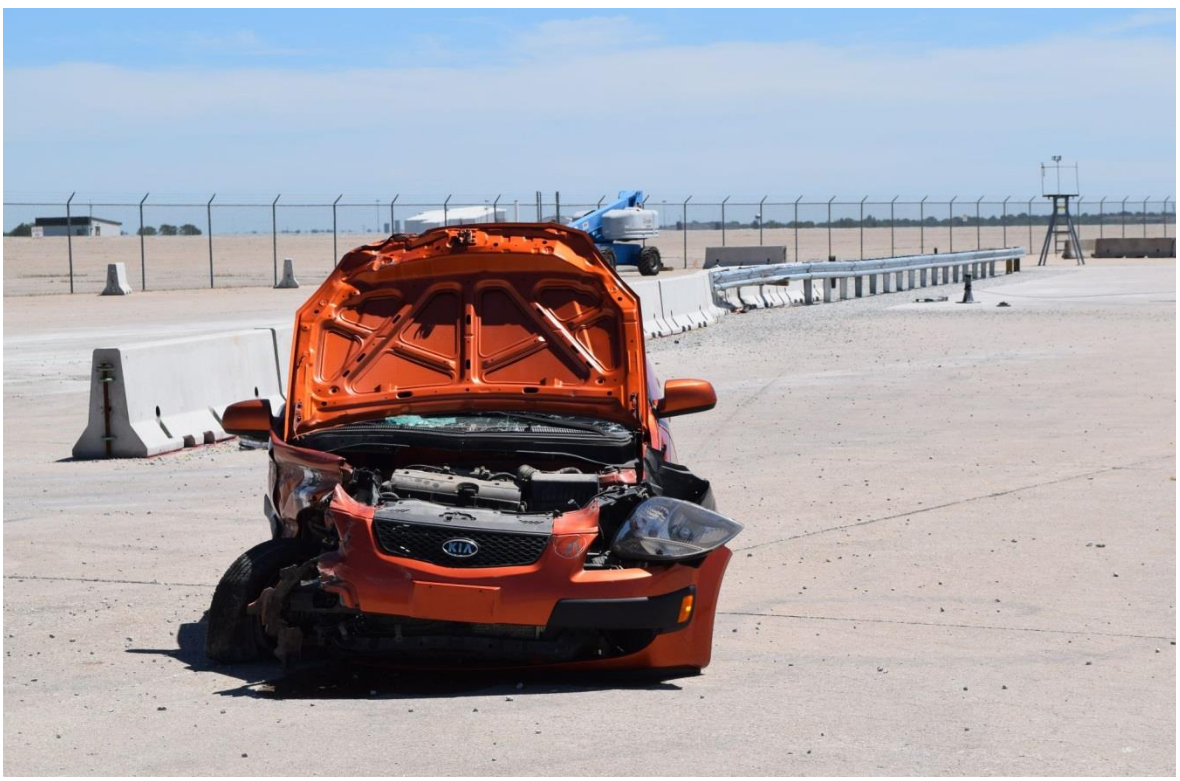


Figure 84. Vehicle Final Position, Test No. MGSPCB-2

Figure 85. System Damage, Test No. MGSPCB-2

Figure 86. System Damage Between the End Shoe and Post No. 18, Test No. MGSPCB-2

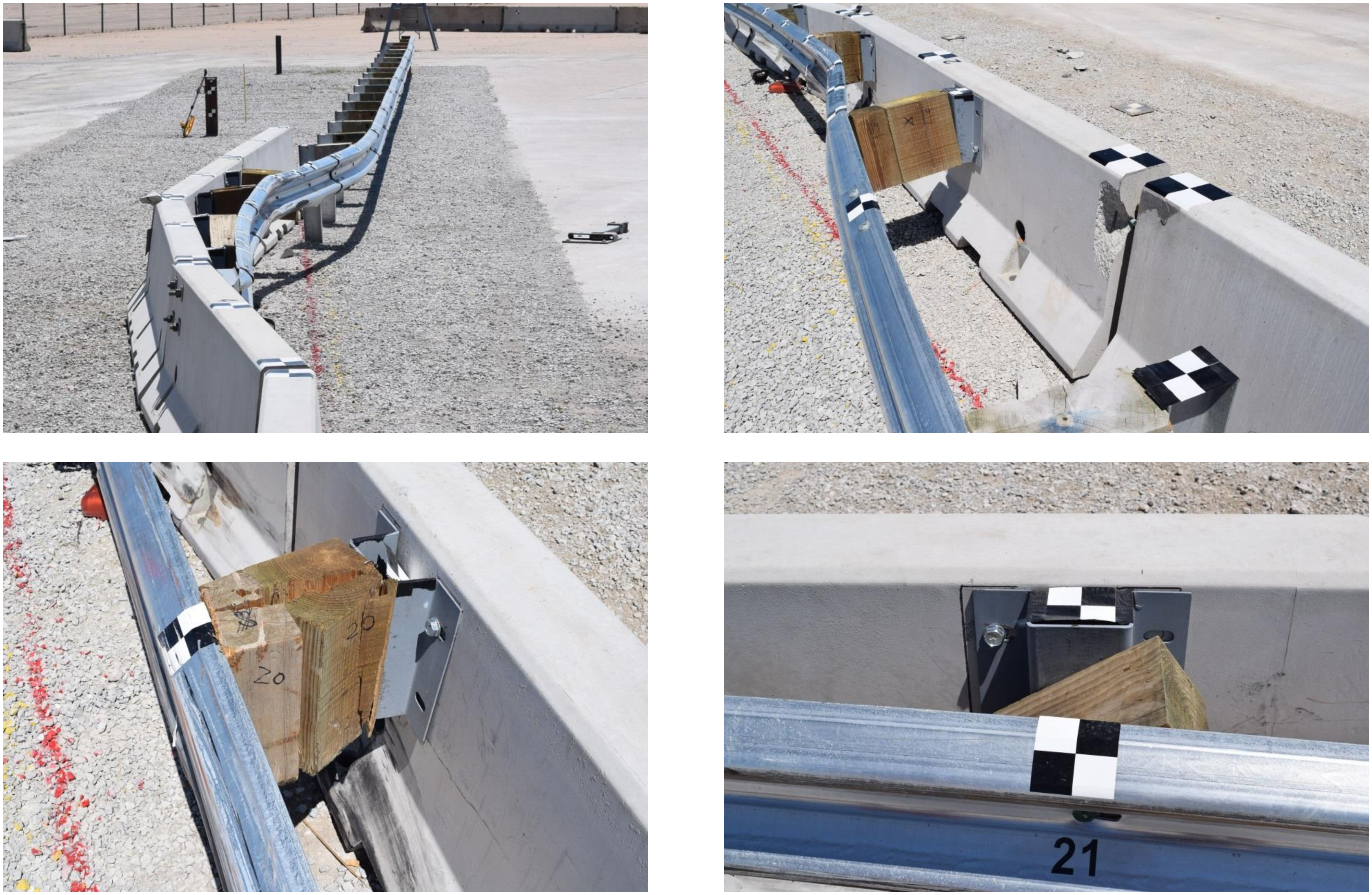


Figure 87. System Damage at the Transition, Test No. MGSPCB-2

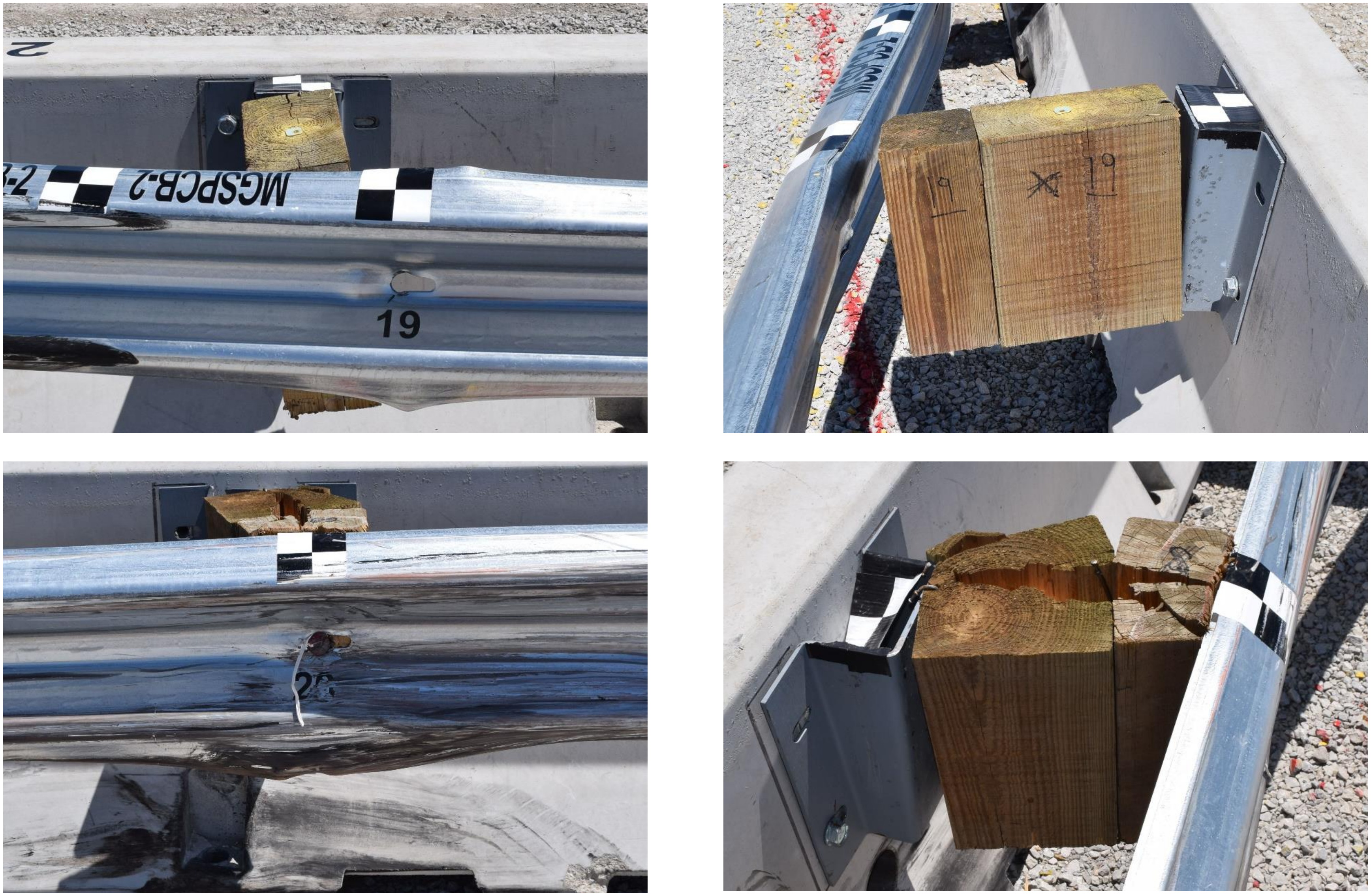


Figure 88. System Damage at the Transition, Test No. MGSPCB-2

Figure 89. System Damage at the Transition, Test No. MGSPCB-2

Figure 90. Vehicle Damage, Test No. MGSPCB-2

Figure 91. Vehicle’s Windshield Damage, Test No. MGSPCB-2

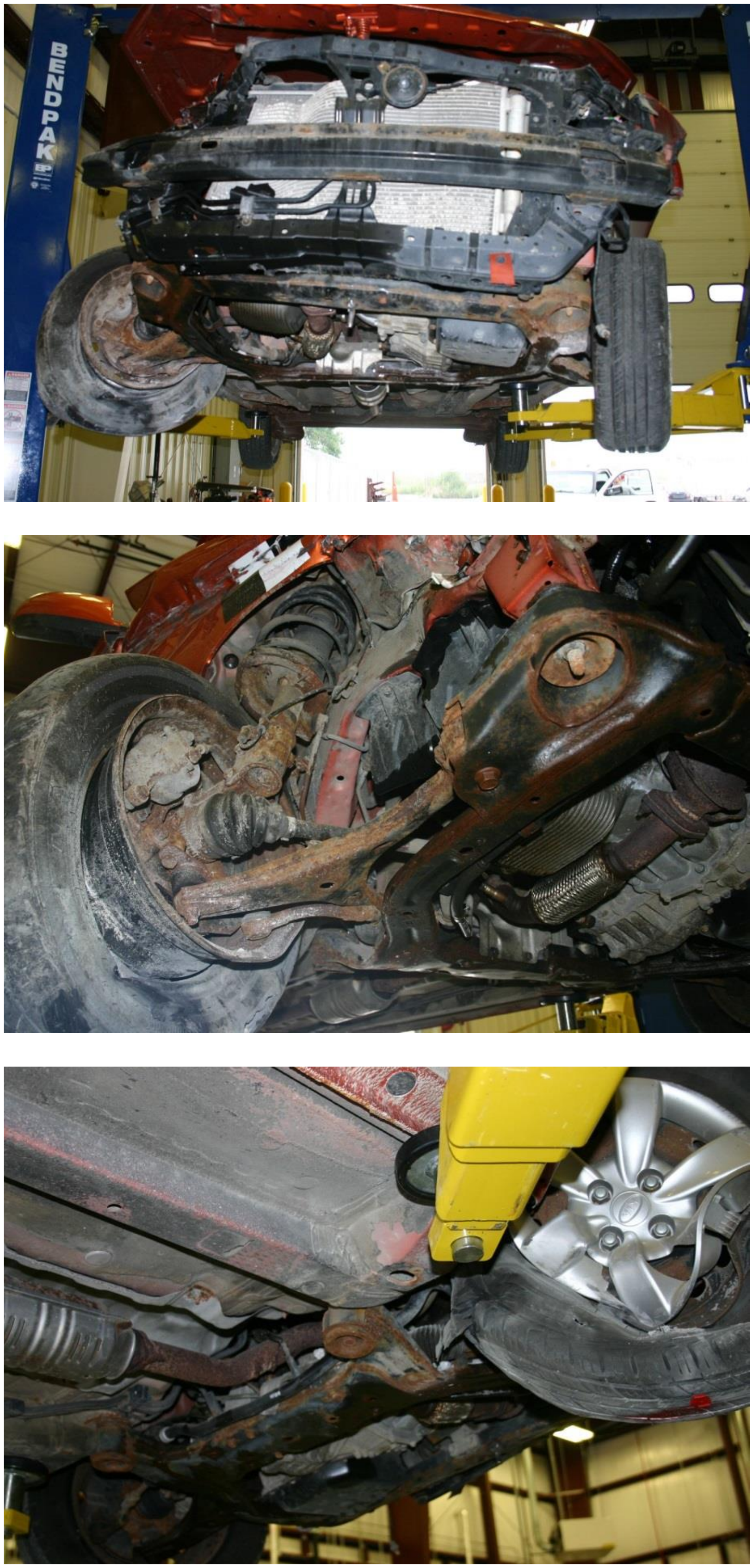
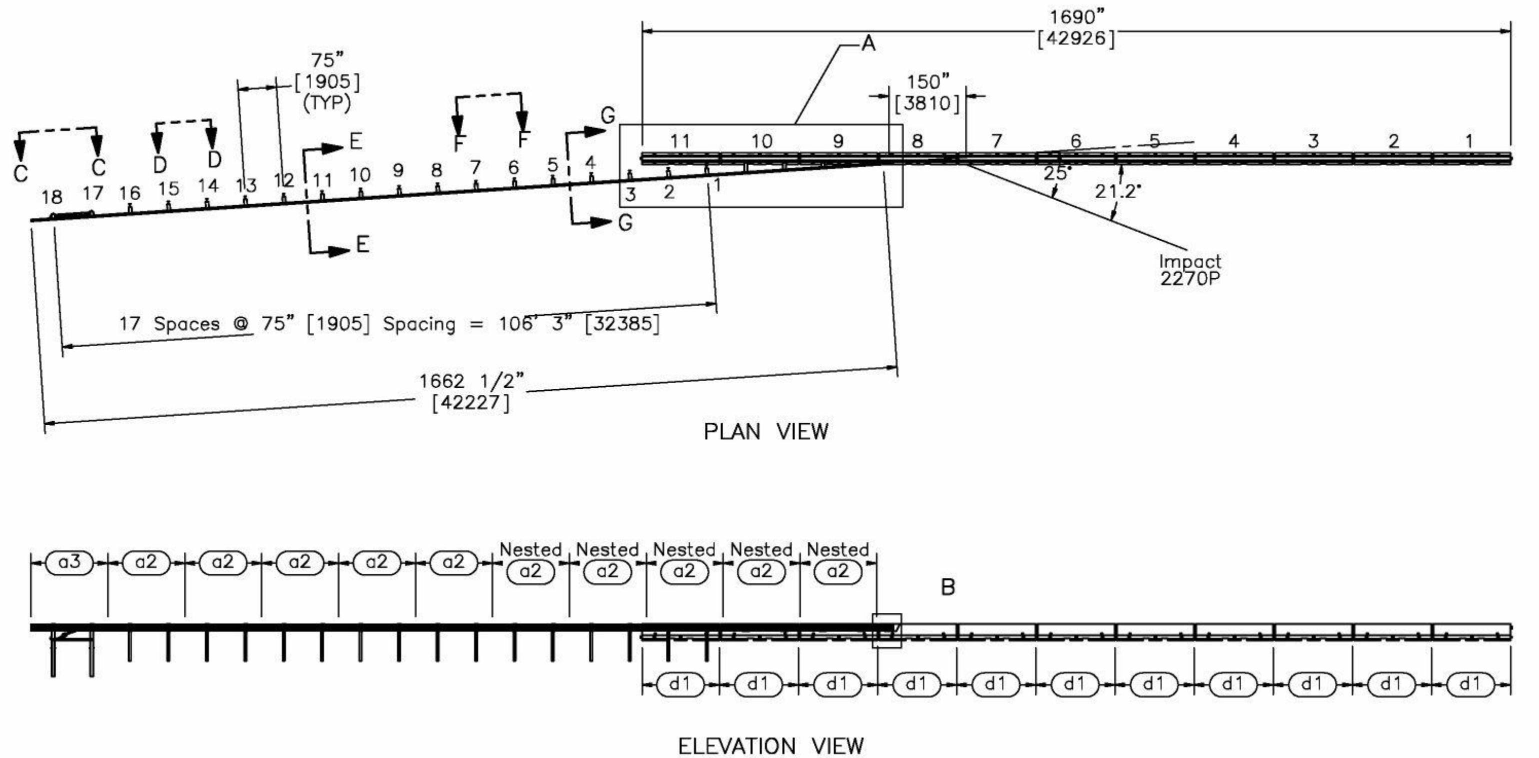


Figure 92. Undercarriage Damage, Test No. MGSPCB-2

9 DESIGN DETAILS, TEST NO. MGSPCB-3

The MGS to PCB transition test installation for test no. MGSPCB-3 was nearly identical to that used in test no. MGSPCB-1, but the system was installed with the PCB on the upstream end transitioning to the MGS on the downstream end. The test installation layout is shown in Figure 93. Photographs of the test installation are shown in Figures 94 and 95. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.



Notes:
(1) Test shall be performed according to test designation no. 3–21 of MASH criteria.

(2) The impact location is 12'6" [3810] upstream from the centerline of the end shoe. Centerline of the end shoe is taken as the center of the single bolt closest to the column of bolts. See Detail B for reference.

(3) The front edge of the soil pit should be at least 5' [1524] from the center of each post. The distance can be adjusted as long as the PCB system does not cross the front edge of the soil pit.

(4) Critical region is between post nos. 1 through 4 (ø3' holes).

(5) BCT anchors are placed in ø3' [914] holes, then backfilled and tamped with soil.

(6) Guardrail should be lapped such that upstream guardrail is behind downstream guardrail.

Midwest Roadside Safety Facility	NDOR PCB–MGS Transition		SHEET: 1 of 36
			DATE: 3/15/2016
	System Layout		DRAWN BY: KLK/ALL/JEK/TJD
	DWG. NAME. PCB–MGS_Trans_R15	SCALE: 1:300 UNITS: in.[mm]	REV. BY: RWB/KAL/JCH/JAH

Figure 93. Test Installation Layout, Test No. MGSPCB-3

Figure 94. Test Installation, Test No. MGSPCB-3

Figure 95. Test Installation, Test No. MGSPCB-3

10 FULL-SCALE CRASH TEST NO. MGSPCB-3

10.1 Static Soil Test

Before full-scale crash test no. MGSPCB-3 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

10.2 Weather Conditions

Test no. MGSPCB-3was conducted on August 25, 2015 at approximately 12:00 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 11.

Table 11. Weather Conditions, Test No. MGSPCB-3

Temperature	76° F
Humidity	48%
Wind Speed	7 mph
Wind Direction	130° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.01 in.
Previous 7-Day Precipitation	0.45 in.

10.3 Test Description

The 5,012-lb (2,273-kg) pickup truck impacted the MGS to PCB transition at a speed of 63.1 mph (101.5 km/h) and at an angle of 24.6 degrees. Initial vehicle impact was to occur 12 ft – 6 in. (3.8 m) upstream from the centerline of the end shoe, as shown in Figure 101, which was selected using LS-DYNA analysis to maximize potential for vehicle instability and capture issues. The actual point of impact was approximately 3 in. (76 mm) upstream from the intended impact point. A sequential description from the impact events is contained in Table 12. A summary of the test results and sequential photographs are shown in Figure 96. Additional sequential photographs are shown in Figures 97 and 98. Documentary photographs of the crash test are shown in Figures 99 and 100. The transition blockouts are numbered C1 through C4, from downstream to upstream. The vehicle came to rest 187 ft – 9 in. (57.2 m) downstream of impact and 56 ft – 10 in. (17.3 m) behind the barrier oriented with the front of the vehicle facing away from the back side of the barrier. The vehicle trajectory and final position are shown in Figures 96 and 102.

Table 12. Sequential Description of Impact Events, Test No. MGSPCB-3

TIME (sec)	EVENT
0.000	Vehicle's right-front tire impacted concrete barrier no. 7 approximately 12 ft - 9 in. (3.9 m) upstream from centerline of end shoe.
0.002	Vehicle's right-front bumper contacted concrete barrier no. 7.
0.010	Vehicle's right headlight contacted concrete barrier no. 7 and deformed, and vehicle's right fender contacted concrete barrier no. 7 and deformed.
0.014	Concrete barrier no. 7 rotated clockwise and vehicle's right-front tire lost contact with ground and rode up barrier.
0.020	Vehicle's right fender overrode the barrier.
0.024	Vehicle's right-front door deformed, and concrete barrier no. 8 rotated counterclockwise.
0.032	Vehicle's hood deformed.
0.042	Vehicle's right-rear door deformed and concrete barrier no. 8 rolled backward.
0.044	Vehicle rolled toward barrier and yawed away from barrier, concrete barrier no. 9 rotated clockwise, and vehicle's left taillight deformed.
0.056	Blockout C3 rotated backward.
0.060	Concrete barrier no. 6 rotated counterclockwise and blockout C2 rotated backward.
0.066	Concrete barrier no. 9 rolled backward.
0.074	Vehicle pitched upward.
0.080	Concrete barrier no. 5 deflected downstream, and blockout C1 rotated counterclockwise.
0.086	Blockout C1 deflected backward, concrete portion disengaged from backside of upstream end of concrete barrier no. 8, and post no. 3 rotated counterclockwise.
0.090	Concrete barrier no. 7 rolled backward, concrete barrier no. 5 deflected backward, and vehicle's right-front window shattered.
0.098	Blockout C2 deflected backward.
0.100	Concrete barrier no. 4 deflected downstream.
0.120	Blockout C2 rotated clockwise, concrete barrier no. 6 rolled backward, concrete barrier no. 10 rotated clockwise, concrete barrier no. 11 deflected upstream, and vehicle's left-front tire became airborne.
0.126	Vehicle's front bumper contacted end shoe bracket, and concrete barrier no. 10 rolled backward.
0.132	Vehicle's left-rear tire became airborne, and concrete barrier no. 6 rotated clockwise.
0.138	Concrete barrier no. 2 deflected downstream.
0.144	Vehicle's right headlight detached, and vehicle's right fender contacted end shoe bracket.
0.154	Blockout C4 rotated clockwise.
0.186	Concrete barrier no. 8 rolled backward.

0.190	Vehicle’s left rear tire became airborne.
0.192	Vehicle was parallel to system at a speed of 52.7 mph (84.8 km/h).
0.224	Vehicle’s tailgate deformed, vehicle’s right quarter panel contacted concrete barrier no. 8, and vehicle’s right taillight contacted concrete barrier no. 8 and deformed.
0.228	Concrete barrier no. 11 deflected downstream, and vehicle’s right taillight shattered.
0.230	Vehicle pitched downward, and concrete barrier nos. 9 and 10 rolled toward traffic side of system.
0.234	Vehicle’s left-front door deformed.
0.246	Concrete barrier no. 7 rolled backward, and vehicle’s right-front tire regained contact with ground.
0.332	Concrete barrier no. 7 rolled backward.
0.358	Concrete barrier no. 8 rolled backward.
0.380	Vehicle’s left taillight detached.
0.396	Post no. 1 deflected backward.
0.474	Vehicle’s right-front tire detached.
0.544	Concrete barrier no. 8 rolled toward traffic side of system.
0.604	Vehicle’s right taillight detached.
0.606	Vehicle exited system at a speed of 43.2 mph (69.5 km/h) and at an angle of 11.3 degrees.
0.612	Concrete barrier no. 7 rolled toward traffic side of system.
0.636	Vehicle rolled away from barrier.
0.654	Vehicle pitched upward.
0.824	Upstream side of post no. 2 was contacted by disengaged component of right-front rim.
1.012	Vehicle yawed toward barrier.
1.240	Vehicle pitched downward.
2.442	Vehicle re-contacted rail at post no. 18.

10.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 103 through 106. Barrier damage consisted of cracking of the concrete, contact marks on the front and top face of the concrete segments, and spalling of the concrete. The length of vehicle contact along the barrier was approximately 38 ft – 8 in. (11.8 m), which spanned from 36 in. (914 mm) upstream of the target impact point to blockout C1.

Concrete barrier no. 7 had vertical cracking along the impact side face extending from the bottom to the top, located 12¾ in. (324 mm), 11½ in. (292 mm), and 20 in. (508 mm) downstream of the midspan of the segment. The backside of the barrier had hairline cracks located at the same distances as the cracks on the front side. Tire contact marks started on the front toe 50 in. (1,270 mm) upstream of the downstream end of concrete barrier no. 7. Vehicle contact continued upward and downstream to the end of the concrete barrier. Contact marks on top of the barrier started 19½ in. (495 mm) upstream from the downstream end and extended 3 in. (76 mm) backward from the front edge. The downstream impact side corner of the barrier had a 5½-in. (140-mm) vertical by 1½-in. (38-mm) lateral by 1-in. (25-mm) long spall located 16 in. (406 mm) from the bottom.

Concrete barrier no. 8 had a 14-in. (356-mm) vertical by 2½-in. (64-mm) lateral by 7-in. (178-mm) long spall and a 14-in. (356-mm) vertical by 3-in. (76-mm) lateral by 5¼-in. (133-mm) long spall, located on the front and backside of the upstream corner of the barrier, respectively, which exposed the internal reinforcement loops. Contact marks on the top of the barrier extended through the entire barrier and contact marks on the front face extended to the guardrail end shoe. A crack extended from the impact side toe up and over the barrier to the backside toe 8 in. (203 mm) upstream of center. Two cracks on the back face, located 11 in. (279 mm) upstream from center and 15 in. (381 mm) downstream from center, extended from the toe upward 18 in. (457 mm).

Concrete barrier no. 9 had vehicle contact marks on the top of the barrier and a hairline crack on the impact side face extending from the toe to the top and located 12 in. (305 mm) upstream of center. Concrete barrier no. 10 had 8 in. (203 mm) of wheel contact on the lower sloped face on the upstream end.

The end shoe mounting bracket had a 21-in. (533-mm) long piece of metal from the vehicle wedged beneath the leading edge of the bracket. The end shoe mounting bracket had scuff marks on the front face of the ramp and the shoe was displaced ⅛ in. (3 mm) downstream. The overall damage to the end shoe mounting bracket was minimal. The end shoe buckled 12 in. (305 mm) on the top and bottom corrugation starting 3½ in. (89 mm) from the upstream end. The guardrail had a ⅜-in. (10-mm) long gouge on the bottom corrugation at blockout C4 and a 2-in. (51-mm) long gouge located 13 in. (330 mm) downstream of blockout C4 on the bottom corrugation. Blockout C4 had a vertical crack through the entire length and located 4½ in. (114 mm) from the upstream end.

The rail buckled at the top edge at 2½ in. (64 mm) downstream from the upstream end of blockout C3 and on the bottom edge at ½ in. (13 mm) downstream from the upstream end of blockout C3. Blockout C3 had a 2-in. (51-mm) long vertical crack on the upstream face extending from the top to the bottom and a gouge in the top upstream-front corner from the guardrail. Blockout C2 rotated downstream and the guardrail gouged into the top and bottom upstream-front corners of the blockout. Blockout C1 rotated downstream and had vehicle contact marks on the top edge.

The guardrail gouged into blockout no. 1. The front upstream flange of post no. 2 had a ¼-in. (6-mm) dent which was located 14½ in. (368 mm) from the ground. The vehicle exited the system and then impacted again at the downstream end anchorage, post no. 18. Contact marks began 34½ in. (876 mm) upstream of post no. 18 through the end of the guardrail. The guardrail had a 3-in. (76-mm) tall x 3-in. (76-mm) deep buckle in the valley which was 2 in. (51 mm) downstream of the bolt in post no. 18 and the free end deflected backward 3½ in. (89 mm).

The maximum permanent set of the rail, posts, and concrete barriers for the system was 30½ in. (775 mm) at the rail at blockout C4, ¼ in. (6 mm) at post no. 3, and 34⅜ in. (873 mm) at the upstream target on concrete barrier no. 8, as measured in the field. The maximum lateral dynamic deflection of the rail, posts, and concrete barriers for the system was 30.6 in. (777 mm) at the rail at blockout C3, 0.4 in. (10 mm) at post no. 2, and 37.2 in. (945 mm) at the middle target on concrete barrier no. 8, as determined from high-speed digital video analysis. The working width of the system was found to be 58.7 in. (1,491 mm), also determined from high-speed digital video analysis.

10.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 107 through 109. The maximum occupant compartment deformations are listed in Table 13 along with the deformation limits established in MASH for various areas of the occupant compartment. Note that none of the MASH established deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Table 13. Maximum Occupant Compartment Deformations by Location, Test No. MGSPCB-3

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	0.31 (8)	≤ 9 (229)
Floor Pan & Transmission Tunnel	0.14 (4)	≤ 12 (305)
Side Front Panel (in Front of A-Pillar)	0.20 (5)	≤ 12 (305)
Side Door (Above Seat)	0.53 (14)	≤ 9 (229)
Side Door (Below Seat)	0.50 (13)	≤ 12 (305)
Roof	0.12 (3)	≤ 4 (102)
Windshield	0	≤ 3 (76)

The majority of the damage was concentrated on the right-front corner and right side of the vehicle where the impact occurred. The right-front bumper had denting and buckling starting on the right end and extending 23 in. (584 mm) toward the center. The right-front headlight disengaged.

The front one-third of the right-front wheel well disengaged, the front wheel assembly disengaged at the wheel bearing, and the right-front brake caliper disengaged. A 3½-in. (89-mm) by 1-in. (25-mm) puncture was located at the rear of the right-front wheel well and 3 in. (76 mm) from the bottom. The right fender was bent upward 9 in. (229 mm) from the top edge of the wheel well, starting at the back of the fender and extending 20 in. (508 mm) forward.

The front of the right-front door had a 1½-in. (38-mm) gap at the top, and the rear of the right-front door was separated 1 in. (25 mm). The front of the right-front door had a 23-in. (584-mm) wide tear that was 15 in. (381 mm) across at the top, 11 in. (279 mm) across at the bottom, and began at the bottom of the frame. Contact marks started 18 in. (457 mm) from the bottom of the right-front door and extended to the right-rear wheel well. The right-rear door had a 8½-in. (216-mm) long by 3-in. (76-mm) tall tear located 17 in. (432 mm) from the bottom and 5-in. (127-mm) tall by 2-in. (51-mm) deep denting and gouging across the entire length. The back of the right-rear door had a ¾-in. (19-mm) gap at the top. The tears in the door were to the exterior sheet metal only and did not compromise the occupant compartment.

A 1-in. (25-mm) deep by 11-in. (279-mm) tall dent started 18 in. (457 mm) from the bottom of the right C-Pillar. Contact marks on the right quarter panel were located 21 in. (533 mm) from the bottom and 22 in. (559 mm) from the C-Pillar. The right quarter panel had a 1-in. (25-mm) deep dent extending from the C-Pillar to the wheel well, and a ½-in. (13-mm) long by 1-in. (25-mm) tall tear located 4 in. (102 mm) left of the C-Pillar.

The right-rear tire deflated due to a 2-in. (51-mm) tear located 3 in. (76 mm) from the wheel rim. The rim also had a 5-in. (127-mm) long crack on the edge. The outer lip was gouged around three-quarters of the circumference. A 1½-in. (38-mm) by 1-in. (25-mm) dent was located at the back of the right-rear wheel well and 11 in. (279 mm) from the bottom. The right quarter panel had a 17-in. (432-mm) tall by 1-in. (25-mm) deep dent located near the rear of the vehicle and scraping 10 in. (254 mm) from the bottom starting at the rear of the right-rear wheel well and extending back.

The right taillight disengaged, and the right side of the rear bumper had a 1-in. (25-mm) deep dent. The left side of the tailgate disengaged, and the lower left corner of the tailgate was bent ⅛ in. (3 mm). The left taillight disengaged.

The front of the left-front door had a ½-in. (13-mm) gap. The windshield had minor cracking starting 4 in. (102 mm) right of the lower-left corner of the windshield and extended 21 in. (533 mm) upward. The front of the hood had a 1½-in. (38-mm) gap and was separated ½ in. (13 mm) on the left side. The top edge of the bumper buckled 13 in. (330 mm) left of center. The lower bumper was bent back 19½ in. (495 mm) from center. The right side of the grill cracked 4½ in. (114 mm) from the top.

10.6 Occupant Risk

The calculated OIVs and maximum 0.010-sec ORAs in both the longitudinal and lateral directions are shown in Table 14. Note that the OIVs and ORAs were within the suggested limits provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 14. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 96. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix H.

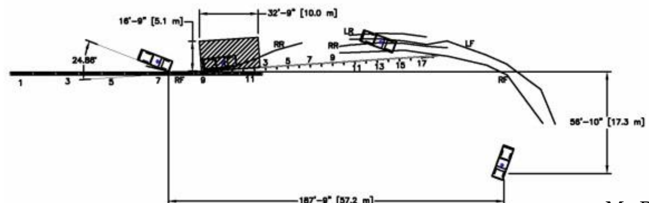
10.7 Discussion

The analysis of the test results for test no. MGSPCB-3 showed that the MGS to PCB transition system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. There were no detached elements nor fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix H, were deemed acceptable, because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle exited the barrier at an angle of 11.3 degrees and its trajectory did not violate the bounds of the exit box. Therefore, test no. MGSPCB-3, conducted on the MGS to PCB transition system, was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-21.

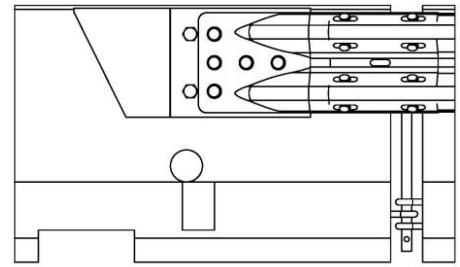
Table 14. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MGSPCB-3

Evaluation Criteria		**Transducer**		**MASH Limits**
		SLICE-1	**SLICE-2 (primary)**	
OIV ft/s (m/s)	Longitudinal	-11.26 (-3.43)	-11.59 (-3.53)	±40 (12.2)
	Lateral	-19.27 (-5.87)	-17.94 (-5.47)	±40 (12.2)
ORA g's	Longitudinal	-14.02	-14.09	±20.49
	Lateral	-13.35	-15.18	±20.49
MAX. ANGULAR DISPL. deg.	Roll	33.23	30.55	±75
	Pitch	-10.60	-11.10	±75
	Yaw	-42.23	-41.75	not required
THIV ft/s (m/s)		22.84 (6.96)	21.85 (6.66)	not required
PHD g's		14.29	15.40	not required
ASI		1.01	1.03	not required

0.000 sec | 0.092 sec | 0.186 sec | 0.544 sec | 0.774 sec



- Test Agency .... MwRSF
- Test Number MGSPCB-3
- Date 8/25/2015
- MASH Test Designation 3-21
- Test Article .... MGS to PCB Transition
- Total Length .... 240.0 ft (73.2 m)
- Key Component – W-beam Guardrail
  - Thickness .... 12 ga. (2.66 mm)
  - Mounting Height .... 31 in. (787 mm)
- Key Component – ASTM 992 Steel Post
  - Length .... 72 in. (1,829 mm)
  - Embedment Depth .... 40 in. (1,016 mm)
  - Spacing .... 75 in. (1,905 mm)
- Key Component – 5,000 psi PCB
  - Length .... 150 in. (3,810 mm)
  - Width .... 22½ in. (572 mm)
  - Height .... 32 in. (813 mm)
- Soil Type .... Coarse Crushed Limestone
- Vehicle Make /Model .... 2008 Dodge Ram 1500
  - Curb .... 5,017 lb (2,276 kg)
  - Test Inertial .... 5,012 lb (2,273 kg)
  - Gross Static .... 5,177 lb (2,348 kg)
- Impact Conditions
  - Speed .... 63.1 mph (101.5 km/h)
  - Angle .... 24.6 deg
  - Impact Location. approximately 12 ft – 9 in. (3.9 m) US from centerline of end shoe
- Impact Severity (IS) .... 115.6 kip-ft (156.7 kJ) > 106 kip-ft (144 kJ) limit from MASH
- Exit Conditions
  - Speed .... 43.2 mph (69.5 km/h)
  - Angle .... 11.3 deg
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 187 ft – 9 in. (57.2 m) downstream
  - Lateral .... 56 ft – 10 in. (17.3 m) behind



- Vehicle Damage .... Moderate
  - VDS [16] 01-RFQ-5
  - CDC [17] 01-RYEW-3
  - Maximum Interior Deformation .... 0.532 in. (13 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 34⅜ in. (873 mm)
  - Dynamic .... 37.2 in. (945 mm)
  - Working Width .... 58.7 in. (1,491 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH Limit
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-11.26 (-3.43)	-11.59 (-3.53)	±40 (12.2)
	Lateral	-19.27 (-5.87)	-17.94 (-5.47)	±40 (12.2)
ORA g's	Longitudinal	-14.02	-14.09	±20.49
	Lateral	-13.35	-15.18	±20.49
MAX ANGULAR DISP. deg.	Roll	33.23	30.55	±75
	Pitch	-10.60	-11.10	±75
	Yaw	-42.23	-41.75	not required
THIV – ft/s (m/s)		22.84 (6.96)	21.85 (6.66)	not required
PHD – g's		14.29	15.40	not required
ASI		1.01	1.03	not required

Figure 96. Summary of Test Results and Sequential Photographs, Test No. MGSPCB-3

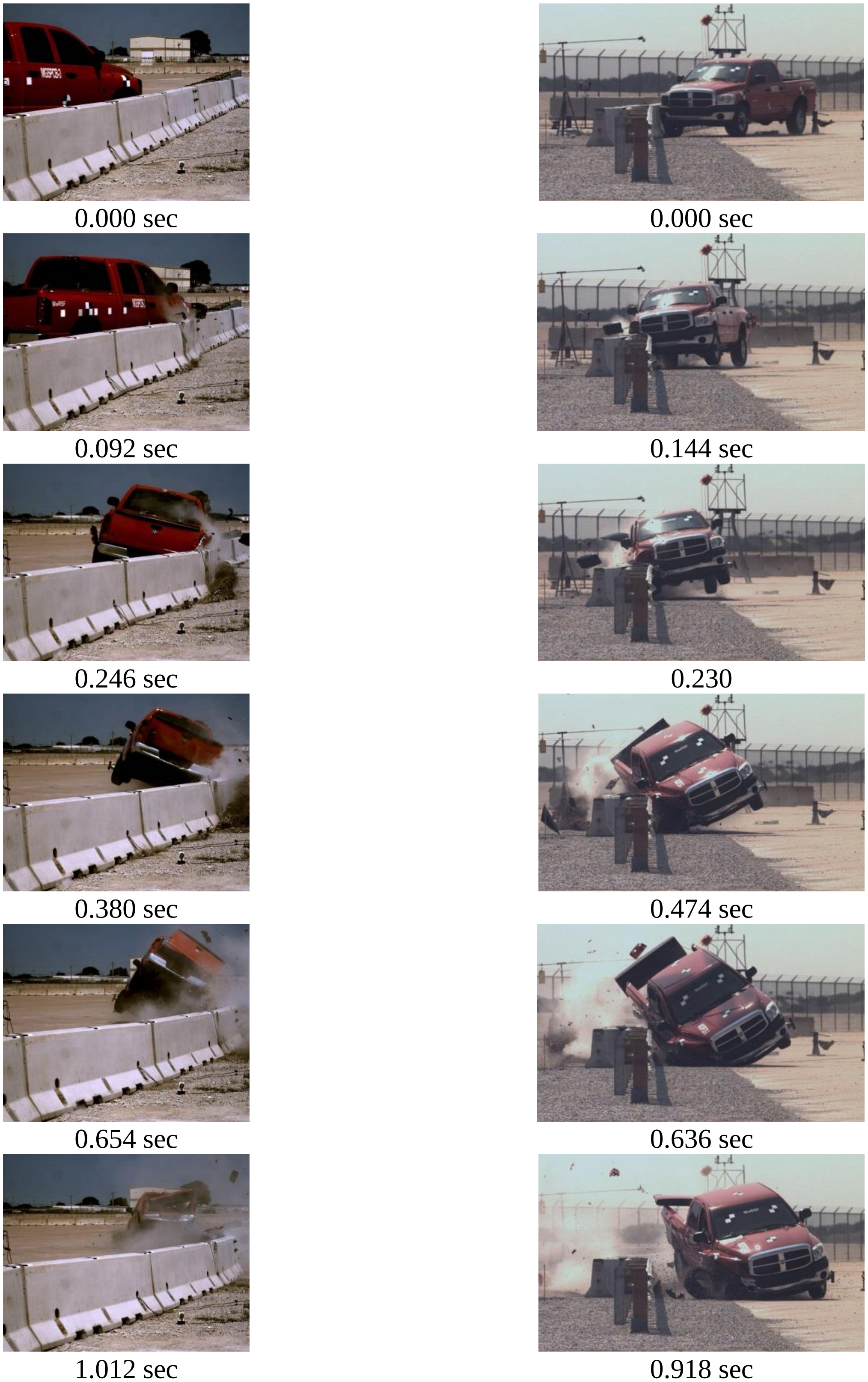


Figure 97. Additional Sequential Photographs, Test No. MGSPCB-3

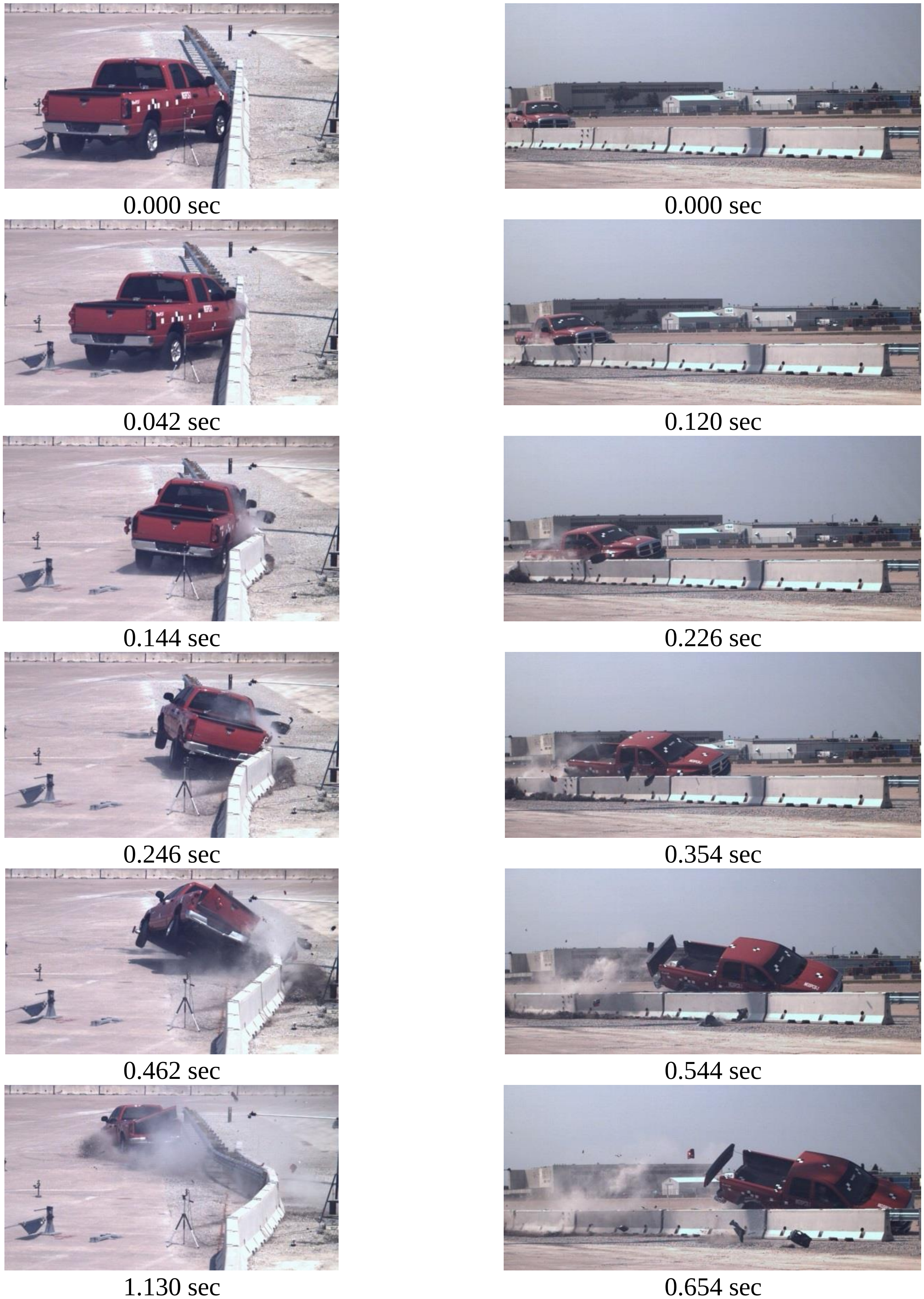


Figure 98. Additional Sequential Photographs, Test No. MGSPCB-3

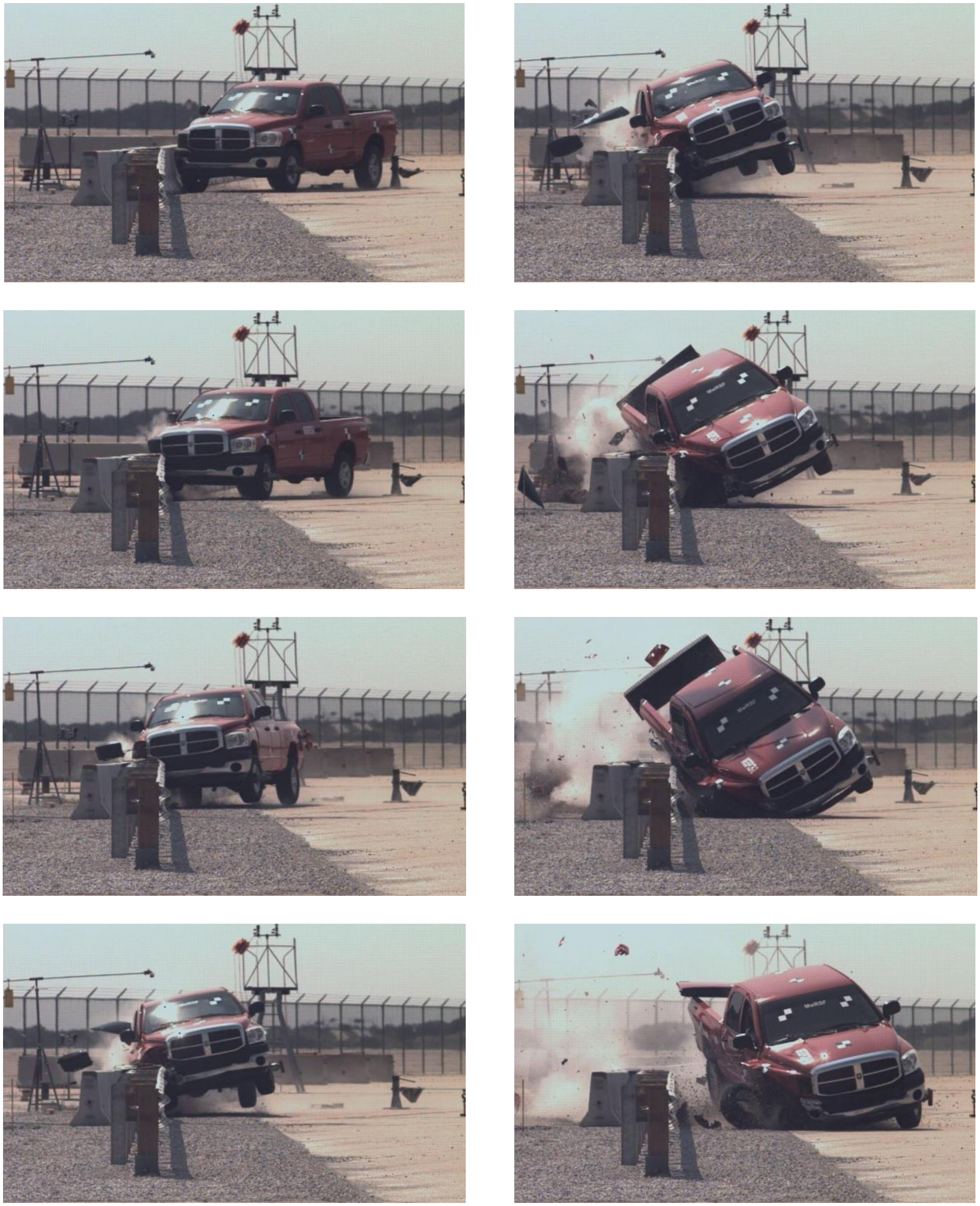


Figure 99. Documentary Photographs, Test No. MGSPCB-3

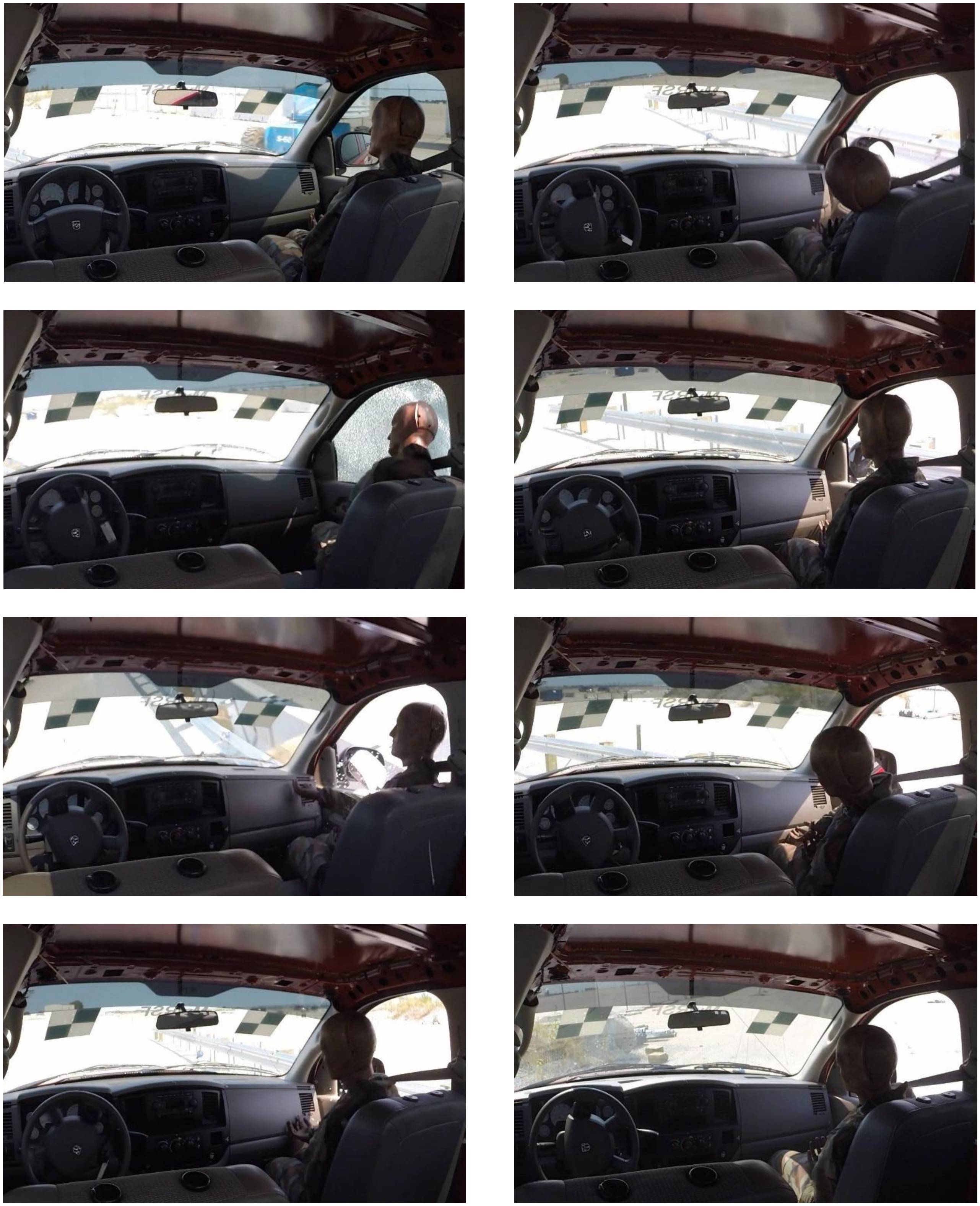


Figure 100. Documentary Photographs, Test No. MGSPCB-3

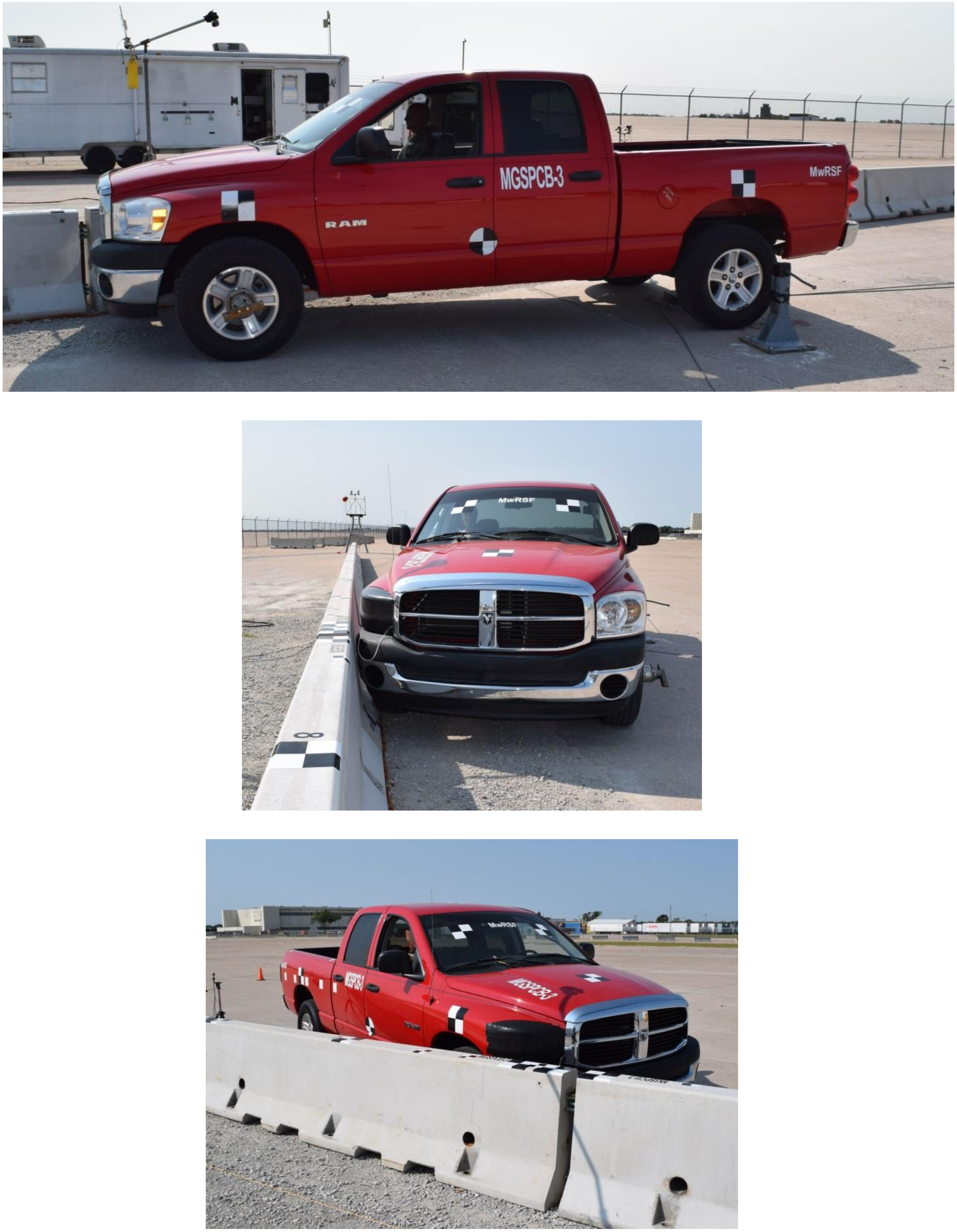


Figure 101. Impact Location, Test No. MGSPCB-3

Figure 102. Vehicle Final Position, Test No. MGSPCB-3

Figure 103. System Damage, Test No. MGSPCB-3

Figure 104. System Damage Between End Shoe and Concrete Barrier No. 7, Test No. MGSPCB-3

Figure 105. Backside Concrete Barrier Damage Between Concrete Barrier Nos. 7 and 8, Test No. MGSPCB-3

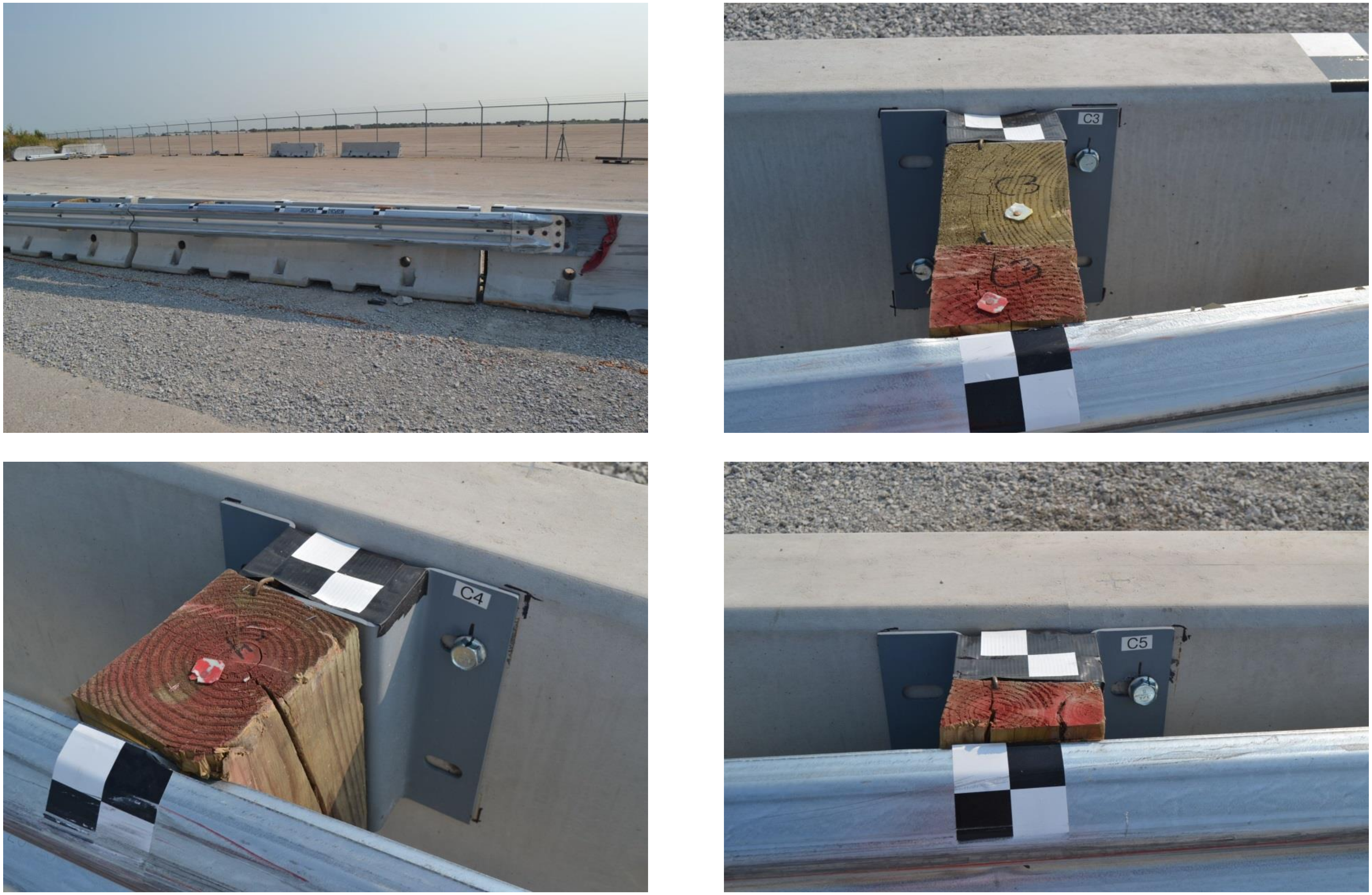


Figure 106. Rail and Blockout Damage Between End Shoe and Blockout C3, Test No. MGSPCB-3

Figure 107. Vehicle Damage, Test No. MGSPCB-3

Figure 108. Windshield Damage and Occupant Compartment Deformation, Test No. MGSPCB-3

Figure 109. Undercarriage Damage, Test No. MGSPCB-3

11 SUMMARY AND CONCLUSIONS

The objective of the research project was to evaluate the safety performance of a transition between guardrail and PCB, specifically the MGS and a free-standing, F-shape PCB. The guardrail to PCB transition design was developed during Phase I of this research effort and evaluation of the design was completed through the full-scale testing detailed herein. The Phase I research effort developed a transition system comprised of a tangent, nested-MGS that overlapped an adjacent, flared PCB system The barrier was subjected to three full-scale crash tests and evaluated according to TL-3 impact safety standards provided in MASH. The safety performance criteria are summarized in Table 15.

Prior to evaluation of the transition design, attachments between the end of the W-beam and the W-beam guardrail that overlapped the PCB segments to the PCBs were developed. These connections were developed to be relatively easy to install, crashworthy, and reusable after a worst case impact on the transition. To this end, a special W-beam end shoe mounting bracket and blockout mounting bracket were developed and implemented into the design.

Test no. MGSPCB-1 was conducted on the MGS to PCB transition with the 2270P vehicle to evaluate the structural integrity of the transition and the potential for vehicle snag. During test no. MGSPCB-1, a 4,914-lb (2,229-kg) pickup truck impacted the system at an angle of 25.3 degrees and a speed of 63.2 mph (101.8 km/h), which resulted in an impact severity of 119.6 kip-ft (162.2 kJ). The vehicle was safely contained and redirected, and all occupant risk values were within MASH limits, so test no. MGSPCB-1 passed the safety criteria of MASH test designation no. 3-21.

Test no. MGSPCB-2 was conducted on the MGS to PCB transition with the 1100C vehicle to evaluate the potential for vehicle snag, vehicle instability, and combined loading of the guardrail splice. During test no. MGSPCB-2, a 2,436-lb (1,105-kg) small car impacted the system at an angle of 24.0 degrees and a speed of 65.1 mph (104.8 km/h), which resulted in an impact severity of 57.2 kip-ft (77.6 kJ). The vehicle was safely contained and redirected, and all occupant risk values were within MASH limits, so test no. MGSPCB-2 passed the safety criteria of MASH test designation no. 3-20.

Test no. MGSPCB-3 was conducted in the reverse direction on the MGS to PCB transition with the 2270P vehicle to evaluate the vehicle capture and the potential for vehicle instability. During test no. MGSPCB-3, a 5,012-lb (2,273-kg) pickup truck impacted the system at an angle of 24.6 degrees and a speed of 63.1 mph (101.5 km/h), which resulted in an impact severity of 115.6 kip-ft (156.7 kJ). The vehicle was safely contained and redirected, and all occupant risk values were within MASH limits, so test no. MGSPCB-3 passed the safety criteria of MASH test designation no. 3-21.

The successfully-evaluated MASH TL-3 transition between the MGS and F-shape PCBs provides State DOTs with the first crashworthy transition between these two common, non-proprietary barrier systems. The transition design should be easy to implement as it does not require any unique barrier sections or alterations of the guardrail and PCBs other than two simple connection pieces. Additional recommendations for implementation of the barrier system are given in the subsequent chapter.

Table 15. Summary of Safety Performance Evaluation Results

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. MGSPCB-1</th><th>Test No. MGSPCB-2</th><th>Test No. MGSPCB-3</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td><td>S</td><td>S</td></tr>
<tr><td rowspan="5">Occupant Risk</td><td>D.</td><td>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. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</td><td>S</td><td>S</td><td>S</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td><td>S</td><td>S</td></tr>
<tr><td>G.</td><td>It is preferable, although not essential, that the vehicle remain upright during and after collision.</td><td>S</td><td>S</td><td>S</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:<table><tr><th colspan="3">Occupant Impact Velocity Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr></table></td><td>S</td><td>S</td><td>S</td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.3 of MASH for calculation procedure) should satisfy the following limits:<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr></table></td><td>S</td><td>S</td><td>S</td></tr>
<tr><td colspan="3">MASH Test Designation</td><td>3-21</td><td>3-20</td><td>3-21</td></tr>
<tr><td colspan="3">Final Evaluation (Pass or Fail)</td><td>Pass</td><td>Pass</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

12 RECOMMENDATIONS

The guardrail to PCB transition system developed, tested, and evaluated herein has been considered for implementation with guidance and recommendations provided below. For the guardrail to PCB transition, implementation guidance includes minimum installation parameters, allowable tolerances on blockout geometry and placement, grading and surfacing requirements, repair recommendations, and integration with other barrier systems.

12.1 Minimum Installation Requirements

The transition system detailed herein was comprised of a tangent, nested-MGS that overlapped an adjacent, flared PCB system. Based on the simulation analysis of the system and the full-scale crash testing, the recommended minimum system configuration are noted below:

1. Use a minimum 137.5-ft (41.91-m) long MGS and an eleven segment PCB system at a 15H:1V flare. A minimum of eight PCBs should be placed downstream from, the point where the W-beam guardrail attaches to the PCBs. Potential shorter lengths for either barrier would need to be further evaluated.

2. The transition requires a minimum of three PCB segments extending behind the nested MGS at the 15H:1V flare. Thus, the end of the guardrail attaches to the upstream end of the fourth PCB segment. Additional length of PCBs flared behind the MGS would not be an issue as the potential for vehicle and barrier interaction with the PCBs is maximized for the minimum overlap condition.

3. In order to provide adequate anchorage of the end shoe mounting bracket to the PCB, the anchor bracket mounting bolts that extend through the PCB must be mounted to a minimum segment overlap length of 12¼ in. (311 mm) onto the upstream end of the PCB. This select ion ensures that the mounting bolts are inside the first two shear stirrups in the PCB segment in order to provide adequate anchorage for the bracket. Placement of the bracket closer to the barrier edge may reduce the anchorage of the W-beam guardrail.

4. A minimum of five 12-ft 6-in. (3,810 mm) long, nested W-beam sections must be utilized upstream from the end shoe connection to the PCB. For the minimum PCB overlap noted above, this corresponds to one complete 12.5-ft (3.81-m) long section of nested rail upstream from the end of the PCBs.

5. In order to create the work zone, the 15H:1V flare used in the transition to offset PCBs behind the guardrail will likely convert to PCBs tangent to the roadway once the work-zone area has been established. In order to maintain the safety performance of the as-tested transition, it is recommended that conversion from the 15H:1V flare to tangent to the roadway not begin until a minimum of two PCB segments have been installed downstream from the W-beam end shoe connection.

12.2 Blockout Placement and Tolerances

Placement of the blockout holders on the PCBs in actual field installations may be difficult to accomplish due to difficulties with alignment of the barriers, construction tolerances, and interference with PCB reinforcement. Thus, some placement tolerance for the blockout holder should exist to account for these difficulties. The blockout holder and the guardrail have slotted holes that allow for some installation tolerance, and the blockout holders only require two diagonally-placed anchors to account for installation tolerance issues. Additionally, it is believed that minor variations in the placement of the blockout holder will have no adverse effect on the system. Thus, it is recommended that the blockout holder can have a longitudinal tolerance of ±1 in. (25 mm). Similar vertical tolerance is acceptable as long as the post bolt can still be attached to the rail without modification of the hardware.

12.3 Grading and Surfacing

As with most longitudinal barrier systems, the transition detailed herein was tested and evaluated on level terrain. Typically, it has been acceptable to allow installations of longitudinal barriers and transitions on cross slopes of 10H:1V or flatter based on guidance in the AASHTO Roadside Design Guide [18]. Thus, 10H:1V or flatter cross slopes are recommended in front of the transition system.

Additionally, steep slopes are a common hazard behind barrier systems. However, these slope conditions can affect the performance of strong-post guardrail by altering post-soil interaction forces and may also affect PCB function due to the barriers traversing the steep slope as they deflect laterally. Previous guidance for the standard MGS installed adjacent to steep slopes has recommended a minimum of 2 ft (610 mm) of level terrain or 10H:1V or flatter cross slope behind the guardrail posts in order to provide similar performance to the system when installed on level terrain. As such, a 2-ft (610-mm) wide segment of level terrain, or 10H:1V or flatter cross slope, would be recommended for the MGS portion of the guardrail to PCB transition system detailed herein.

As noted previously, installation of PCB segments on a soil foundation is typically not recommended due to potential concerns for the back edge of the PCB segment to dig into the soil, thus leading to increased barrier rotation and potential vehicle instabilities. Thus, a well-compacted, crushed limestone base is recommended beneath the PCBs placed behind the MGS and supported on soil. The compacted crushed limestone material must meet AASHTO Grade B soil specifications and should be installed to a depth of 6 in. (152 mm). The compacted base should be placed underneath all PCB segments in the transition not installed on a paved road surface and its dimensions should extend for 1 ft (305 mm) in front of the barrier segments, underneath the barrier segments, and for a minimum lateral width of 4 ft (1,219 mm) behind the barrier segments. The compacted base should also be installed at a 10V:1H or flatter cross slope.

Portable concrete barriers have similar concerns with placement adjacent to slopes based on the desire to retain deflected barriers on level terrain rather than having the segments deflect down a steep slope. Based on the 37.2-in. (945-mm) maximum dynamic deflection of the PCBs observed in the three crash tests conducted herein and the need for 4 ft (1,219 mm) of compacted base behind the barrier segments, it is recommended that a minimum of 4 ft (1,219 mm) of 10V:1H or flatter cross slope grading be provided behind the PCB segments in the transition.

12.4 Repair Recommendations

Currently, most state DOTs have guidance regarding the level of damage to guardrail and/or PCB systems that would and require repair or replacement. The transition system developed in this study uses these two types of barrier systems. Thus, state DOTs should follow their current standard guidance for repair and replacement of damaged PCB and MGS components.

The only non-standard components in the transition system were the mounting brackets for the W-beam end shoe and the blockouts. During full-scale testing of the transition, none of these components nor their anchorages were damaged, and they were reusable from test to test. Thus, it is unlikely these components will require replacement during their normal service life. However, these components should be replaced if any of the follow damage is observed:

1. Displacement or permanent deformation of either the end shoe or blockout mounting brackets greater than ½ in. (13 mm) from their nominal dimensions

2. Tearing or fracture of the bracket's base material or any welds

3. Anchor bracket damage or disengagement. For the end shoe bracket, it may only require installation of new mounting bolts if the bracket is undamaged. The blockout mounting bracket could be replaced using the two unused anchor holes if one of the anchors is damaged or becomes disengaged.

12.5 Integration with Other Barrier Systems

The guardrail to PCB transition system developed herein focused on the MGS guardrail system and the 12.5-ft (3.81-m) long, F-shape PCBs that were developed through the Midwest States Pooled Fund Program. While the transition was designed specifically for these two barrier systems, there may be a desire to integrate this transition using other barrier systems, including existing G4(1S) W-beam guardrail or alternative PCB designs.

Because a majority of the guardrail currently on the highway system consists of the G4(1S) guardrail, there will likely be a need to attach the G4(1S) guardrail to a PCB transition. Two issues must be addressed to transition the G4(1S) system to the MGS guardrail and are related to differences in rail height and splice location. Previous guidance has been given to raise rail height from the G4(1S) to the MGS over a distance of 25 ft to 50 ft (7.62 m to 15.21 m). Several options exist to reposition the rail splices from the posts to the midspan locations by omitting a post or using ½-post spacing. Three layout options are proposed, but each requires a slightly different layout depending on the preferred splice repositioning method. In addition, each guardrail to PCB transition option requires a slightly different connection point to the nested MGS guardrail to provide a short length of standard MGS prior to the beginning of the guardrail to PCB transition. The three recommended G4(1S) to MGS transitions are detailed below.

1. Omitted Post Option – The transition between the rail splice locations for the G4(1S) to MGS transition can be accomplished through omission of a post after the rail height transition is completed, as shown in Figure 110. Recent research has shown that the omission of a single post in the MGS and creation of a 12.5-ft (3.81-m) unsupported span is acceptable under MASH TL-3 impact conditions [19]. As such, it is recommended that

the splice repositioning can occur following the rail height transition through omission of the post at the first splice following the height transition. This option creates a 9 ft – 4½ in. (2.86 m) span between G4(1S) spacing and MGS spacing. MGS attachment to the nested MGS may begin at the first splice following the splice repositioning.

2. Half-Post Spacing in MGS Option – A second option for transitioning from G4(1S) to MGS consists of adding an additional post following the rail height transition, as shown in Figure 111. For this transition, a post at ½-post spacing is added after the second post following the rail height repositioning, and standard MGS begins after that point. Attachment of the MGS to the nested rail in the guardrail to PCB transition may begin after one 12.5-ft (3.81-m) long section of standard MGS following the splice repositioning.

3. Half-Post Spacing in G4(1S) Option – A third option for transitioning from G4(1S) to MGS consists of adding an additional post prior to the rail height repositioning, as shown in Figure 112. For this transition, a post at ½-post spacing is added after the final post in the G4(1S) prior to the rail height repositioning, and standard MGS post spacing begins after that point. Attachment of the MGS to the nested rail in the guardrail to PCB transition may begin after one 12.5-ft (3.81-m) long section of standard MGS following the rail height repositioning.

The blockout depth may be converted from the 8-in. (203-mm) deep G4(1S) blockouts to the 12-in. (305-mm) deep MGS blockouts at whatever point is convenient.

Finally, the guardrail to PCB transition that was tested and evaluated herein used a common 12.5-ft (3.81-m) long, F-shape PCB that is used by a majority of the Pooled Fund states in the Midwest. However, there may be potential to use this transition system with alternative PCBs if basic criteria are met.

1. The reinforcement in alternative PCB designs would need to provide equal or greater barrier capacity to that provided by the PCBs used in this research.

2. Alternative PCB segment connections must have comparable or greater structural capacity and torsional rigidity about the longitudinal barrier axis when compared to the as-tested PCB.

3. Alternative PCB geometry may affect the performance of the system. As such, barrier height should be maintained at 32 in. (813 mm) to maintain a similar or less risk for wheel snag. Differences in the barrier face geometry, such as New Jersey and single-slope barriers, may be acceptable, but they are not recommended at this time without further study. There are concerns that the difference in face geometry may affect vehicle interaction with the PCB in the overlapped barrier region. Thus, it may require revised connection hardware for the W-beam end shoe and blockouts.

4. The PCB segments with alternative lengths could potentially be used but are not recommended without further study due to concerns for potential differences in the PCB deflection and stiffness.

5. Any alternative PCB should have similar mass per unit length to the as-tested PCB system to provide similar inertial resistance, stiffness, and dynamic deflections.

6. Finally, it is recommended that any alternative PCB should meet MASH TL-3. It is also recommended that any alternative PCB have similar MASH TL-3 dynamic deflections to the as-tested PCB. Significantly increased or decreased dynamic deflections may adversely affect the performance of the guardrail to PCB transition system.

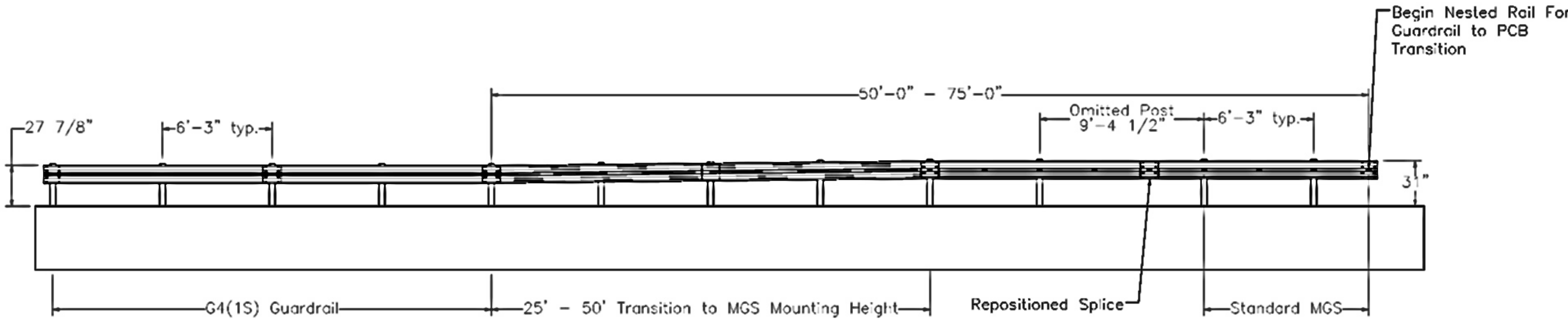


Figure 110. Schematic for Transitioning G4(1S) to MGS Prior to Guardrail to PCB Transition, Omitted Post Option

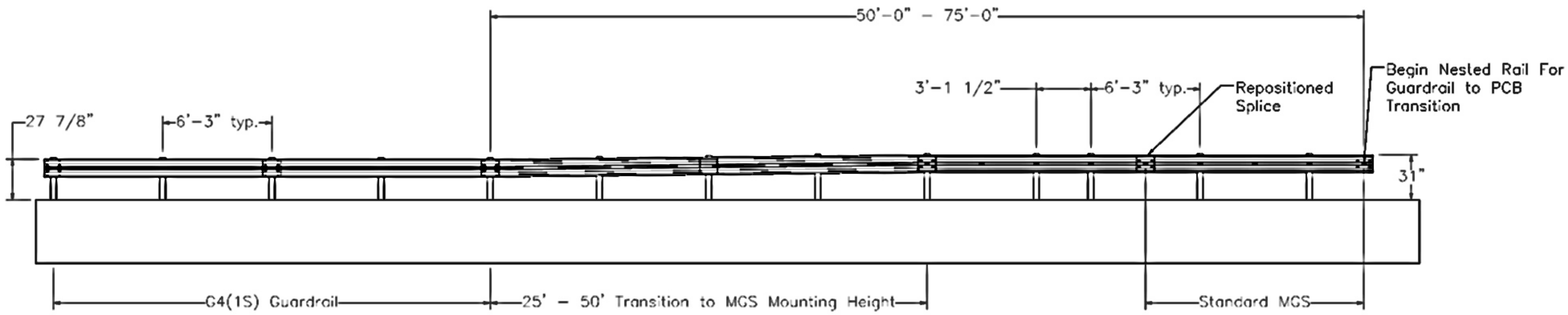


Figure 111. Schematic for Transitioning between G4(1S) and MGS Prior to Guardrail to PCB Transition, Half-Post Spacing in MGS Option

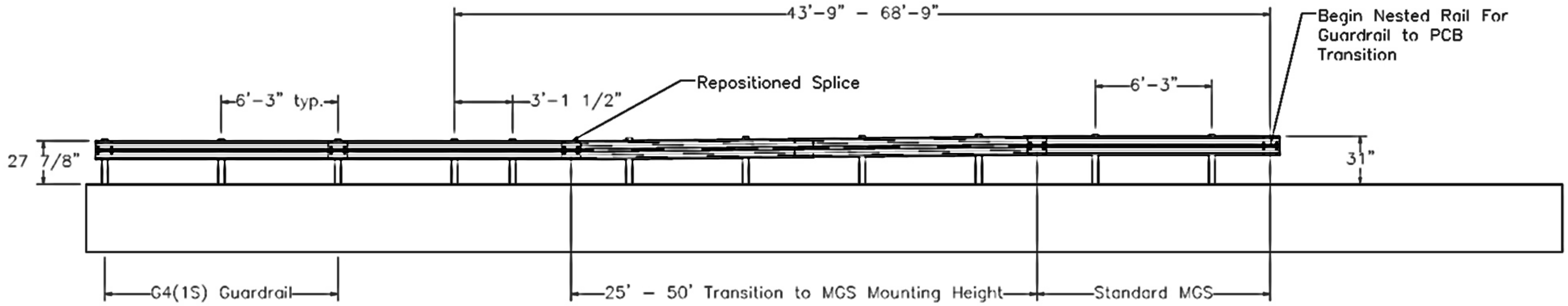


Figure 112. Schematic for Transitioning between G4(1S) and MGS Prior to Guardrail to PCB Transition, Half-Post Spacing in G4(1S) Option

13 REFERENCES

1. *Manual for Assessing Safety Hardware (MASH)*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2009.

2. Gutierrez, D.A., Bielenberg, R.W., Faller, R.K., Reid, J.D., and Lechtenberg, K.A., *Development of a MASH TL-3 Transition Between Guardrail and Portable Concrete Barriers*, Final Report to the Nebraska Department of Roads and the Smart Work Zone Deployment Initiative, Report No. TRP-03-300-14, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, June 26, 2014.

3. Polivka, K.A., Faller, R.K., Sicking, D.L., Reid, J.D., Rohde, J.R., Holloway, J.C., Bielenberg, R.W., and Kuipers, B.D., *Development of the Midwest Guardrail System (MGS) for Standard and Reduced Post Spacing and in Combination with Curbs*, Final Report to the Midwest States' Regional Pooled Fund Program, Report No. TRP-03-139-04, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, September 2004.

4. Polivka, Faller, Sicking, Rohde, Bielenberg, and Reid, *Performance Evaluation of the Midwest Guardrail System - Update to NCHRP 350 Test No. 3-11 with 28" C.G. Height (2214MG-2)*, Final Report to the National Cooperative Highway Research Program, Report No. TRP-03-171-06, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, October 11, 2006.

5. Polivka, Faller, Sicking, Rohde, Bielenberg, and Reid, *Performance Evaluation of the Midwest Guardrail System - Update to NCHRP 350 Test No. 3-10 (2214MG-3)*, Final Report to the National Cooperative Highway Research Program, Report No. TRP-03-172-06, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, October 11, 2006.

6. Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Bielenberg, B.W., Reid, J.D., and Coon, B.A., *Performance Evaluation of the Free-Standing Temporary Barrier – Update to NCHRP 350 Test No. 3-11 with 28" C.G. Height (2214TB-2)*, Final Report to the National Cooperative Highway Research Program, Report No. TRP-03-174-06, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, October 2006.

7. Winkelbauer, B.J., Putjenter, J.G., Rosenbaugh, S.K., Lechtenberg, K.A., Bielenberg, R.W., Faller, R.K., and Reid, J.D., *Dynamic Evaluation of MGS Stiffness Transition with Curb*, Final Report to the Midwest State's Pooled Fund Program, Report No. TRP 03-291-14, Midwest Roadside Safety Facility, University of Nebraska Lincoln, Lincoln, Nebraska, June 30, 2014.

8. Hinch, J., Yang, T.L., and Owings, R., *Guidance Systems for Vehicle Testing*, ENSCO, Inc., Springfield, Virginia, 1986.

9. *Center of Gravity Test Code - SAE J874 March 1981*, SAE Handbook Vol. 4, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1986.

10. MacInnis, D., Cliff, W., and Ising, K., *A Comparison of the Moment of Inerita Estimation Techniques for Vehicle Dynamics Simulation*, SAE Technical Paper Series – 970951, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1997.

11. Society of Automotive Engineers (SAE), *Instrumentation for Impact Test – Part 1 – Electronic Instrumentation*, SAE J211/1 MAR95, New York City, NY, July, 2007.

12. Mongiardini, M., Faller, R.K., Reid, J.D., Sicking, D.L., Stolle, C.S., and Lechtenberg, K.A., *Downstream Anchoring Requirements for the Midwest Guardrail System*, Final Report to the Wisconsin Department of Transportation, Report No. TRP-03-279-13, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, October 28, 2013.

13. Mongiardini, M., Faller, R.K., Reid, J.D., and Sicking, D.L., *Dynamic Evaluation and Implementation Guidelines for a Non-Proprietary W-Beam Guardrail Trailing-End Terminal*, Paper No. 13-5277, Transportation Research Record No. 2377, Journal of the Transportation Research Board, TRB AFB20 Committee on Roadside Safety Design, Transportation Research Board, Washington D.C., January 2013, pages 61-73.

14. Stolle, C.S., Reid, J.D., Faller, R.K., and Mongiardini, M., *Dynamic Strength of a Modified W-Beam BCT Trailing-End Termination*, Paper No. IJCR 886R1, Manuscript ID 1009308, International Journal of Crashworthiness, Taylor & Francis, Vol. 20, Issue 3, Published online February 23, 2015, pages 301-315.

15. Griffith, M.S., Federal Highway Administration (FHWA). *Eligibility Letter HSST/B-256 for: Trailing-End Anchorage for 31" Tall Guardrail*, December 18, 2015.

16. *Vehicle Damage Scale for Traffic Investigators*, Second Edition, Technical Bulletin No. 1, Traffic Accident Data (TAD) Project, National Safety Council, Chicago, Illinois, 1971.

17. *Collision Deformation Classification – Recommended Practice J224 March 1980*, Handbook Volume 4, Society of Automotive Engineers (SAE), Warrendale, Pennsylvania, 1985.

18. *Roadside Design Guide*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2011.

19. Lingenfelter, J.L., Rosenbaugh, S.K., Bielenberg, R.W., Lechtenberg, K.A., Faller, R.K., and Reid, J.D., *Midwest Guardrail System (MGS) with an Omitted Post*, Final Report to the Midwest States Pooled Fund Program, Report No. TRP-03-326-16, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, February 22, 2016.

14 APPENDICES

Appendix A. Material Specifications

Description	Material Specification	Reference
W-Beam End Shoe Section	10 gauge [3.4] AASHTO M180 Galv.	R#15-0515 H#635222
12'-6" [3810] W-Beam MGS Section	12 gauge [2.7] AASHTO M180 Galv.	R#15-0602 H#8479 AND H#4614
12'-6" [3810] W-Beam MGS End Section	12 gauge [2.7] AASHTO M180 Galv.	R#15-0602 H#8479
W6"x8.5" [W152x12.6], 72" Long [1829] Steel Post	ASTM A992 Min. 50 ksi [345 MPa] Steel Galv. or W6x9 [W152x13.4] ASTM A36 Min. 36 ksi [248 MPa] Steel Galv.	R#15-0505 H#2413988, R#14-0097 H#55028671 Red, R#14-0554 H#1311743, R#12-0348 Blue
6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	Green, Blue, Dark Blue, and Light Blue
16D Double Head Nail	N/A	N/A
BCT Timber Post - MGS Height	SYP Grade No. 1 or better (No knots 18" [457] above or below ground tension face)	R#16-0010 Ch#3547
72" [1829] Long Foundation Tube	ASTM A500 Grade B Galv.	H#0173175 R#15-0157
Ground Strut Assembly	ASTM A36 Steel Galv.	R# 090453-8
2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A500 Grade B (.C)	R#15-0626 H#E86298
8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36 Steel Galv.	R#090453-9 H#6106195
Anchor Bracket Assembly	ASTM A36 Steel Galv.	"A2Black" H#V911470
Blockout Mounting Plate	ASTM A36 Steel Galv.	R#15-0536 H#B417196
6"x17 3/4"x14 1/4" [152x451x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	R#10-0142 Red
6"x12 3/4"x14 1/4" [152x324x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	R#10-0142 Red
6"x7 3/4"x14 1/4" [152x197x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	R#10-0142 Red
6"x2 3/4"x14 1/4" [152x70x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	R#10-0142 Red
Portable Concrete Barrier	min f'c=5000 psi [34.5 MPa]	Letter of Strength Compliance provided R#15-0531
1 1/4" [32] Dia., 28" [711] Long Connector Pin	ASTM A36 ASTM 1018	R#15-0531 H#15100585
1/2" [13] Dia., 72" [1829] Long Form Bar	ASTM A615 Grade 60	R#15-0531 H#64050283
1/2" [13] Dia., 146" [3708] Long Longitudinal Bar	ASTM A615 Grade 60	R#15-0531 H#64050283
5/8" [16] Dia., 146" [3708] Long Longitudinal Bar	ASTM A615 Grade 60	R#15-0531 H#58020158
3/4" [19] Dia., 36" [914] Long Anchor Loop Bar	ASTM A615 Grade 60	R#15-0531 H#57147245
3/4" [19] Dia., 102" [2591] Long Connection Loop Bar	ASTM A709 Grade 70 or A706 Grade 60	R#15-0531 H#54130870 L#H1401012620
3/4" [19] Dia., 91" [2311] Long Connection Loop Bar	ASTM A709 Grade 70 or A706 Grade 60	R#15-0531 H#54130870 L#H1401012620
3/4" [19] Dia., 101" [2565] Long Connection Loop Bar	ASTM A709 Grade 70 or A706 Grade 60	R#15-0531 H#54130870 L#H1401012620

Figure A-1. Bill of Materials, Test Nos. MGSPCB-1 through MGSPCB-3

Certified Analysis

Trinity Highway Products, LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE **TARP LOAD**

Order Number: 1235474 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3013
BOL Number: 86543 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 2/6/15

R#15-0515 H#635222
MGS/PCB Transition Guardrail Shoe
April 2015 SMT

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
20	11G	12/12'6/3'1.5/S			2	L10215													
			M-180	A	2	C72676	65,100	86,000	24.2	0.220	0.870	0.010	0.002	0.030	0.110	0.002	0.040	0.001	4
			M-180	A	2	C72677	59,200	77,600	20.1	0.210	0.880	0.012	0.002	0.030	0.150	0.003	0.050	0.001	4
12	907G	12/BUFFER/ROLLED	A-36			A71723	57,200	78,900	25.3	0.190	0.470	0.009	0.001	0.030	0.080	0.001	0.040	0.001	4
12	923G	BRONSTAD 98" W/O	A-36			A71723	57,200	78,900	25.3	0.190	0.470	0.009	0.001	0.030	0.080	0.001	0.040	0.001	4
20	929G	10/END SHOE/KS/2 EXT	M-180	B	2	635222	64,600	74,500	28.0	0.060	0.730	0.016	0.011	0.011	0.063	0.035	0.059	0.001	4
2	1005G	12/12'6/6'3/S 5'CX			2	L14514													
			M-180	A	2	183112	60,390	78,610	27.6	0.190	0.730	0.012	0.005	0.010	0.110	0.000	0.050	0.001	4
			M-180	A	2	183933	61,680	82,860	27.0	0.190	0.730	0.011	0.002	0.020	0.120	0.000	0.080	0.000	4
			M-180	A	2	183935	63,310	81,580	26.5	0.190	0.720	0.011	0.003	0.020	0.130	0.000	0.070	0.000	4
			M-180	A	2	183936	63,740	81,890	26.6	0.190	0.730	0.012	0.003	0.010	0.120	0.000	0.070	0.001	4
			M-180	A	2	183938	64,330	82,800	26.6	0.190	0.730	0.011	0.002	0.020	0.130	0.000	0.060	0.001	4
			M-180	A	2	183977	64,240	82,200	23.2	0.190	0.710	0.011	0.002	0.020	0.110	0.000	0.060	0.001	4
			M-180	A	2	183978	62,370	78,860	26.9	0.190	0.720	0.013	0.003	0.020	0.110	0.000	0.060	0.000	4
			M-180	A	2	184182	61,800	79,610	26.0	0.200	0.720	0.011	0.003	0.020	0.120	0.000	0.050	0.000	4
			M-180	A	2	179952	61,100	78,570	25.3	0.190	0.720	0.007	0.004	0.010	0.080	0.000	0.040	0.001	4
1	1010G	12/12'6/6'3/S 10'RCX			2	L14614													
			M-180	A	2	183933	61,680	82,860	27.0	0.190	0.730	0.011	0.002	0.020	0.120	0.000	0.080	0.000	4
			M-180	A	2	183934	63,290	81,350	26.9	0.190	0.730	0.011	0.005	0.010	0.100	0.000	0.060	0.001	4
			M-180	A	2	183935	63,310	81,580	26.5	0.190	0.720	0.011	0.003	0.020	0.130	0.000	0.070	0.000	4
			M-180	A	2	183936	63,740	81,890	26.6	0.190	0.730	0.012	0.003	0.010	0.120	0.000	0.070	0.001	4
			M-180	A	2	183938	64,330	82,800	26.6	0.190	0.730	0.011	0.002	0.020	0.130	0.000	0.060	0.001	4
			M-180	A	2	183977	64,240	82,200	23.2	0.190	0.710	0.011	0.002	0.020	0.110	0.000	0.060	0.001	4

Figure A-2. W-Beam End Shoe Section, Test Nos. MGSPCB-1 through MGSPCB-3

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

Customer: MIDWEST MACHINERY & SUPPLY CO.
P. O. BOX 703

MILFORD,NE,68405

Test Report
Ship Date: 6/2/2015
Customer P.O.: 3078
Shipped to: MIDWEST MACHINERY & SUPPLY CO.
Project: STOCK
GHP Order No.: 181769

HT # code	Heat #	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
8424	4135788	0.2	0.72	0.01	0.006	0.01	77194	55406	25.48	10	A	1	12GA 15FT 7.5IN WB TI HS 2@6FT3IN 1@3FT1.5IN
8331	4134527	0.24	0.77	0.011	0.005	0.01	82673	63255	27.87	40	A	1	12GA 12FT6IN/3FT1 1/2IN WB T1
8479	9511340	0.21	0.74	0.009	0.005	0.01	77105	59917	21	40	A	1	12GA 12FT6IN/3FT1 1/2IN WB T1
8244	31504980	0.2	0.85	0.01	0.002	0.03	84559	62542	13.3	40	A	1	12GA 12FT6IN/3FT1 1/2IN WB T1
8418	31512700	0.22	0.84	0.008	0.03	0.03	77442	54762	24.66	16	A	1	12GA 12FT6IN/3FT1 1/2IN WB T1
8420	C74349	0.2	0.49	0.008	0.002	0.03	79319	56709	23.4	10	A	1	12 GA 12FT6IN WB T1 FLEAT-SKT COMBO PAN
8367	4166272	0.21	0.78	0.01	0.007	0.01	78865	55889	21.61	6	A	1	12 GA 12FT6IN WB T1 FLEAT-SKT COMBO PAN
8479	9511340	0.21	0.74	0.009	0.005	0.01	77105	59917	21	100	A	1	12GA 25FT0IN 3FT1 1/2IN WB T1
8466	4135789	0.21	0.76	0.009	0.008		79006	61740	23.78	6	A	1	12GA 9FT4 1/2IN 3FT1 1/2IN WB T1

R#15-0602 H#8479
MGS 12'6" Guardrail W-Beam QTY 40
June 2015 SMT

NOTARIAL SEAL STATE OF OHIO
James P. Dehnke
Notary Public, State of Ohio
My Commission Expires 10-19-2019

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-653
All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By: ______________________
Andrew Artar, VP of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by
Andrew Artar this 3 day of June, 2015

Notary Public, State of Ohio

Figure A-3. W-Beam MGS End Section, Test Nos. MGSPCB-1 through MGSPCB-3

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. P.O. Box 80508
Canton, Ohio 44708

MAY 14 2009

Customer: UNIVERSITY OF NEBRASKA-LINCOLN
401 CANFIELD ADMIN BLDG
P O BOX 880439
LINCOLN, NE. 68588-0439

Test Report
B.O.L. # 39963
Customer P.O. 4500204081/ 04/06/2009
Shipped to: UNIVERSITY OF NEBRASKA-LINCOLN
Project : TEST PANELS
GHP Order No 105271

DATE SHIPPED: 05/07/09

HT # code	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
4614	0.21	0.84	0.011	0.003	0.03	89432	67993	19.8	160	A	2	12GA 12FT6IN/3FT1 1/2IN WB T2

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-525
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By: [signature]
Andrew Artar
Vice President of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by Andrew Artar this 8th day of May, 2009.
[signature]
Notary Public, State of Ohio

NOTARIAL SEAL STATE OF OHIO

CYNTHIA K. CRAWFORD
Notary Public, State of Ohio
My Commission Expires 09-16-2012

Figure A-4. W-Beam MGS Section, Test Nos. MGSPCB-1 through MGSPCB-3

NUCOR STEEL BERKELEY
P.O. Box 2259
Mt. Pleasant, S.C. 29464
Phone: (843) 336-6000

CERTIFIED MILL TEST REPORT

12/22/14 18:46:36
100% MELTED AND MANUFACTURED IN THE USA
All beams produced by Nucor-Berkeley are cast and rolled to a fully killed and fine grain practice.
Mercury has not been used in the direct manufacturing of this material.

Sold To: HIGHWAY SAFETY CORP
PO BOX 358
GLASTONBURY, CT 06033

Ship To: HIGHWAY SAFETY CORP
473 WEST FAIRGROUND STREET
MARION, OH 43301

Customer #.: 352 - 3
Customer PO: 1627044
B.O.L. #...: 1110076
MOS: I

SPECIFICATIONS: Tested in accordance with ASTM specification A6/A6M-14 and A370. Quality Manual Rev #27.
ASTM : A572 5013a:A529-14-50 IB-B0600800

Description	Heat# Grade(s) Test/Heat JW	Yield/ Tensile Ratio	Yield (PSI) (MPa)	Tensile (PSI) (MPa)	Elong %	C Cr ******	Mn Mo Ti	P Sn ******	S B ******	Si V N	Cu Nb ******	Ni ****** CI	CE1 CE2 Pcm
W6X8.5	2413985	.83	57200	69300	25.54	.07	.84	.013	.039	.21	.20	.05	.25
042' 00.00"	A572 5013a		394	478		.06	.01	.0091	.0005	.005	.015		.2835
W150X12.6	A992-11	.82	56400	69100	26.69		.001			.0051		4.59	.1404
012.8016m	ANS		389	476	90 Pc(s) 32,130 lbs							Inv#:	0
W6X8.5	2413988	.83	58300	70600	26.70	.07	.86	.014	.034	.17	.23	.06	.25
042' 00.00"	A572 5013a		402	487		.06	.01	.0091	.0005	.004	.015		.2773
W150X12.6	A992-11	.82	57200	69800	28.55		.001			.0051		4.87	.1356
012.8016m	ANS		394	481	36 Pc(s) 12,852 lbs							Inv#:	0

2 Heat(s) for this MTR.

R#15-0515 H#2413988

W6x8.5x6'

April 2015 SMT

Elongation based on 8" (20.32cm) gauge length. 'No Weld Repair' was peformed.
CI = 26.01Cu+3.88Ni+1.20Cr+1.49Si+17.28P (7.29Cu*Ni) (9.10Ni*P) 33.39(Cu*Cu)
Pcm = C+(Si/30)+(Mn/20)+(Cu/20)+(Ni/60)+(Cr/20)+(Mo/15)+(V/10)+5B

CE1 = C+(Mn/6)+((Cr+Mo+V)/5)+((Ni+Cu)/15)
CE2 = C+((Mn+Si)/6)+((Cr+Mo+V+Cb)/5)+((Ni+Cu)/15)

I hereby certify that the contents of this report are accurate and correct. All test results and operations performed by the material manufacturer are in compliance with material specifications, and when designated by the Purchaser, meet applicable specifications.

Bruce A. Work
Metallurgist

Figure A-5. Steel Posts, Test Nos. MGSPCB-1 through MGSPCB-3

HIGHWAY SAFETY CORP

P.O. BOX 358
GLASTONBURY, CT 06033

CERTIFICATE OF COMPLIANCE/ANALYSIS REPORT

SOLD TO:
MIDWEST MACHINERY & SUPPLY
P.O. BOX 703

Milford, NE, USA

SHIP TO:
MIDWEST MACHINERY & SUPPLY
974 238TH ROAD
MILFORD,

INVOICE / S.O.: 0182117 / 0127524
CUSTOMER P.O.: 3019

REFERENCE: STOCK
DATE SHIPPED: 2/16/2015

QTY:	ITEM NUMBER: HEAT/LOT NO:	YIELD:	CC: TENSILE:	%ELONG:	DESCRIPTION: C:	Mn:	P:	S:	Si:	Cl:	Type	ACW
850	T-POG060080600		IB-B0600800		THRIE POST W06 x 008.5# x 06'00 GALV							
(750)	2413988											
(100)	55033234											

ALL STEEL USED IN MANUFACTURING IS MADE AND MELTED IN THE USA, INCLUDING HARDWARE FASTENERS, AND COMPLIES WITH THE BUY AMERICA ACT. ALL COATINGS PROCESSES ARE PERFORMED IN THE USA AND COMPLY WITH THE BUY AMERICA ACT. BOLTS COMPLY WITH ASTMA-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153, UNLESS OTHERWISE STATED. NUTS COMPLY WITH ASTMA-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 AND/OR F-844 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153, UNLESS OTHERWISE STATED. ALL GUARDRAIL MEETS AASHTO M-180 AND ALL STRUCTURAL STEEL MEETS AASHTO M-270. ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTMA-123. ALL OTHER ITEMS COMPLY WITH AASHTO M-111, M-165, M-133, M-265, ASTM A36, ASTMA-709, ASTMA-123, ASTM A505, AND ASTMA588 SPECIFICATIONS IF APPLICABLE. COMPLIANCE WITH ALL SPECIFICATIONS OF DEPARTMENT OF PUBLIC WORKS, DEPARTMENT OF HIGHWAYS AND TRANSPORTATION, DIVISION OF ROADS AND BRIDGES AND STATE HIGHWAY ADMINISTRATION IS MET IN ALL RESPECTS.

HIGHWAY SAFETY CORPORATION

[signature]
QUALITY ASSURANCE MANAGER

NOTARIZED UPON REQUEST:
STATE OF CONNECTICUT COUNTY OF HARTFORD
SWORN AND SUBSCRIBED BEFORE ME THIS 19 DAY OF Feb, 20 15

Margaret J Satalino
Notary Public

MARGARET J. SATALINO
NOTARY PUBLIC
MY COMMISSION EXPIRES OCT. 31, 2016

Page 1 - 0127524

Figure A-6. Steel Posts, Test Nos. MGSPCB-1 through MGSPCB-3

W6x8.5 R#14-0097 Red Paint
September 2013 SMT

HIGHWAY SAFETY CORP

P.O. BOX 358
GLASTONBURY, CT 06033

CERTIFICATE OF COMPLIANCE/ANALYSIS REPORT

SOLD TO:

MIDWEST MACHINERY & SUPPLY
P.O. BOX 703
Milford, NE, USA

SHIP TO:

MIDWEST MACHINERY & SUPPLY
974 238TH ROAD
MILFORD

INVOICE / S.O.: 0172110 / 0116560
CUSTOMER P.O.: 2795

REFERENCE: STOCK
DATE SHIPPED: 08/08/13

QTY:	ITEM NUMBER: HEAT/LOT NO:	YIELD:	CC: TENSILE:	%ELONG:	DESCRIPTION: C:	Mn:	P:	S:	Si:	Cl:	Type	ACW
850	T-POG060080600		IB-B0600800		THRIE POST W06 x 008.5# x 06'00 GALV							
(350)	55028671											
			IB-B0600800									
(500)	55028670											

ALL STEEL USED IN MANUFACTURING IS MADE AND MELTED IN THE USA, INCLUDING HARDWARE FASTENERS, AND COMPLIES WITH THE BUY AMERICA ACT. ALL COATINGS PROCESSES ARE PERFORMED IN THE USA AND COMPLY WITH THE BUY AMERICA ACT. BOLTS COMPLY WITH ASTMA-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153, UNLESS OTHERWISE STATED. NUTS COMPLY WITH ASTMA-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153 UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 AND/OR F-844 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153 UNLESS OTHERWISE STATED. ALL GUARDRAIL MEETS AASHTO M-180, AND ALL STRUCTURAL STEEL MEETS AASHTO M-270. ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTMA-123. ALL OTHER ITEMS COMPLY WITH AASHTO M-111, M-165, M-133, M-265, ASTM A36, ASTMA-709, ASTMA-123, ASTM A505, AND ASTMA588 SPECIFICATIONS IF APPLICABLE. COMPLIANCE WITH ALL SPECIFICATIONS OF DEPARTMENT OF PUBLIC WORKS, DEPARTMENT OF HIGHWAYS AND TRANSPORTATION, DIVISION OF ROADS AND BRIDGES AND STATE HIGHWAY ADMINISTRATION IS MET IN ALL RESPECTS.

HIGHWAY SAFETY CORPORATION

QUALITY ASSURANCE MANAGER

NOTARIZED UPON REQUEST:
STATE OF CONNECTICUT COUNTY OF HARTFORD
SWORN AND SUBSCRIBED BEFORE ME THIS 14 DAY OF August, 20 13

Margaret J Satalino
Notary Public

MARGARET J. SATALINO
NOTARY PUBLIC
MY COMMISSION EXPIRES OCT. 31, 2016

Page 1 - 0116560

Figure A-7. Steel Posts, Test Nos. MGSPCB-1 through MGSPCB-3

GERDAU

US-ML-CARTERSVILLE
384 OLD GRASSDALE ROAD NE
CARTERSVILLE, GA 30121
USA

CERTIFIED MATERIAL TEST REPORT Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
HIGHWAY SAFETY CORP 473 W FAIRGROUND ST MARION,OH 43302-1701 USA	HIGHWAY SAFETY CORP GLASTONBURY,CT 06033-0358 USA	A992/A709-36	Wide Flange Beam / 6 X 8.5#

LENGTH	WEIGHT	HEAT / BATCH
42'00"	37,485 LB	55028671/02

SALES ORDER	CUSTOMER MATERIAL N°
448220/000020	

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
001562143 IB-B0600800	1323-0000008317	07/17/2013

SPECIFICATION / DATE or REVISION
1-ASTM A6/A6M-11
2-A992/A992M-11
3-A709/A709M-11
4-A36/A36M-08

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	N %	Pb %
0.14	0.90	0.015	0.020	0.19	0.29	0.10	0.07	0.034	0.016	0.002	0.0090	0.0080

CHEMICAL COMPOSITION

Sn %
0.012

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS 0.2% PSI	YS MPa
20.20	8.000	74300	512	50900	351
22.10	8.000	74000	510	54800	378

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

YAN WANG
QUALITY ASSURANCE MGR.

Figure A-8. Steel Posts, Test Nos. MGSPCB-1 through MGSPCB-3

R#14-0554 July 2014 SMT QTY 10

HIGHWAY SAFETY CORP

P.O. BOX 358
GLASTONBURY, CT 06033

CERTIFICATE OF COMPLIANCE/ANALYSIS REPORT

SOLD TO:

MIDWEST MACHINERY & SUPPLY
P.O. BOX 703
Milford, NE, USA

SHIP TO:

MIDWEST MACHINERY & SUPPLY
MILFORD

INVOICE / S.O.: 0176846 / 0121723
CUSTOMER P.O.: 2932

REFERENCE: STOCK
DATE SHIPPED: 5/27/2014

QTY: HEAT/LOT NO:	ITEM NUMBER: YIELD:	CC: TENSILE:	%ELONG:	DESCRIPTION: C: Mn: P: S: Si: Cl: Type ACW
850	T-POG060080600	IB-B0600800		THRIE POST W06 x 008.5# x 06'00 GALV
(550) 1311748				
		IB-B0600800		
(300) 1311743				

ALL STEEL USED IN MANUFACTURING IS MADE AND MELTED IN THE USA, INCLUDING HARDWARE FASTENERS, AND COMPLIES WITH THE BUY AMERICA ACT. ALL COATINGS PROCESSES ARE PERFORMED IN THE USA AND COMPLY WITH THE BUY AMERICA ACT. BOLTS COMPLY WITH ASTMA-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153, UNLESS OTHERWISE STATED. NUTS COMPLY WITH ASTMA-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153 UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 AND/OR F-844 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153 UNLESS OTHERWISE STATED. ALL GUARDRAIL MEETS AASHTO M-180, AND ALL STRUCTURAL STEEL MEETS AASHTO M-270. ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTMA-123. ALL OTHER ITEMS COMPLY WITH AASHTO M-111, M-165, M-133, M-265, ASTM A36, ASTMA-709, ASTMA-123, ASTM A505, AND ASTMA588 SPECIFICATIONS IF APPLICABLE. COMPLIANCE WITH ALL SPECIFICATIONS OF DEPARTMENT OF PUBLIC WORKS, DEPARTMENT OF HIGHWAYS AND TRANSPORTATION, DIVISION OF ROADS AND BRIDGES AND STATE HIGHWAY ADMINISTRATION IS MET IN ALL RESPECTS.

HIGHWAY SAFETY CORPORATION

QUALITY ASSURANCE MANAGER

NOTARIZED UPON REQUEST:
STATE OF CONNECTICUT COUNTY OF HARTFORD
SWORN AND SUBSCRIBED BEFORE ME THIS 29 DAY OF May, 20 14

Margaret J Satalino
Notary Public

MARGARET J. SATALINO
NOTARY PUBLIC
MY COMMISSION EXPIRES OCT. 31, 2016

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Figure A-9. Steel Posts, Test Nos. MGSPCB-1 through MGSPCB-3

NUCOR STEEL - BERKELEY
P.O. Box 2259
Mt. Pleasant, S.C. 29464
Phone: (843) 336-6000

CERTIFIED MILL TEST REPORT

10/14/13 7:20:46

100% MELTED AND MANUFACTURED IN THE USA
All beams produced by Nucor-Berkeley are cast and rolled to a fully killed and fine grain practice.
Mercury has not been used in the direct manufacturing of this material.

Sold To: HIGHWAY SAFETY CORP
PO BOX 358

GLASTONBURY, CT 06033

Ship To: HIGHWAY SAFETY CORP
473 WEST FAIRGROUND STREET

MARION, OH 43301

Customer #.: 352 - 3
Customer PO: 0001574038
B.o.L. #...: 1038540
MOS: T

SPECIFICATIONS: Tested in accordance with ASTM specification A6-13/A6M-12 and A370. Quality Manual Rev #27.
ASME : SA-36 07a
ASTM : A992-11:A36-12/A529-05-50/A572 5012a/A70913 50s
CSA : CSA-44W/G40.21-50w/G40.21300W/G40.21350w

IB-B0600800

Description	Heat# Grade(s) Test/Heat JW	Yield/ Tensile Ratio	Yield (PSI) (MPa)	Tensile (PSI) (MPa)	Elong %	C Cr xxxxxx	Mn Mo Ti	P Sn xxxxxx	S B xxxxxx	Si V N	Cu Nb xxxxxx	Ni xxxxxx CI	CE1 CE2 Pcm
W6X8.5	1311748	.79	54100	68100	27.20	.06	.83	.008	.032	.20	.17	.05	.23
042' 00.00"	A992-11		373	470		.03	.01	.0088	.0003	.003	.014		.2627
W150X12.6		.80	55200	68900	27.74		.001			.0054		4.13	.1263
012.8016m	ANS		381	475	42 Pc(s)	14,994 lbs						Inv#:	0
W6X8.5	1311743	.81	57600	71200	28.29	.07	.88	.009	.027	.24	.17	.05	.24
042' 00.00"	A992-11		397	491		.04	.01	.0088	.0003	.004	.016		.2835
W150X12.6		.81	58400	71900	27.46		.001			.0057		4.19	.1335
012.8016m	ANS		403	496	84 Pc(s)	29,988 lbs						Inv#:	0

2 Heat(s) for this MTR.

Elongation based on 8" (20.32cm) gauge length. 'No Weld Repair' was peformed.
CI = 26.01Cu+3.88Ni+1.20Cr+1.49Si+17.28P-(7.29Cu*Ni)-(9.10Ni*P)-33.39(Cu*Cu)
Pcm = C+(Si/30)+(Mn/20)+(Cu/20)+(Ni/60)+(Cr/20)+(Mo/15)+(V/10)+5B

CE1 = C+(Mn/6)+((Cr+Mo+V)/5)+((Ni+Cu)/15)
CE2 = C+((Mn+Si)/6)+((Cr+Mo+V+Cb)/5)+((Ni+Cu)/15)

I hereby certify that the contents of this report are accurate and correct. All test results and operations performed by the material manufacturer are in compliance with material specifications, and when designated by the Purchaser, meet applicable specifications.

Bruce A. Work
Metallurgist

Figure A-10. Steel Posts, Test Nos. MGSPCB-1 through MGSPCB-3

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. P.O. Box 80508
Canton, Ohio 44708

Customer: MIDWEST MACHINERY & SUPPLY CO.
2200 Y STREET

LINCOLN,NE,68501

Test Report
B.O.L. # 5239AA-1
Customer P.O.: 2551
Shipped to: MIDWEST MACHINERY & SUPPLY CO.
Project: STOCK
GHP Order No. 5239AA

DATE SHIPPED: 02/29/12

HT # code	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
L81665	0.1	0.8	0.01	0.025	0.19	63000	53300	20	200		2	6IN WF AT 8.5 X 6FT 0IN GR POST
L83827	0.09	0.94	0.013	0.031	0.23	70400	56300	24	200		2	6IN WF AT 8.5 X 6FT 0IN GR POST
L83786	0.09	0.85	0.011	0.038	0.23	66500	52300	20	200		2	6IN WF AT 8.5 X 6FT 0IN GR POST
L83766	0.09	0.88	0.011	0.036	0.19	67200	53300	21	200		2	6IN WF AT 8.5 X 6FT 0IN GR POST
L81670	0.09	0.92	0.014	0.028	0.2	62000	47400	21	50		2	6IN WF AT 8.5 X 6FT 0IN GR POST

Bolts comply with ASTM A-307 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
Nuts comply with ASTM A-563 specifications and are galvanized in accordance with ASTM A-153, unless otherwise stated.
All other galvanized material conforms with ASTM-123 & ASTM-653
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By:
Andrew Artar
Vice President of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by
Andrew Artar this 1 st day of March 2012

Notary Public, State of Ohio

James P. Dehnke
Notary Public, State of Ohio
My Commission Expires 10-19-2014

Figure A-11. Steel Post, Test Nos. MGSPCB-2

CENTRAL NEBRASKA WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

CWNP Invoice 10048570
Shipped To MIDWEST-MILFORD
Customer PO 2892

Central Nebraska Wood Preservers, Inc.
Certification of Inspection

Date: 4/23/14

Specifications: Highway Construction Use

Preservative: CCA – C 0.60 pcf

Charge #	Date Treated	Grade	Material Size, Length & Dressing	# Pieces	White Moisture Readings	Penetration # of Borings & % Conforming	Actual Retentions % Conforming
18379	4/16/14	#1	6x12-14" Blocks	756	19	1/20 95%	.651 pcf
18379	4/16/14	#1	6x8-22" Blocks	84	19	1/20 95%	.651 pcf

Number of pieces rejected and reason for rejection:
None

Statement: The above reference material was treated and inspected in accordance with the above referenced specifications.

Kurt Andres, General Manager

4/23/14
Date

MGS Wood Blockouts 6x12x14" R#14-0554
GREEN TAGS don't mistaken these for the 2part blockouts because they are also GREEN. July 2014 SMT

Figure A-12. Timber Blockouts, Test Nos. MGSPCB-1 through MGSPCB-3

CENTRAL NEBRASKA WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

R#15-0515
6x12x14 OCD Wood Blockouts
Light Blue Paint

Date: 1/30/15

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery – Milford BOL# 10050796

Customer PO# 3004 Ther 1 Preservative: CCA – C 0.60 pcf

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
GR6814 BLK	6x8-14" BLK Tapered	252	19877	.708 pcf
GR61214 BLK	6x12-14" BLK OCD	168	19815	.603 pcf
↓	↓	420	19814	.681 pcf
↓	↓	588	19809	.694 pcf

I certify the above referenced material has been produced, treated and tested in accordance with and conforms to AASHTO M133 & M168 standards.

Kurt Andres, General Manager

1/30/15
Date

Figure A-13. Timber Blockouts, Test Nos. MGSPCB-1 through MGSPCB-3

R#15-0627 H#20297970 L#140530L
5/8x10" Guardrail Bolt
June 2015 SMT

35006

TRINITY HIGHWAY PRODUCTS, LLC
425 East O'Connor Ave.
Lima, Ohio 45801
419-227-1296

7/31/14

MATERIAL CERTIFICATION

Customer: Stock
Date: June 25,2014
Invoice Number:
Lot Number: 140530L
Part Number: 3500G
Quantity: 17,173 Pcs.
Description: 5/8" x 10" G.R. Bolt
Heat Numbers: 20297970 17,173

Specification: ASTM A307-A / A153 / F2329

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
20297970	.09	.33	.006	.001	.06	.03	.04	.01	.08	.002	.001	.026	.008	.0001	.001	.002

PLATING OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.54 (2.0 Mils Minimum)

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA****

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A
WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

TRINITY HIGHWAY PRODUCTS LLC

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 11th day of July 2014

Sherri Braun NOTARY PUBLIC

425 E. O'CONNOR AVENUE LIMA, OHIO 45801 419-227-1296.

NOTARIAL SEAL STATE OF OHIO
SHERRI BRAUN
Notary Public, State of Ohio
My Commission Expires
April 20, 2019

RECEIVED
JUL 11 2014
Trinity Highway Products, LLC
Dallas, Texas. Plant 99

Figure A-14. ⅝-in. (16-mm) x 10-in. (254-mm) Guardrail Bolts, Test Nos. MGSPCB-1 through MGSPCB-3

5/8"x14" Post Bolts
Green Paint R#14-0554
July 2014 SMT

35406

CERTIFICATE OF COMPLIANCE

ROCKFORD BOLT & STEEL CO.
126 MILL STREET
ROCKFORD, IL 61101
815-968-0514 FAX# 815-968-3111

CUSTOMER NAME: TRINITY INDUSTRIES

CUSTOMER PO: 159892

SHIPPER#: 050883
DATE SHIPPED: 01/13/14

INVOICE #:

LOT#: 25512

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

TENSILE: SPEC: 60,000 psi*min RESULTS: 76,318 78,539 78,075 78,380

HARDNESS: 100 max 86.80 86.76 86.00 90.10

*Pounds Per Square Inch.

COATING: ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE

CHEMICAL COMPOSITION

MILL	GRADE	HEAT#	C	Mn	P	S	Si	Cu	Ni	Cr	Mo
NUCOR	1010	NF13102751	13	.60	.009	.026	.18				

QUANTITY AND DESCRIPTION:

9,100 PCS 5/8" X 14" GUARD RAIL BOLT
P/N 3540G

WE HEREBY CERTIFY THE ABOVE BOLTS HAVE BEEN MANUFACTURED BY ROCKFORD BOLT AND STEEL AT OUR FACILITY IN ROCKFORD, ILLINOIS, USA. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE USA. WE FURTHER CERIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENT PER ABOVE SPECIFICATION.

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS 14 DAY OF January 2014
Diana Rasmussen

OFFICIAL SEAL
DIANA RASMUSSEN
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES:10/15/14

Deida Metomas
APPROVED SIGNATORY

1/14/14
DATE

Figure A-15. ⅝-in. (16-mm) x 14-in. (356-mm) Post Bolts, Test Nos. MGSPCB-1 through MGSPCB-3

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE **TARP LOAD** **TARP LOAD** **TARP LOAD**

Order Number: 1236801 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3028
BOL Number: 86849 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 3/13/15

5/8x14" Guardrail Bolts R#15-0515 H#26859
Light Blue April 2015 SMT

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	3000G	CBL 3/4X6'6/DBL	HW			192900													
4,000	3340G	5/8" GR HEX NUT	HW			DECKER1411N2													
3,000	3360G	5/8"X1.25" GR BOLT	HW			150220B													
225	3500G	5/8"X10" GR BOLT A307	HW			141121L													
875	3540G	5/8"X14" GR BOLT A307	HW			26859													
250	4235G	3/16"X1.75"X3" WSHR	HW			C6086													
20	9852A	STRUT & YOKE ASSY	A-36			4119013	49,500	66,000	33.0	0.180	0.380	0.006	0.008	0.010	0.040	0.001	0.030	0.000	4
	9852A		A-36			163373	47,260	65,650	33.6	0.190	0.530	0.012	0.004	0.020	0.120	0.000	0.050	0.000	4
	9852A		A-36			0171684	45,900	69,340	32.7	0.190	0.760	0.015	0.006	0.007	0.040	0.001	0.030	0.002	4
	9852A		HW			0806489398													
6	10967G	12/9'4.5/3'1.5/S			2	L13313													
			M-180	A	2	168413	54,570	71,150	31.7	0.190	0.720	0.012	0.004	0.020	0.130	0.000	0.070	0.001	4
			M-180	A	2	168415	55,740	72,640	31.3	0.190	0.730	0.012	0.004	0.020	0.140	0.000	0.060	0.001	4
			M-180	A	2	168416	53,470	71,880	30.8	0.190	0.730	0.011	0.002	0.020	0.120	0.000	0.060	0.001	4
			M-180	A	2	168417	57,590	73,620	30.1	0.190	0.740	0.012	0.003	0.020	0.130	0.000	0.060	0.001	4
			M-180	A	2	168748	56,810	73,060	30.5	0.190	0.730	0.011	0.005	0.020	0.130	0.000	0.060	0.001	4
			M-180	A	2	168749	57,900	73,710	28.4	0.200	0.730	0.012	0.004	0.020	0.120	0.001	0.060	0.000	4
			M-180	A	2	168750	55,480	72,750	29.5	0.190	0.730	0.010	0.003	0.020	0.130	0.000	0.060	0.001	4

2 of 7

Figure A-16. ⅝-in. (16-mm) x 14-in. (356-mm) Guardrail Bolts, Test Nos. MGSPCB-1 through MGSPCB-3

Certified Analysis

rinity Highway Products , LLC
50 East Robb Ave.
ima, OH 45801
ustomer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405

Order Number: 1236801 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3028
BOL Number: 86849 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 3/13/15

roject: RESALE **TARP LOAD** **TARP LOAD** **TARP LOAD**

LL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.
LL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
LL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
LL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

INISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
OLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
UTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
'ASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING
TRENGTH – 46000 LB

State of Ohio, County of Allen. Sworn and subscribed before me this 13rd day of March, 2015
Notary Public:
ommission Expires: 1/23/2016

STATE OF OHIO ANGELA COUNTS NOTARY PUBLIC ID# 2011NT0814 Commission Expires January 23, 2016 AUGLAIZE COUNTY

Trinity Highway Products , LLC
Certified By:
Quality Assurance

7 of 7

Figure A-17. ⅝-in. (16-mm) x 14-in. (356-mm) Guardrail Bolts, Test Nos. MGSPCB-1 through MGSPCB-3

10-05-09;04:15PM;Bennett-Bolt-Works Midwest Machinery ;3156893999 # 5/ 10

INSPECTION CERTIFICATE

ROCKFORD BOLT & STEEL CO.
126 MILL STREET
ROCKFORD, IL 61101
815-968-0514 FAX# 815-968-3111

CUSTOMER NAME: BENNETT BOLT WORKS

CUSTOMER P.O. : 6005874

INVOICE #: 941845 **DATE SHIPPED:** 7/24/09

LOT #: 19934

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

	SPECIFICATION	ACTUAL			
TENSILE RESULTS:	60,000 min.	76,513	75,053	77,617	76,876
		76,796	74,699	77,628	76,938
HARDNESS RESULTS:	100 MAX	81.22	86.60	86.96	81.62
		81.80	85.25	87.10	81.00

COATING: ASTM SPECIFICATION F2329 HOT DIP GALVANIZE

STEEL SUPPLIER: NUCOR, NUCOR, NUCOR, NUCOR

HEAT NO. 848653, 749237, 849289, 846672

QUANTITY AND DESCRIPTION:

600 PCS 5/8" X 22" GUARD RAIL BOLT

WE HEREBY CERTIFY THE ABOVE BOLTS HAVE BEEN MANUFACTURED BY ROCKFORD BOLT AND STEEL. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE U.S.A. WE FURTHER CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENTS PER ABOVE SPECIFICATION.

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS
27th DAY OF July 2009
Lisa A. Berg

Linda Melomas 7/27/09
APPROVED SIGNATORY DATE

OFFICIAL SEAL
LISA A. BERG
Notary Public - State of Illinois
My Commission Expires Dec 11, 2011

Figure A-18. ⅝-in. (16-mm) x 22-in. (559-mm) Post Bolts, Test Nos. MGSPCB-1 through MGSPCB-3

From:MID WEST FABRICATING ROCKMILL 740 681 4433 03/17/2010 04:43 #003 P.002

55 35806

MID WEST
FABRICATING CO.

CERTIFICATE OF COMPLIANCE

WE CERTIFY THAT ALL BOLTS ARE MADE AND MANUFACTURED IN THE USA.

TO: TRINITY INDUSTRIES INC.
Plant #55
550 East Robb Ave. 419-222-7398
Lima, Ohio 45801

SHIP DATE: 3/16/2010
MANUFACTURER: MID WEST FABRICATING CO.
ASTM: A307A
GALVANIZERS: Bristol/Pilot TO A-153 CLASS C

QTY	PART NO.	HEAT NO.	LOT NO.	P.O.NO.
4,464	5/8 x 18-6"	20055460	05045	134079
25,350	5/8 x 18-6"	20057071	5010	134079

Signature D. Smith D. Smith
TITLE: QUALITY CONTROL
DATE: 3/16/2010

313 North Johns Street • Amanda, Ohio 43102 • 740/969-4411 • FAX: 740/969-4433

Figure A-19. 18-in. (457-mm) Post Bolts, Test Nos. MGSPCB-1 through MGSPCB-3

5/8x10" post bolt
R#14-0207 Green Paint

8/26/13

3500G

TRINITY HIGHWAY PRODUCTS, LLC
425 East O'Connor Ave.
Lima, Ohio 45801
419-227-1296

MATERIAL CERTIFICATION

Customer: Stock

Date: August 16, 2013

Invoice Number:

Lot Number: 130809L

Part Number: 3500G

Quantity: 16,233 Pcs.

Description: 5/8" x 10" G.R. Bolt

Heat Numbers: 10240100 10,820; 10231650 5,413

PASSED & CERTIFIED
AUG 20 2013
Trinity Highway Products, LLC
Dallas, Texas Plant 99

Specification: ASTM A307-A / A153 / F2329

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
10240100	.09	.49	.01	.007	.09	.04	.09	.02	.08	.008	.002	.023	.005	.0001	.001	.001
10231650	.09	.49	.008	.011	.09	.05	.08	.02	.09	.006	.002	.023	.007	.0001	.001	.001

PLATING OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.51 (2.0 Mils Minimum)

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA****

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A
WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

TRINITY HIGHWAY PRODUCTS LLC

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 19th day of Aug 2013

Sherri Brown NOTARY PUBLIC

425 E. O'CONNOR AVENUE LIMA, OHIO 45801

STATE OF OHIO NOTARY PUBLIC ID# 2009NT0139 Commission Expires April 20, 2014 419-227-1296 ALLEN COUNTY

Figure A-20. ⅝-in. (16-mm) x 10-in. (254-mm) Post Bolts, Test Nos. MGSPCB-1 through MGSPCB-3

06/04/2009 16:36 402-761-3288 MIDWEST MACHINERY

MID WEST
FABRICATING CO.

CERTIFICATE OF COMPLIANCE

WE CERTIFY THAT ALL BOLTS ARE MADE AND MANUFACTURED IN THE USA.

TO: TRINITY INDUSTRIES INC.
Plant #55
425 E. O'Connor 419-222-7398
Lima,Ohio 45801
SHIP DATE: 11/6/2008
MANUFACTURER: MID WEST FABRICATING CO.
ASTM: A307A
GALVANIZERS: Columbus/Piolt TO A-153 CLASS C

QTY	PART NO.	HEAT NO.	LOT NO.	P.O.NO.
3,524	5/8 X 10-6"	7261134	85204	126266BR80
1,076	5/8 X 10-6"	7261134	85204	126266BR78
8,900	5/8 X 10-6"	7261134	85204	126266BR74
Y116 4,500	5/8 X 10-6"	7261611	85217	126266BR74
2,550	5/8 X 10W-6"	7261286	85180	126266BR84
4,500	5/8 X 14-6"	7366618	85199	126266BR68
6,000	5/8 X 18-6"	7366618	85157	126266BR84
1,536	5/8 X 18-6"	7366618	85157	126266BR74
130	5/8 X 18-6"	7366618	85156	126266BR74
2,964	5/8 X 18-6"	7366618	85149	126266BR74
4,370	5/8 X 18-6"	7261611	85146	126266BR74
400	5/8 X 3.5"	5978691	85016	126266BR82

Signature D. Smith D. Smith
TITLE: QUALITY CONTROL
DATE: 11/6/2008

313 North Johns Street • Amanda, Ohio 43102 • 740/969-4411 • FAX: 740/969-4433

Figure A-21. ⅝-in. (16-mm) x 10-in. (254-mm) Post Bolts, Test Nos. MGSPCB-1 through MGSPCB-3

AMERICAN TIMBER AND STEEL

R#16-0010
BCT Wood Posts
12posts

This is to certify that the materials shipped, as indicated, conform to the State of Nebraska specifications.
Order Number: 158755
Project Number: N/A

QUANTITY	DESCRIPTION	CHARGE NO.	TREATMENT	TREATER
60	6X8-19" (2H) BLOCK	TX-3547	CCA	ATS-NAC
120	6X8-19" (2H) OS THRIE BLOCK	TX-3547	CCA	ATS-NAC
100	6X12-19" (2H) OS THRIE BLOCK	TX-3547	CCA	ATS-NAC
400	6X12-19" (2H) OS THRIE BLOCK	TX-3546	CCA	ATS-NAC
48	6X8-6' 2H THRIE POST	TX-2360	CCA	ATS-NAC
96	6X8-6' MGS CRT POST	TX-3547	CCA	ATS-NAC
40	5.5X7.5-45" BCT POST	TX-3227	CCA	ATS-NAC
40	5.5X7.5-46" BA POST	TX-3547	CCA	ATS-NAC

ATS – AMERICAN TIMBER AND STEEL, NORWALK, OH
MWT-OK - MIDWEST WOOD TREATING, INC., CHICKASHA, OK
ATS-NAC – AMERICAN TIMBER AND STEEL, NACADOCHES, TX
GAT- GREAT AMERICAN TREATING, TYLER,TX

Made & Treated in the USA. Meets AASHTO Specs M133 & M168.

AMERICAN TIMBER AND STEEL
By Derek Hoebing [signature]
Title Guardrail Salesman
Date May 8, 2015

NOTARIZED
Sworn to and subscribed before me
this 8 day of May 2015.
by [signature]

NOTARY PUBLIC STATE OF OHIO
ANDREA L. BENDER
Seneca County
NOTARY PUBLIC, STATE OF OHIO
My Commission Expires
March 26, 2020

American Timber And Steel Corp ★ 4832 Plank Rd / PO Box 767 ★ Norwalk, OH 44857 ★ Ph: 419.668.1610 ★ Fax: 419.663.1077

" T H E T I M B E R S P E C I A L I S T S "

Figure A-22. BCT Timber Posts, Test Nos. MGSPCB-1 through MGSPCB-3

3540G

INSPECTION CERTIFICATE

ROCKFORD BOLT & STEEL CO.
126 MILL STREET
ROCKFORD, IL 61101
815-968-0514 FAX# 815-968-3111

CUSTOMER NAME: TRINITY INDUSTRIES

CUSTOMER P.O.: 143227

INVOICE #: 946256 **DATE SHIPPED:** 6/20/11

LOT #: 22191

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

	SPECIFICATION	ACTUAL		
TENSILE RESULTS:	60,000 min.	81,460	70,642	76,898
		81,389	70,341	76,623
HARDNESS RESULTS:	SPECIFICATION 100 MAX	80.63	83.90	84.00
		86.33	77.90	85.00

COATING: ASTM SPECIFICATION F2329 HOT DIP GALVANIZE

STEEL SUPPLIER: NUCOR, CHARTER, NUCOR

HEAT NO. NF11101335, 10132120, NF11101336

QUANTITY AND DESCRIPTION:

18,900 PCS 5/8" X 14" GUARD RAIL BOLT
P/N 3540G

WE HEREBY CERTIFY THE ABOVE BOLTS HAVE BEEN MANUFACTURED BY ROCKFORD BOLT AND STEEL. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE U.S.A. WE FURTHER CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENTS PER ABOVE SPECIFICATION.

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS 21 DAY OF June 20 11
Diane Rasmussen

Linda McComas 6/21/11
APPROVED SIGNATORY DATE

OFFICIAL SEAL
DIANA RASMUSSEN
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES:10/15/14

Figure A-23. ⅝-in. (16-mm) x 14-in. (356-mm) Guardrail Bolts, Test No. MGSPCB-3

Mill Certification Details

NUCOR

NUCOR CORPORATION
NUCOR STEEL NEBRASKA

Mill Certification Details - 4/11/2011 10:10 AM

Customer: KRUEGER & CO - ELMHURST
Bill of Lading #: 197576
Chief Metallurgist : Jim Hill **Date :** 4/4/2011
Heat # : NF1110133502 **Tag # :** NF1111050255
Product : RDC **Size :** .594-19/32 Wire Rod
Grade: 1010 **Division :** Norfolk, NE
Comments : **Billet Heat #:** NF11101335

Chemical Properties -Wt.%

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.13	0.57	0.17	0.020	0.014	0.23	0.13	0.09	0.03	0.001	0.000	0.000	0.000	0.008	0.0002

[illegible]	[illegible]
0.0000	0.001

Physical Properties

[illegible]
Tensile: 64127
Yield: 46541
Elongation (in 8 inches):
Elongation (in 2 inches):

The testing was conducted in accordance with the requirements of this specification. All melting and manufacturing processes were performed in the United States of America.

Jim Hill
Division Metallurgist

Figure A-24. ⅝-in. (16-mm) x 14-in. (356-mm) Guardrail Bolts, Test No. MGSPCB-3

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405

Project: STOCK

Order Number: 1215324 Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: 2884
BOL Number: 80821 Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

As of: 4/14/14

Foundation Tubes Green Paint
R#15-0157 September 2014 SMT

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
10	701A	.25X11.75X16 CAB ANC	A-36			A3V3361	48,600	69,000	29.1	0.180	0.410	0.010	0.005	0.040	0.270	0.000	0.070	0.001	4
	701A		A-36			JJ4744	50,500	71,900	30.0	0.150	1.060	0.010	0.035	0.240	0.270	0.002	0.090	0.021	4
12	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
15	736G	5'/TUBE SL/.188"X6"X8"FLA	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
12	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
5	783A	5/8X8X8 BEAR PL 3/16 STP	A-36			10903960	56,000	79,500	28.0	0.180	0.810	0.009	0.005	0.020	0.100	0.012	0.030	0.000	4
	783A		A-36			DL13106973	57,000	72,000	22.0	0.160	0.720	0.012	0.022	0.190	0.360	0.002	0.120	0.050	4
20	3000G	CBL 3/4X6'6/DBL	HW			99692													
25	4063B	WD 6'0 POST 6X8 CRT	HW			43360													
15	4147B	WD 3'9 POST 5.5"X7.5"	HW			2401													
20	15000G	6'0 SYT PST/8.5/31" GR HT	A-36			34940	46,000	66,000	25.3	0.130	0.640	0.012	0.043	0.220	0.310	0.001	0.100	0.002	4
10	19948G	.135(10Ga)X1.75X1.75	HW			P34744													
2	33795G	SYT-3"AN STRT 3-HL 6'6	A-36			JJ6421	53,600	73,400	31.3	0.140	1.050	0.009	0.028	0.210	0.280	0.000	0.100	0.022	4
4	34053A	SRT-31 TRM UP PST 2'6.625	A-36			JJ5463	56,300	77,700	31.3	0.170	1.070	0.009	0.016	0.240	0.220	0.002	0.080	0.020	4

1 of 3

Figure A-25. Foundation Tubes, Test Nos. MGSPCB-1 through MGSPCB-3

425 E. O'Connor
Lima, OH

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Sales Order: 1093497
Customer PO: 2030
BOL # 43073
Document # 1

Print Date: 6/30/08
Project: RESALE
Shipped To: NE
Use State: KS

Trinity Highway Products. LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SLOTTED RAIL TERMINAL **

NCHRP Report 350 Compliant

Pieces	Description
64	5/8"X10" GR BOLT A307
192	5/8"X18" GR BOLT A307
32	1" ROUND WASHER F844
64	1" HEX NUT A563
192	WD 6'0 POST 6X8 CRT
192	WD BLK 6X8X14 DR
64	NAIL 16d SRT
64	WD 3'9 POST 5.5X7.5 BAND
32	STRUT & YOKE ASSY
128	SLOT GUARD '98
32	3/8 X 3 X 4 PL WASHER

MGSBR

Ground Strut

090453-8

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

402-761-3288

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

06/04/2009 16:36

State of Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

Notary Public:
Commission Expires

Trinity Highway Products, LLC
Certified By:

2 of 4

Figure A-26. Ground Strut Assembly, Test Nos. MGSPCB-1 through MGSPCB-3

09Mar'15 13:22 TEST CERTIFICATE No: MAR 268339

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

P/O No 4500240795
Rel
S/O No MAR 280576-001
B/L No MAR 163860-003 Shp 09Mar'15
Inv No Inv

Sold To: (5016)
STEEL & PIPE SUPPLY
1003 FORT GIBSON ROAD
CATOOSA, OK 74015

Ship To: (1)
STEEL & PIPE SUPPLY
1003 FORT GIBSON ROAD
CATOOSA, OK 74015

Tel: 918-266-6325 Fax: 918 266-4652

CERTIFICATE of ANALYSIS and TESTS Cert. No: MAR 268339
05Mar'15

Part No 0010
ROUND A500 GRADE B(C)
2.375"OD (2"NPS) X SCH40 X 21'

		Pcs	Wgt
		111	8,508

Heat Number	Tag No	Pcs	Wgt
E86298	927111	37	2,836
	YLD=69600/TEN=79070/ELG=24.2		
E86298	927113	37	2,836
E86298	927114	37	2,836

Heat Number *** Chemical Analysis ***
E86298 C=0.1700 Mn=0.5100 P=0.0100 S=0.0110 Si=0.0190 Al=0.0450
Cu=0.0300 Cr=0.0300 Mo=0.0030 V=0.0010 Ni=0.0100 Cb=0.0010
MELTED AND MANUFACTURED IN THE USA

R#15-0626 H#E86298
BCT Pipe Sleeves
June 2015 SMT

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-13
.................................A513-12
.................................A252-10
.................................A847/A847M-12

MATERIAL IDENTIFIED AS A500 GRADE B(C) MEETS BOTH
ASTM A500 GRADE B AND A500 GRADE C SPECIFICATIONS.

Page: 1 .... Last

Figure A-27. BCT Post Sleeves, Test Nos. MGSPCB-1 through MGSPCB-3

Certified Analysis

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

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Project: RESALE

Order Number: 1095199
Customer PO: 2041
BOL Number: 24481
Document #: 1
Shipped To: NE
Use State: KS

As of: 6/20/08

Qty	Part#	Description	Spec CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	6G	12/6'3/S	M-180 A		84964	64,230	81,300	25.4	0.180	0.720	0.012	0.001	0.000	0.080	0.000	0.060	0.000	4
20	701A	.25X11.75X16 CAB ANC	A-36		4153095	44,900	60,800	34.0	0.240	0.750	0.012	0.003	0.020	0.020	0.000	0.040	0.002	4
10	742G	6'0 TUBE SL/.188X8X6	A-500		A8P1160	74,000	87,000	25.2	0.050	0.670	0.013	0.005	0.030	0.220	0.000	0.060	0.021	4
20	782G	5/8"X8"X8" BEAR PL/OF	A-36		6105195	46,700	69,900	23.5	0.180	0.830	0.010	0.005	0.020	0.230	0.000	0.070	0.006	4
40	907G	12/BUFFER/ROLLED	M-180 A		L0049	54,200	73,500	25.0	0.160	0.700	0.011	0.008	0.020	0.200	0.000	0.100	0.000	4

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

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 20th day of June, 2008

Notary Public:
Commission Expires

RACHEL R. MEDINA
Notary Public
State of Texas
My Commission Expires

Trinity Highway Products, LLC
Certified By: Stefanie Ornal.a

Figure A-28. Anchor Bearing Plate, Test Nos. MGSPCB-1 through MGSPCB-3

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1145215
Customer PO: 2441
BOL Number: 61905
Document #: 1
Shipped To: NE
Use State: KS

As of: 4/15/11

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
10	206G	T12/6'3/S	M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.00	0.060	0.000	4
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.000	0.050	0.002	4
			M-180	A	2	139589	55,670	74,810	27.7	0.190	0.720	0.012	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	0.001	4
55	260G	T12/25/6'3/S	M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.00	0.050	0.002	4
			M-180	A	2	139206	61,730	78,580	26.0	0.180	0.710	0.012	0.004	0.020	0.140	0.000	0.050	0.001	4
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	0.001	4
			M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.000	0.060	0.000	4
	260G		M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.00	0.060	0.000	4
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.000	0.050	0.002	4
			M-180	A	2	139589	55,670	74,810	27.7	0.190	0.720	0.012	0.003	0.020	0.130	0.000	0.060	0.002	4
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	0.001	4
26	701A	.25X11.75X16 CAB ANC	A-36			V911470	51,460	71,280	27.5	0.120	0.800	0.015	0.030	0.190	0.300	0.00	0.090	0.023	4
	701A		A-36			N3540A	46,200	65,000	31.0	0.120	0.380	0.010	0.019	0.010	0.180	0.00	0.070	0.001	4
24	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			N4747	63,548	85,106	27.0	0.150	0.610	0.013	0.001	0.040	0.160	0.00	0.160	0.004	4
24	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			N4747	63,548	85,106	27.0	0.150	0.610	0.013	0.001	0.040	0.160	0.00	0.160	0.004	4
22	782G	5/8"X8"X8" BEAR PL/OF	A-36			18486	49,000	78,000	25.1	0.210	0.860	0.021	0.036	0.250	0.260	0.00	0.170	0.014	4
25	974G	T12/TRANS RAIL/6'3"/3'1.5	M-180	A	2	140735	61,390	80,240	27.1	0.200	0.740	0.014	0.005	0.010	0.120	0.00	0.070	0.001	4

Figure A-29. Anchor Bracket Assembly, Test Nos. MGSPCB-1 through MGSPCB-3

STEEL AND PIPE SUPPLY
SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 04/14/2015
TIME 08:56:53
USER GIANGRER

SOLD TO:
16105
Pacific Steel & Recycling
Call
1549
Great Falls MT 59403

SHIP TO:
16105
Pacific Steel & Recycling-Will

5275 Bird Creek
GREAT FALLS MT 59403

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
1825489-0010	70872120TM	1/4 72 X 120 A36 TEMPERPASS STPMLPL				21049562	04/14/2015

Chemical Analysis

Heat No. B417196 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS **Melted and Manufactured in the USA**
Batch 0003862738 6 EA 3,675.600 LB **Produced from Coil**

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.2000	0.8100	0.0080	0.0030	0.0200	0.0400	0.0800	0.0100	0.0001	0.0900	0.0280	0.0010	0.0020	0.0010	0.0068	0.0040

Mechanical/ Physical Properties

Mill Coil No. B417196-06

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
72400.000	51200.000	29.00			0	NA			
69700.000	49500.000	32.30			0	NA			
75400.000	53600.000	25.90			0	NA			
73300.000	51200.000	28.30			0	NA			

R#15-0536 H#B417196
MGS/PCB Transition
Blockout Mounting Brackets
QTY 12
May 2015 SMT

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.

Figure A-30. Blockout Mounting Plates, Test Nos. MGSPCB-1 through MGSPCB-3

S.I. Storey
LUMBER COMPANY, INC.

CERTIFICATE OF COMPLIANCE

AUGUST 4, 2009

MIDWEST MACHINERY & SUPPLY
PO BOX 81097
LINCOLN, NE 68501

THE FOLLOWING MATERIAL DELIVERED ON 8/3/09 ON BILL OF LADING NUMBER 19477 HAS BEEN INSPECTED BEFORE AND AFTER TREATMENT AND IS IN FULL COMPLIANCE WITH APPLICABLE NEBRASKA DEPARTMENT OF ROADS REQUIREMENTS FOR SOUTHERN YELLOW PINE TIMBER GUARDRAIL COMPONENTS, PRESERVATIVE TREATED WITH CHROMATED-COPPER-ARSENATE (CCA-C) TO A MINIMUM RETENTION OF .60 LBS/CU.FT. THE ACCEPTANCE OF EACH PIECE BY COMPANY QUALITY CONTROL IS INDICATED BY A HAMMER BRAND ON THE END OF EACH PIECE.

	Material		Charge #	Date	Retention	Quantity
X	6x8x14"	Blockout (CD)	09-283	7/29/09	0.67	70
	6x8x6'	Line Post	09-283	7/29/09	0.67	175
X	51/2x71/2-46"	TB Bullnose	09-283	7/29/09	0.67	48
	6x6x8"	Blockout	09-283	7/29/09	0.67	100
	6x8x22"	Blockout	09-283	7/29/09	0.67	70

THIS CERTIFICATE APPLIES TO MATERIAL ORDERED FOR your order no.: .2191

FOR ANY INQUIRIES, PLEASE RETAIN THIS DOCUMENT FOR FUTURE REFERENCE.

THANK YOU FOR YOUR ORDER.

SINCERELY,

Karen Storey

SIGNED BEFORE ME THIS 4 DAY OF AUGUST 2009.

Notary: Notary Public Floyd County Georgia
My Commission Expires Oct. 19, 2010

WILLIAM S. HOUSTON NOTARY PUBLIC EXP. Oct. 19, 2010 FLOYD COUNTY, GA

Phone: 706-234-1605 P.O. Box 99, Armuchee, GA 30105 Fax: 706-235-8132

Figure A-31. Timber Blockouts, Test Nos. MGSPCB-1 through MGSPCB-3

Charge Report

Plant No. : 1

Address

S.I. Storey Lumber Co.
285 Sike Storey Rd.
Armuchee, GA 30105
PH: 706 234-1605
Fax:706 235-8132

EPA Reg. No. 3008-36

Charge : 283
Treatment : Guardrail Type 1
Date : 7/29/09 12:42:23PM
Chemical : CCA
Target Retention : .60
Cylinder : 1 (9,090)
Tank : 3
Operator : Richard
Total Time : 2:06:43
Turn Around Time (min) : 2,676
Time/Date Off Drip Pad :

Total Board Ft : 6,037
Total Cubic Ft : 491
Total Treatable Cubic Ft : 491
Displaced Volume In : 502
Displaced Volume Out : 535
Volume Start : 8,616
Volume Finish : 7,598
Volume Used : 1,018
Penetration Sampled : 0
Penetration Failed : 0
Treat By Tally : True

Step	Time Min	Time Max	Time Act	Pressure Min	Pressure Max	Pressure Act	Injection Min	Injection Max	Injection Act	Retention Min	Retention Max	Retention Act	Flow Rate Min	Flow Rate Max	Flow Rate Act	Ramp	Time Start	Time End	Volume End	Reason
Initial Vacuum	0	17	17	0	-23	-23	0.00	0.00	0.00	.00	.00	.00	0.00	0.00	0.00	0	12:42:23	12:59:25	8,616	Time
Fill	0	10	7	0	-23	10	0.00	0.00	0.00	.00	.00	.00	0.00	0.00	0.00	0	12:59:25	13:06:05	3,281	Full
Raise Press	0	2	0	0	75	78	0.00	0.00	0.08	.00	.00	.01	0.00	0.00	0.00	0	13:06:06	13:06:26	3,159	PSI
Pressure	1	45	45	75	140	128	0.00	3.20	1.97	.00	.00	.32	0.00	0.00	0.01	1	13:06:26	13:51:27	2,229	Time
Press Relief	0	1	1	0	25	13	0.00	0.00	1.93	.00	.00	.31	0.00	0.00	0.00	1	13:51:27	13:52:15	2,249	PSI
Empty	0	10	9	0	0	0	0.00	0.00	2.61	.00	.00	.42	0.00	0.00	0.00	0	13:52:15	14:00:55	7,334	Empty
Final Vacuum	0	45	45	0	-29	-26	0.00	1.75	2.10	.00	.00	.34	0.00	0.00	0.01	0	14:00:55	14:45:57	7,588	Time
Final Empty	0	1	2	-1	-1	-1	0.00	0.00	2.09	.00	.00	.34	0.00	0.00	0.00	0	14:45:57	14:48:02	7,593	Empty
Finish	0	1	1	0	-1	0	0.00	0.00	2.07	.00	.00	.34	0.00	0.00	0.00	0	14:48:03	14:49:06	7,598	Time

Chemical	Solution Percent Start	Solution Percent Finish	Lbs. Per Gallon Start	Lbs. Per Gallon Finish	Lbs. Per Gallon Absorbed	Total Lbs. Gauge	Total Lbs. Absorbed	Retention Gauge	Retention Absorbed	Assay Min Reten	Assay Wood
CCA	1.90 %	1.90 %	.1624	.1624	.1624	165	165	.337	.337	-	-
Totals :	1.90 %	1.90 %	.1624	.1624	.1624	165	165	.337	.337	.60	-

Additive List

Additives	Solution %

Automatic Mix Information

Chemical	Current Value	Target Value	Required	Actual	Difference
Water	- Gals.	- Gals.	1,319 Gals.	1,311 Gals.	-8 Gals.
CCA	1.88 %	1.90 %	25 Gals.	25 Gals.	- Gals.

1 021.001021.60 Pieces: 175 Packs/Size : 5 @ 35 Desc: 6 x 8 x 6 Line Post Rough Nebraska #1 Dense BF: 4,200 CF: 350 HW: - % Moist. Cont.: - %
Std.: .60 Mill: Cust Num: None Retreat?: False Chg#: 0 Species: SYP Rem1: None

2 021.001008.60 Pieces: 70 Packs/Size : 1 @ 70 Desc: 6 x 8 x 0-14 Blockout Rough BF: 329 CF: 27 HW: - % Moist. Cont.: - %
Std.: .60 Mill: Cust Num: None Retreat?: False Chg#: 0 Species: SYP Rem1: None

3 9999 Pieces: 48 Packs/Size : 1 @ 48 Desc: 5-1/2 x 7-1/2 x 0-46 TB Bullnose Post BF: 720 CF: _
Std.: .60 Mill: Cust Num: None Retreat?: False Chg#: 0 Species: SYP

4 9999 Pieces: 70 Packs/Size : 1 @ 70 Desc: 6 x 8 x 0-22" Rough Blockout BF: 513 CF: _
Std.: .60 Mill: Cust Num: None Retreat?: False Chg#: 0 Species: SYP

5 9999 Pieces: 100 Packs/Size : 1 @ 100 Desc: 6 x 6 x 8" Post Block CCA .60 BF: 275 CF: _
Std.: .40 Mill: Cust Num: None Retreat?: False Chg#: 0 Species: SYP

ANALYSIS REPORT
****

RETENTION

CRO3 = 0.32 PCF
CUO = 0.12 PCF
AS205 = 0.23 PCF

TOTAL RETENTION
0.67 PCF
****

Printed on: 8/4/09 9:34:53AM Plant Number : 1 Charge Number : 283 Page 1 of 1

Figure A-32. Timber Blockouts, Test Nos. MGSPCB-1 through MGSPCB-3

General Testing Laboratories

TELEPHONE (402)434-1891
FAX (402)434-2161
P. O. BOX 29529
LINCOLN, NEBRASKA 68529

June 23, 2015

Dave Borchers
Concrete Industries
6300 Cornhusker Hwy,
Lincoln, NE 68507

Dear Dave,

Below are the strength values to date for the UNL Barrier Curbs produced at Concrete Industries.

Cast Date	Release Strength	7 Day Strength	28 Day Strength
6/8/15	5082	7838	
6/9/15	5444	7894	
6/10/15	5639	7937	
6/11/15	4639	6641	

General Testing Lab,

Rod Leber

Rod Leber, Manager

Concrete and Rebar for MGS/PCB Trans Barriers
R#15-0531

Figure A-33. Portable Concrete Barriers, Test Nos. MGSPCB-1 through MGSPCB-3

GERDAU

US-ML-KNOXVILLE
1919 TENNESSEE AVENUE N. W.
KNOXVILLE, TN 37921
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	
NEBCO INC STEEL DIVISION HAVELOCK,NE 68529 USA	CONCRETE INDUSTRIES INC LINCOLN,NE 68529-0529 USA	60 (420) TMX	Rebar / #6 (19MM)	
		LENGTH	WEIGHT	HEAT / BATCH
		60'00"	18,654 LB	57147245/02
SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION		
1877695/000010		ASTM A615/A615M-14		

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
111201	1326-0000030908	02/16/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.32	0.53	0.012	0.049	0.19	0.31	0.10	0.08	0.016	0.003	0.002	0.43

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
80040	552	97970	676	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
14.80	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
4.00	0.056	0.106	0.474

COMMENTS / NOTES

This grade meets the requirements for the following grades:

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

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

LISA CHURNETSKI
QUALITY ASSURANCE MGR.

Figure A-34. ¾-in. (19-mm) Dia., 36-in. (914-mm) Long Anchor Loop Bar, Test Nos. MGSPCB-1 through MGSPCB-3

GERDAU

US-ML-ST PAUL
1678 RED ROCK ROAD
SAINT PAUL, MN 55119
USA

CERTIFIED MATERIAL TEST REPORT Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
NEBCO INC STEEL DIVISION HAVELOCK,NE 68529 USA	CONCRETE INDUSTRIES INC LINCOLN,NE 68529-0529 USA	60 (420)	Rebar / #4 (13MM)

LENGTH	WEIGHT	HEAT / BATCH
60'00"	139,395 LB	64050283/02

SALES ORDER	CUSTOMER MATERIAL Nº	SPECIFICATION / DATE or REVISION
2046316/000010		ASTM A615/A615M-14

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
111827	1332-0000027289	04/02/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %
0.42	1.10	0.012	0.034	0.22	0.33	0.09	0.12	0.027	0.016

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
68000	469	105500	727	8.000	203.2

MECHANICAL PROPERTIES

Elong. %	BendTest
13.80	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
-1.50	0.037	0.090	0.332

COMMENTS / NOTES

Material 100% melted and rolled in the USA. Manufacturing processes for this steel, which may include scrap melted in an electric arc furnace and hot rolling, has been performed at Gerdau St. Paul Mill, 1678 Red Rock Rd., St. Paul, Minnesota, USA. All products produced from strand cast billets. Silicon killed (deoxidized) steel. No weld repairment performed. Steel not exposed to mercury or any liquid alloy which is liquid at ambient temperatures during processing or while in Gerdau St. Paul Mill's possession. Any modification to this certification as provided by Gerdau St. Paul Mill without the expressed written consent of Gerdau St. Paul Mill negates the validity of this test report. This report shall not be reproduced except in full, without the expressed written consent of Gerdau St. Paul Mill. Gerdau St. Paul Mill is not responsible for the inability of this material to meet specific applications.
Roll batch 64050283/02 roll dtd 11/21/2014

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

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

ALEA BRANDENBURG
QUALITY ASSURANCE MGR.

Figure A-35. ½-in. (13-mm) Dia., 72-in. (1,829-mm) Long Form Bar and ½-in. (13-mm) Dia., 146-in. (3,708-mm) Long Longitudinal Bar, Test Nos. MGSPCB-1 through MGSPCB-3

GERDAU

US-ML-MIDLOTHIAN
300 WARD ROAD
MIDLOTHIAN, TX 76065
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
NEBCO INC STEEL DIVISION HAVELOCK,NE 68529 USA	CONCRETE INDUSTRIES INC LINCOLN,NE 68529-0529 USA	60 (420)	Rebar / #5 (16MM)

LENGTH	WEIGHT	HEAT / BATCH
60'00"	154,706 LB	58020158/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
1642346/000010		ASTM A615/A615M-14

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
110378	1327-0000137043	12/16/2014

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	Al %
0.43	0.81	0.011	0.018	0.19	0.24	0.22	0.18	0.081	0.006	0.016	0.009	0.004

CHEMICAL COMPOSITION

CEqyA706 %
0.60

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
75900	643	110336	761	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
14.20	OK

COMMENTS / NOTES

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

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

TOM HARRINGTON
QUALITY ASSURANCE MGR.

Figure A-36. ⅝-in. (16-mm) Dia., 146-in. (3,708-mm) Long Longitudinal Bar, Test Nos. MGSPCB-1 through MGSPCB-3

ABC COATING CO. OF MINNESOTA, INC.

3200 COMO AVENUE SE
MINNEAPOLIS, MN 55414
(612) 378-1855
FAX (612) 378-3262

AN ACUÑA CO.

January 5, 2015

To Whom It May Concern:

All "Epoxy Coated Reinforcing Steel "supplied to Construction jobsites, from ABC Coating Co, is manufactured, coated and fabricated in the United States of America.

Complete process is done at ABC Coating Co - Minnesota, located in Minneapolis , MN .

We are currently using Axalta , 7-2719 Epoxy Fusion Bonded Coating .

Reinforcing steel supplied is made in the USA. Mill certificates are Available upon request .

We currently coat and fabricate in accordance with:
ASTM-A775M-07b , specifications.

Sincerely,

Fred Rocha
Vice-President
ABC Coating Co - Minnesota

EPOXY COATING PLANT CERTIFICATION — CONCRETE REINFORCING STEEL INSTITUTE

CRSI. MEMBER

Figure A-37. Epoxy Coated Reinforcing Steel, Test Nos. MGSPCB-1 through MGSPCB-3

ABC COATING CO. OF MINNESOTA, INC.

3200 COMO AVENUE SE
MINNEAPOLIS, MN 55414
(612) 378-1855
FAX (612) 378-3262

AN ACUÑA CO.

DATE SHIPPED :
ABC JOB NO. : NE 458
CUSTOMER : CONCRETE INDUSTRIES
P.O. # : 112814

CONTR: CONCRETE INDUSTRIES
COUNTY : LINCOLN, NE
PROJECT : STOCK
RELEASE : 7E,66E
72 CITY CURB INLET TOPS

WE CERTIFY THAT THE FOLLOWING DESCRIBED BAR MATERIAL HAS BEEN CLEANED, COATED WITH 3M #413 OR O'BRIEN 7-2719 OR VALSPAR # 720A009 POWDER. INSPECTED IN ACCORDANCE WITH AND MEETS THE SPECIFICATION REQUIREMENTS OF THE NEBRASKA DEPARTMENT OF TRANSPORTATION AND ASTM A775-07b ,AASHTO M-284-06, ASTM D3963-01. MANUFACTURES CERTIFICATIONS FOR THE BAR MATERIAL ARE ON FILE

MILL	HEAT	POWDER	SIZE	LBS	KG
AMERISTEEL	5413087002	H1401012620	#3/4 SM A706	2,178	988
AMERISTEEL	5714335802	H1409024435	#4 (13MM)	20,458	9,280
AMERISTEEL	5714661402	H1410025461	#4 (13MM)	18,997	8,617
AMERISTEEL	5714280502	H1410025461	#4 (13MM)	5,354	2,429
				46,987	21,313

CERTIFICATIONS FOR THE LISTED MATERIAL AND RESIN ARE ATTACHED.

STATE OF MINNESOTA)
COUNTY OF RAMSEY)

ALFREDO ROCHA
NOTARY PUBLIC - MINNESOTA
MY COMMISSION EXPIRES 01/31/17

SUSCRIBED AND SWORN BEFORE ME, a Notary Public in and for the said County and State. On this 27th day of May, 2015.

My commission expires 1-31-17
Notary Public in and for Roseville, MN

EPOXY COATING PLANT CERTIFICATION
CONCRETE REINFORCING STEEL INSTITUTE

ALL COATING, MANUFACTURING AND FABRICATION HAS OCCURRED IN THE UNITED STATES OF AMERICA

CRSI. MEMBER

Figure A-38. ¾-in. (19-mm) Dia., 102-in. (2,591-mm), 91-in. (2,311-mm), and 101-in. (2,565-mm) Long Connection Loop Bar, Test Nos. MGSPCB-1 through MGSPCB-3

CERTIFIED MATERIAL TEST REPORT Page 1/1

GERDAU

US-ML-CHARLOTTE
6601 LAKEVIEW ROAD
CHARLOTTE, NC 28269
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
ABC COATING COMPANY INC 3200 COMO AVE SE MINNEAPOLIS,MN 55414-2838 USA	ABC COATING COMPANY INC WYOMING,MI 49509-0484 USA	A706-60	Dowel Bar / 3/4"

LENGTH	WEIGHT	HEAT / BATCH
40'00"	47,614 LB	54130870/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
378738/000010		1-ASTM A706/A706M-09

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
041513-MINN	1321-0000003786	05/30/2013

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	CEqyA706 %
0.27	1.22	0.015	0.033	0.19	0.42	0.12	0.14	0.030	0.018	0.033	0.002	0.50

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	Elong. %
71834	495	96893	668	8.000	20.60

MECHANICAL PROPERTIES

BendTest
OK

COMMENTS / NOTES

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

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

KERRY CARRINGTON
QUALITY ASSURANCE MGR.

Figure A-39. ¾-in. (19-mm) Dia., 102-in. (2,591-mm), 91-in. (2,311-mm), and 101-in. (2,565-mm) Long Connection Loop Bar, Test Nos. MGSPCB-1 through MGSPCB-3

NORFOLK IRON & METAL CO.

05/23/2015
M.T.R. Cover Sheet

NORFOLK IRON NORFOLK
3001 N VICTORY RD
NORFOLK, NE 68702

APOLLO STEEL CO
7200 AMANDA RD
LINCOLN, NE 68507

Order #: 01056944
Customer PO: PO-08577

Certifications For The Material You Ordered Are Listed Below
Thank You For Your Business

Heat	Item	Item Description	Width	Length
15100584	01344	CR ROUND 1-1/4 C1018		20'

Concrete Barrier Pins MGSPCB Barriers
R#15-0531 H#15100584
July 2015 SMT

* * * End Of Page * * *

Figure A-40. 1¼-in. (32-mm) Dia., 28-in. (711-mm) Long Connector Pins, Test Nos. MGSPCB-1 through MGSPCB-3

NORFOLK IRON & METAL CO
ATTENTION: CYNDI JONES
NORFOLK IRON & METAL

NORFOLK, NE 68701

Nucor Cold Finish
Division of Nucor Corporation

P.O. Box 94 • Norfolk, Nebraska 68702-0094 • Telephone (402) 644-8600
800-228-8107

Date: 4/16/15
10:15:23
B/L#: 201360
Load #: 55965

-------- Chemical Analysis ---------

Heat Number	Size	Grade	C	Mn	P	S	Si	Pb
	CC#: 01344				PO#: 01016821			
C.D.	RD							
15100584	1.2500	1018	.180	.820	.010	.030	.310	
		Cu= .180	Cr= .100	Ni= .060	Mo= .020	Sn= .008		
	Reduction ratio = 32.0:1							
	CC#: 01347				PO#: 01016821			
C.D.	RD							
15201103	1.3750	1018	.160	.820	.012	.025	.290	
		Cu= .170	Cr= .120	Ni= .070	Mo= .020	Sn= .008		
	Reduction ratio = 27.0:1							
	CC#: 01349				PO#: 01016821			
C.D.	RD							
14104383	1.5000	1018	.170	.860	.008	.032	.290	
		Cu= .190	Cr= .100	Ni= .080	Mo= .020	Sn= .009		
	Reduction ratio = 23.0:1							
	CC#: 01349				PO#: 01016821			
C.D.	RD							
15100585	1.5000	1018	.170	.800	.009	.025	.310	
		Cu= .190	Cr= .100	Ni= .070	Mo= .020	Sn= .008		
	Reduction ratio = 23.0:1							

** Material Certifies to ASTM A108-13 unless otherwise noted

Matt Hicks - Metallurgist Approved By
ncfS007

Figure A-41. 1¼-in. (32-mm) Dia., 28-in. (711-mm) Long Connector Pins, Test Nos. MGSPCB-1 through MGSPCB-3

Appendix B. Vehicle Center of Gravity Determination

Test: MGSPCB-1 Vehicle: RAM 1500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vert CG (in.)	Vert M (lb-in.)
+	Unbalasted Truck (Curb)	4977	28.45789	141634.9
+	Brake receivers/wires	6	52	312
+	Brake Frame	9	26	234
+	Brake Cylinder (Nitrogen)	28	28	784
+	Strobe/Brake Battery	5	32	160
+	Hub	26	14.8125	385.125
+	CG Plate (EDRs)	8	34	272
-	Battery	-29	42	-1218
-	Oil	-9	20	-180
-	Interior	-72	27	-1944
-	Fuel	-163	21	-3423
-	Coolant	-6	35	-210
-	Washer fluid	0	41	0
BALLAST	Water	112	23.5	2632
	Supplemental Battery	14	26	364
	Misc.			0
				139803.1

Estimated Total Weight (lb)	4906
Vertical CG Location (in.)	28.49634

Wheel Base (in.) 140.25

MASH Targets	Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	4914	-86.0
Long CG (in.)	63 ± 4	60.54	-2.46474
Lat CG (in.)	NA	-0.56214	NA
Vert CG (in.)	28 or greater	28.50	0.49634

Note: Long. CG is measured from front axle of test vehicle
Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side
Note: Cells highlighted in red do not meet target requirements

CURB WEIGHT (lb)

	Left	Right
Front	1443	1386
Rear	1094	1054

FRONT	2829 lb
REAR	2148 lb
TOTAL	4977 lb

TEST INERTIAL WEIGHT (lb)
(from scales)

	Left	Right
Front	1437	1356
Rear	1061	1060

FRONT	2793 lb
REAR	2121 lb
TOTAL	4914 lb

Figure B-1. Vehicle Mass Distribution, Test No. MGSPCB-1

Test: MGSPCB-2 Vehicle: Kia Rio

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)
+	Unballasted Car (curb)	2434
+	Brake receivers/wires	5
+	Brake Actuator and Frame	9
+	Nitrogen Cylinder	22
+	Strobe/Brake Battery	5
+	Hub	26
+	Data Acquisition Tray	13
+	DTS Rack	0
-	Battery	-32
-	Oil	-7
-	Interior	-40
-	Fuel	0
-	Coolant	-8
-	Washer fluid	-7
BALLAST	Water	
	Supplemental Battery	14
	Misc.	

Estimated Total Weight (lb) 2434

Roof Height (in.) 57 1/2
Wheel base (in.) 98 5/8

MASH Targets	Targets	Test Inertial	Difference
Test Inertial Weight	2420 (+/-)55	2436	16.0
Long CG (in.)	39 (+/-)4	36.03	-2.96706
Lat CG (in.)	NA	- 7/9	NA
Vert CG (in.)	NA	22.43	NA

Note: Long. CG is measured from front axle of test vehicle
Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side
Note: Cells Highlighted in Red do not meet target requirements

CURB WEIGHT (lb)

	Left	Right
Front	802	769
Rear	438	425

FRONT 1571 lb
REAR 863 lb
TOTAL 2434 lb

TEST INERTIAL WEIGHT (lb)
(from scales)

	Left	Right
Front	790	756
Rear	461	429

FRONT 1546 lb
REAR 890 lb
TOTAL 2436 lb

Figure B-2. Vehicle Mass Distribution, Test No. MGSPCB-2

Test: MGSPCB-3 Vehicle: RAM 1500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb.)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unbalasted Truck (Curb)	5017	29.05145	145751.13
+	Brake receivers/wires	7	54	378
+	Brake Frame	9	26.5	238.5
+	Brake Cylinder (Nitrogen)	22	30	660
+	Strobe/Brake Battery	5	31	155
+	Hub	19	15.125	287.375
+	CG Plate (EDRs)	8	32.25	258
-	Battery	-43	42.5	-1827.5
-	Oil	-6	21	-126
-	Interior	-88	35	-3080
-	Fuel	-162	21	-3402
-	Coolant	-15	36	-540
-	Washer fluid	-8	32	-256
	Water Ballast	217	21	4557
	Supp. Battery	14	26.5	371
	Misc.			0
				143424.5

Estimated Total Weight (lb.)	4996
Vertical CG Location (in.)	28.70787

Wheel Base (in.) 140.5

Center of Gravity	2270P MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb.)	5000 ± 110	5012	12.0
Longitudinal CG (in.)	63 ± 4	62.43	-0.57113
Lateral CG (in.)	NA	-0.83654	NA
Vertical CG (in.)	28 or greater	28.71	0.70787

Note: Long. CG is measured from front axle of test vehicle
Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side
Note: Cells highlighted in red do not meet target requirements

CURB WEIGHT (lb.)

	Left	Right
Front	1464	1375
Rear	1093	1085

FRONT	2839 lb.
REAR	2178 lb.
TOTAL	5017 lb.

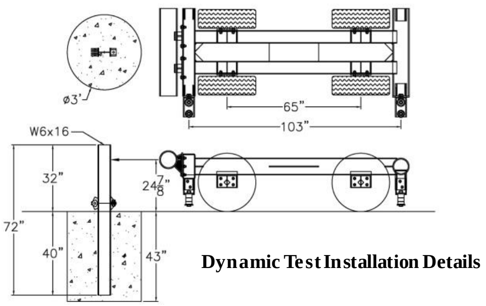
TEST INERTIAL WEIGHT (lb.)
(from scales)

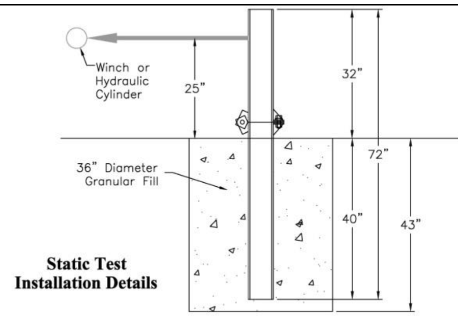
	Left	Right
Front	1454	1331
Rear	1114	1113

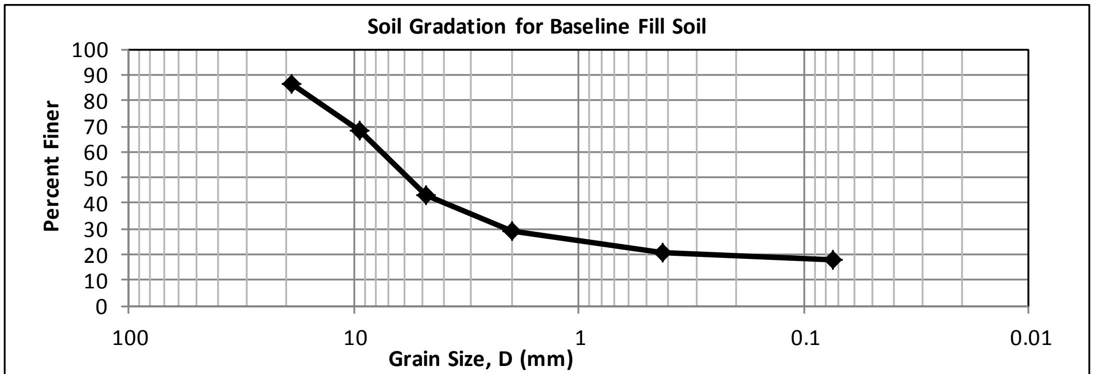
FRONT	2785 lb.
REAR	2227 lb.
TOTAL	5012 lb.

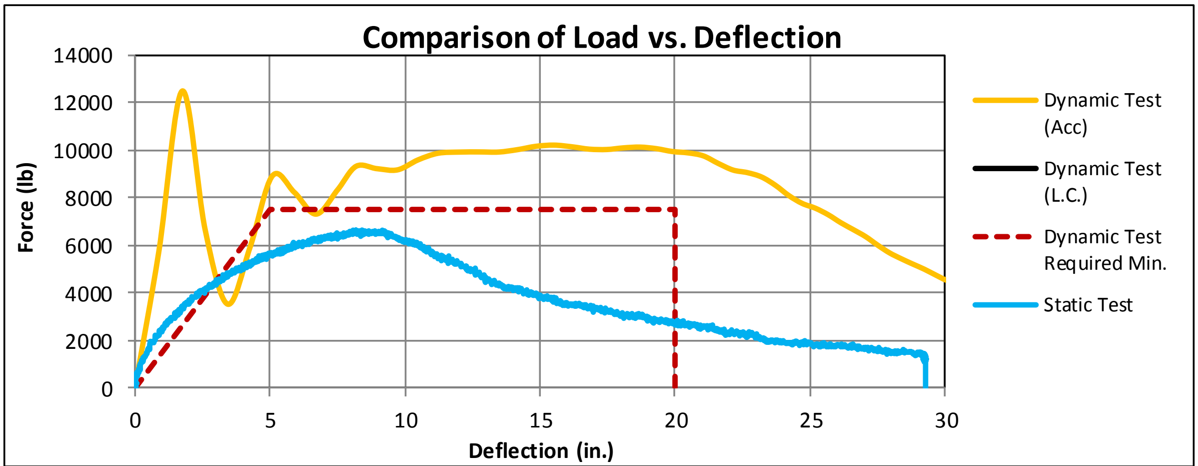
Figure B-3. Vehicle Mass Distribution, Test No. MGSPCB-3

Appendix C. Static Soil Tests







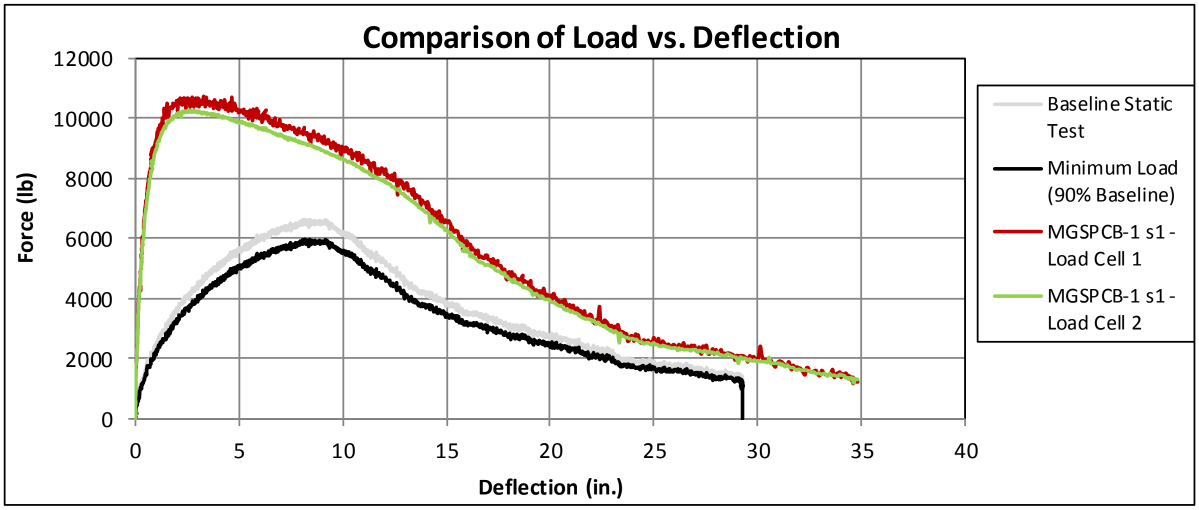


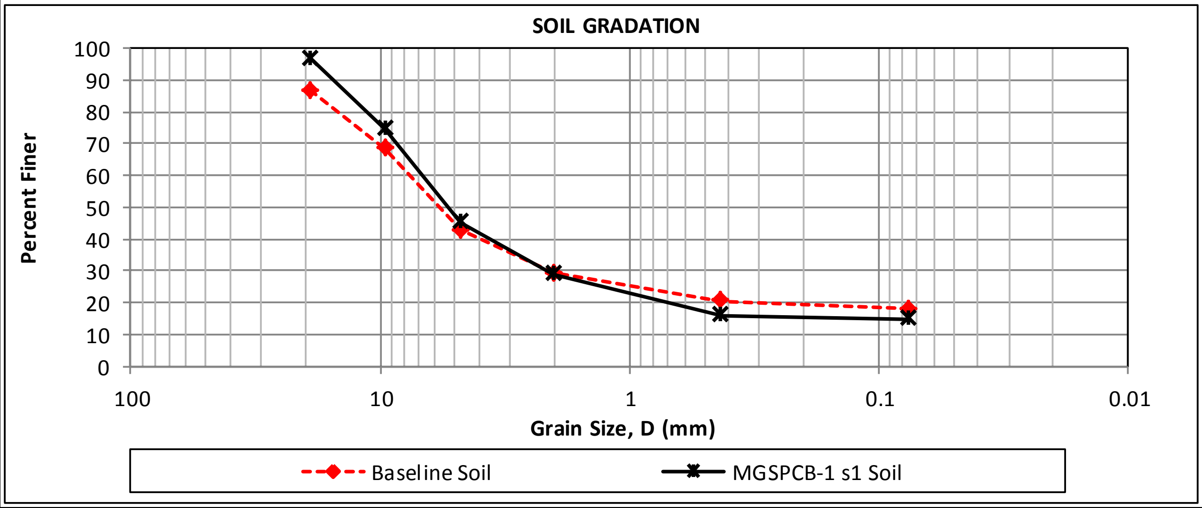
Date...	4/4/2012	
Test Facility & Site Location....................	Midwest Roadside Safety Facility	
In situ soil description (ASTM D2487).........	Well-Graded Gravel (GW)	
Fill material description (ASTM D2487)......	Well-Graded Gravel (GW) (see sieve analyses above)	
Description of fill placement procedure.....	3 Pass, 8" Lift	
Bogie Weight...	1844 lb	836 kg
Impact Velocity......................................	20.1 mph	32.3 km/h

Figure C-1. Soil Strength, Initial Calibration Tests

Static Load Test Setup

Post-Test Photo of Post



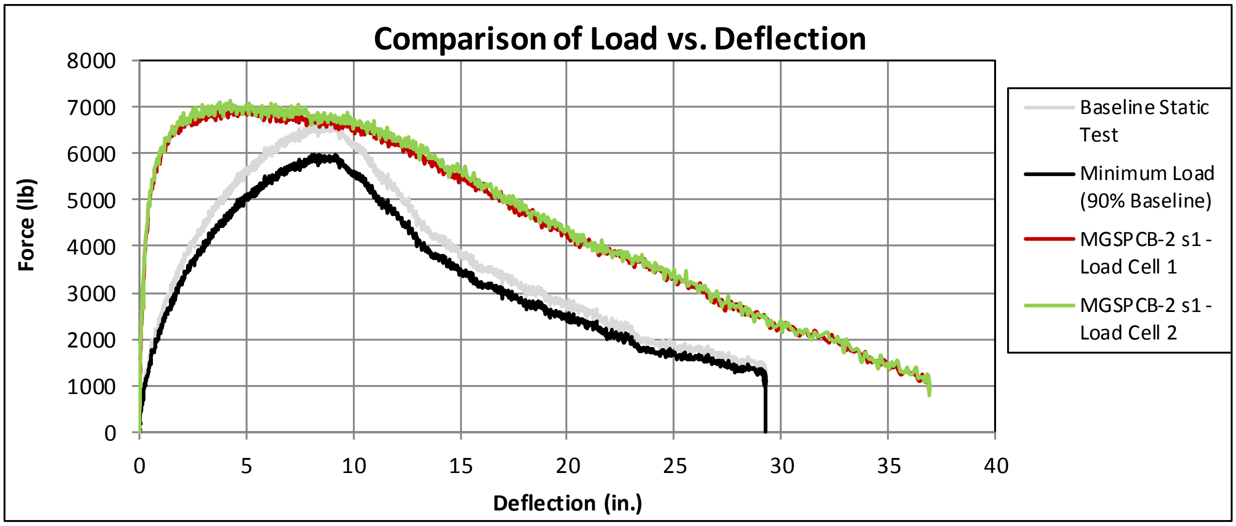


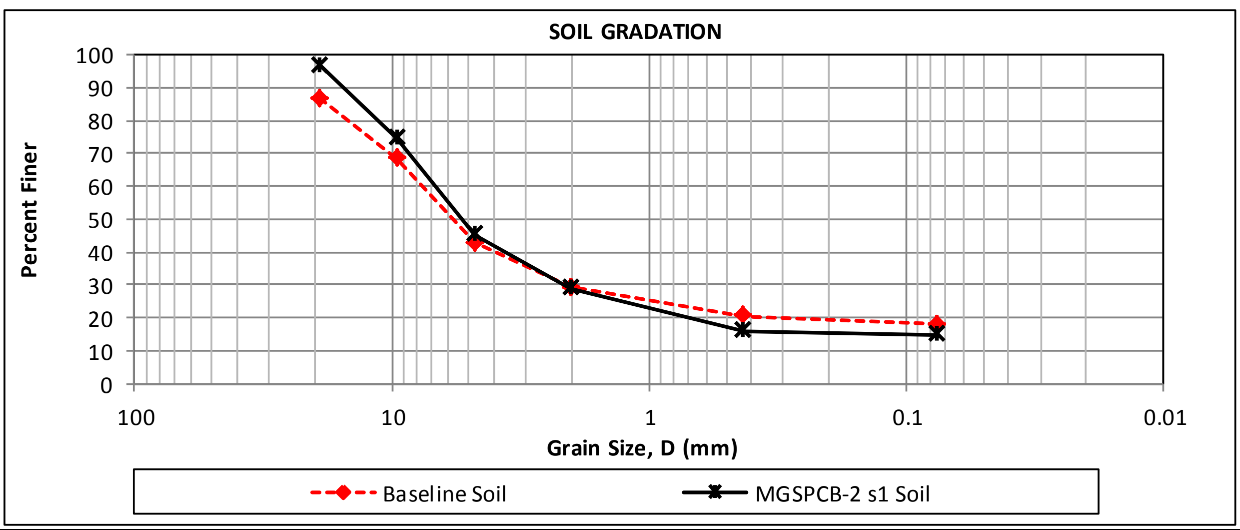
Date	7/20/2015
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Well-Graded Gravel (GW)
Fill material description (ASTM D2487)	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	8-inch lifts tamped with a pneumatic compactor

Figure C-2. Static Soil Test, Test No. MGSPCB-1

Static Load Test Setup

Post-Test Photo of Post

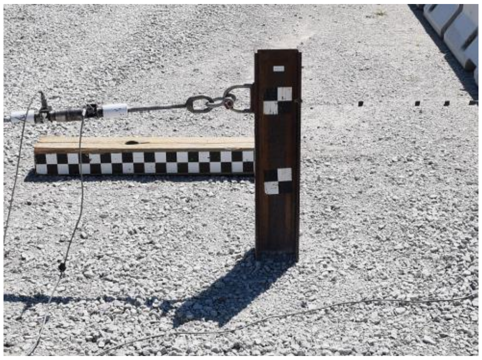




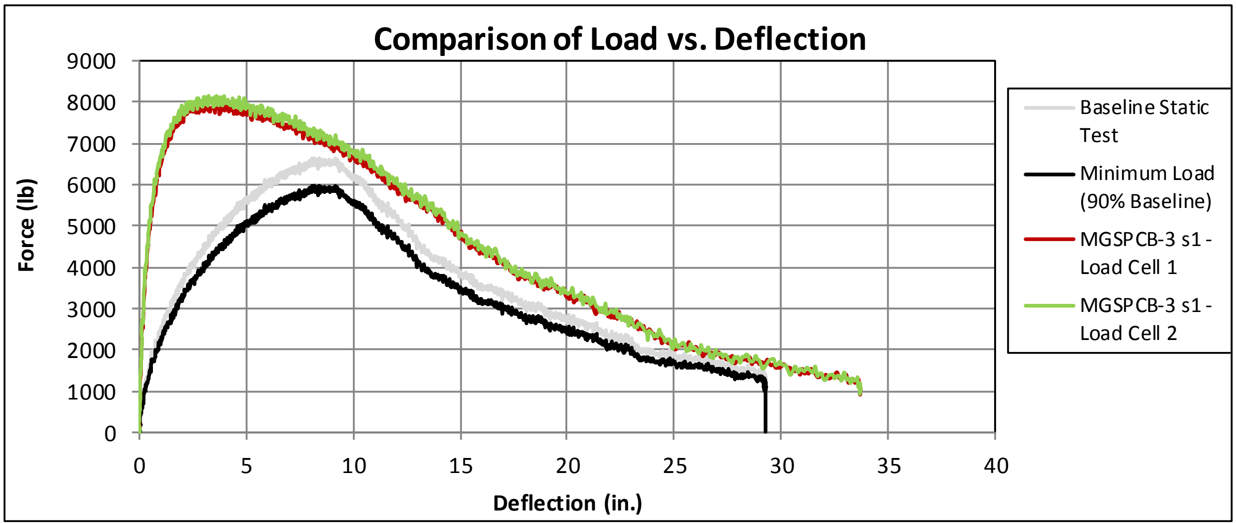
Date...	7/29/2015
Test Facility & Site Location......................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487).........	Well-Graded Gravel (GW)
Fill material description (ASTM D2487)......	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure.....	8-inch lifts tamped with a pneumatic compactor

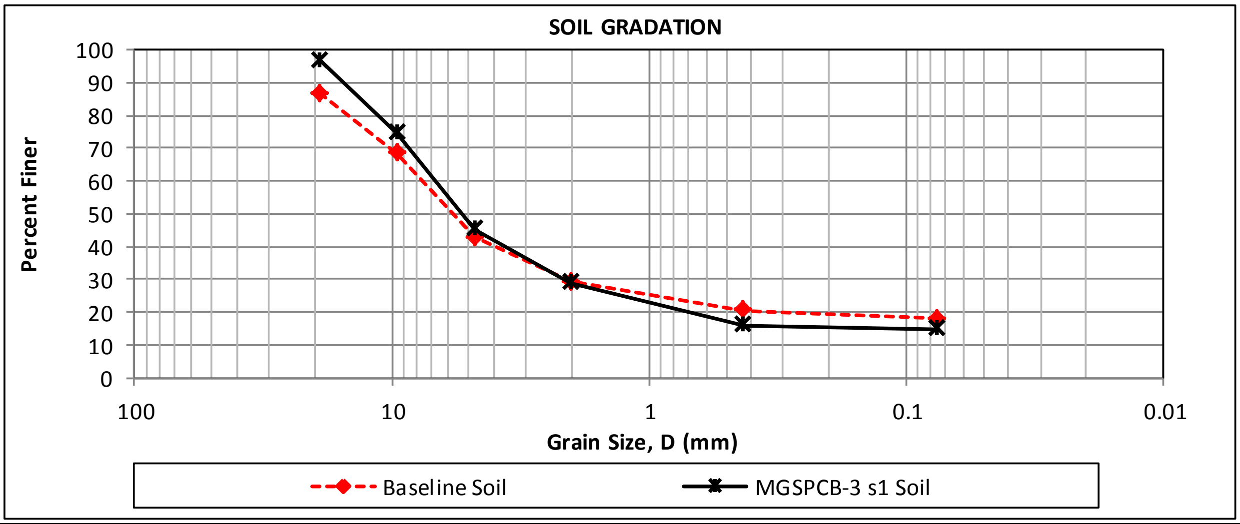
Figure C-3. Static Soil Test, Test No. MGSPCB-2

Static Load Test Setup



Post-Test Photo of Post





Date	8/24/2015
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Well-Graded Gravel (GW)
Fill material description (ASTM D2487)	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	8-inch lifts tamped with a pneumatic compactor

Figure C-4. Static Soil Test, Test No. MGSPCB-3

Appendix D. Vehicle Deformation Records

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MGSPCB-1
VEHICLE: Dodge RAM 1500

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	27.240	12.843	3.709	27.430	12.904	3.949	0.191	0.061	0.240
2	29.360	16.819	2.843	29.547	16.798	3.148	0.188	-0.021	0.304
3	31.314	21.384	1.260	31.633	21.149	1.378	0.318	-0.235	0.118
4	30.077	28.462	4.783	30.342	28.257	4.891	0.265	-0.205	0.108
5	23.926	10.775	2.983	24.162	10.839	3.180	0.236	0.064	0.197
6	25.003	16.772	0.205	25.279	16.782	0.395	0.276	0.010	0.191
7	26.073	21.752	-2.004	26.395	21.549	-1.943	0.322	-0.203	0.061
8	26.598	29.245	-0.431	26.853	29.043	-0.361	0.255	-0.202	0.070
9	20.673	9.314	1.795	20.844	9.311	2.013	0.172	-0.003	0.218
10	21.771	15.829	-0.974	21.949	15.715	-0.894	0.178	-0.114	0.080
11	22.893	19.775	-3.847	23.234	19.587	-3.892	0.340	-0.189	-0.045
12	22.917	29.354	-2.808	23.239	29.185	-2.699	0.322	-0.169	0.109
13	16.393	7.066	0.605	16.645	6.973	0.766	0.252	-0.093	0.161
14	18.525	14.666	-2.753	18.777	14.491	-2.748	0.252	-0.176	0.005
15	19.346	20.287	-5.304	19.775	20.132	-5.246	0.429	-0.154	0.058
16	19.746	29.761	-4.385	20.162	29.518	-4.339	0.416	-0.243	0.046
17	10.923	5.802	-0.126	11.183	5.775	-0.119	0.260	-0.027	0.007
18	12.421	13.556	-5.914	12.728	13.496	-5.876	0.307	-0.060	0.038
19	13.123	22.713	-5.045	13.503	22.532	-5.018	0.380	-0.181	0.027
20	13.009	30.315	-4.405	13.409	30.151	-4.293	0.399	-0.165	0.111
21	7.353	5.007	-0.443	7.636	5.034	-0.446	0.283	0.027	-0.003
22	9.805	12.620	-5.661	10.116	12.443	-5.660	0.311	-0.177	0.001
23	9.907	19.688	-4.943	10.289	19.478	-4.954	0.383	-0.211	-0.011
24	10.004	29.674	-4.070	10.391	29.465	-4.009	0.387	-0.209	0.060
25	0.975	6.235	0.495	1.303	6.277	0.531	0.328	0.042	0.036
26	0.598	12.014	-1.540	0.898	11.857	-1.651	0.300	-0.157	-0.111
27	0.525	18.478	-0.893	0.950	18.334	-0.963	0.425	-0.144	-0.069
28	0.638	26.495	-0.119	1.047	26.398	-0.154	0.409	-0.098	-0.035

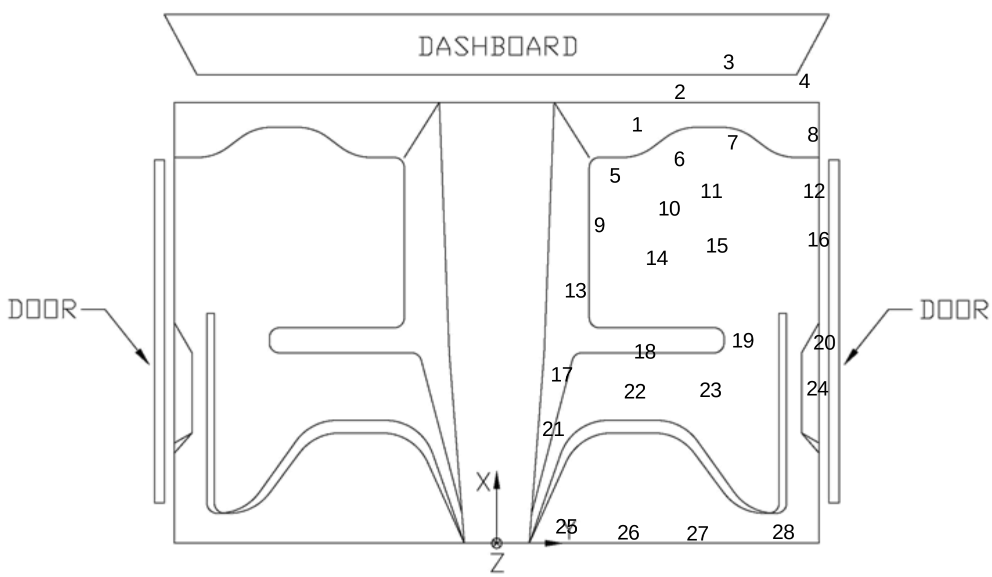


Figure D-1. Floor Pan Deformation Data – Set 1, Test No. MGSPCB-1

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MGSPCB-1
VEHICLE: Dodge RAM 1500

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	44.735	16.955	4.370	44.632	16.675	4.454	-0.103	-0.281	0.084
2	46.799	20.899	3.540	46.751	20.666	3.616	-0.048	-0.233	0.076
3	48.749	25.490	2.033	48.819	25.038	1.889	0.071	-0.452	-0.145
4	47.622	32.542	5.705	47.641	32.087	5.533	0.020	-0.455	-0.172
5	41.396	14.970	3.574	41.310	14.714	3.636	-0.086	-0.255	0.061
6	42.475	21.002	0.934	42.405	20.668	1.027	-0.070	-0.334	0.093
7	43.444	26.051	-1.174	43.456	25.532	-1.342	0.013	-0.520	-0.168
8	43.998	33.547	0.559	44.072	32.986	0.475	0.074	-0.560	-0.084
9	38.130	13.547	2.451	38.047	13.253	2.557	-0.082	-0.294	0.106
10	39.177	20.054	-0.180	39.099	19.693	-0.235	-0.078	-0.361	-0.055
11	40.222	24.095	-3.006	40.252	23.548	-3.249	0.029	-0.547	-0.243
12	40.320	33.685	-1.736	40.378	33.231	-1.845	0.058	-0.454	-0.109
13	33.782	11.234	1.297	33.797	10.950	1.359	0.015	-0.284	0.062
14	35.893	18.981	-1.924	35.858	18.527	-2.068	-0.035	-0.455	-0.144
15	36.739	24.627	-4.342	36.772	24.194	-4.527	0.033	-0.433	-0.185
16	37.079	34.048	-3.231	37.203	33.652	-3.412	0.124	-0.395	-0.181
17	28.288	10.043	0.643	28.316	9.768	0.586	0.027	-0.275	-0.057
18	29.701	18.055	-4.988	29.785	17.575	-5.087	0.084	-0.480	-0.099
19	30.405	27.021	-3.956	30.561	26.664	-4.074	0.156	-0.356	-0.118
20	30.403	34.648	-3.149	30.503	34.235	-3.206	0.100	-0.413	-0.057
21	24.712	9.260	0.376	24.746	9.015	0.333	0.033	-0.244	-0.043
22	27.126	17.002	-4.724	27.153	16.459	-4.788	0.026	-0.543	-0.063
23	27.256	24.038	-3.847	27.259	23.627	-3.958	0.003	-0.411	-0.111
24	27.369	34.001	-2.761	27.502	33.584	-2.845	0.133	-0.417	-0.084
25	18.400	10.505	1.449	18.426	10.217	1.483	0.026	-0.289	0.034
26	17.965	16.330	-0.449	18.005	15.907	-0.580	0.040	-0.422	-0.131
27	17.949	22.771	0.343	18.043	22.412	0.237	0.094	-0.359	-0.105
28	18.099	30.778	1.287	18.226	30.433	1.179	0.127	-0.346	-0.108

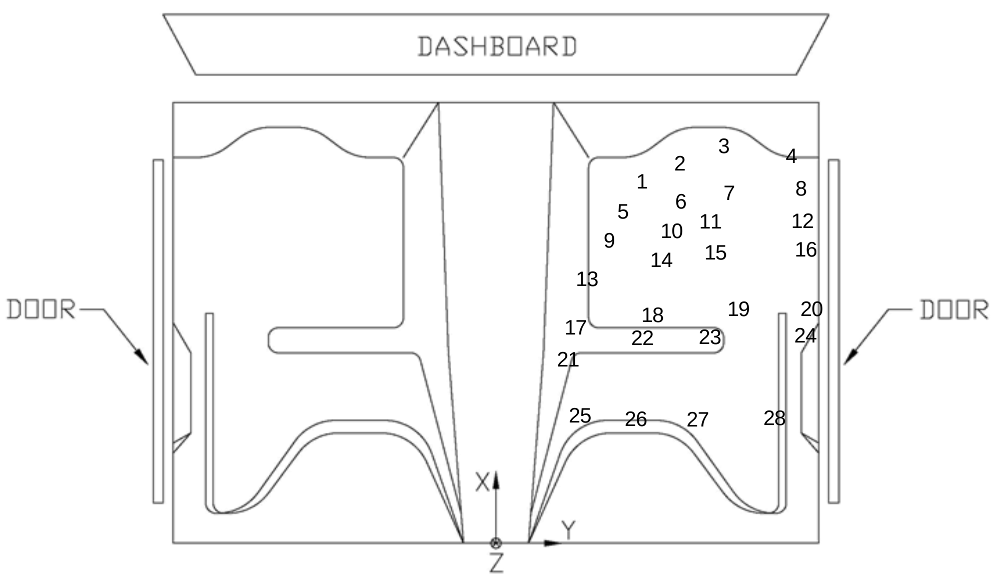


Figure D-2. Floor Pan Deformation Data – Set 2, Test No. MGSPCB-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MGSPCB-1
VEHICLE: Dodge RAM 1500

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	13.968	-3.640	26.512	14.158	-3.721	26.606	0.191	-0.081	0.094
	2	15.375	7.222	26.081	15.574	7.200	26.163	0.199	-0.022	0.082
	3	15.734	29.339	26.560	15.986	29.349	26.605	0.252	0.010	0.045
	4	11.573	-3.173	18.620	11.799	-3.275	18.597	0.226	-0.102	-0.023
	5	11.775	7.013	16.924	12.036	6.998	16.965	0.261	-0.015	0.041
	6	12.741	30.056	18.794	13.054	30.034	18.882	0.313	-0.021	0.089
SIDE PANEL	7	20.733	31.980	7.381	20.965	31.471	7.371	0.232	-0.509	-0.009
	8	20.272	32.438	2.418	20.619	31.878	2.392	0.347	-0.560	-0.026
	9	26.342	32.132	6.650	26.777	31.834	6.674	0.435	-0.298	0.024
IMPACT SIDE DOOR	10	12.924	32.841	22.741	12.621	32.868	22.801	-0.304	0.027	0.059
	11	0.046	32.700	23.743	-0.200	33.045	23.904	-0.245	0.346	0.161
	12	-12.523	32.478	24.648	-12.687	33.034	24.819	-0.164	0.556	0.172
	13	10.230	33.897	5.531	9.850	33.472	5.636	-0.380	-0.425	0.105
	14	2.422	33.865	4.905	2.042	33.808	5.141	-0.380	-0.058	0.237
	15	-13.186	34.149	5.002	-13.386	35.021	5.183	-0.200	0.871	0.181
ROOF										

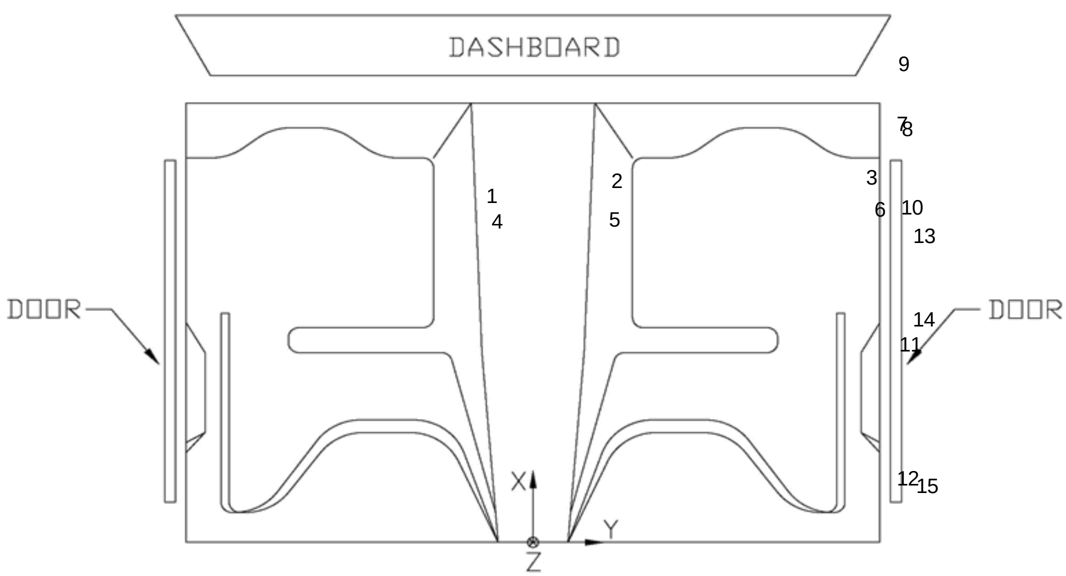


Figure D-3. Occupant Compartment Deformation Data – Set 1, Test No. MGSPCB-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MGSPCB-1
VEHICLE: Dodge RAM 1500

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	31.755	-0.027	27.012	31.852	-0.223	26.949	0.096	-0.195	-0.062
	2	33.199	10.917	26.832	33.314	10.698	26.757	0.115	-0.219	-0.075
	3	33.633	32.975	27.748	33.727	32.806	27.610	0.094	-0.169	-0.138
	4	29.249	0.651	19.226	29.369	0.417	19.123	0.119	-0.234	-0.103
	5	29.445	10.865	17.710	29.548	10.638	17.670	0.103	-0.228	-0.040
	6	30.540	33.820	20.097	30.611	33.652	19.916	0.072	-0.168	-0.181
SIDE PANEL	7	38.275	36.018	8.557	38.374	35.321	8.288	0.099	-0.697	-0.269
	8	37.790	36.591	3.573	37.874	35.809	3.393	0.084	-0.782	-0.181
	9	44.003	36.173	7.705	44.125	35.687	7.434	0.123	-0.486	-0.271
IMPACT SIDE DOOR	10	30.790	36.555	24.060	30.439	36.444	23.920	-0.351	-0.111	-0.140
	11	17.933	36.425	25.308	17.621	36.618	25.349	-0.311	0.193	0.041
	12	5.402	36.217	26.478	5.111	36.595	26.658	-0.291	0.378	0.181
	13	27.748	38.003	6.924	27.155	37.364	6.902	-0.593	-0.640	-0.022
	14	19.966	37.999	6.538	19.350	37.732	6.674	-0.616	-0.267	0.136
	15	4.398	38.343	6.756	3.883	38.940	7.021	-0.515	0.597	0.265
ROOF										

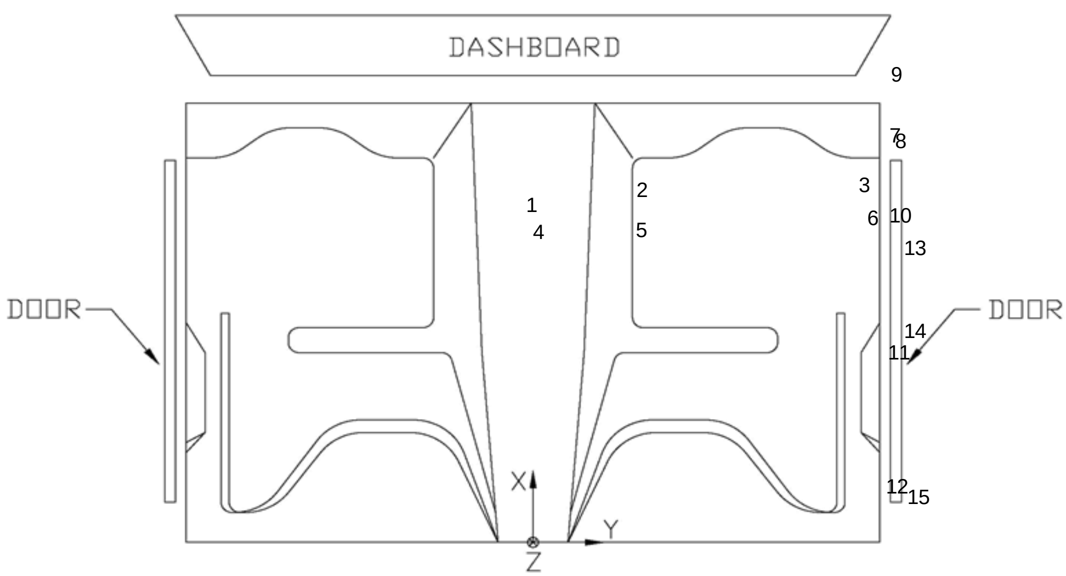
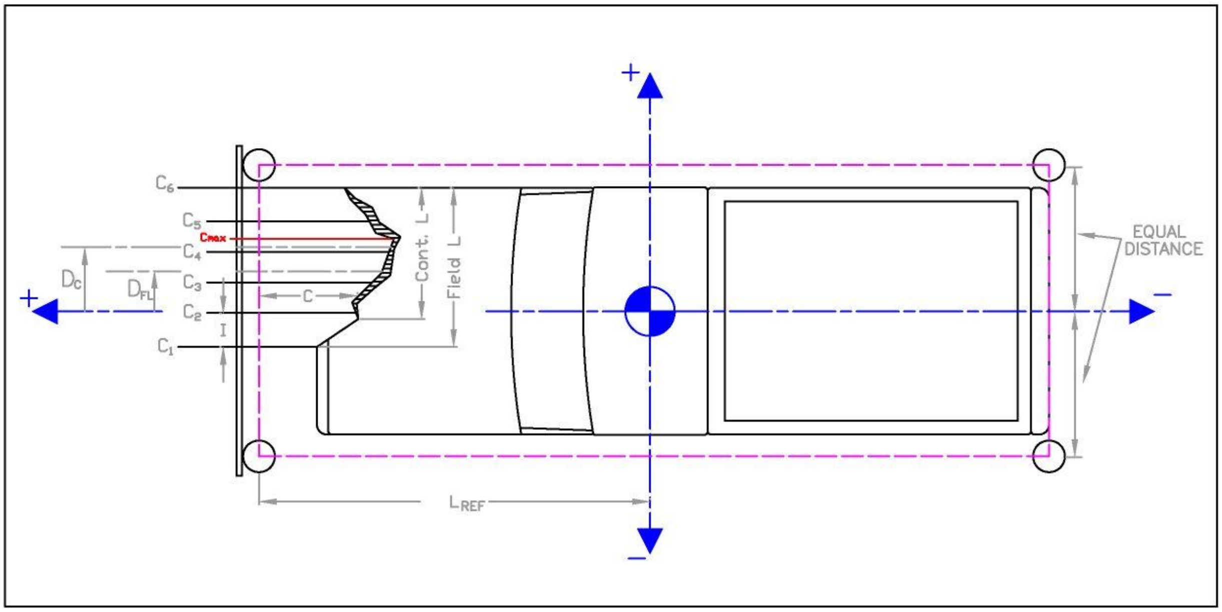


Figure D-4. Occupant Compartment Deformation Data – Set 2, Test No. MGSPCB-1

Date: 7/20/2015 **Test Number:** MGSPCB-1

Make: Dodge **Model:** RAM 1500 **Year:** 2008



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	100	(2540)
Total Vehicle Width:	78.5	(1994)
Width of contact and induced crush - Field L:	78 1/2	(1994)
Crush measurement spacing interval (L/5) - I:	15.7	(399)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	78 1/2	(1994)
Distance from center of vehicle to center of contect damage - D_C:	0	()

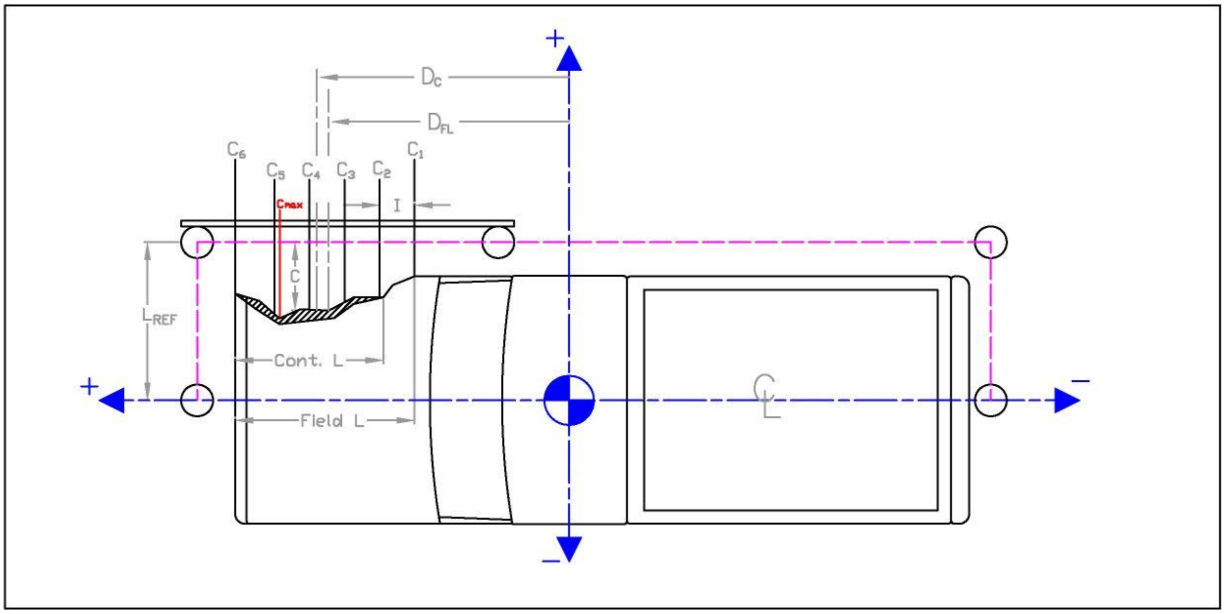
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurments are filled out.

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	NA	NA	-39 1/4	-(997)	29	(737)	-10 2/7	-(261)	NA	NA
C_2	7 3/4	(197)	-23 5/9	-(598)	13 5/9	(344)			4 1/2	(114)
C_3	6 1/4	(159)	-7 6/7	-(199)	10 1/2	(267)			6	(153)
C_4	6	(152)	7 6/7	(199)	10 1/2	(266)			5 4/5	(147)
C_5	7 1/2	(191)	23 5/9	(598)	13 1/2	(342)			4 1/3	(110)
C_6	NA	NA	39 1/4	(997)	29	(737)			NA	NA
C_{MAX}	16	(406)	31	(787)	16 4/5	(427)			9 1/2	(241)

Figure D-5. Exterior Vehicle Crush (NASS) - Front, Test No. MGSPCB-1

Date: 7/20/2015 **Test Number:** MGSPCB-1

Make: Dodge **Model:** RAM 1500 **Year:** 2008



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	45	(1143)
Total Vehicle Length:	227.5	(5779)
Width of contact and induced crush - Field L:	227 1/2	(5779)
Crush measurement spacing interval (L/5) - I:	45.5	(1156)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-13	-(330)
Width of Contact Damage:	227 1/2	(5779)
Distance from vehicle c.g. to center of contect damage - D_C:	-13	-(330)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been remeoved)
NOTE: All values must be filled out above before crush measurments are filled out.

	Crush Measurement in.	Crush Measurement (mm)	Longitudinal Location in.	Longitudinal Location (mm)	Original Profile Measurement in.	Original Profile Measurement (mm)	Dist. Between Ref. Lines in.	Dist. Between Ref. Lines (mm)	Actual Crush in.	Actual Crush (mm)
C_1	11 3/4	(298)	-126 3/4	-(3219)	16	(406)	-5	-(127)	3/4	(19)
C_2	7 1/4	(184)	-81 1/4	-(2064)	10 1/2	(267)			1 3/4	(44)
C_3	6 1/2	(165)	-35 3/4	-(908)	11 5/8	(295)			- 1/8	-(3)
C_4	6	(152)	9 3/4	(248)	11 1/4	(286)			- 1/4	-(6)
C_5	NA	NA	55 1/4	(1403)	10 1/2	(267)			NA	NA
C_6	NA	NA	100 3/4	(2559)	35 1/4	(895)			NA	NA
C_{MAX}	12 1/4	(311)	81	(2057)	11 1/2	(292)			5 3/4	(146)

Figure D-6. Exterior Vehicle Crush (NASS) - Side, Test No. MGSPCB-1

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MGSPCB-2
VEHICLE: Kia Rio

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	30.349	4.190	-2.245	30.351	4.129	-2.153	0.002	-0.061	0.092
2	30.780	9.990	-1.626	30.680	9.919	-1.335	-0.100	-0.071	0.291
3	30.802	14.373	-1.045	30.701	14.302	-0.683	-0.101	-0.072	0.362
4	28.151	18.986	1.037	27.459	18.531	1.412	-0.691	-0.455	0.376
5	25.574	3.741	-4.522	25.559	3.658	-4.459	-0.015	-0.084	0.063
6	26.353	10.562	-3.780	26.310	10.533	-3.580	-0.043	-0.028	0.200
7	26.917	16.251	-3.104	26.815	16.235	-2.815	-0.102	-0.017	0.289
8	25.817	22.544	-0.941	25.172	22.253	-0.604	-0.646	-0.291	0.337
9	22.639	4.852	-5.711	22.720	4.881	-5.606	0.082	0.029	0.104
10	22.774	10.680	-5.409	22.763	10.661	-5.196	-0.011	-0.019	0.212
11	22.720	16.268	-4.902	22.639	16.204	-4.737	-0.081	-0.064	0.166
12	23.072	21.834	-4.543	23.066	21.769	-4.361	-0.006	-0.066	0.182
13	19.252	4.434	-5.412	19.259	4.350	-5.355	0.007	-0.084	0.057
14	19.944	9.885	-5.351	19.832	9.816	-5.214	-0.111	-0.068	0.137
15	19.448	15.904	-5.043	19.389	15.910	-4.874	-0.059	0.005	0.170
16	19.321	21.293	-4.590	19.302	21.228	-4.395	-0.019	-0.065	0.194
17	14.083	4.877	-5.796	14.081	4.933	-5.730	-0.002	0.056	0.066
18	15.625	11.189	-5.031	15.617	11.210	-4.930	-0.008	0.022	0.101
19	15.669	16.424	-4.754	15.632	16.427	-4.633	-0.037	0.003	0.122
20	15.688	22.223	-4.702	15.682	22.221	-4.557	-0.005	-0.002	0.144
21	9.526	4.434	-5.436	9.506	4.488	-5.394	-0.020	0.053	0.043
22	9.192	11.001	-4.580	9.067	11.016	-4.532	-0.125	0.015	0.048
23	9.023	16.031	-4.293	8.995	16.036	-4.242	-0.028	0.006	0.050
24	8.784	22.524	-4.087	8.755	22.510	-3.997	-0.029	-0.015	0.091
25	2.155	2.172	-1.278	2.129	2.195	-1.286	-0.026	0.023	-0.008
26	1.876	7.231	-0.786	1.822	7.253	-0.781	-0.055	0.022	0.005
27	1.514	12.169	-0.390	1.517	12.154	-0.381	0.003	-0.015	0.009
28	1.671	18.524	-0.128	1.638	18.550	-0.133	-0.032	0.026	-0.005

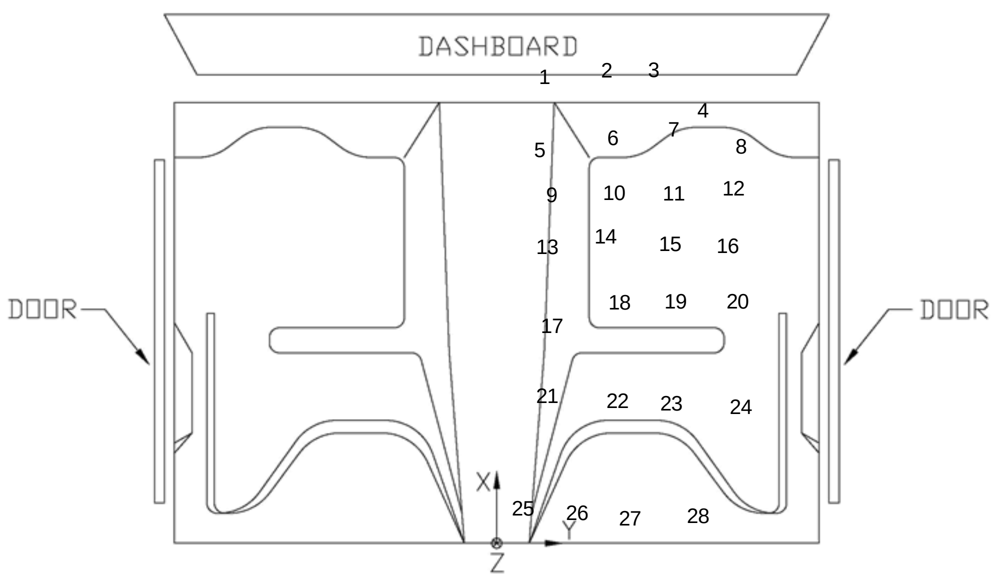


Figure D-7. Floor Pan Deformation Data – Set 1, Test No. MGSPCB-2

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MGSPCB-2
VEHICLE: Kia Rio

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	42.667	8.420	-2.982	42.475	8.426	-2.871	-0.193	0.006	0.111
2	43.260	14.172	-2.779	42.874	14.235	-2.494	-0.386	0.063	0.286
3	43.397	18.605	-2.504	43.030	18.562	-2.108	-0.366	-0.043	0.396
4	40.952	23.373	-0.669	39.973	23.027	-0.205	-0.979	-0.346	0.465
5	37.920	7.863	-5.068	37.659	7.888	-5.049	-0.261	0.025	0.019
6	38.808	14.700	-4.854	38.554	14.715	-4.625	-0.255	0.014	0.230
7	39.537	20.463	-4.587	39.219	20.489	-4.246	-0.319	0.026	0.340
8	38.621	26.908	-2.853	37.781	26.549	-2.340	-0.840	-0.359	0.514
9	34.886	8.938	-6.289	34.584	8.999	-6.228	-0.302	0.061	0.061
10	35.235	14.763	-6.391	34.958	14.813	-6.173	-0.277	0.051	0.218
11	35.330	20.405	-6.280	35.071	20.384	-6.051	-0.259	-0.021	0.229
12	35.807	26.010	-6.329	35.566	26.060	-6.064	-0.241	0.050	0.264
13	31.511	8.594	-5.866	31.312	8.637	-5.826	-0.199	0.043	0.040
14	32.319	14.034	-6.209	32.030	14.059	-6.066	-0.289	0.025	0.144
15	32.032	20.103	-6.326	31.663	20.143	-6.110	-0.368	0.040	0.215
16	31.942	25.502	-6.246	31.718	25.544	-5.978	-0.224	0.042	0.268
17	26.387	9.225	-6.179	26.175	9.302	-6.128	-0.212	0.077	0.051
18	28.061	15.525	-5.890	27.839	15.588	-5.770	-0.222	0.063	0.120
19	28.272	20.753	-5.992	27.988	20.795	-5.818	-0.284	0.042	0.173
20	28.424	26.492	-6.352	28.167	26.573	-6.126	-0.257	0.081	0.226
21	21.807	8.925	-5.691	21.573	8.984	-5.651	-0.234	0.059	0.040
22	21.592	15.483	-5.282	21.358	15.524	-5.210	-0.234	0.042	0.072
23	21.570	20.580	-5.354	21.350	20.622	-5.248	-0.220	0.041	0.107
24	21.510	27.096	-5.580	21.260	27.043	-5.416	-0.251	-0.053	0.164
25	14.550	7.123	-1.219	14.310	7.074	-1.245	-0.240	-0.049	-0.026
26	14.303	12.205	-1.058	14.089	12.182	-1.049	-0.214	-0.023	0.009
27	14.087	17.110	-1.009	13.942	17.150	-0.971	-0.145	0.039	0.037
28	14.415	23.468	-1.200	14.135	23.515	-1.164	-0.280	0.047	0.036

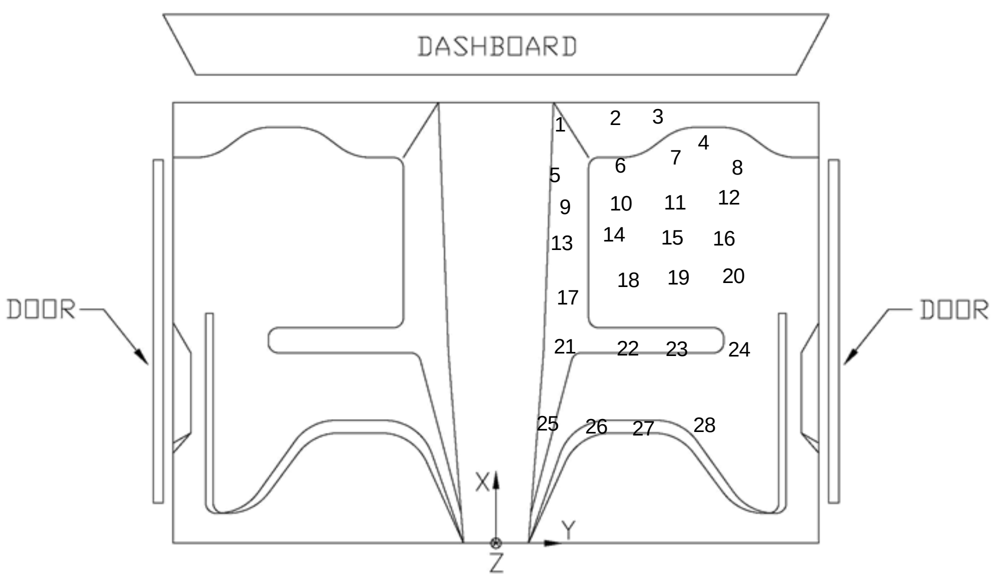


Figure D-8. Floor Pan Deformation Data – Set 2, Test No. MGSPCB-2

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MGSPCB-2
VEHICLE: Kia Rio

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	16.027	-3.049	22.733	15.797	-3.211	22.703	-0.230	-0.163	-0.031
	2	14.566	4.563	22.888	14.219	4.306	22.836	-0.347	-0.257	-0.052
	3	16.010	21.649	23.156	15.252	21.318	23.191	-0.758	-0.331	0.036
	4	11.603	-3.125	16.337	11.499	-3.336	16.299	-0.105	-0.211	-0.038
	5	13.088	5.987	16.802	12.932	5.690	16.649	-0.156	-0.297	-0.153
	6	13.234	21.601	18.332	12.586	21.200	18.454	-0.648	-0.401	0.122
SIDE PANEL	7	20.959	24.183	6.773	20.457	23.367	6.953	-0.502	-0.816	0.180
	8	19.286	24.610	1.405	19.027	24.310	1.493	-0.259	-0.300	0.089
	9	24.465	24.615	3.265	24.160	24.034	3.514	-0.305	-0.581	0.249
IMPACT SIDE DOOR	10	16.143	24.360	21.992	15.266	24.414	22.222	-0.877	0.053	0.230
	11	2.212	23.826	24.233	1.507	26.655	24.546	-0.705	2.830	0.313
	12	-11.318	23.464	26.084	-11.932	25.849	26.299	-0.614	2.385	0.215
	13	8.672	25.670	6.528	8.278	27.365	6.864	-0.395	1.694	0.336
	14	0.040	25.576	4.850	-0.221	26.167	5.011	-0.261	0.591	0.161
	15	-9.228	25.066	8.566	-9.381	25.945	8.683	-0.153	0.879	0.117
ROOF	1	3.269	-4.523	38.998	3.247	-2.993	39.353	-0.022	1.530	0.355
	2	2.771	2.338	39.411	2.678	3.904	39.958	-0.093	1.567	0.546
	3	1.910	8.505	39.632	1.705	9.985	40.383	-0.204	1.480	0.751
	4	0.514	14.053	39.952	0.328	15.467	40.821	-0.186	1.415	0.869
	5	-2.525	-4.630	42.405	-2.639	-3.213	42.870	-0.114	1.417	0.464
	6	-3.858	5.001	42.963	-4.041	6.352	43.573	-0.183	1.352	0.610
	7	-5.177	11.760	43.093	-5.468	13.073	43.808	-0.292	1.313	0.715
	8	-9.101	-5.090	43.765	-9.153	-3.828	44.137	-0.052	1.262	0.372
	9	-9.322	4.653	44.064	-9.590	5.955	44.612	-0.268	1.302	0.549
	10	-9.604	11.785	43.969	-9.967	13.033	44.557	-0.363	1.249	0.588

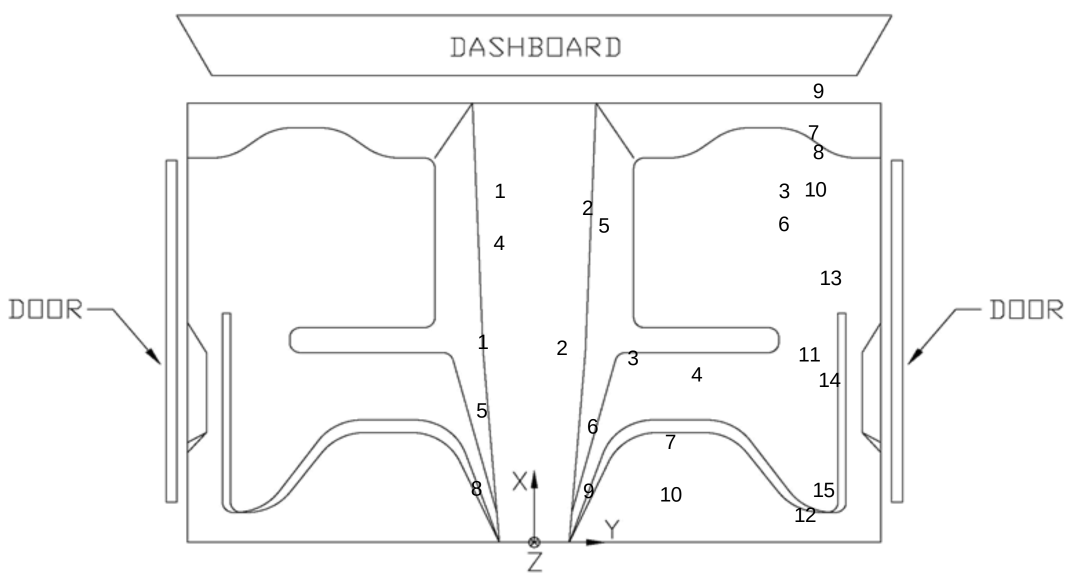


Figure D-9. Occupant Compartment Deformation Data – Set 1, Test No. MGSPCB-2

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MGSPCB-2
VEHICLE: Kia Rio

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	28.741	3.231	22.712	28.292	2.913	22.694	-0.449	-0.318	-0.018
	2	27.585	10.868	22.476	26.986	10.512	22.460	-0.599	-0.356	-0.015
	3	29.359	27.951	21.440	28.378	27.553	21.648	-0.981	-0.398	0.208
	4	24.308	2.810	16.536	23.868	2.509	16.423	-0.440	-0.301	-0.113
	5	25.976	11.902	16.329	25.537	11.501	16.274	-0.439	-0.401	-0.055
	6	26.529	27.547	16.812	25.584	27.221	16.975	-0.944	-0.326	0.163
SIDE PANEL	7	33.997	29.160	4.906	33.279	28.345	5.183	-0.719	-0.815	0.278
	8	32.151	29.247	-0.482	31.725	28.955	-0.236	-0.426	-0.292	0.246
	9	37.473	29.263	1.216	36.849	28.697	1.650	-0.623	-0.566	0.434
IMPACT SIDE DOOR	10	29.573	30.514	20.153	28.406	30.528	20.510	-1.167	0.013	0.356
	11	15.700	30.473	22.712	14.784	33.251	22.878	-0.915	2.778	0.166
	12	2.204	30.581	24.937	1.359	32.858	25.052	-0.845	2.277	0.114
	13	21.780	30.913	4.740	21.125	32.613	4.952	-0.655	1.701	0.212
	14	13.066	30.910	3.259	12.669	31.515	3.579	-0.397	0.605	0.319
	15	3.885	30.897	7.244	3.442	31.714	7.368	-0.443	0.816	0.125
ROOF	1	16.571	3.273	39.357	16.161	4.586	39.670	-0.410	1.313	0.314
	2	16.156	10.116	39.336	15.807	11.483	39.804	-0.349	1.367	0.468
	3	15.367	16.310	39.175	15.013	17.720	39.820	-0.354	1.409	0.645
	4	14.100	21.861	39.137	13.697	23.135	39.963	-0.404	1.274	0.826
	5	10.771	3.516	42.943	10.419	4.748	43.295	-0.352	1.231	0.352
	6	9.671	13.178	42.836	9.277	14.351	43.382	-0.394	1.174	0.546
	7	8.433	19.849	42.558	8.007	21.065	43.206	-0.426	1.216	0.648
	8	4.245	3.269	44.481	3.875	4.325	44.765	-0.370	1.055	0.284
	9	4.144	13.091	44.111	3.707	14.086	44.601	-0.437	0.995	0.490
	10	4.086	20.114	43.506	3.502	21.172	44.074	-0.584	1.058	0.567

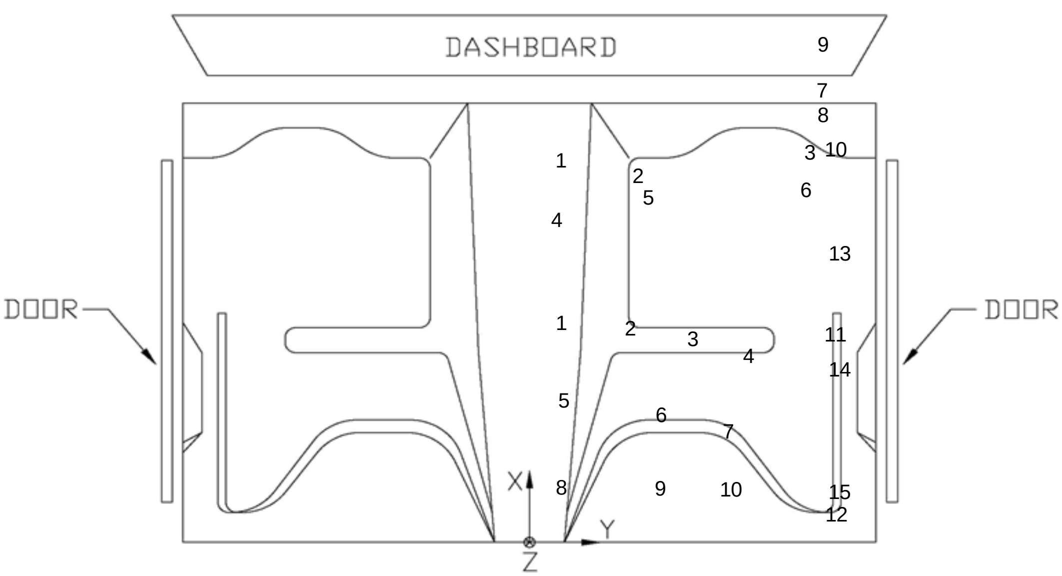
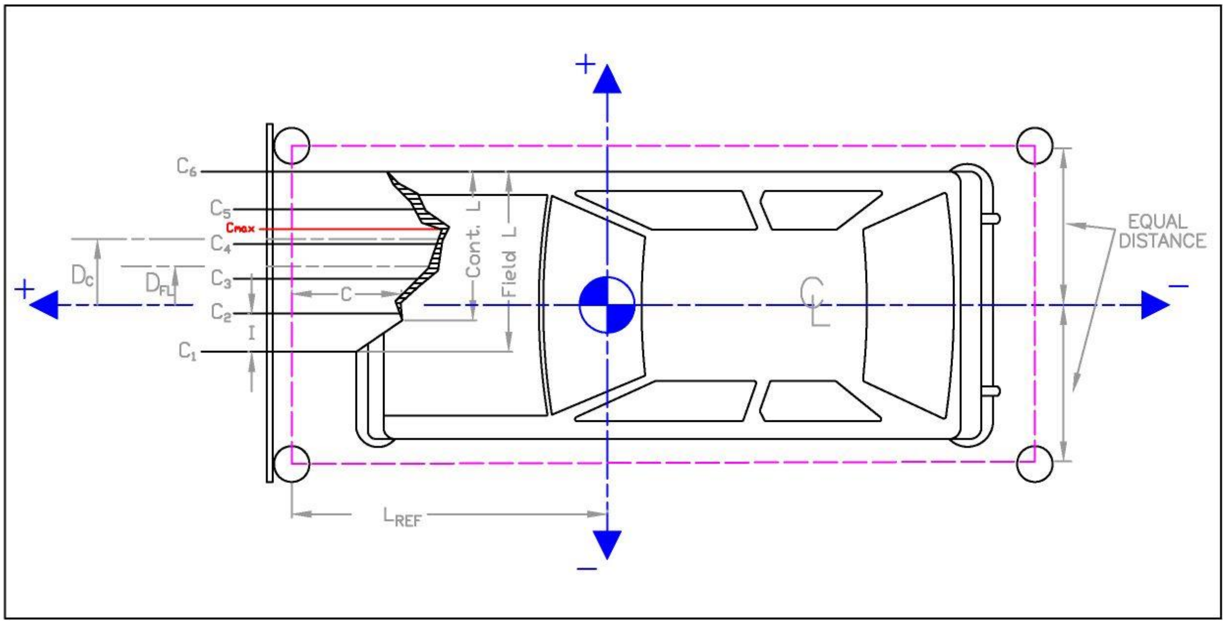


Figure D-10. Occupant Compartment Deformation Data – Set 2, Test No. MGSPCB-2

Date: 8/4/2015 **Test Number:** MGSPCB-2

Make: Kia **Model:** Rio **Year:** 2008



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	74	(1880)
Total Width of Vehicle:	61 3/4	(1568)
Width of contact and induced crush - Field L:	61 3/4	(1568)
Crush measurement spacing interval (L/5) - I:	12 1/3	(314)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	24 3/8	(619)
Distance from center of vehicle to center of contect damage - D_C:	18 5/8	(473)

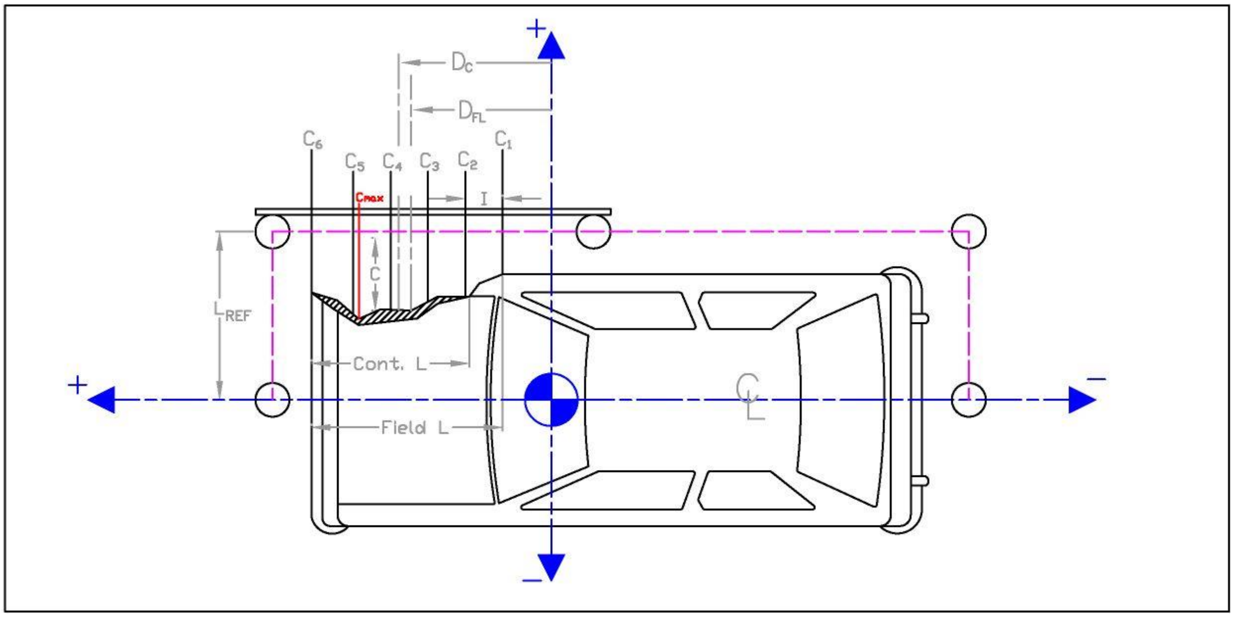
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurments are filled out.

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	na	NA	-30 7/8	-(784)	19 7/8	(505)	-1	-(23)	NA	NA
C_2	11 1/4	(286)	-18 1/2	-(471)	8 1/4	(210)			3 8/9	(99)
C_3	5 3/4	(146)	-6 1/6	-(157)	6 1/7	(156)			1/2	(13)
C_4	5	(127)	6 1/6	(157)	6 1/8	(156)			- 2/9	-(6)
C_5	5 3/4	(146)	18 1/2	(471)	8 2/9	(209)			-1 5/9	-(40)
C_6	9 1/2	(241)	30 7/8	(784)	18 5/6	(479)			-8 3/7	-(214)
C_{MAX}	13 1/2	(343)	-24	-(610)	10 3/8	(264)			4	(102)

Figure D-11. Exterior Vehicle Crush (NASS) - Front, Test No. MGSPCB-2

Date: 8/4/2015 **Test Number:** MGSPCB-2

Make: Kia **Model:** Rio **Year:** 2008



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	39.5	(1003)
Total Vehicle Length:	167.5	(4255)
Width of contact and induced crush - Field L:	167.5	(4255)
Crush measurement spacing interval (L/5) - I:	33.5	(851)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-15.625	-(397)
Width of Contact Damage:	167.5	(4255)
Distance from vehicle c.g. to center of contect damage - D_C:	-15.625	-(397)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been remeoved)
NOTE: All values must be filled out above before crush measurments are filled out.

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	na	NA	-99.38	-(2524)	26.00	(660)	3.5	(89)	NA	NA
C_2	7	(178)	-65.88	-(1673)	4.00	(102)			-0.5	-(13)
C_3	6.75	(171)	-32.38	-(822)	3.63	(92)			-0.4	-(10)
C_4	6.25	(159)	1.125	(29)	3.75	(95)			-1.0	-(25)
C_5	na	NA	34.625	(879)	3.25	(83)			NA	NA
C_6	na	NA	68.125	(1730)	20.19	(513)			NA	NA
C_{MAX}	19	(483)	49.5	(1257)	3.63	(92)			11.9	(302)

Figure D-12. Exterior Vehicle Crush (NASS) - Side, Test No. MGSPCB-2

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: MGSPCB-3
VEHICLE: Dodge RAM 1500

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	26.471	12.900	2.966	26.717	12.821	3.120	0.246	-0.079	0.154
2	28.739	16.792	1.558	28.895	16.749	1.683	0.156	-0.043	0.125
3	31.289	21.435	1.121	31.536	21.419	1.308	0.248	-0.016	0.188
4	30.383	27.207	3.574	30.608	27.096	3.772	0.225	-0.111	0.198
5	24.412	12.821	2.303	24.599	12.757	2.438	0.186	-0.064	0.135
6	25.281	16.961	0.064	25.478	16.876	0.263	0.197	-0.084	0.199
7	26.190	20.165	-2.278	26.377	20.119	-2.170	0.187	-0.046	0.109
8	26.066	28.312	-1.419	26.301	28.172	-1.239	0.235	-0.140	0.180
9	20.978	10.087	1.610	21.083	10.060	1.707	0.105	-0.027	0.097
10	21.962	15.523	-0.733	22.177	15.481	-0.596	0.215	-0.041	0.137
11	23.094	19.837	-3.822	23.294	19.750	-3.719	0.199	-0.087	0.102
12	23.082	29.692	-2.902	23.275	29.666	-2.769	0.193	-0.026	0.133
13	16.901	9.173	-0.183	17.115	9.165	-0.052	0.214	-0.008	0.131
14	18.514	14.609	-2.781	18.731	14.578	-2.669	0.217	-0.030	0.112
15	19.892	19.476	-5.324	20.023	19.420	-5.214	0.131	-0.055	0.110
16	19.761	29.681	-4.475	19.963	29.667	-4.318	0.203	-0.014	0.157
17	13.358	5.687	0.057	13.567	5.678	0.175	0.209	-0.009	0.118
18	15.902	14.566	-5.461	16.064	14.531	-5.366	0.162	-0.034	0.095
19	16.087	20.286	-5.267	16.259	20.208	-5.125	0.172	-0.078	0.142
20	16.126	30.131	-4.440	16.331	30.088	-4.312	0.205	-0.043	0.128
21	7.369	4.955	-0.434	7.563	4.948	-0.351	0.194	-0.007	0.083
22	10.183	13.112	-5.731	10.362	13.052	-5.621	0.179	-0.060	0.109
23	10.411	20.347	-4.964	10.624	20.324	-4.844	0.213	-0.023	0.120
24	10.063	30.416	-4.088	10.359	30.444	-3.985	0.297	0.028	0.103
25	1.185	6.073	0.472	1.416	6.101	0.505	0.231	0.028	0.033
26	0.634	13.091	-1.454	0.865	13.098	-1.431	0.231	0.007	0.023
27	0.620	21.206	-0.666	0.833	21.201	-0.637	0.213	-0.005	0.029
28	0.488	27.543	-0.036	0.675	27.498	-0.012	0.187	-0.045	0.024

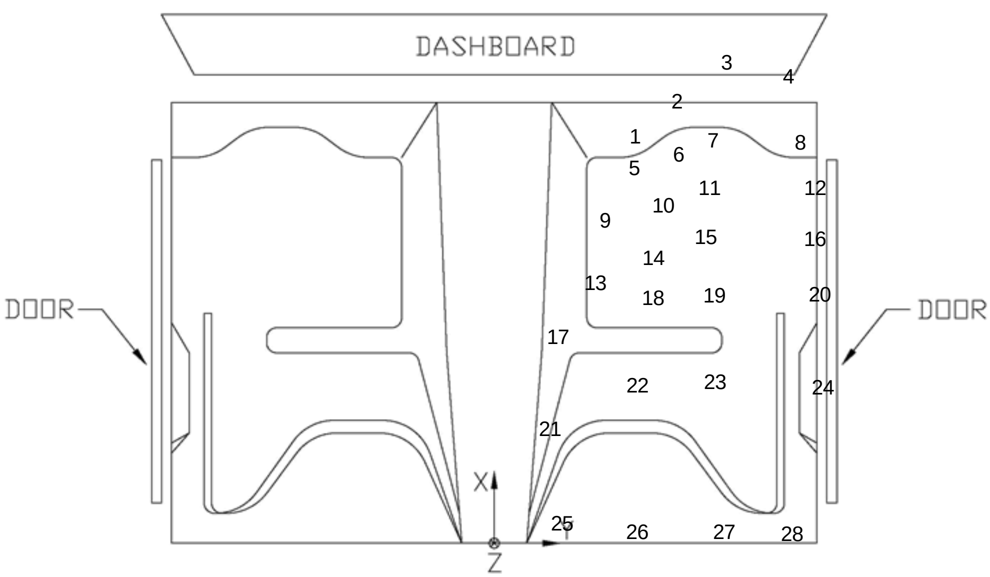


Figure D-13. Floor Pan Deformation Data – Set 1, Test No. MGSPCB-3

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: MGSPCB-3
VEHICLE: Dodge RAM 1500

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	43.534	18.277	2.273	43.564	18.394	2.325	0.029	0.117	0.052
2	45.829	21.933	0.476	45.778	22.059	0.510	-0.050	0.127	0.034
3	48.541	26.522	-0.415	48.497	26.585	-0.338	-0.044	0.063	0.076
4	47.774	32.460	1.388	47.700	32.515	1.560	-0.075	0.055	0.172
5	41.450	18.208	1.573	41.402	18.276	1.621	-0.047	0.067	0.048
6	42.458	22.097	-1.048	42.380	22.083	-0.940	-0.079	-0.014	0.108
7	43.344	25.046	-3.737	43.302	25.023	-3.683	-0.043	-0.023	0.054
8	43.436	33.097	-3.666	43.352	33.079	-3.557	-0.084	-0.018	0.109
9	37.924	15.466	1.148	37.906	15.508	1.276	-0.018	0.042	0.129
10	39.061	20.662	-1.733	38.994	20.690	-1.668	-0.067	0.028	0.065
11	40.242	24.558	-5.235	40.192	24.639	-5.181	-0.050	0.081	0.053
12	40.457	34.459	-5.289	40.392	34.454	-5.249	-0.064	-0.004	0.040
13	33.883	14.487	-0.517	33.840	14.515	-0.410	-0.043	0.028	0.106
14	35.586	19.599	-3.658	35.572	19.614	-3.568	-0.014	0.015	0.090
15	37.136	24.152	-6.661	37.050	24.183	-6.601	-0.086	0.031	0.059
16	37.145	34.390	-6.845	37.031	34.424	-6.806	-0.114	0.034	0.039
17	30.256	11.123	0.076	30.238	11.162	0.184	-0.018	0.039	0.108
18	32.946	19.362	-6.327	32.872	19.331	-6.253	-0.074	-0.031	0.074
19	33.208	25.006	-6.683	33.155	24.998	-6.600	-0.053	-0.008	0.082
20	33.525	34.961	-6.857	33.453	34.858	-6.825	-0.072	-0.103	0.031
21	24.260	10.458	-0.334	24.232	10.488	-0.254	-0.028	0.029	0.080
22	27.137	17.979	-6.418	27.173	17.881	-6.337	0.035	-0.099	0.080
23	27.581	25.221	-6.382	27.478	25.255	-6.316	-0.103	0.035	0.066
24	27.464	35.374	-6.528	27.389	35.348	-6.528	-0.075	-0.026	0.000
25	18.069	11.811	0.464	18.042	11.901	0.517	-0.026	0.090	0.053
26	17.690	18.606	-2.159	17.685	18.613	-2.152	-0.005	0.006	0.007
27	17.840	26.737	-2.188	17.763	26.720	-2.207	-0.077	-0.017	-0.019
28	17.832	33.077	-2.195	17.761	33.068	-2.251	-0.071	-0.009	-0.056

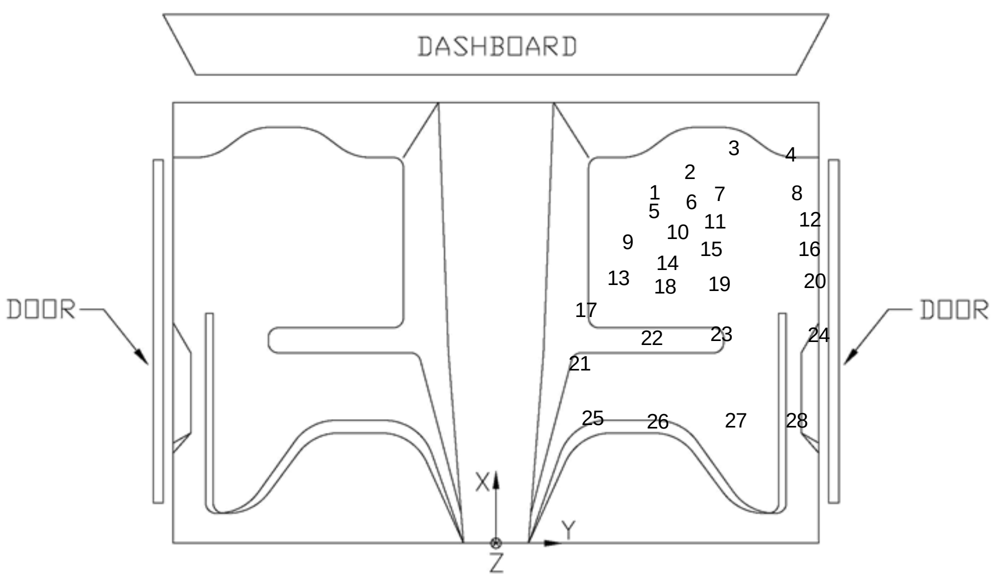


Figure D-14. Floor Pan Deformation Data – Set 2, Test No. MGSPCB-3

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: MGSPCB-3
VEHICLE: Dodge RAM 1500

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	13.917	-3.524	26.452	14.196	-3.569	26.464	0.279	-0.045	0.011
	2	15.364	7.224	26.022	15.579	7.146	26.083	0.214	-0.078	0.061
	3	15.626	29.382	26.390	15.865	29.288	26.560	0.239	-0.094	0.170
	4	11.597	-2.959	18.514	11.805	-2.968	18.388	0.208	-0.009	-0.126
	5	11.810	6.744	17.426	12.054	6.725	17.430	0.244	-0.019	0.004
	6	12.404	29.506	19.402	12.690	29.382	19.538	0.286	-0.124	0.136
SIDE PANEL	7	20.531	31.978	7.164	20.738	31.780	7.321	0.207	-0.198	0.157
	8	19.834	32.681	-1.171	20.078	32.596	-1.082	0.244	-0.085	0.089
	9	25.555	32.276	4.751	25.742	32.202	4.979	0.187	-0.075	0.229
IMPACT SIDE DOOR	10	12.976	32.836	22.597	12.995	33.111	22.768	0.020	0.275	0.171
	11	0.046	32.656	23.662	0.018	33.075	23.767	-0.028	0.419	0.106
	12	-12.844	32.393	24.650	-12.773	32.596	24.575	0.071	0.203	-0.075
	13	11.016	33.858	5.350	11.077	33.498	5.541	0.061	-0.360	0.192
	14	1.574	33.772	5.067	1.740	33.318	5.095	0.166	-0.454	0.028
	15	-13.748	34.096	4.688	-13.630	33.619	4.696	0.118	-0.477	0.008
ROOF	1	7.730	-3.694	41.860	8.040	-3.797	41.844	0.310	-0.103	-0.017
	2	7.250	4.281	42.546	7.455	4.169	42.612	0.205	-0.112	0.065
	3	5.707	13.924	43.024	5.914	13.835	43.139	0.208	-0.090	0.115
	4	4.599	18.677	43.088	4.793	18.613	43.192	0.195	-0.064	0.104
	5	1.802	-2.892	44.430	2.075	-2.989	44.436	0.273	-0.097	0.006
	6	1.292	3.606	45.006	1.656	3.489	44.987	0.363	-0.117	-0.019
	7	0.351	11.421	45.446	0.565	11.258	45.543	0.213	-0.163	0.097
	8	-1.061	17.282	45.603	-0.839	17.154	45.700	0.222	-0.128	0.097
	9	-4.080	-3.346	45.910	-3.805	-3.475	45.897	0.275	-0.129	-0.013
	10	-4.803	3.969	46.545	-4.447	3.866	46.552	0.356	-0.104	0.007
	11	-5.603	10.090	46.911	-5.358	9.968	46.956	0.245	-0.122	0.045
	12	-6.767	16.384	47.107	-6.502	16.210	47.174	0.266	-0.173	0.067
	13	-9.830	-3.705	46.662	-9.567	-3.696	46.669	0.264	0.009	0.007
	14	-11.601	5.539	47.525	-11.291	5.520	47.551	0.309	-0.019	0.026
	15	-12.247	15.878	47.839	-11.975	15.746	47.897	0.272	-0.133	0.058

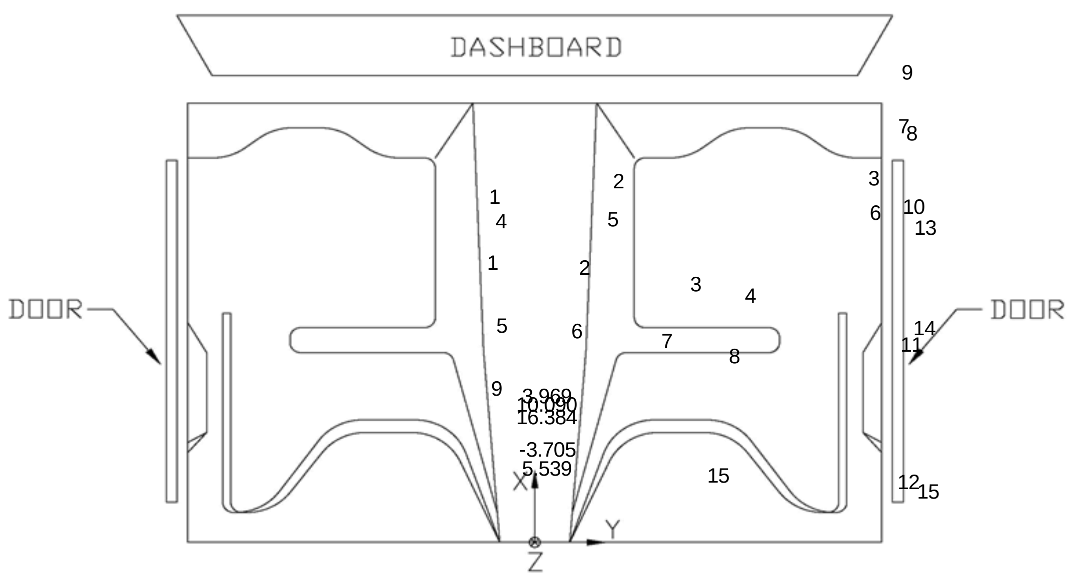


Figure D-15. Occupant Compartment Deformation Data – Set 1, Test No. MGSPCB-3

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: MGSPCB-3
VEHICLE: Dodge RAM 1500

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	30.747	4.633	27.315	30.750	4.710	27.319	0.003	0.077	0.004
	2	32.394	15.237	25.822	32.397	15.290	25.812	0.003	0.053	-0.010
	3	33.068	37.284	23.951	33.010	37.318	23.909	-0.058	0.034	-0.042
	4	28.378	4.419	19.372	28.372	4.490	19.272	-0.006	0.071	-0.100
	5	28.751	13.895	17.240	28.778	14.022	17.215	0.027	0.127	-0.025
	6	29.852	36.769	17.067	29.835	36.818	16.967	-0.017	0.049	-0.100
SIDE PANEL	7	37.992	37.837	4.581	37.856	37.716	4.597	-0.136	-0.122	0.016
	8	37.289	37.717	-3.921	37.220	37.658	-3.896	-0.069	-0.058	0.025
	9	43.122	37.785	2.065	42.916	37.797	2.140	-0.206	0.012	0.075
IMPACT SIDE DOOR	10	30.434	40.393	19.800	30.149	40.811	19.743	-0.284	0.418	-0.057
	11	17.556	40.583	20.928	17.220	41.115	20.786	-0.336	0.532	-0.142
	12	4.608	40.688	21.886	4.445	40.963	21.642	-0.162	0.275	-0.244
	13	28.495	39.717	2.566	28.296	39.416	2.629	-0.198	-0.300	0.063
	14	19.066	39.796	2.288	18.973	39.364	2.228	-0.093	-0.432	-0.060
	15	3.700	40.406	1.857	3.470	39.906	1.732	-0.230	-0.500	-0.125
ROOF	1	24.526	6.081	42.637	24.539	6.216	42.638	0.013	0.136	0.001
	2	24.227	14.127	42.509	24.143	14.284	42.538	-0.084	0.156	0.029
	3	22.901	23.864	41.996	22.845	23.960	42.004	-0.056	0.096	0.008
	4	21.902	28.579	41.582	21.852	28.711	41.559	-0.051	0.132	-0.022
	5	18.674	7.217	45.087	18.679	7.347	45.092	0.005	0.130	0.004
	6	18.337	13.761	44.993	18.263	13.920	45.022	-0.074	0.159	0.030
	7	17.404	21.643	44.728	17.408	21.734	44.707	0.004	0.092	-0.022
	8	16.181	27.473	44.261	16.106	27.618	44.250	-0.075	0.145	-0.011
	9	12.750	7.009	46.631	12.739	7.155	46.626	-0.011	0.145	-0.006
	10	12.277	14.451	46.510	12.230	14.528	46.503	-0.047	0.077	-0.007
	11	11.428	20.573	46.283	11.474	20.668	46.253	0.046	0.095	-0.030
	12	10.484	26.807	45.842	10.359	26.934	45.822	-0.125	0.127	-0.021
	13	7.100	6.927	47.401	7.004	7.075	47.389	-0.096	0.148	-0.012
	14	5.425	16.333	47.332	5.439	16.360	47.303	0.014	0.028	-0.029
	15	5.006	26.489	46.620	4.952	26.569	46.581	-0.054	0.081	-0.039

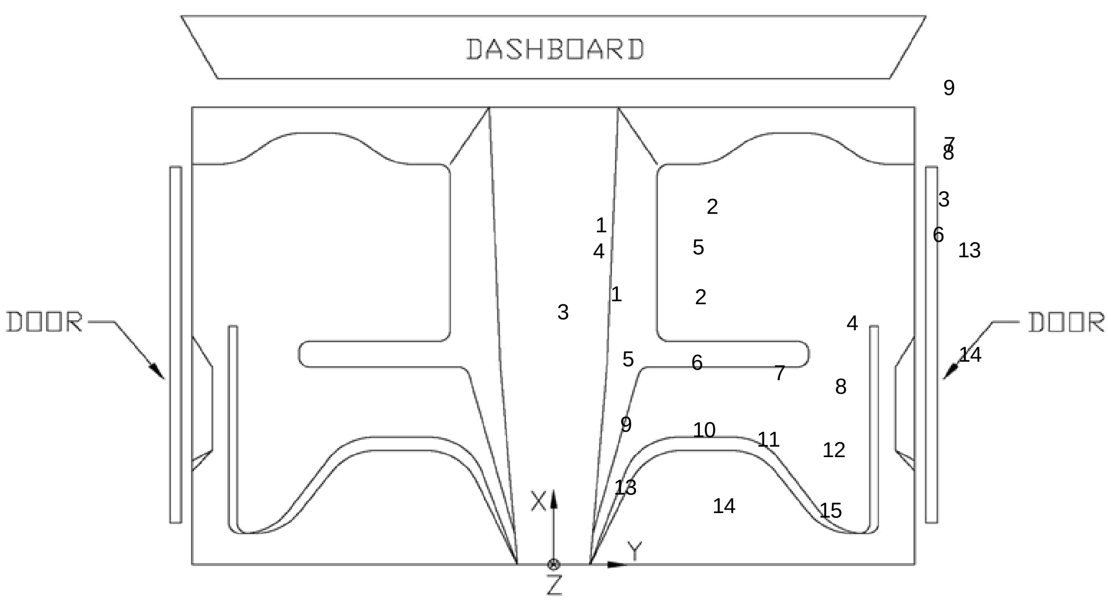
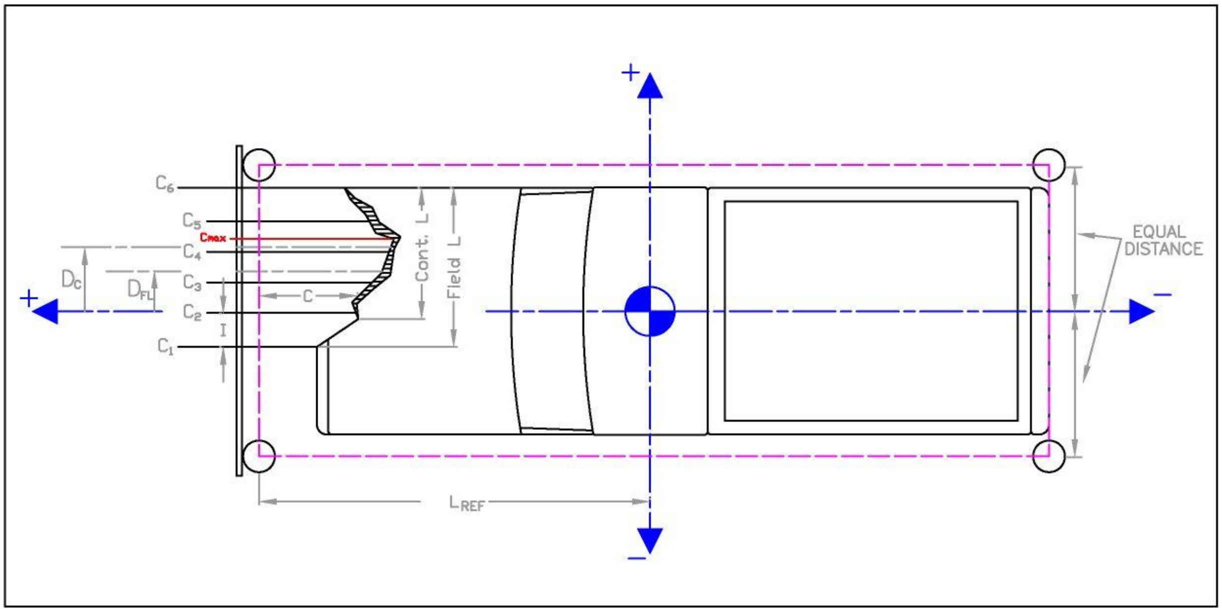


Figure D-16. Occupant Compartment Deformation Data – Set 2, Test No. MGSPCB-3

Date: 8/27/2015 **Test Number:** MGSPCB-3

Make: Dodge **Model:** RAM 1500 **Year:** 2008



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	110	(2794)
Total Vehicle Width:	78	(1981)
Width of contact and induced crush - Field L:	39	(991)
Crush measurement spacing interval (L/5) - I:	7.8	(198)
Distance from center of vehicle to center of Field L - D_{FL}:	19 1/2	(495)
Width of Contact Damage:	19 1/2	(495)
Distance from center of vehicle to center of contact damage - D_C:	29 1/4	(743)

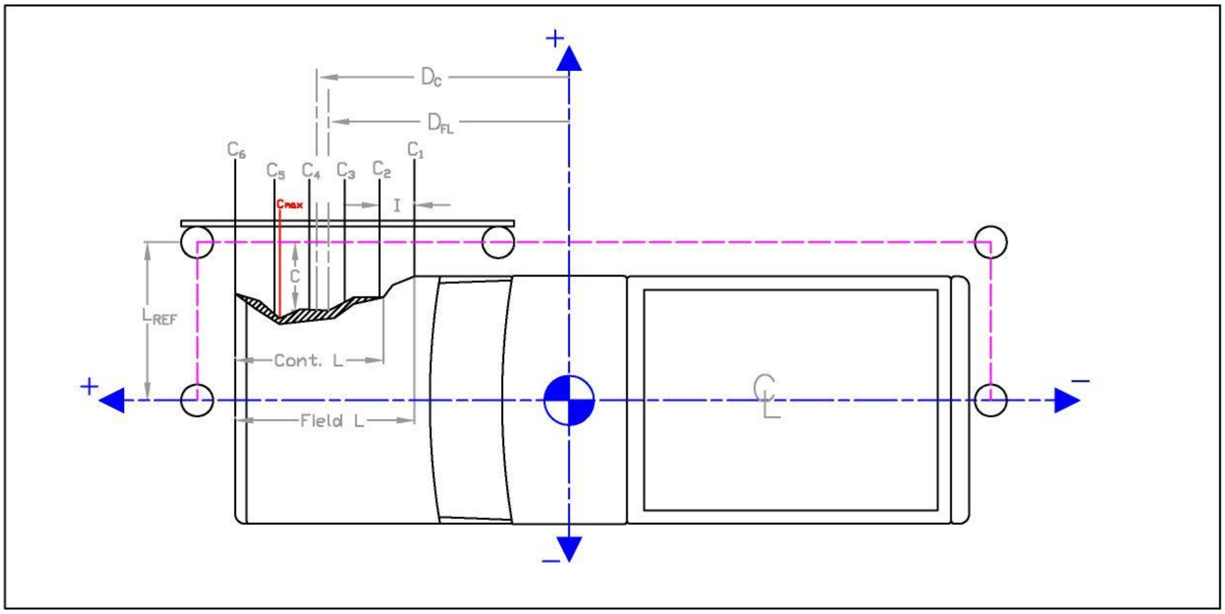
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	7 3/4	(197)	0	()	10 1/4	(260)	-2	-(49)	- 4/7	-(15)
C_2	8	(203)	7 4/5	(198)	10 1/2	(266)			- 5/9	-(14)
C_3	9 3/4	(248)	15 3/5	(396)	11 2/3	(296)			0	(1)
C_4	15	(381)	23 2/5	(594)	13 2/5	(340)			3 1/2	(90)
C_5	NA	NA	31 1/5	(792)	16 4/5	(427)			NA	NA
C_6	NA	NA	39	(991)	29	(737)			NA	NA
C_{MAX}	24 1/4	(616)	28	(711)	15 1/4	(387)			11	(278)

Figure D-17. Exterior Vehicle Crush (NASS) - Front, Test No. MGSPCB-3

Date: 8/27/2015 **Test Number:** MGSPCB-3

Make: Dodge **Model:** RAM 1500 **Year:** 2008



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	45	(1143)
Total Vehicle Length:	227.5	(5779)
Width of contact and induced crush - Field L:	227 1/2	(5779)
Crush measurement spacing interval (L/5) - I:	45.5	(1156)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-11 1/3	-(288)
Width of Contact Damage:	227 1/2	(5779)
Distance from vehicle c.g. to center of contact damage - D_C:	-11 1/3	-(288)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been removed)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	10	(254)	-125	-(3177)	15 3/8	(391)	-5	-(127)	- 3/8	-(10)
C_2	5 3/4	(146)	-79 4/7	-(2021)	10 1/2	(267)			1/4	(6)
C_3	5 1/4	(133)	-34	-(865)	11 4/7	(294)			-1 1/3	-(33)
C_4	6	(152)	11 3/7	(290)	11 1/4	(286)			- 1/4	-(6)
C_5	NA	NA	57	(1446)	10 1/2	(267)			NA	NA
C_6	NA	NA	102 3/7	(2602)	35 1/4	(895)			NA	NA
C_{MAX}	17 3/4	(451)	80	(2032)	11 1/4	(286)			11 1/2	(292)

Figure D-18. Exterior Vehicle Crush (NASS) - Side, Test No. MGSPCB-3

Appendix E. Accelerometer and Rate Transducer Data Plots, Test No. MGSPCB-1

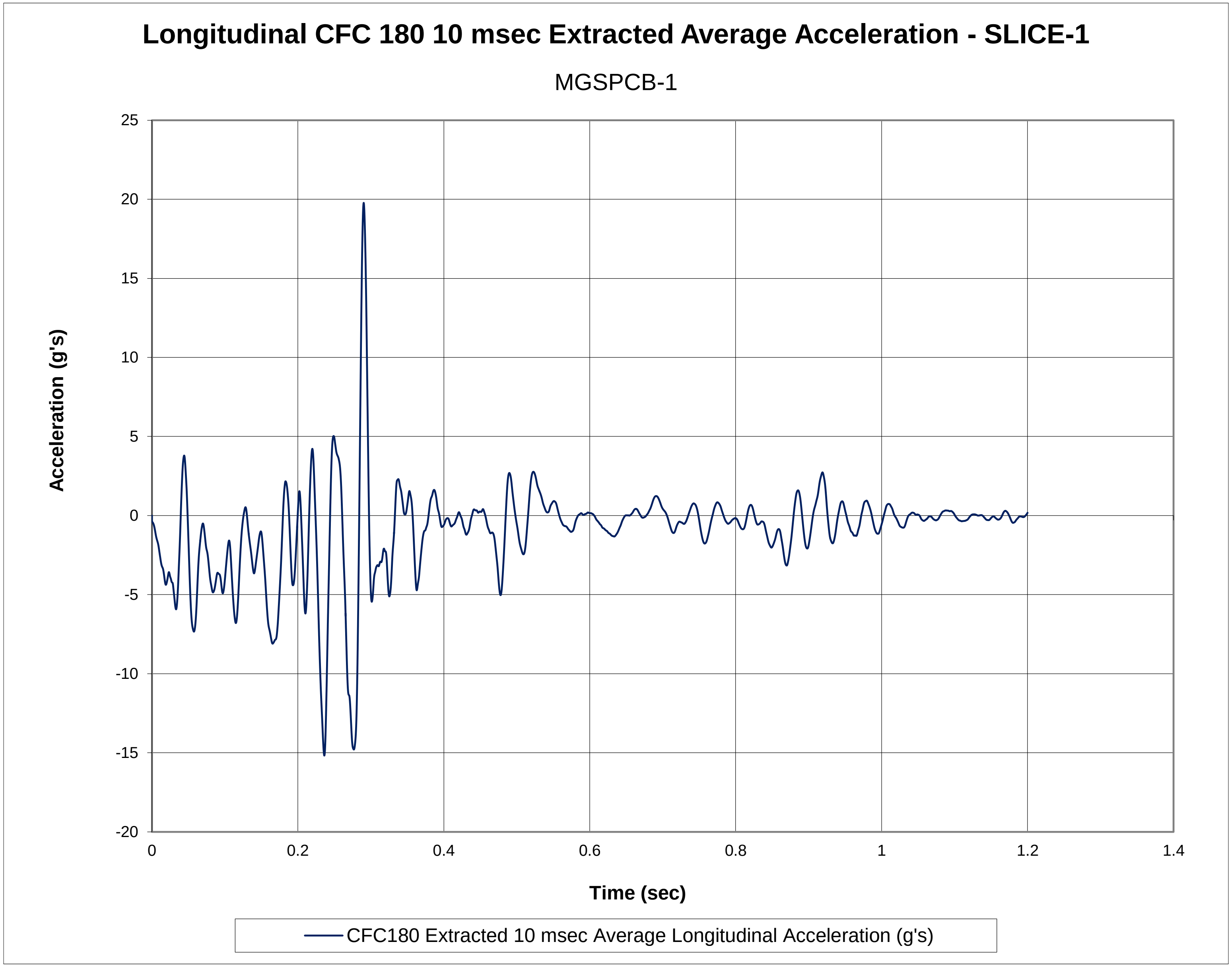


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MGSPCB-1

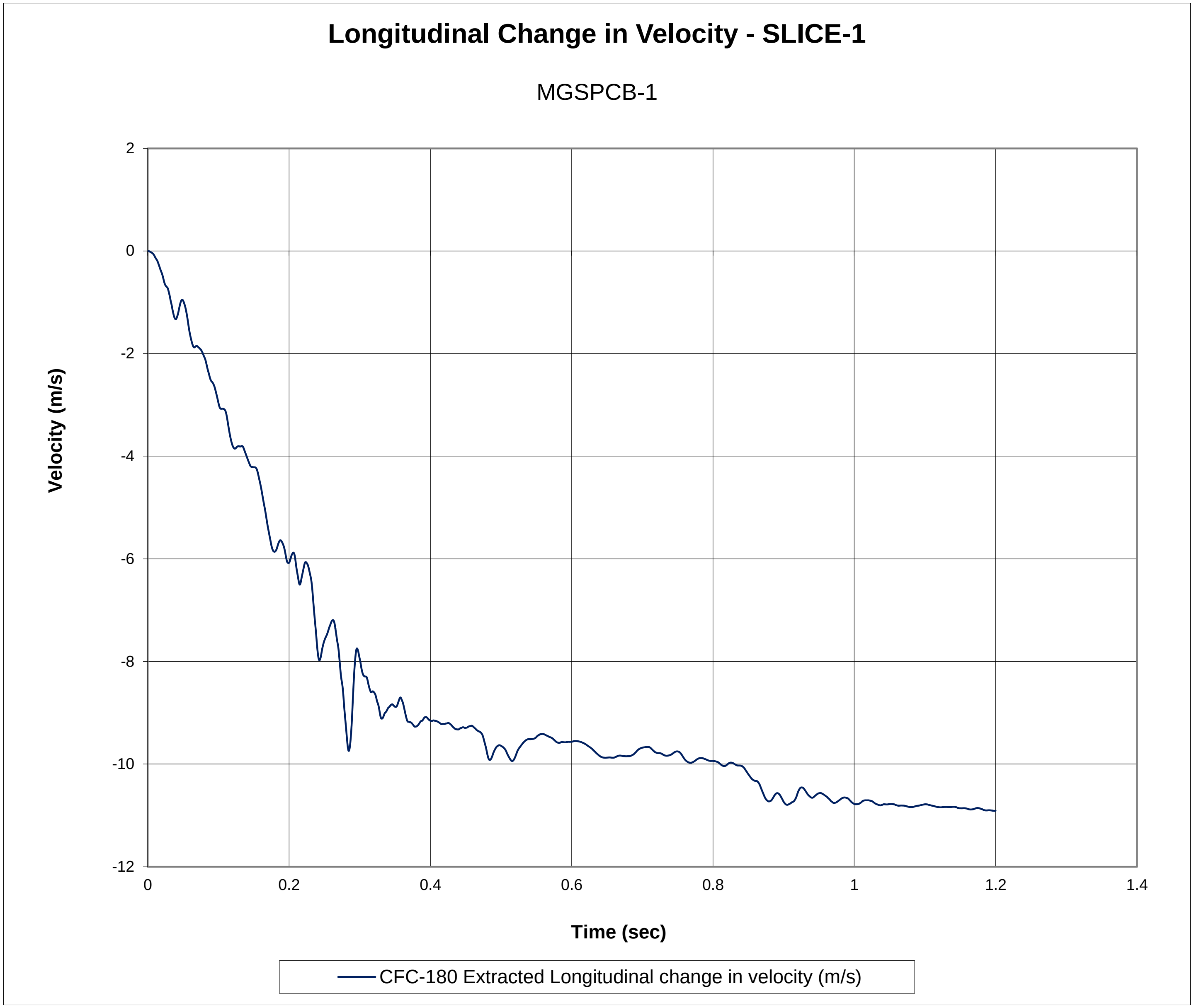


Figure E-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MGSPCB-1

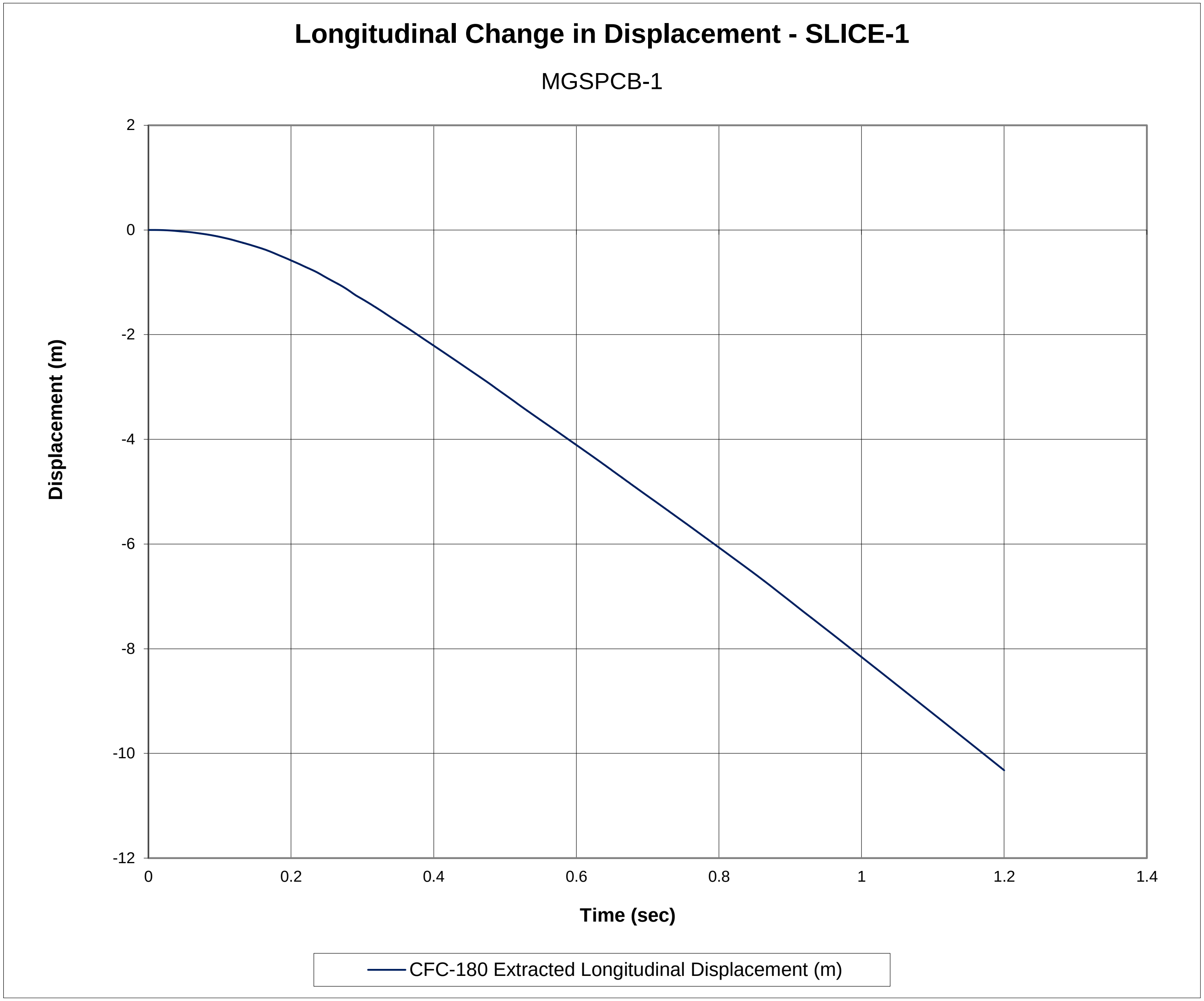


Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MGSPCB-1

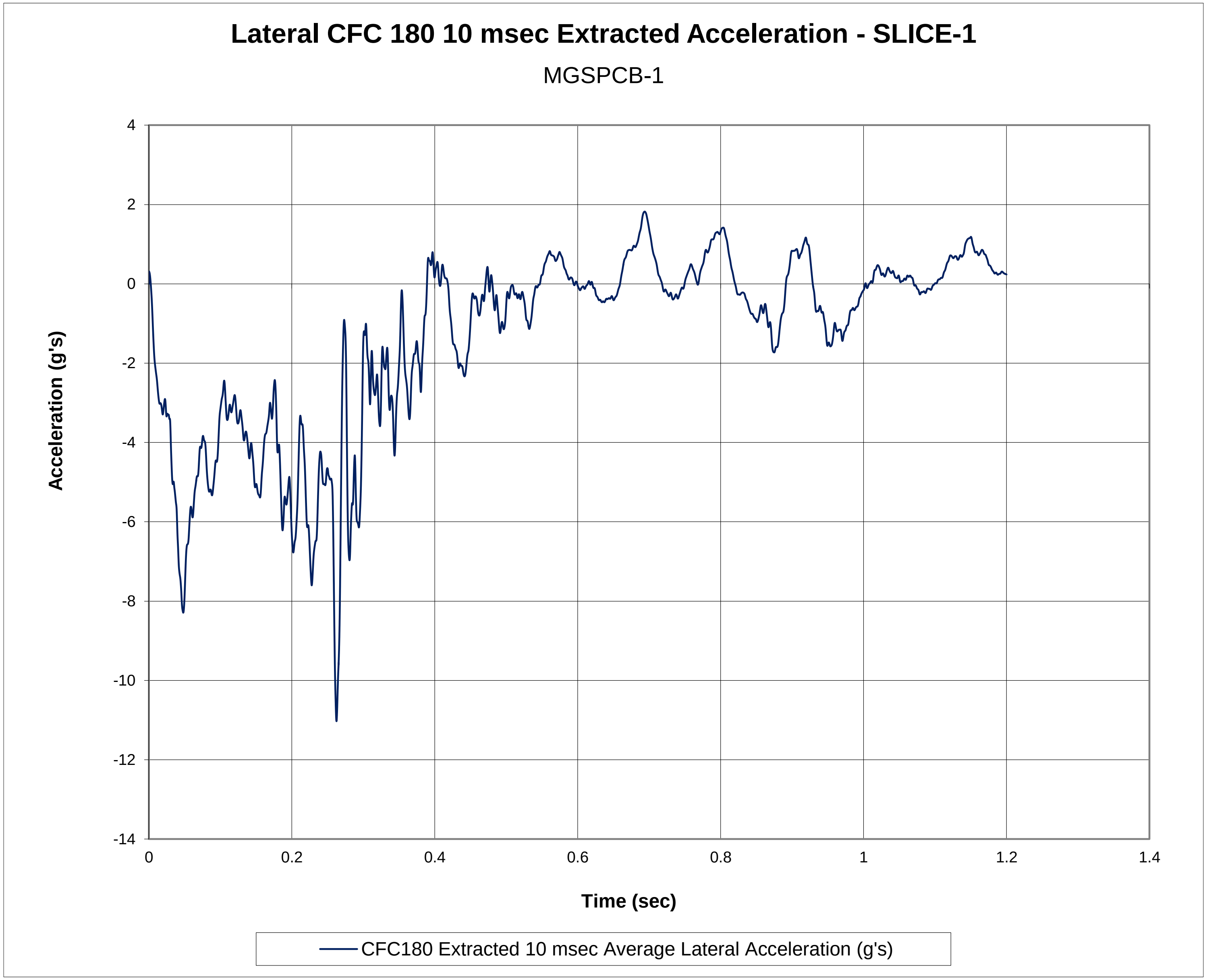


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MGSPCB-1

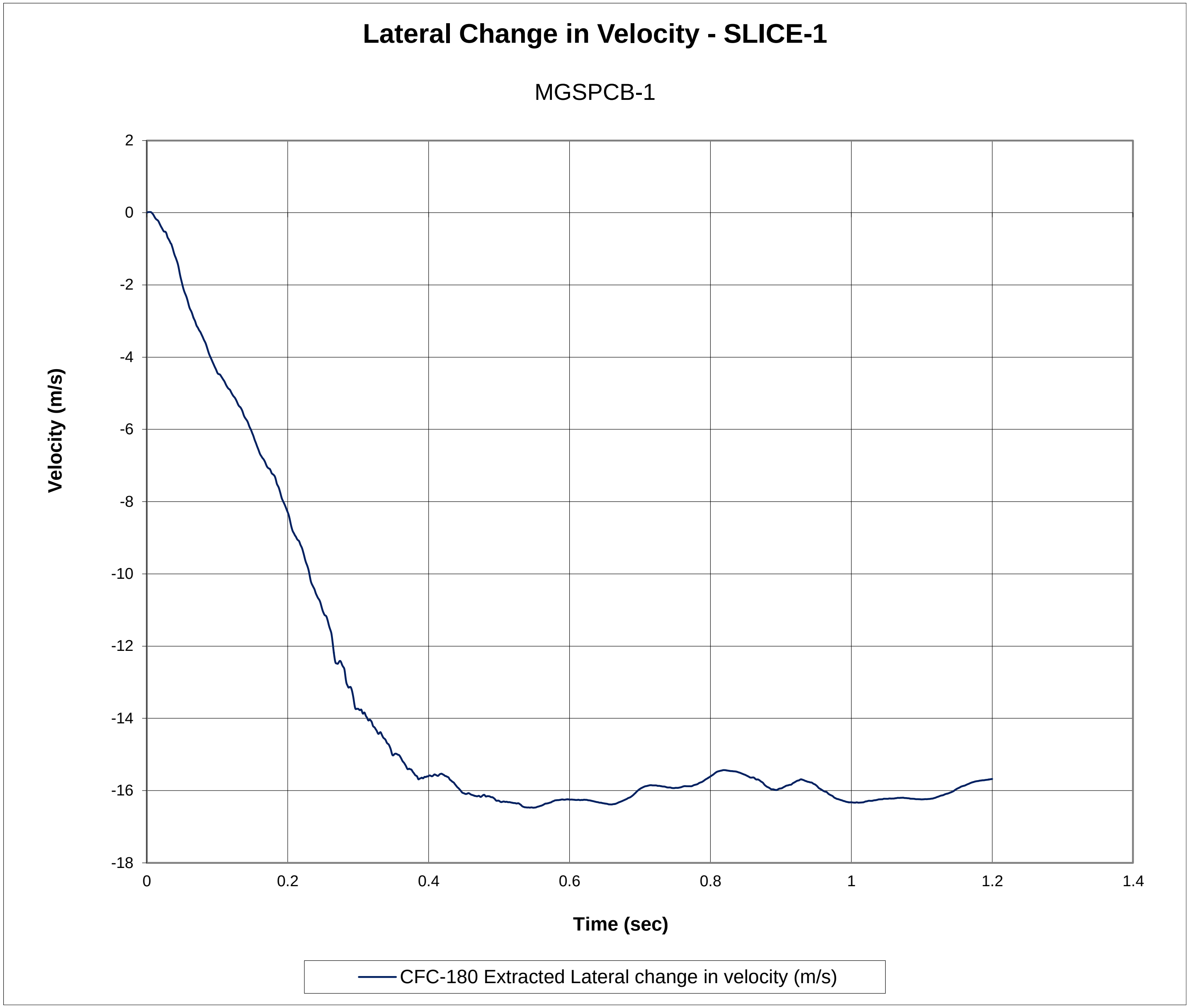


Figure E-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. MGSPCB-1

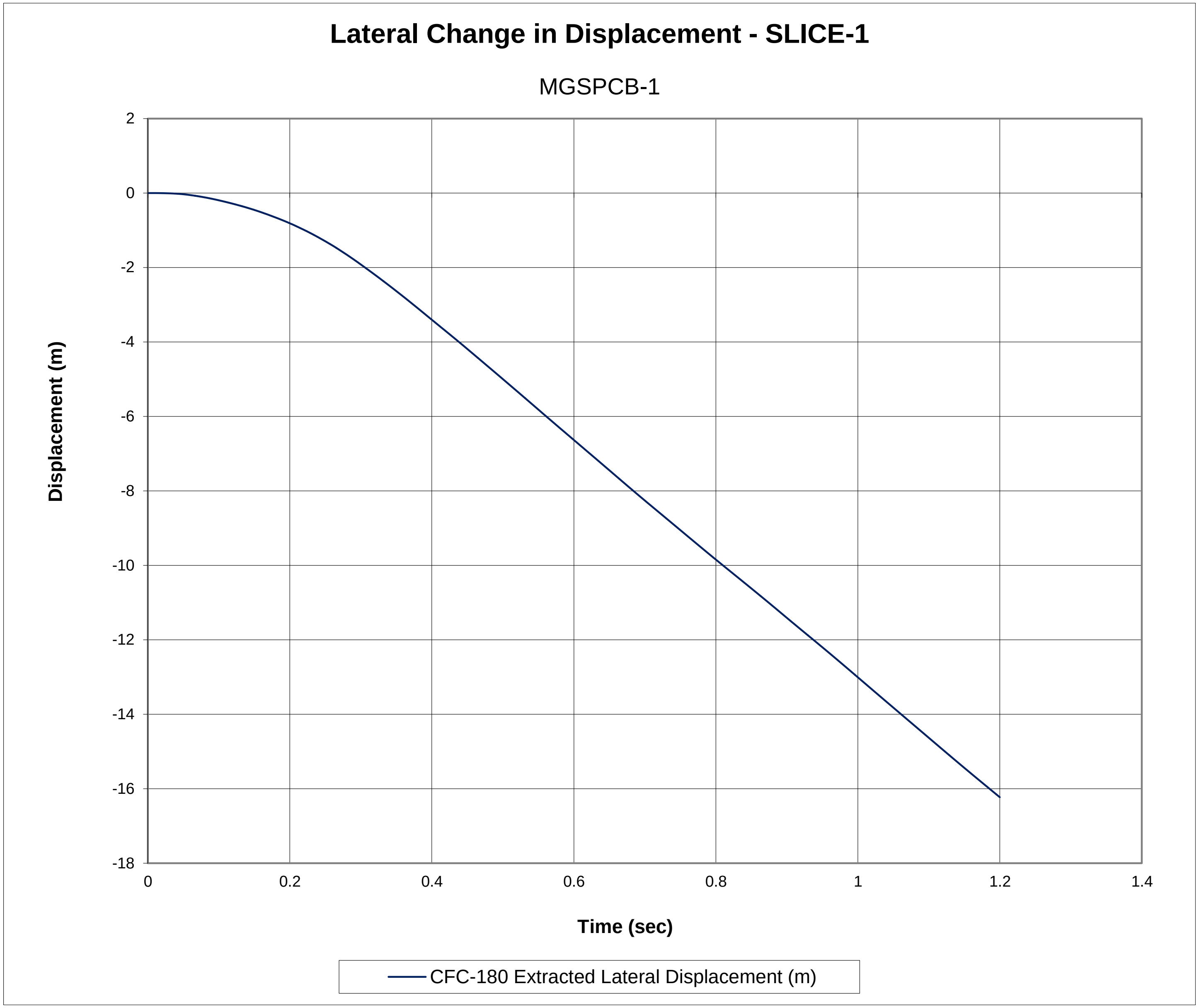


Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. MGSPCB-1

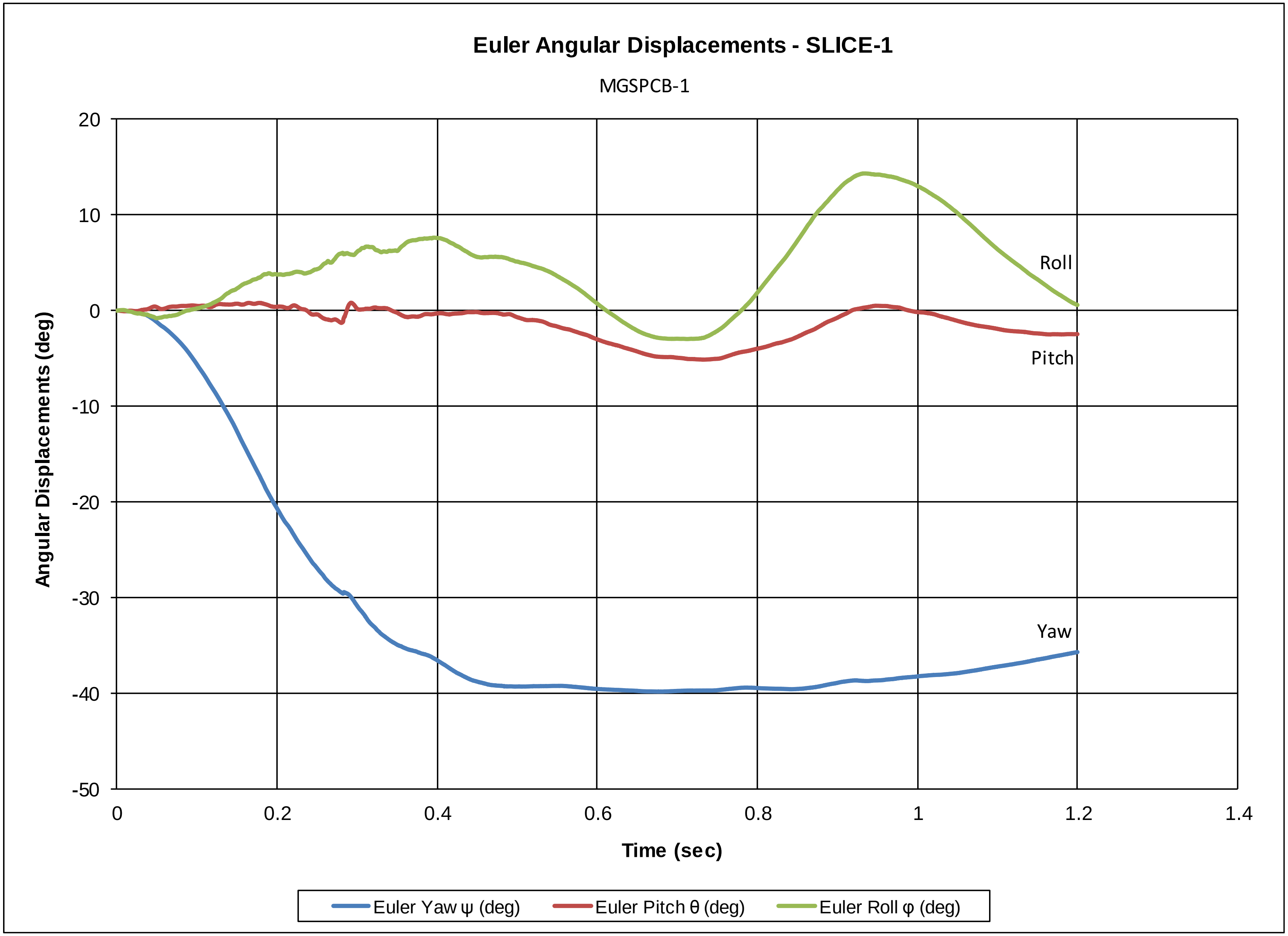


Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. MGSPCB-1

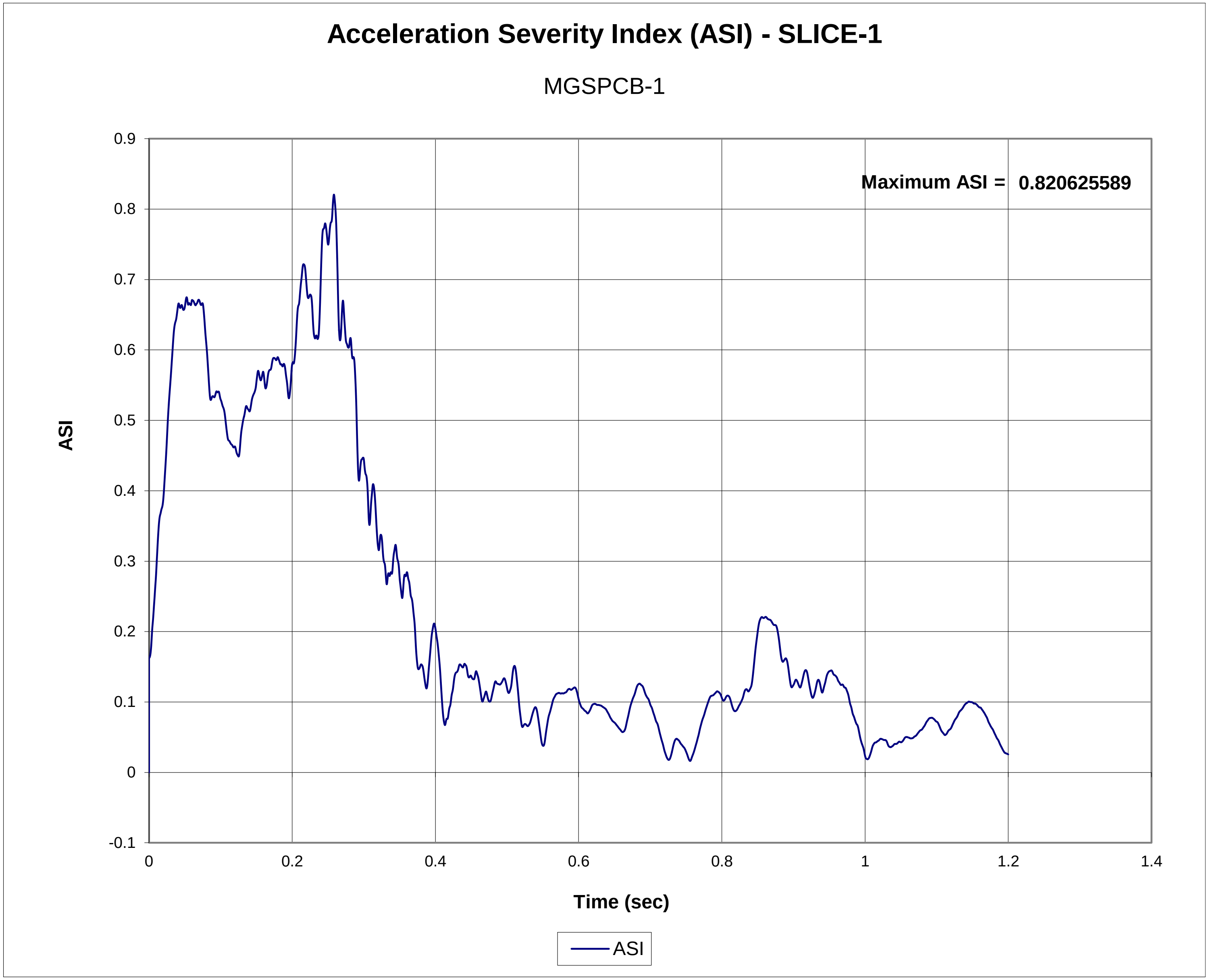


Figure E-8. Acceleration Severity Index (SLICE-1), Test No. MGSPCB-1

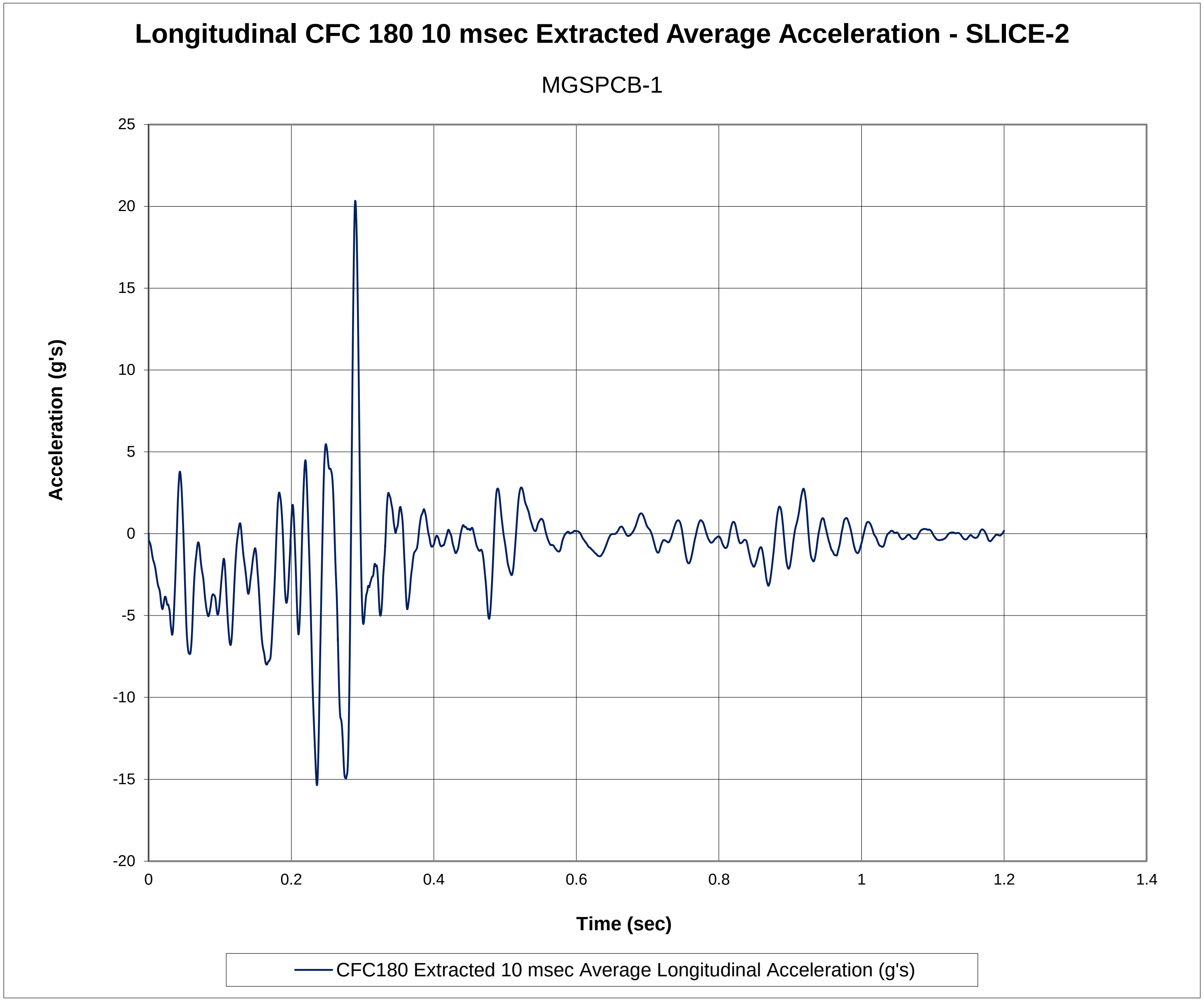


Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MGSPCB-1

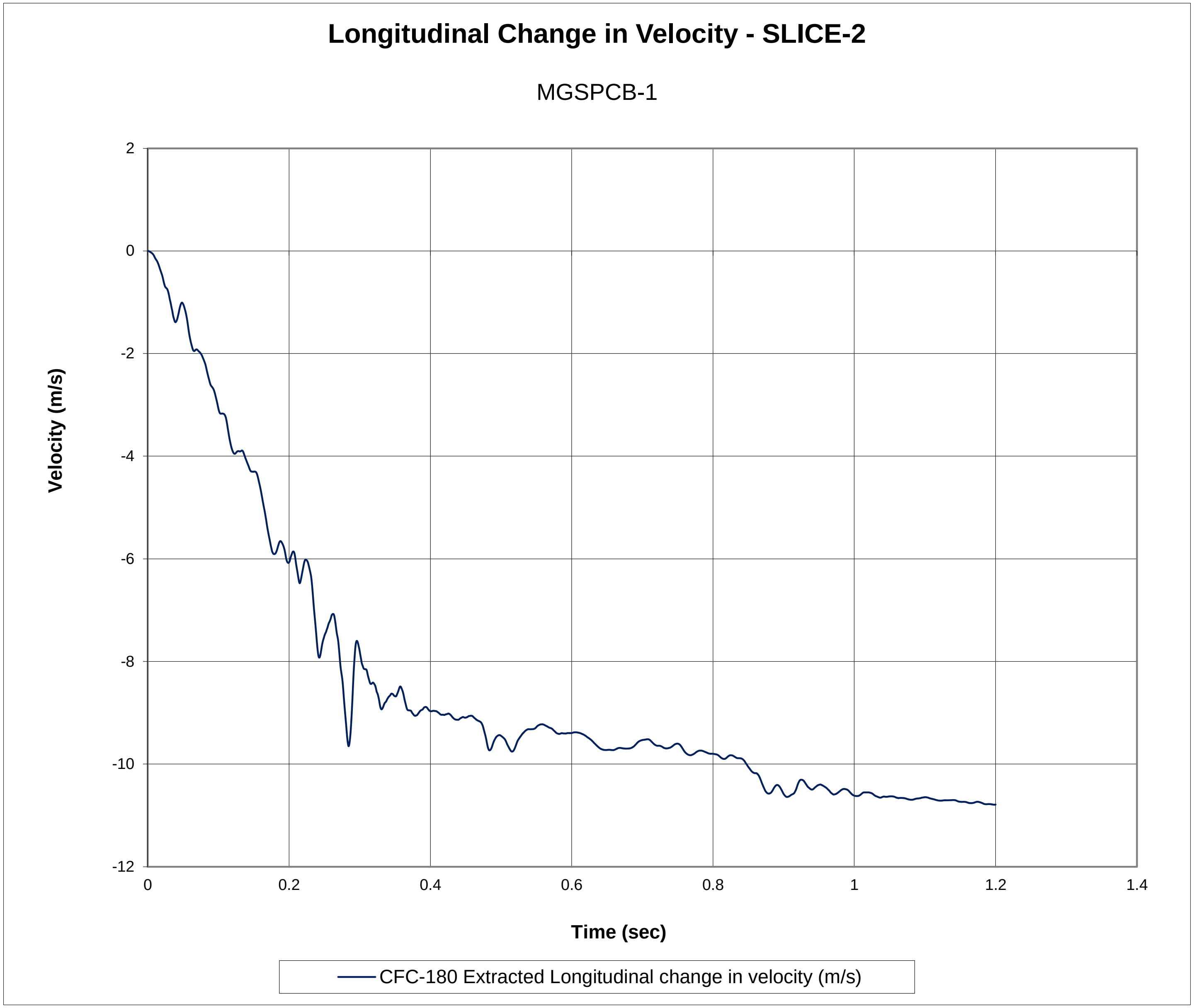


Figure E-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MGSPCB-1

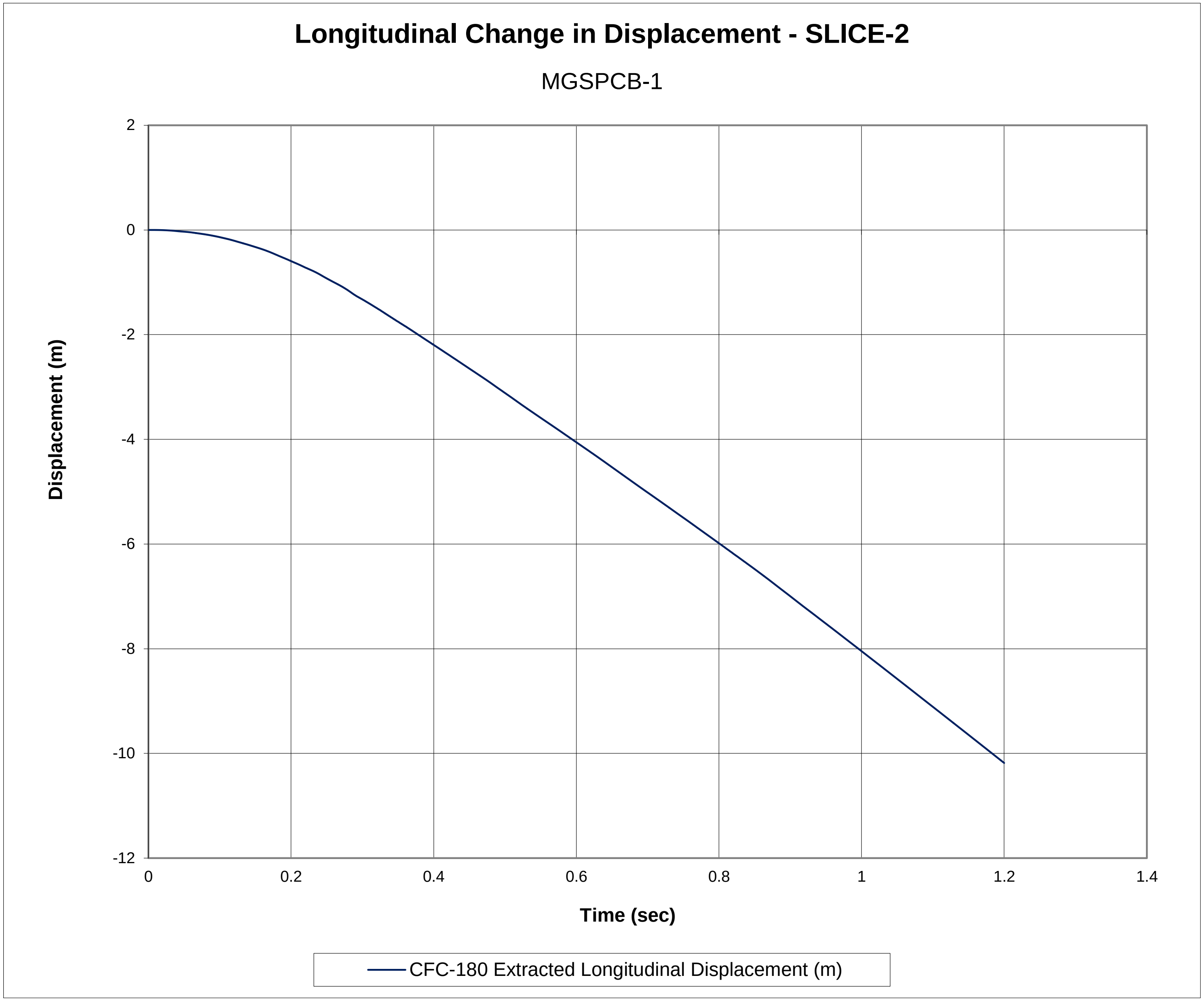


Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MGSPCB-1

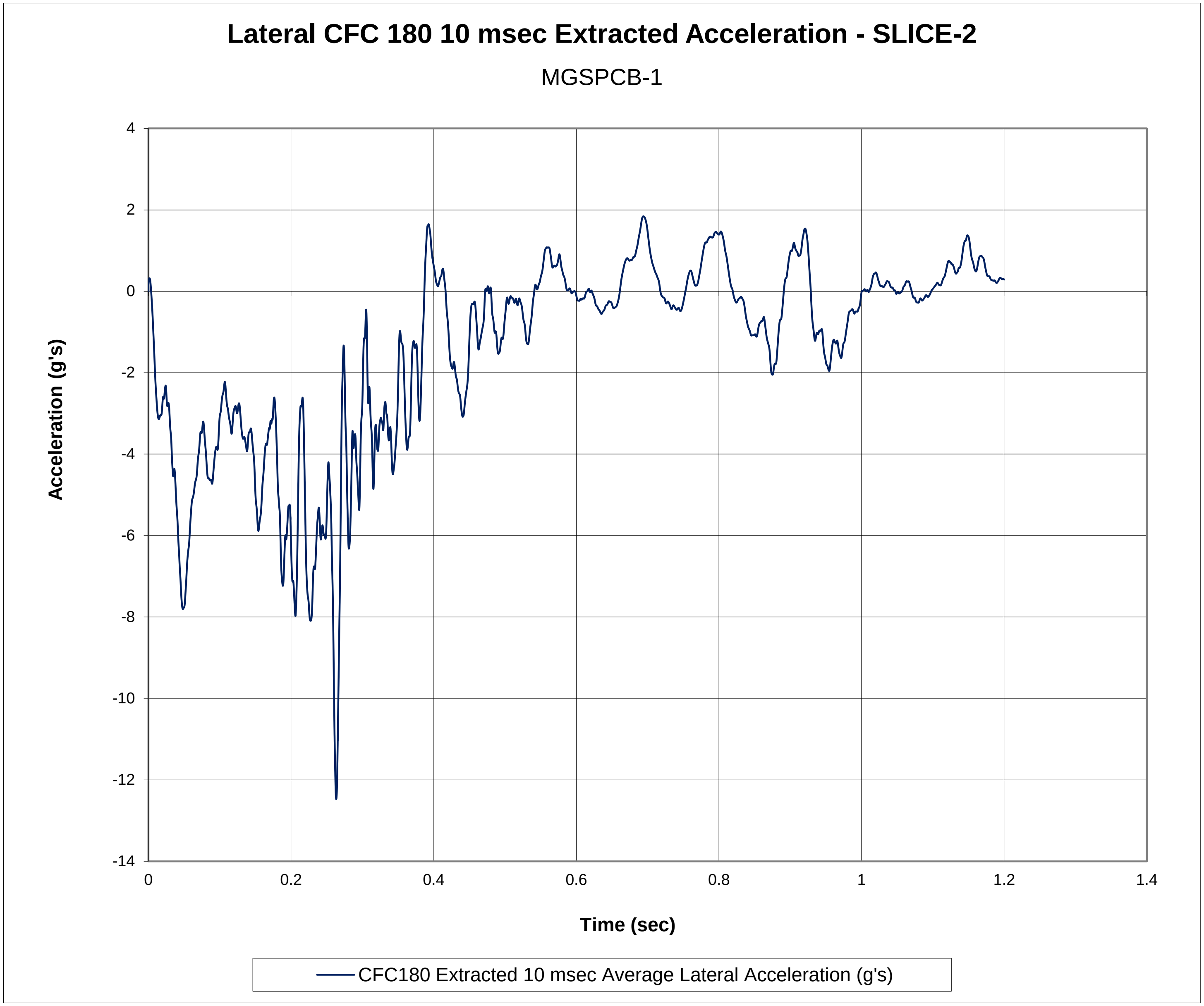


Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MGSPCB-1

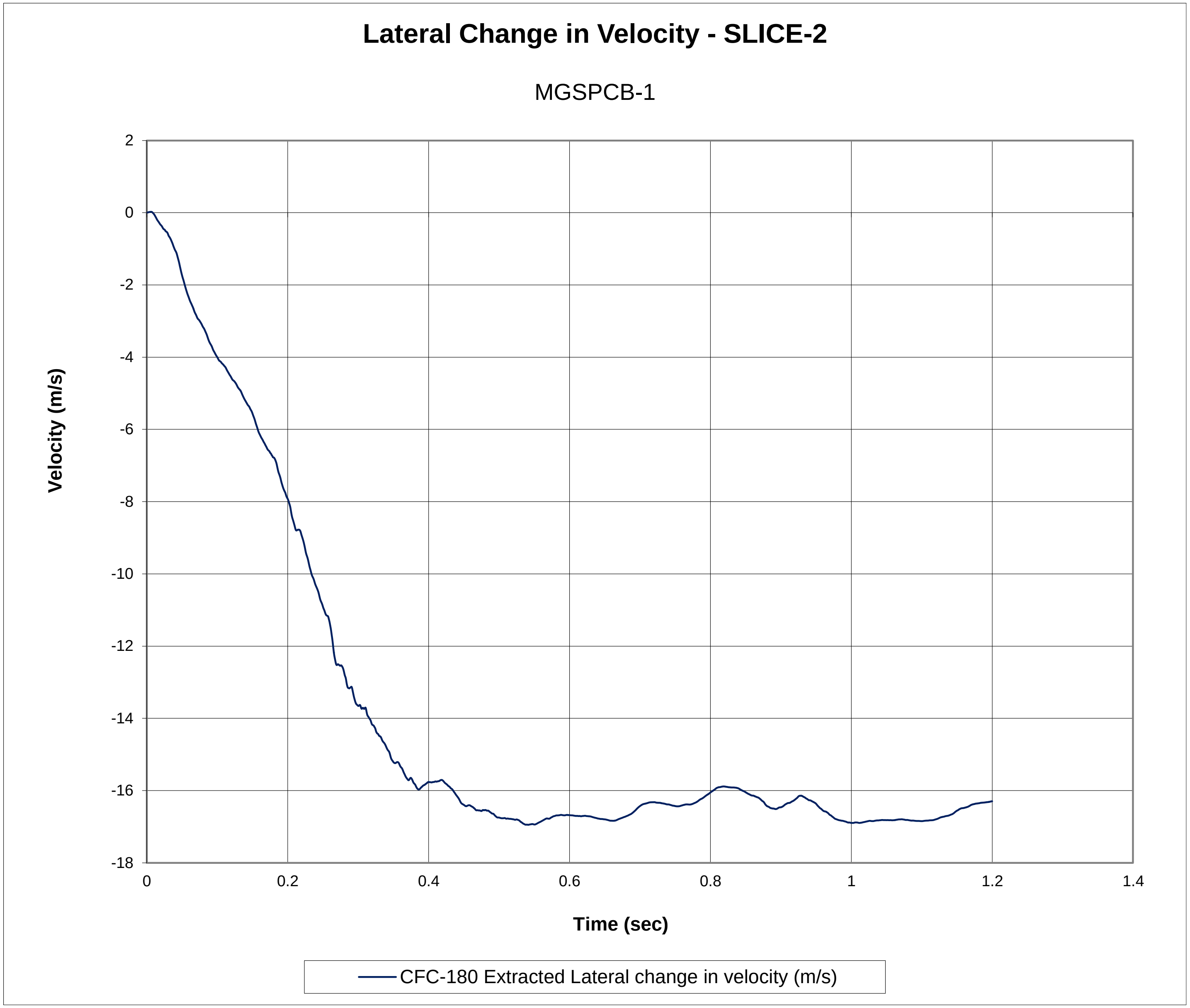


Figure E-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. MGSPCB-1

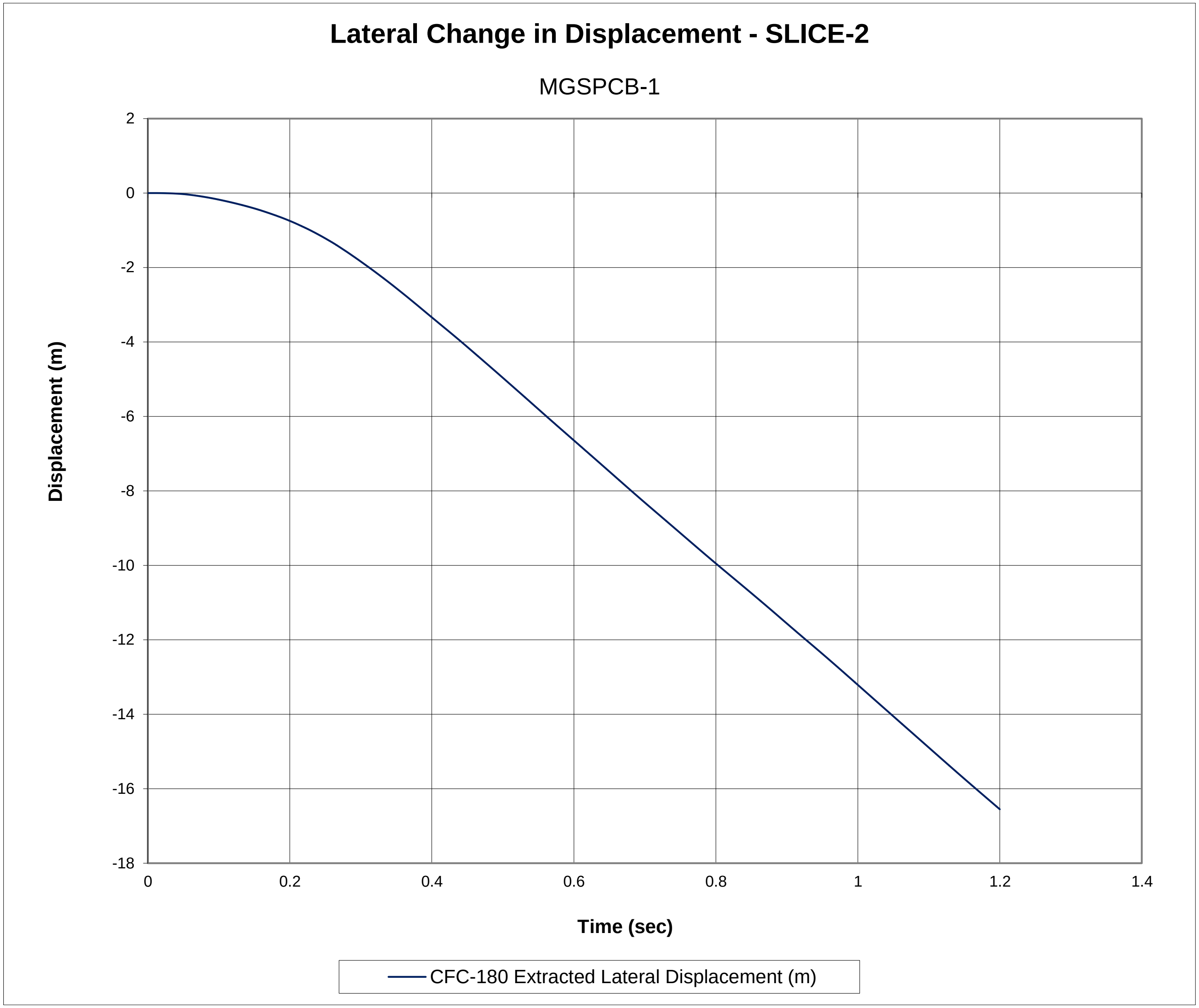


Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. MGSPCB-1

Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. MGSPCB-1

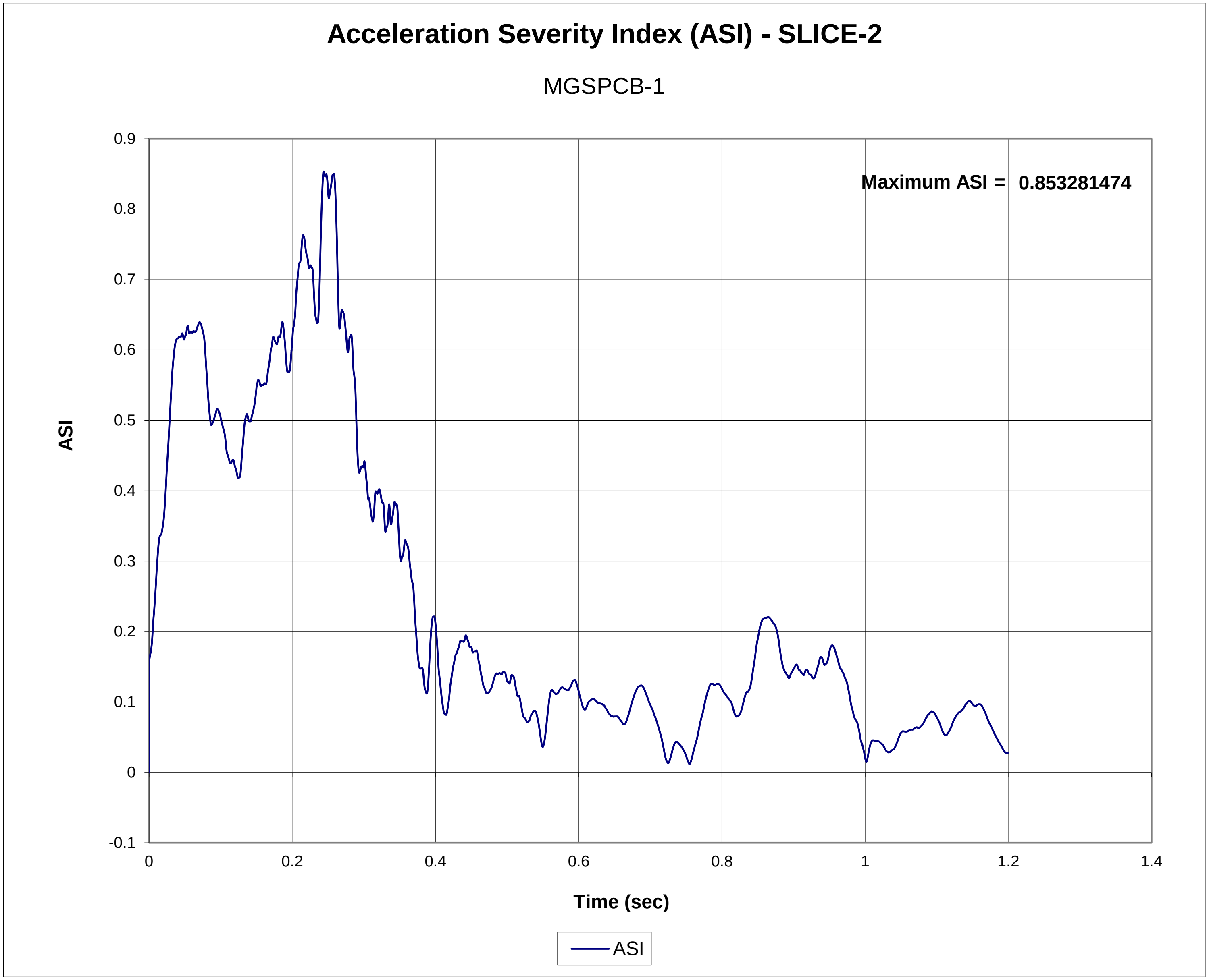


Figure E-16. Acceleration Severity Index (SLICE-2), Test No. MGSPCB-1

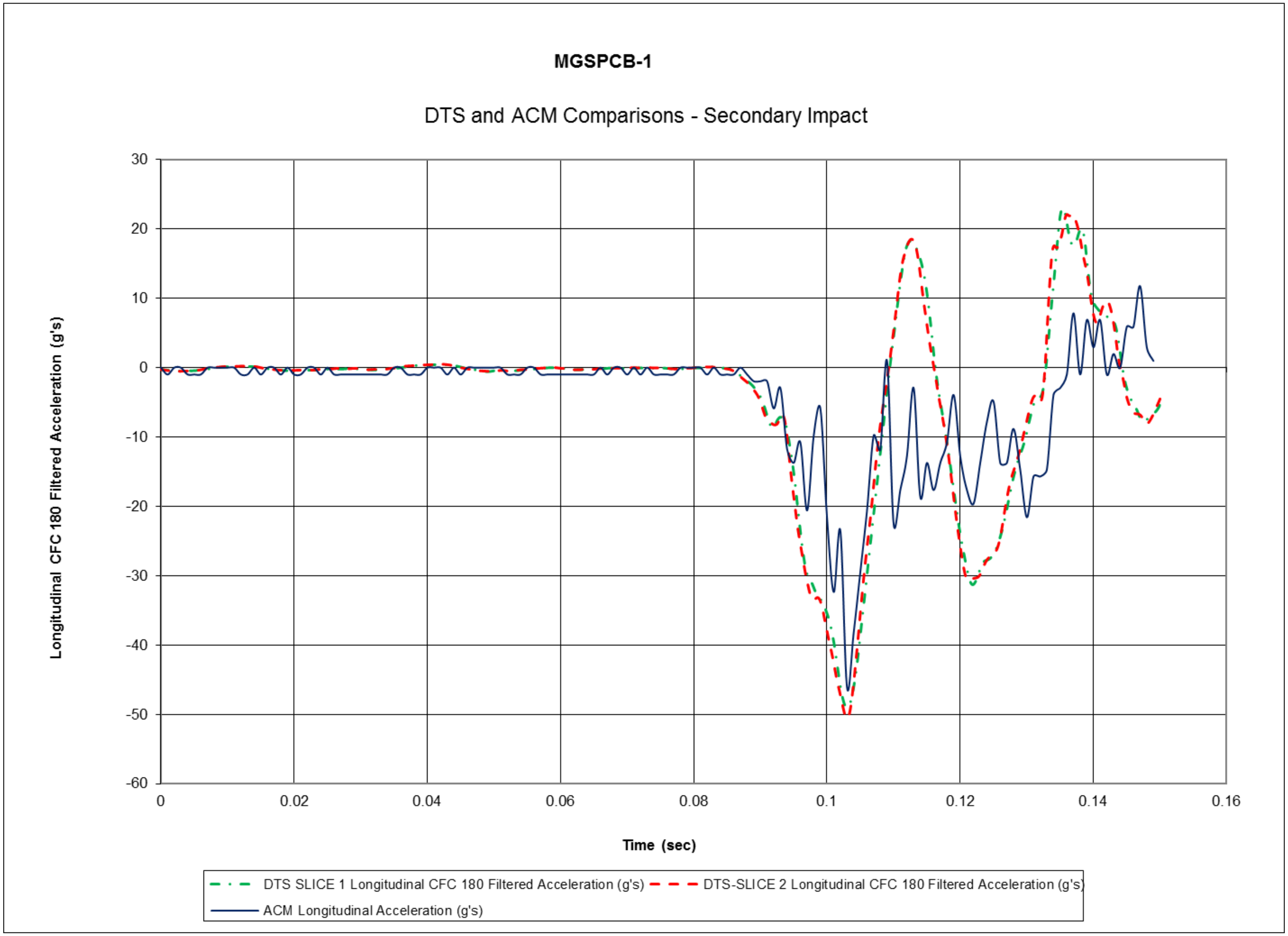


Figure E-17. ACM Longitudinal Acceleration Data Comparison for Secondary Impact, Test No. MGSPCB-1

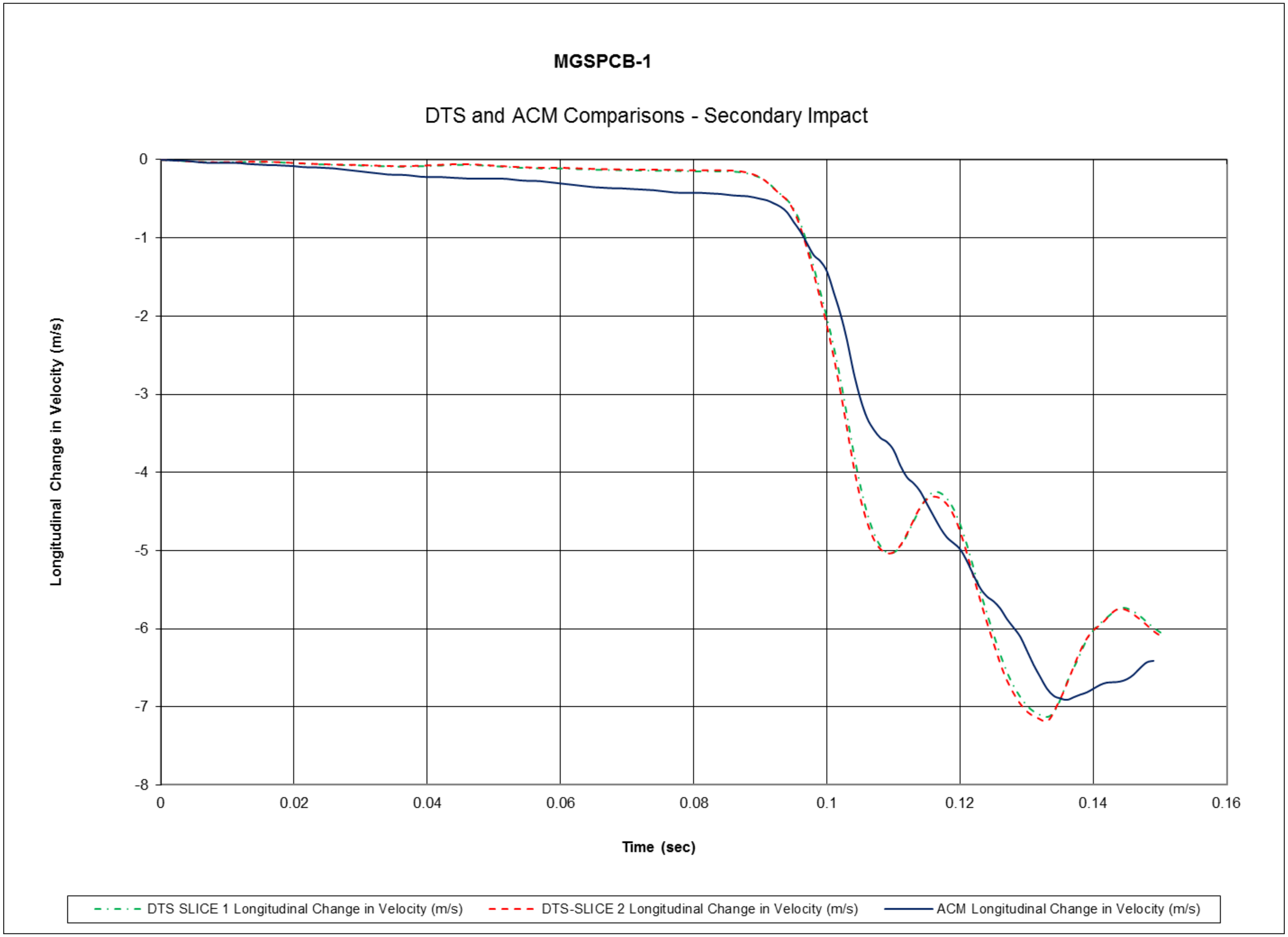


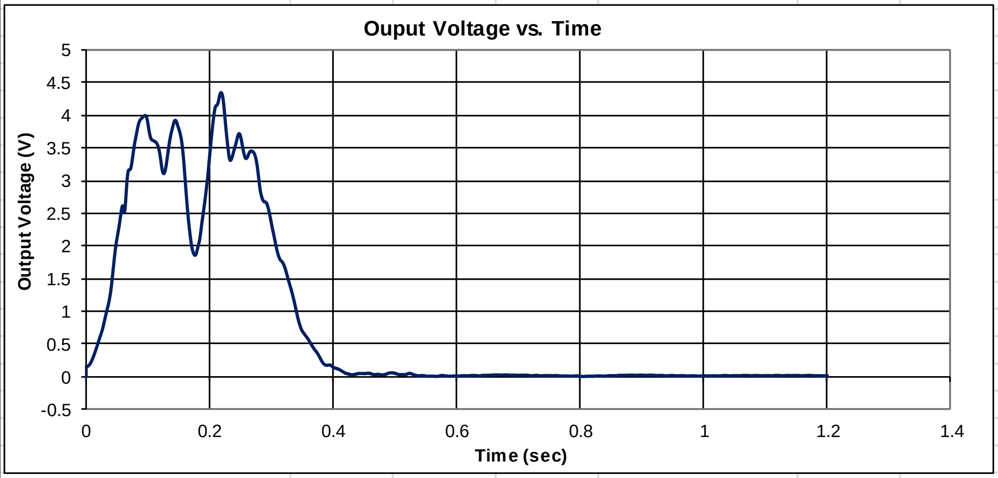
Figure E-18. ACM Longitudinal Change in Velocity Data Comparison for Secondary Impact, Test No. MGSPCB-1

Appendix F. Load Cell and String Potentiometer Data, Test No. MGSPCB-1

MIDWEST ROADSIDE SAFETY FACILITY

Load Cell Summary

Test Information:				
Test No:	MGSPCB-1			
Date:	7/20/2015			
System / Test Article:	PCB-MGS Transition			
LC Location / Component:	Upstream Cable Anchor			
Additional Notes:	None			
Load Cell Information:			**Results:**	
Load Cell No.:	241593		Preload:	0 kips
Calibration Factor:	2.14857	mv/V	Max. Load:	25.30 kips
Input Voltage (excitation):	9.99	Volts	Time of Max. Load:	0.2186 sec
Gain:	400		Event Duration:	1.2 sec
Full Scale Load:	50	kips	Final Load:	0.09 kips
Sample Rate:	10000	Hz		
Cutoff Frequency:	100	Hz		



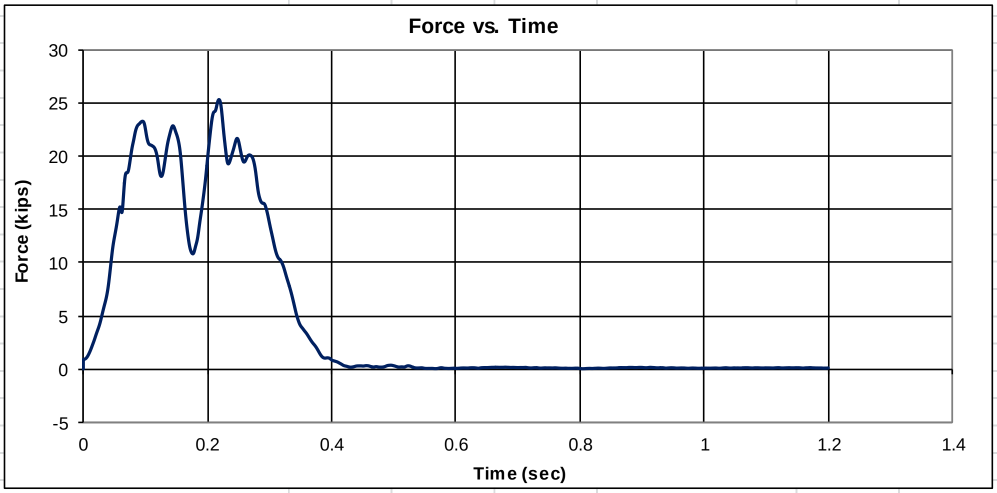
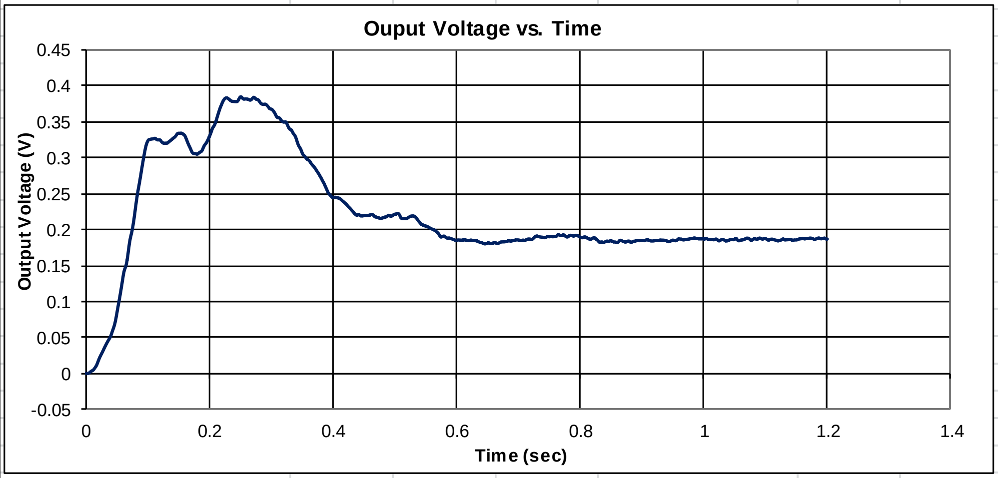


Figure F-1. Load Cell Data, Test No. MGSPCB-1

MIDWEST ROADSIDE SAFETY FACILITY

String Potentiometer Summary

Test Information:					
Test No:	MGSPCB-1				
Date:	7/20/2015				
System / Test Article:	PCB-MGS Transition				
SP Location / Component:	Upstream Cable Anchor				
Additional Notes:	None				
String Potentiometer Information:			**Results:**		
String Pot No.:	27039202		Max. Displacement:	1.98	in.
Calibration Factor:	19.4483	mV/V/in.	Time of Max. Displacement:	0.2505	sec
Input Voltage (excitation):	9.99	Volts	Event Duration:	1.2	sec
Gain:	1		Final Displacement:	0.96	in.
Full Scale Load:	1				
Sample Rate:	10000	Hz			
Cutoff Frequency:	100	Hz			



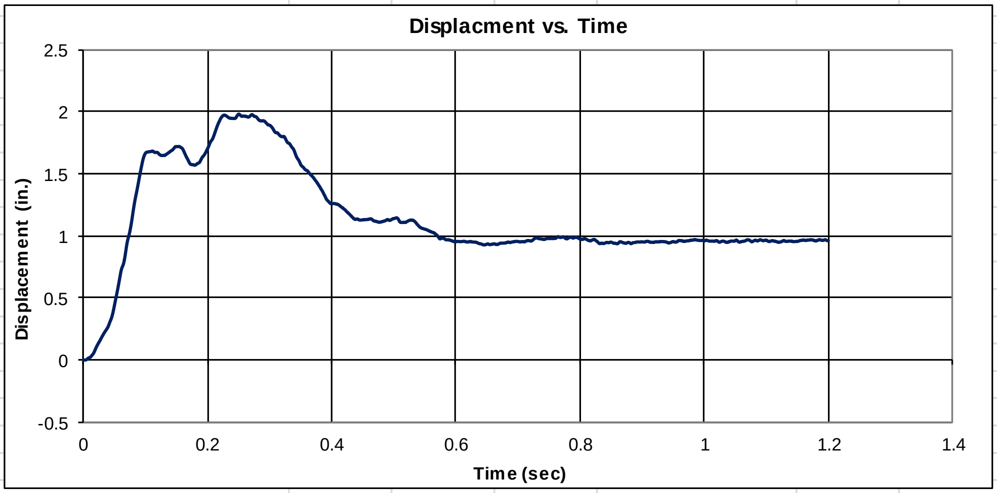


Figure F-2. String Potentiometer Data, Test No. MGSPCB-1

Appendix G. Accelerometer and Rate Transducer Data Plots, Test No. MGSPCB-2

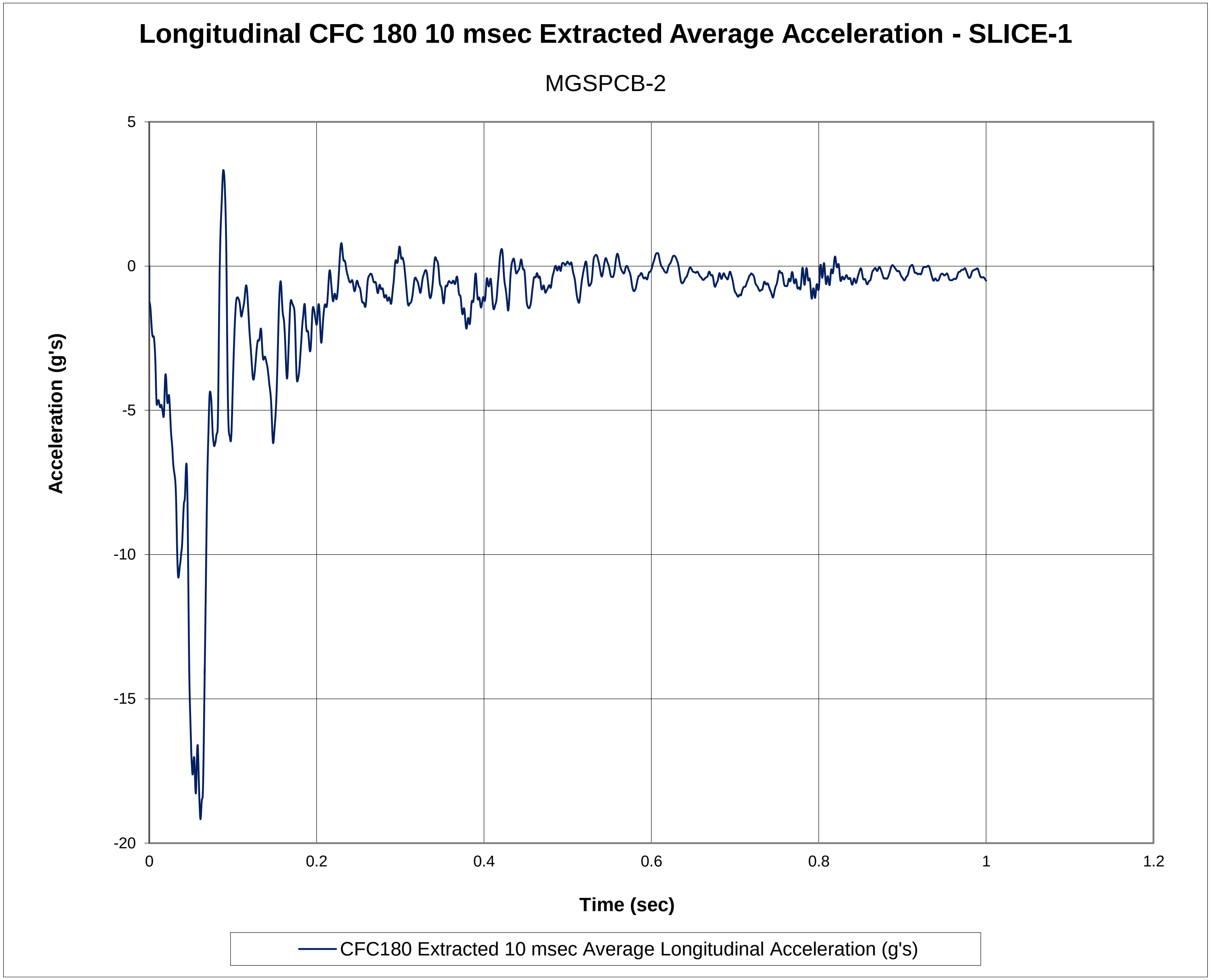


Figure G-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MGSPCB-2

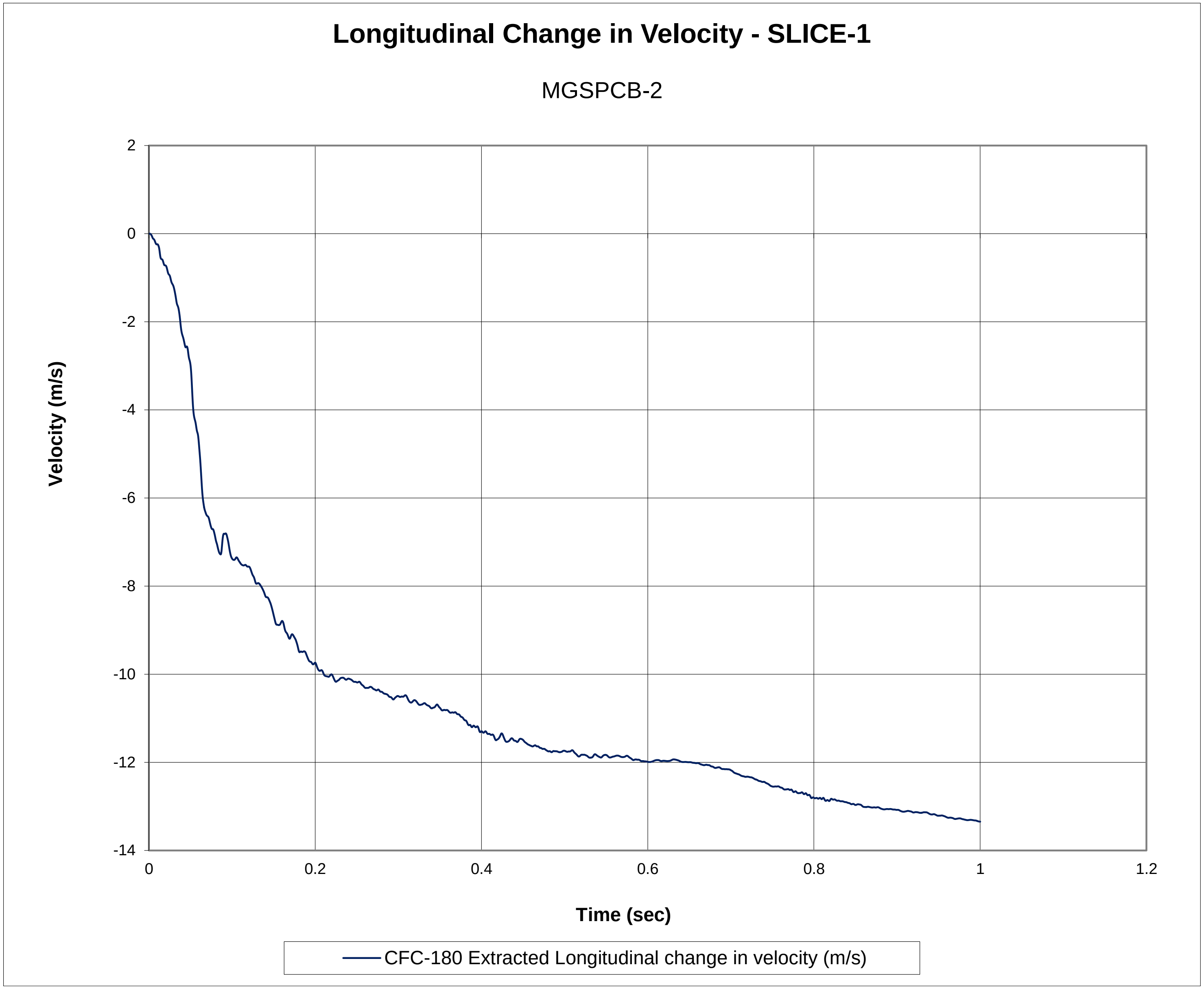


Figure G-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MGSPCB-2

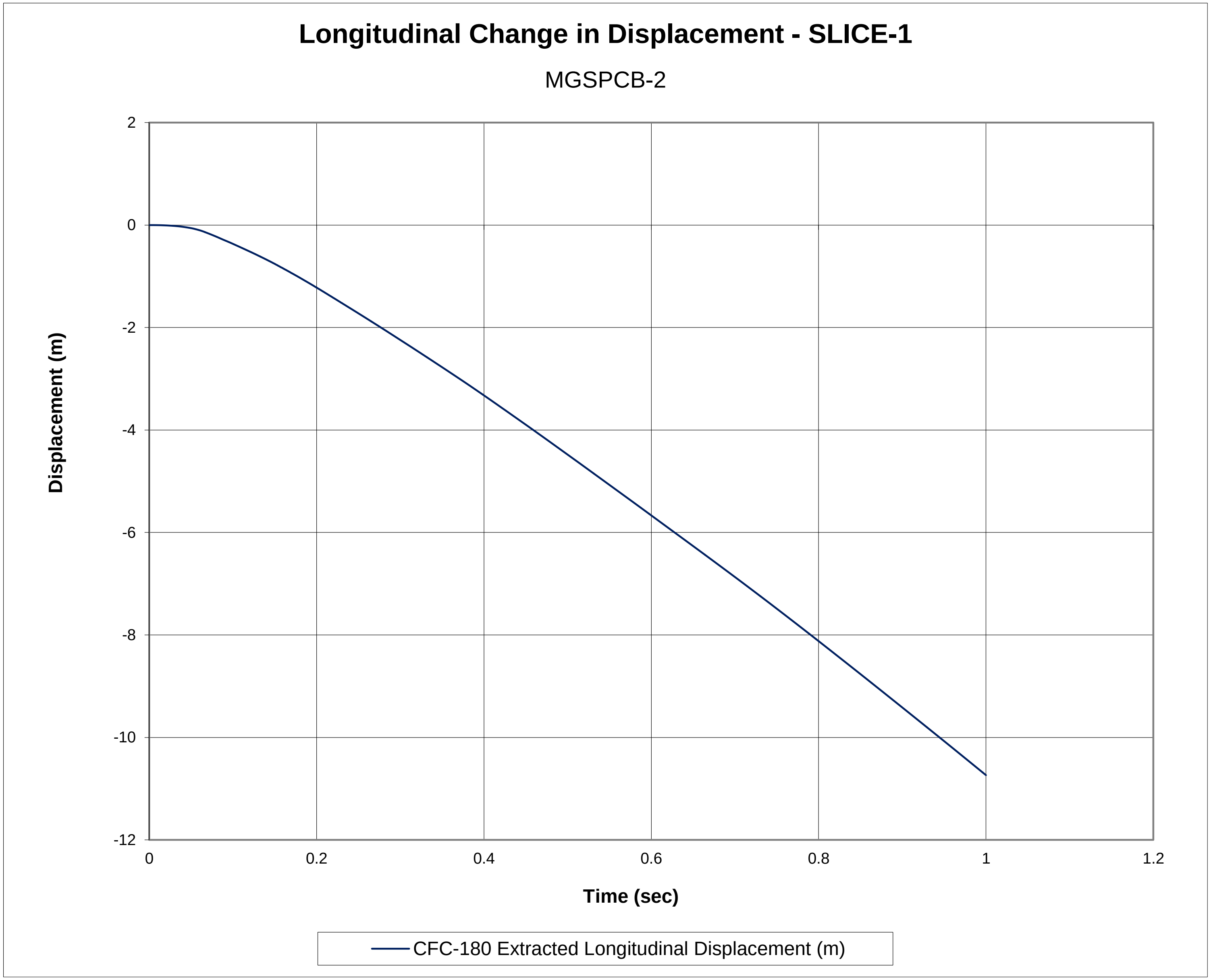


Figure G-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MGSPCB-2

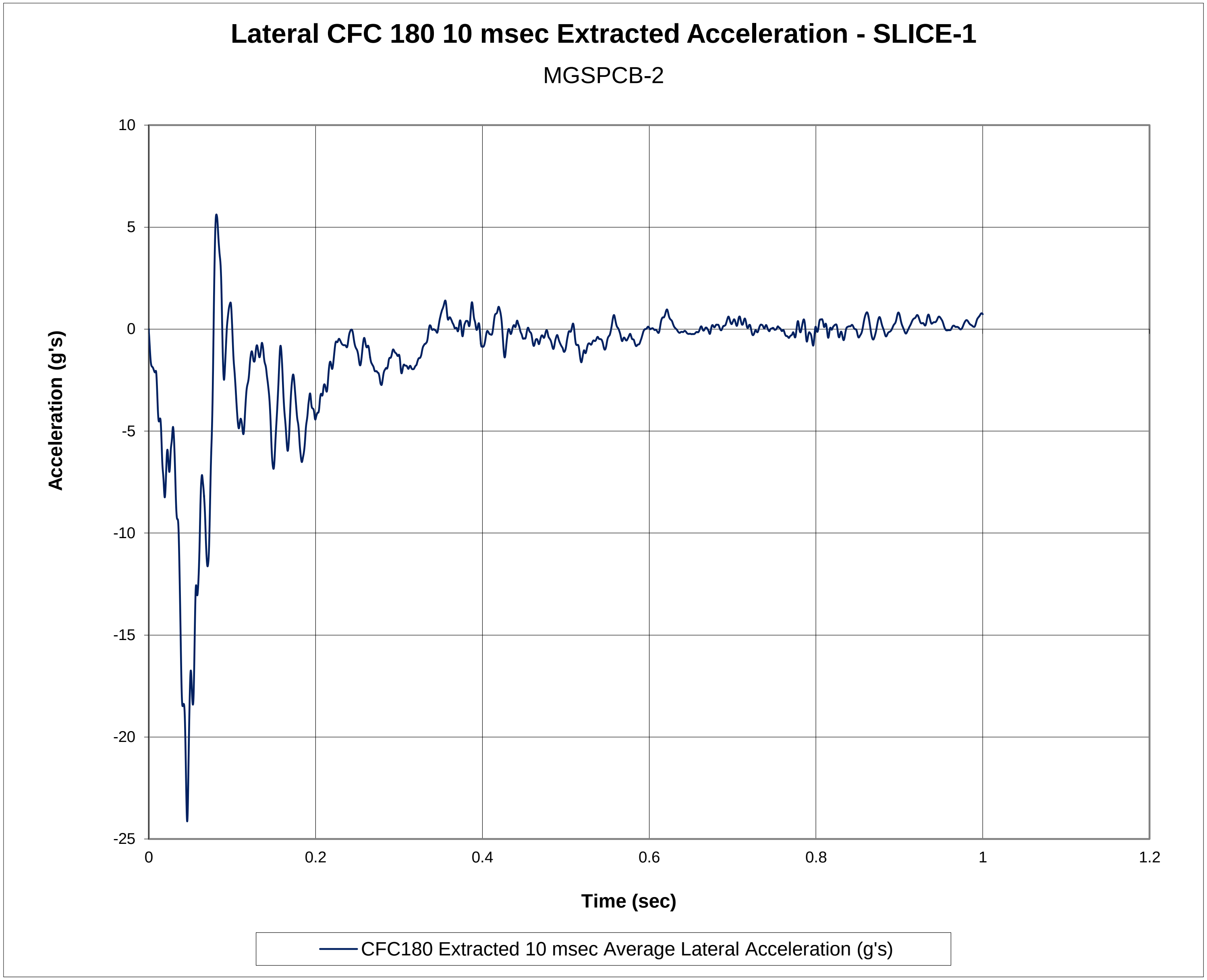


Figure G-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MGSPCB-2

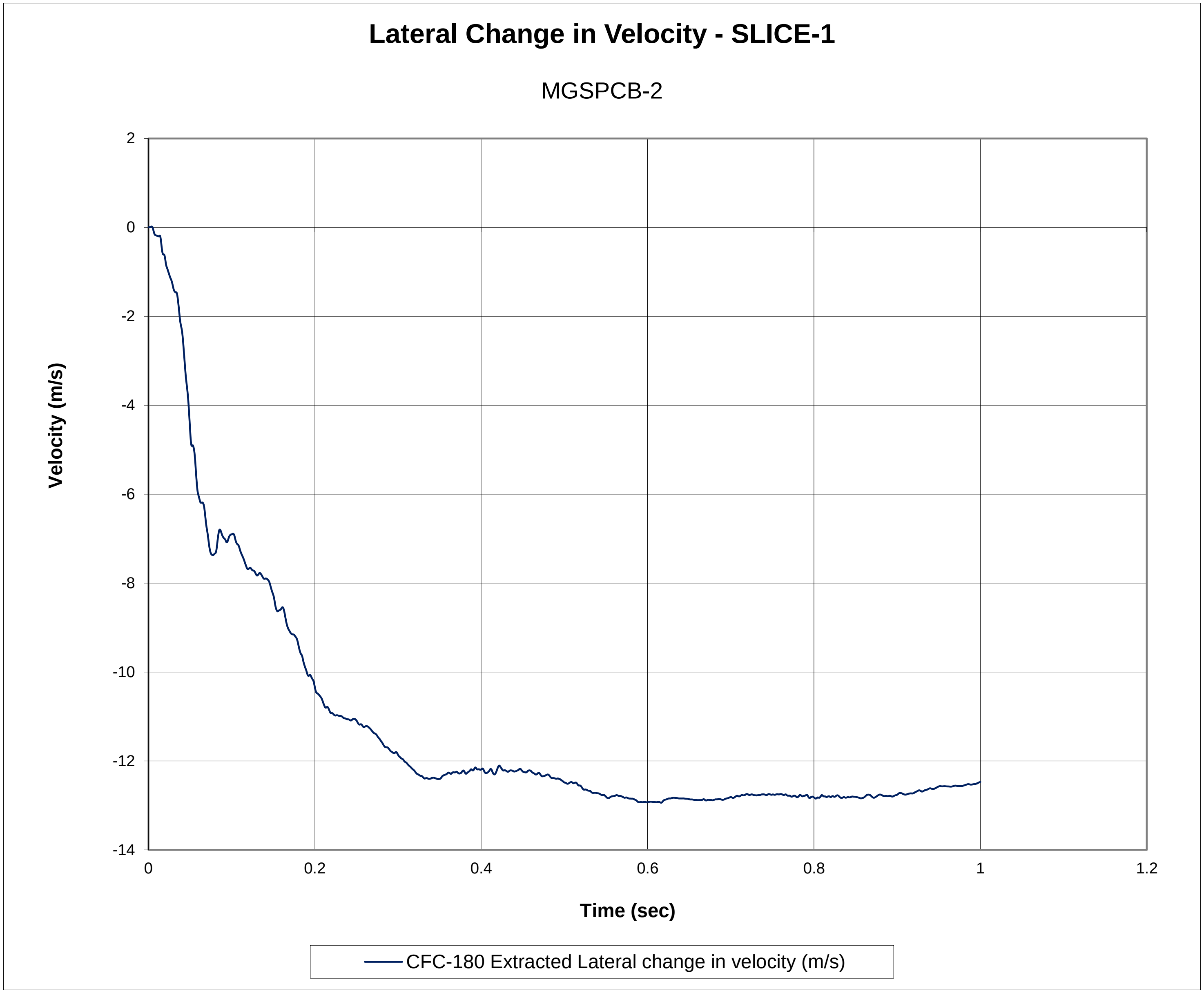


Figure G-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. MGSPCB-2

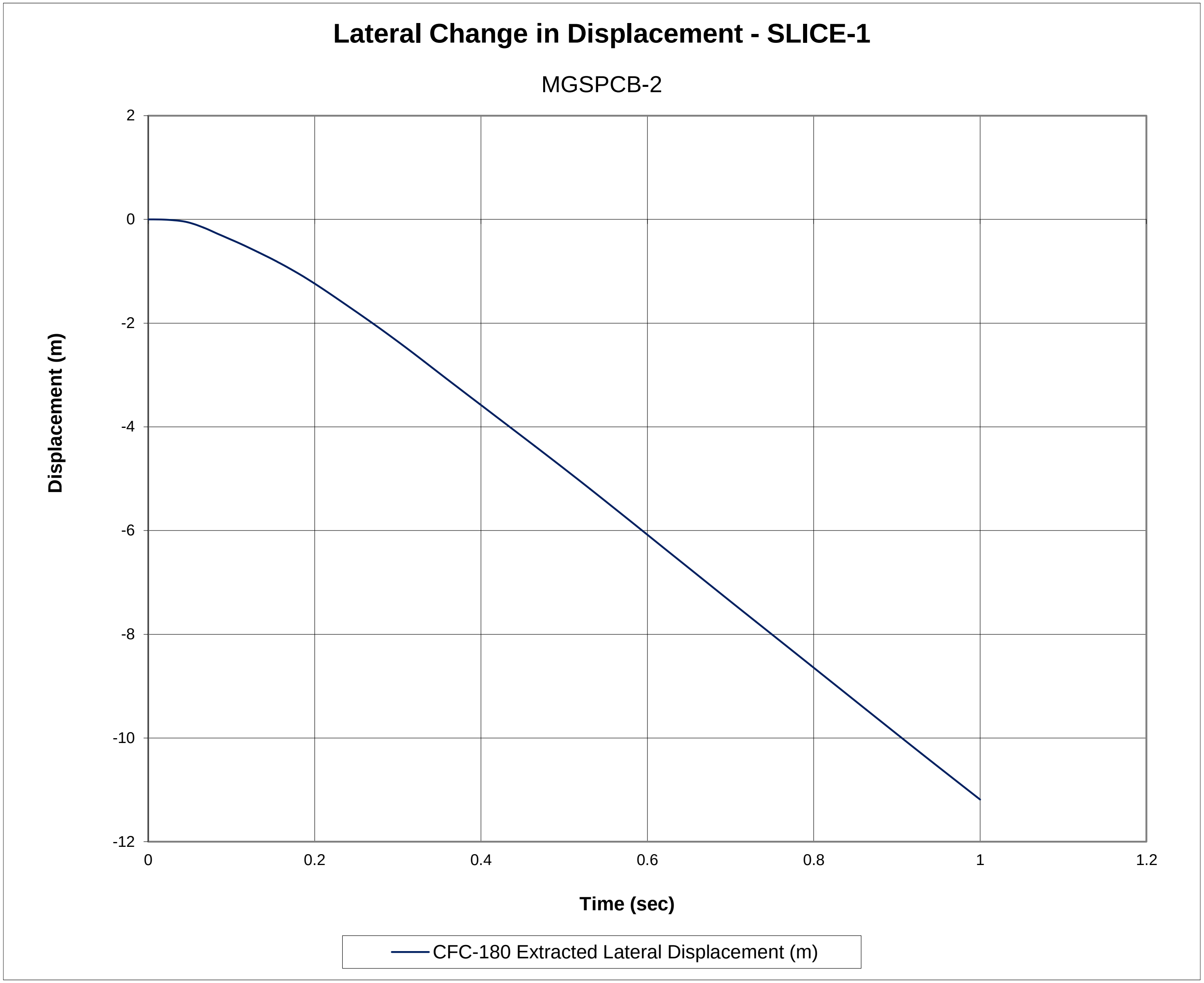


Figure G-6. Lateral Occupant Displacement (SLICE-1), Test No. MGSPCB-2

Figure G-7. Vehicle Angular Displacements (SLICE-1), Test No. MGSPCB-2

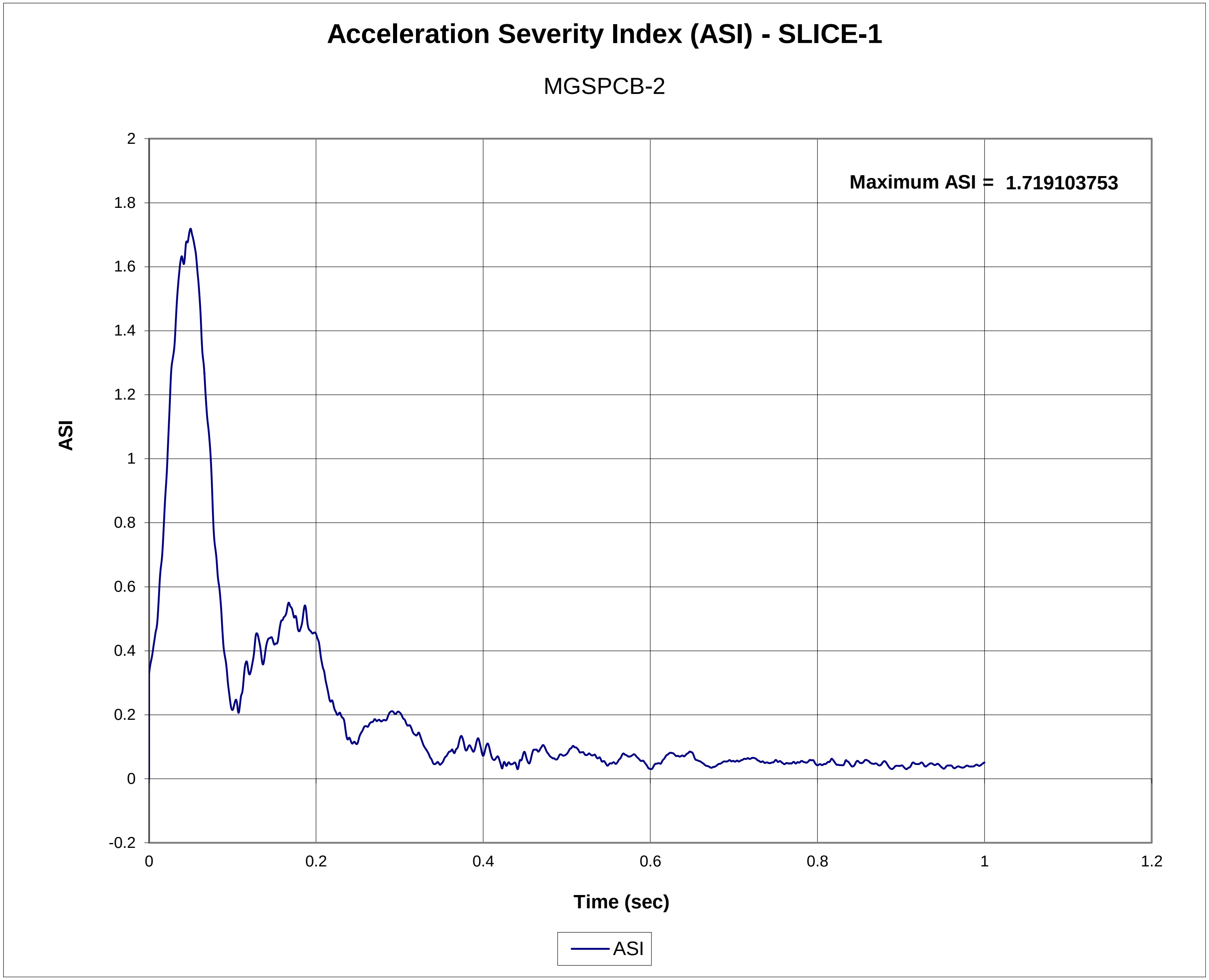


Figure G-8. Acceleration Severity Index (SLICE-1), Test No. MGSPCB-2

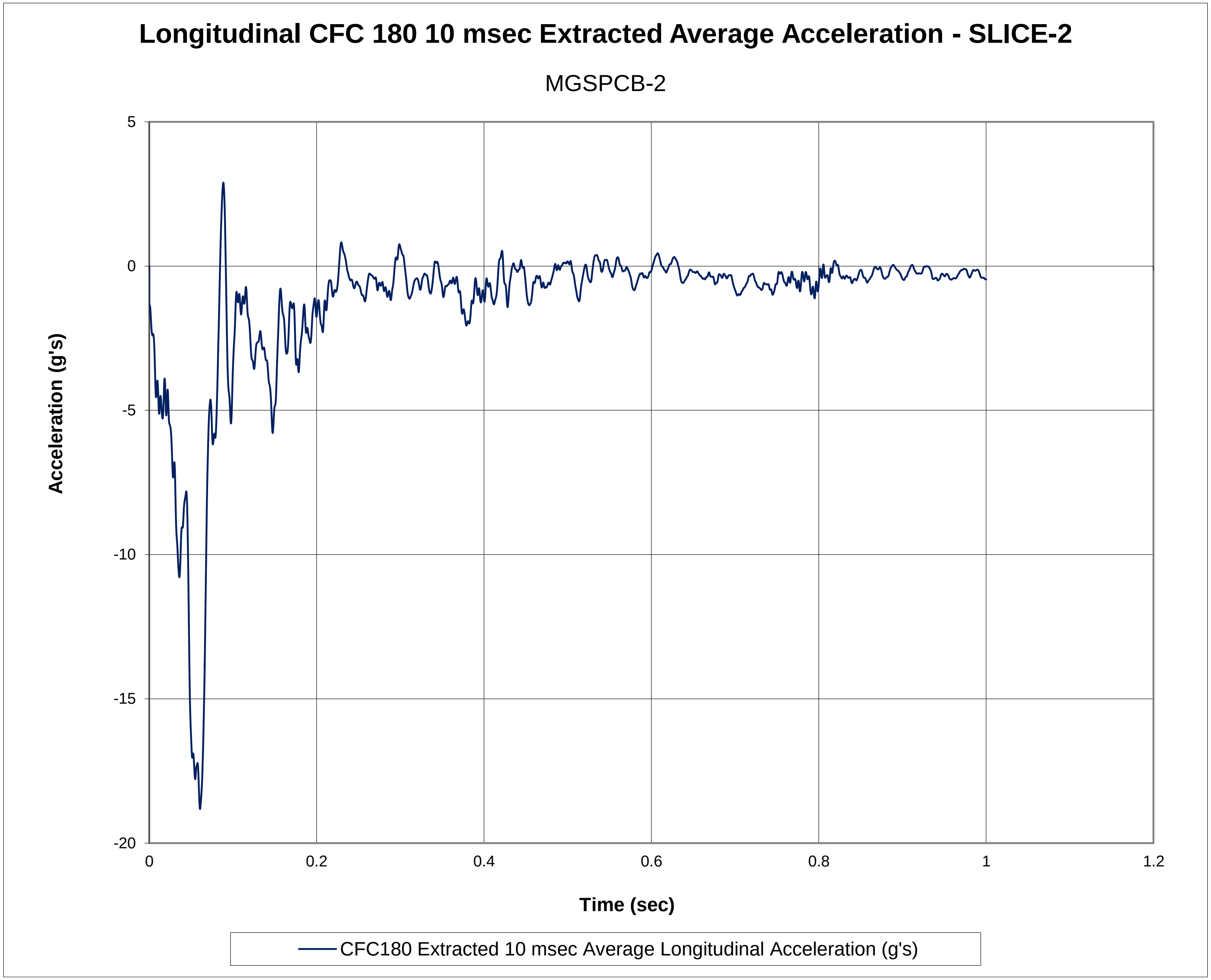


Figure G-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MGSPCB-2

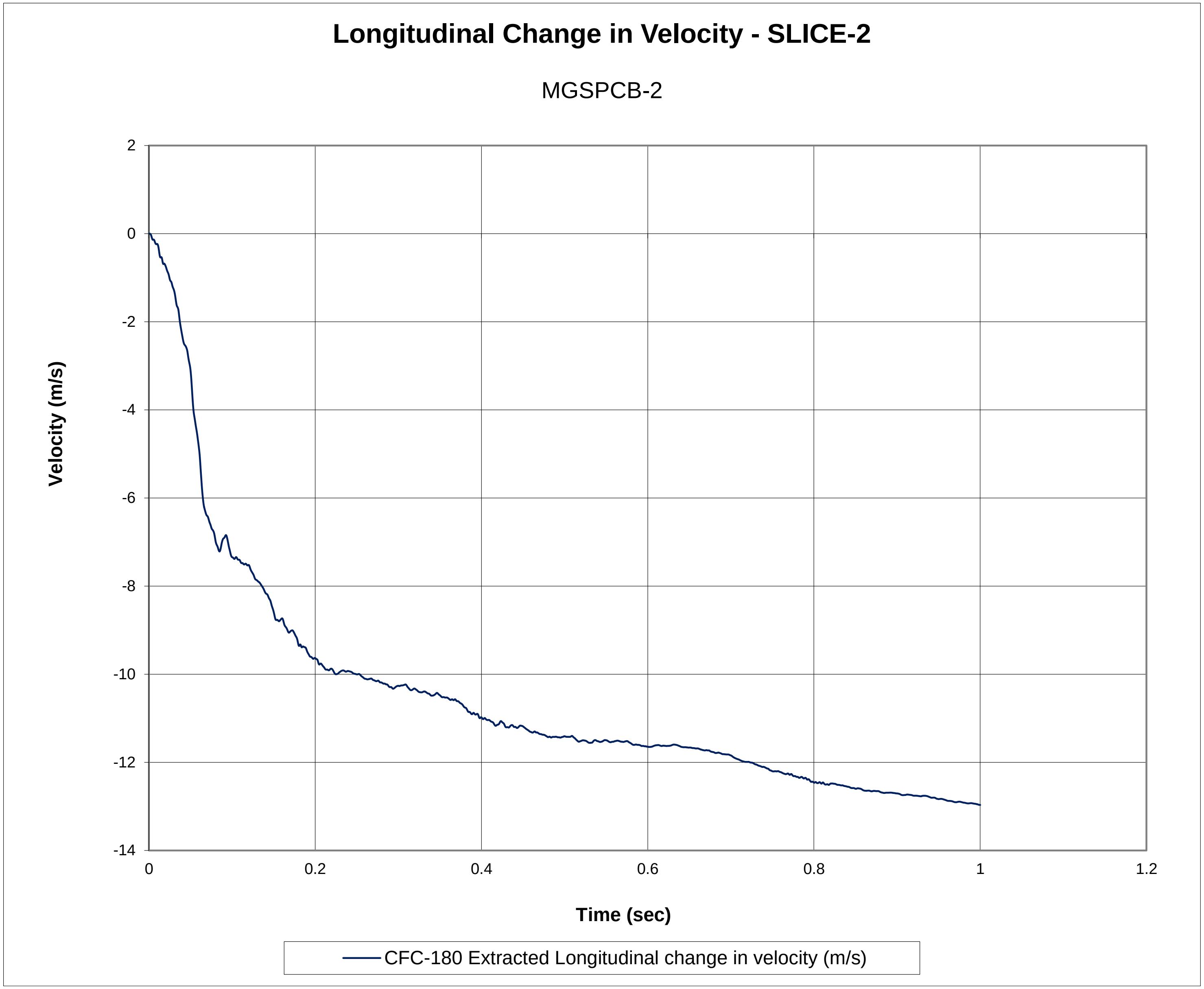


Figure G-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MGSPCB-2

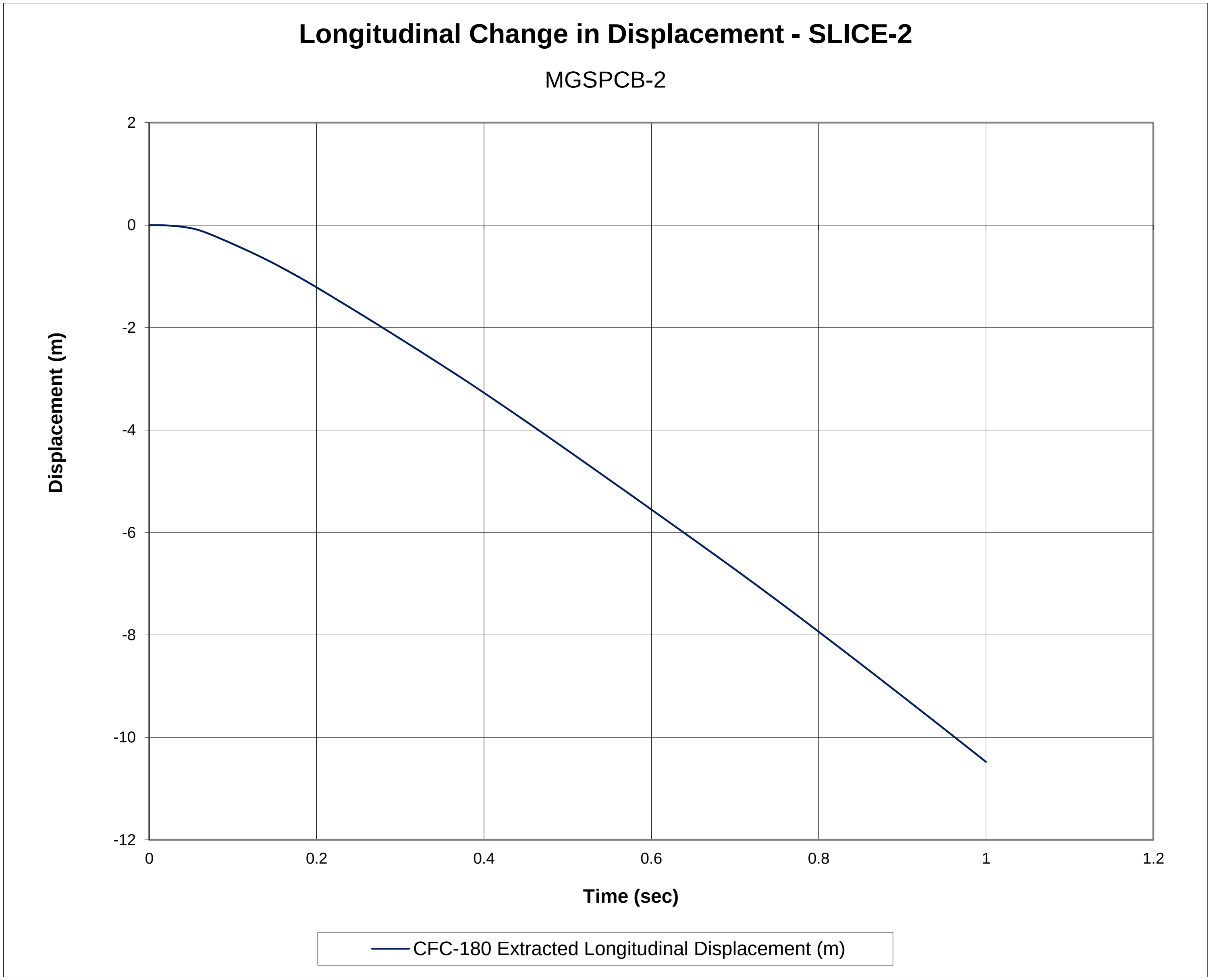


Figure G-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MGSPCB-2

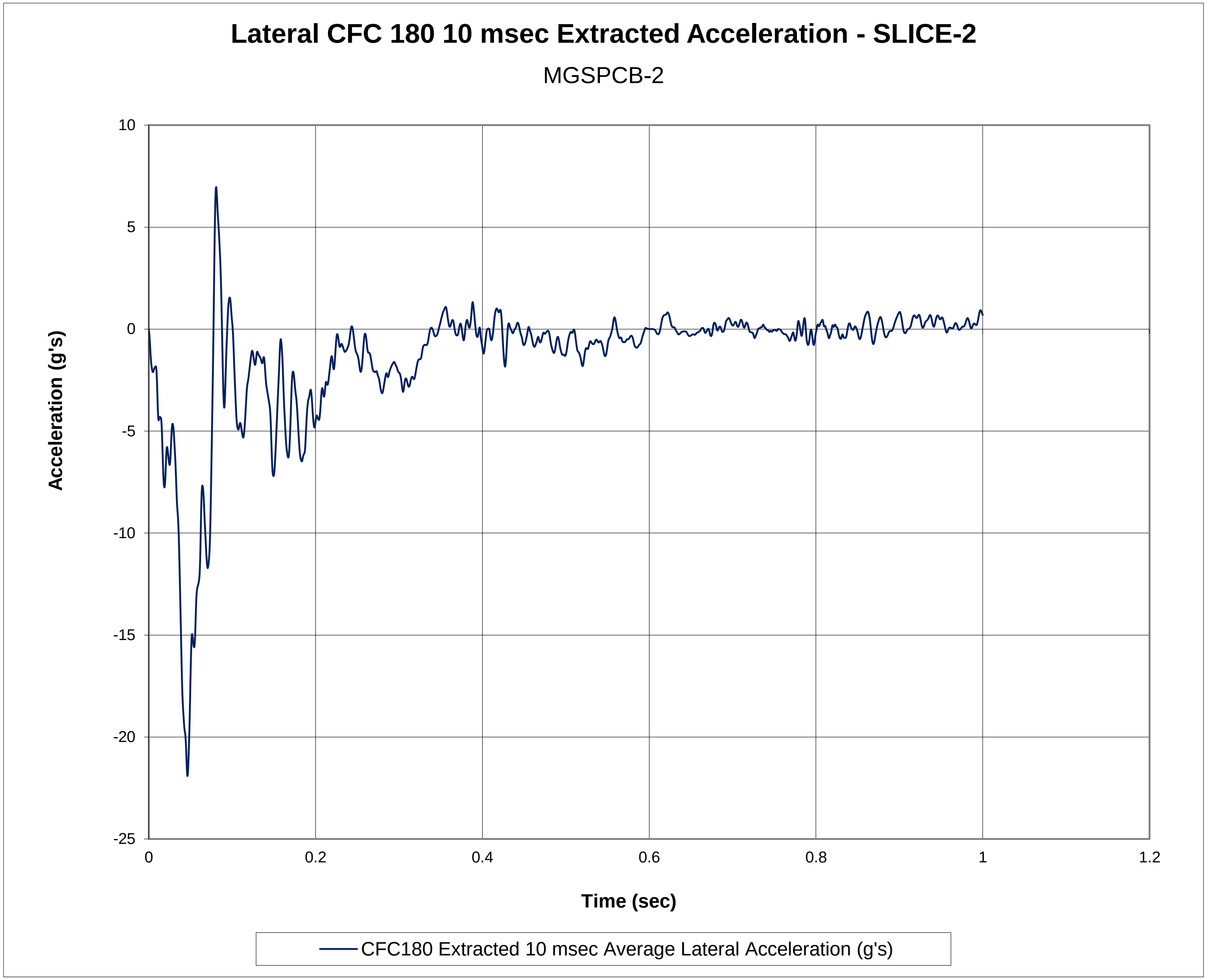


Figure G-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MGSPCB-2

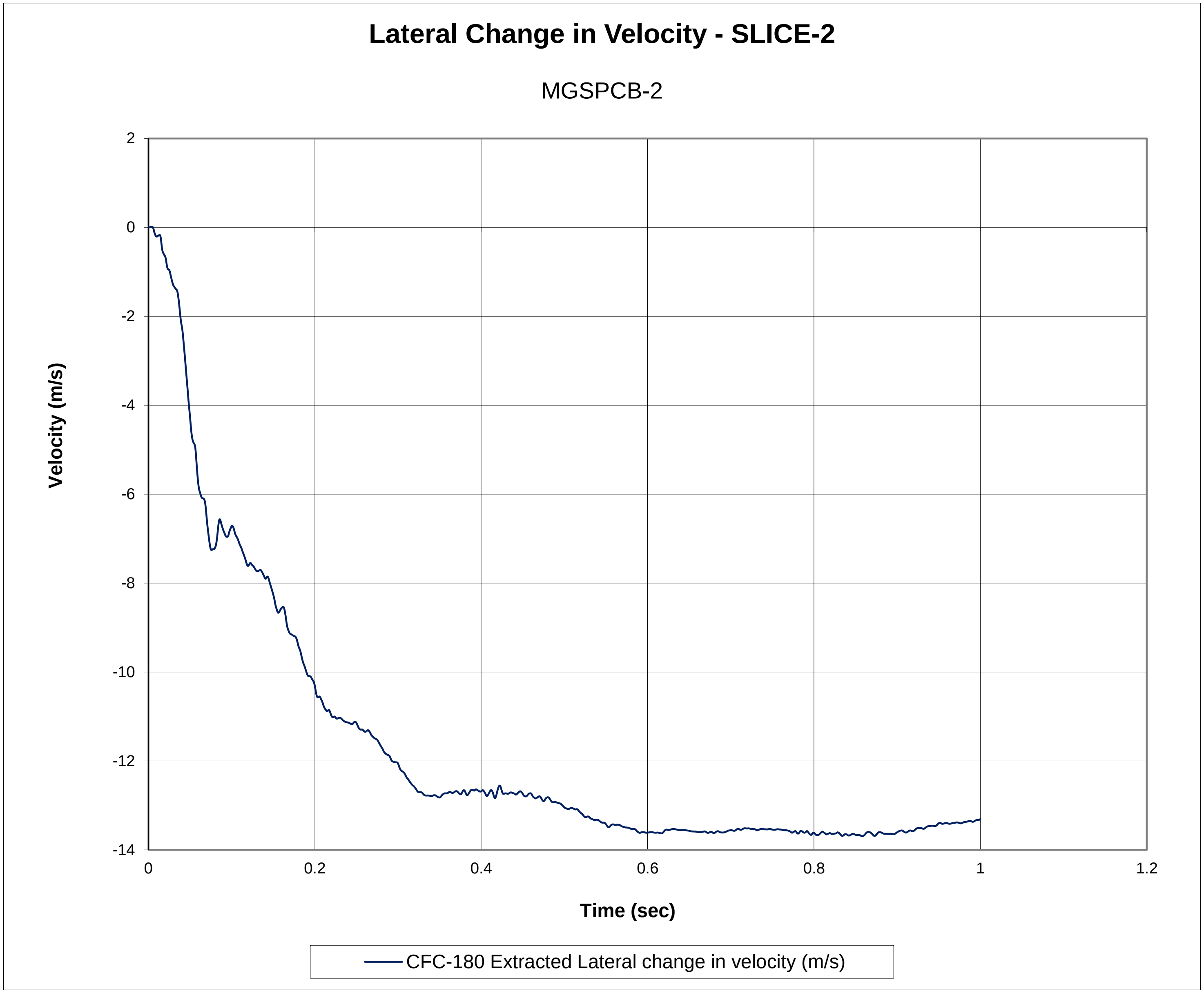


Figure G-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. MGSPCB-2

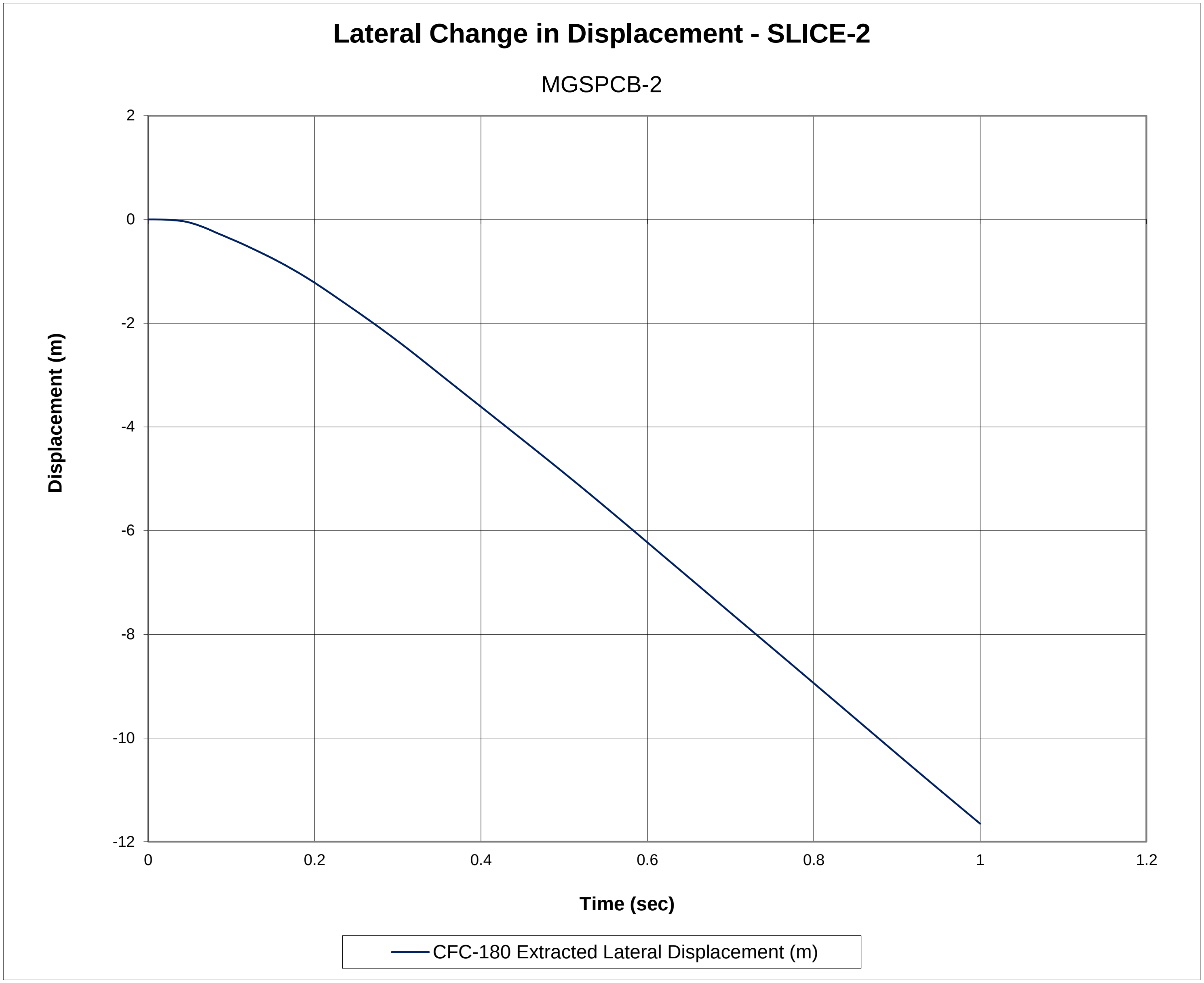


Figure G-14. Lateral Occupant Displacement (SLICE-2), Test No. MGSPCB-2

Figure G-15. Vehicle Angular Displacements (SLICE-2), Test No. MGSPCB-2

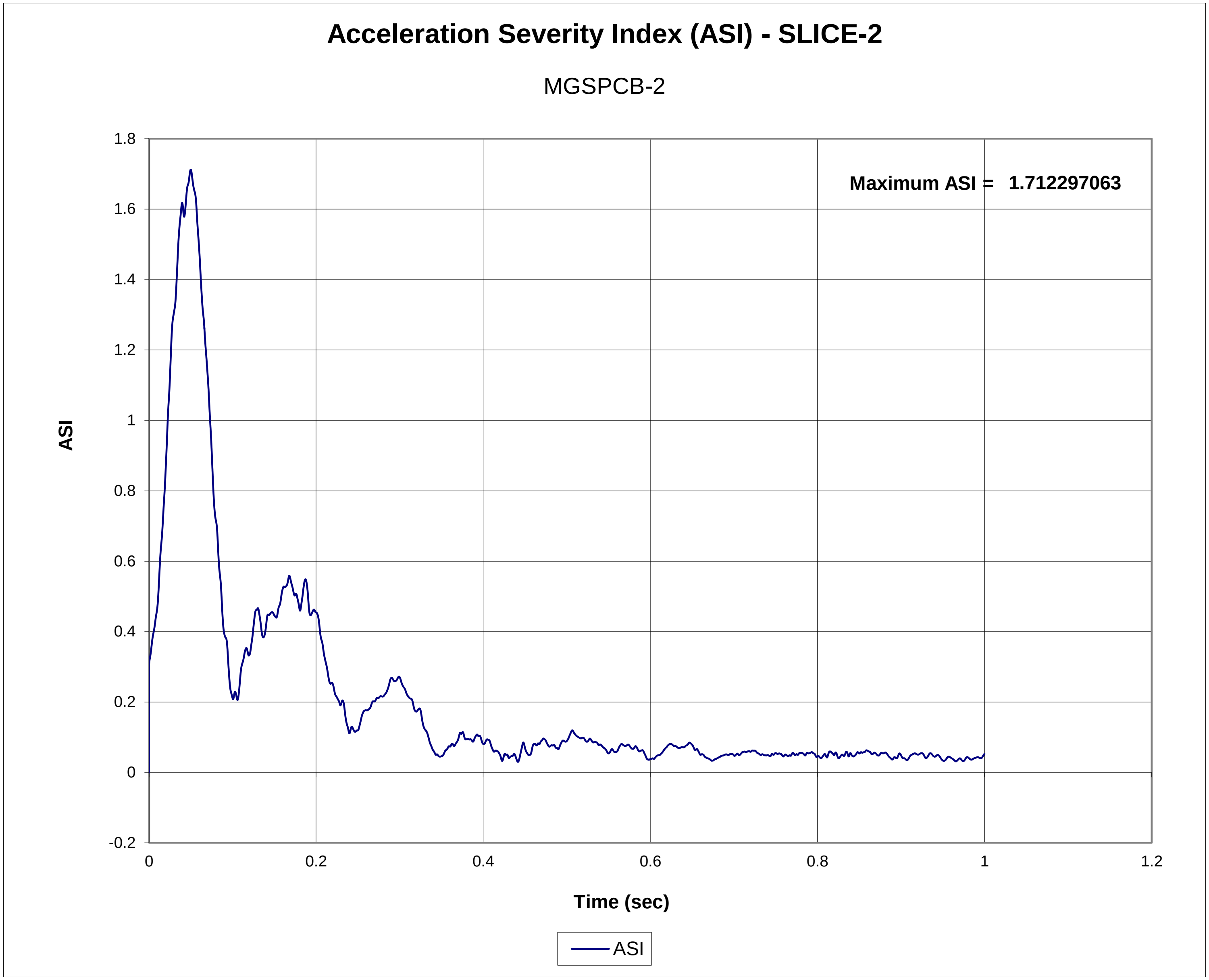


Figure G-16. Acceleration Severity Index (SLICE-2), Test No. MGSPCB-2

Appendix H. Accelerometer and Rate Transducer Data Plots, Test No. MGSPCB-3

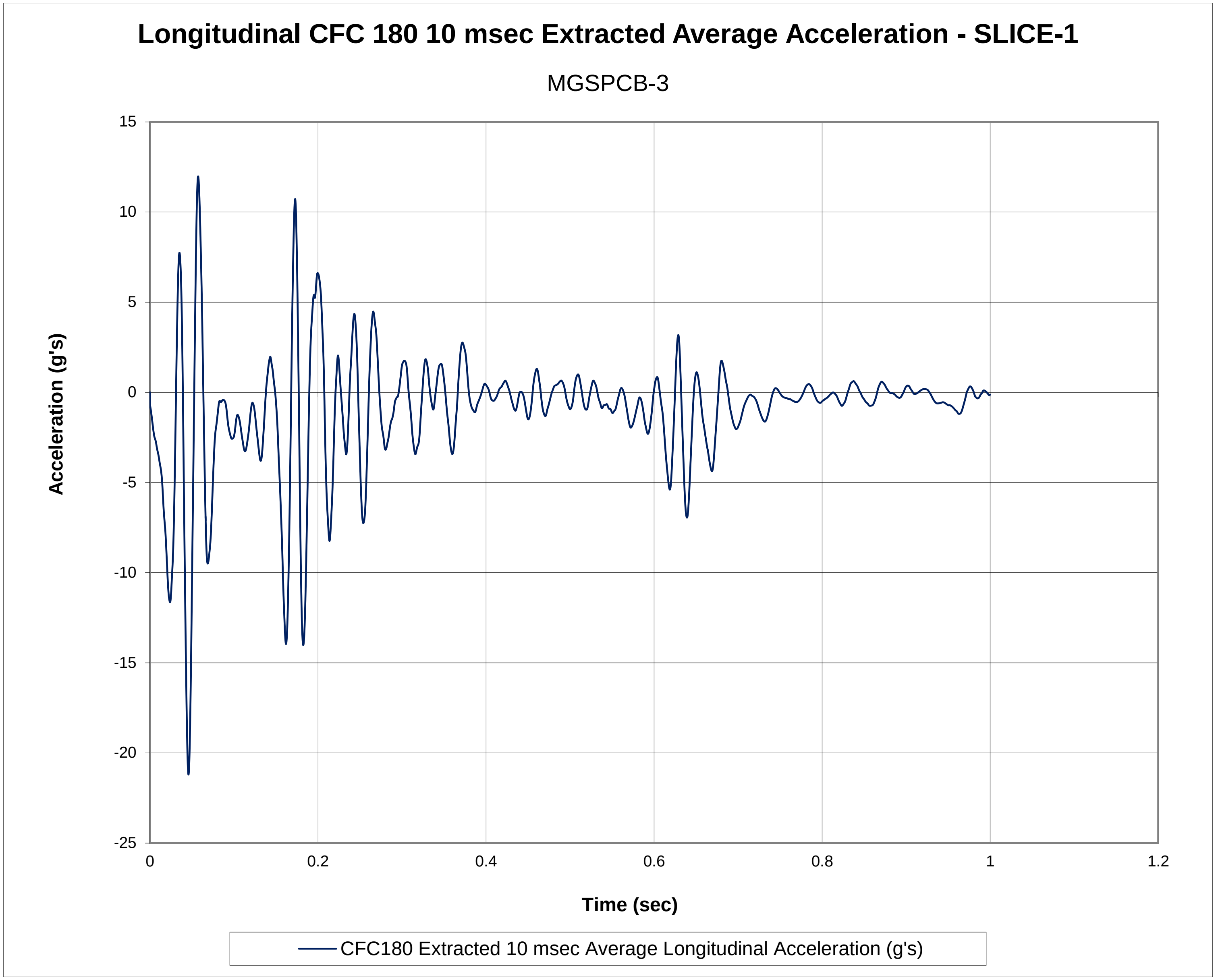


Figure H-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MGSPCB-3

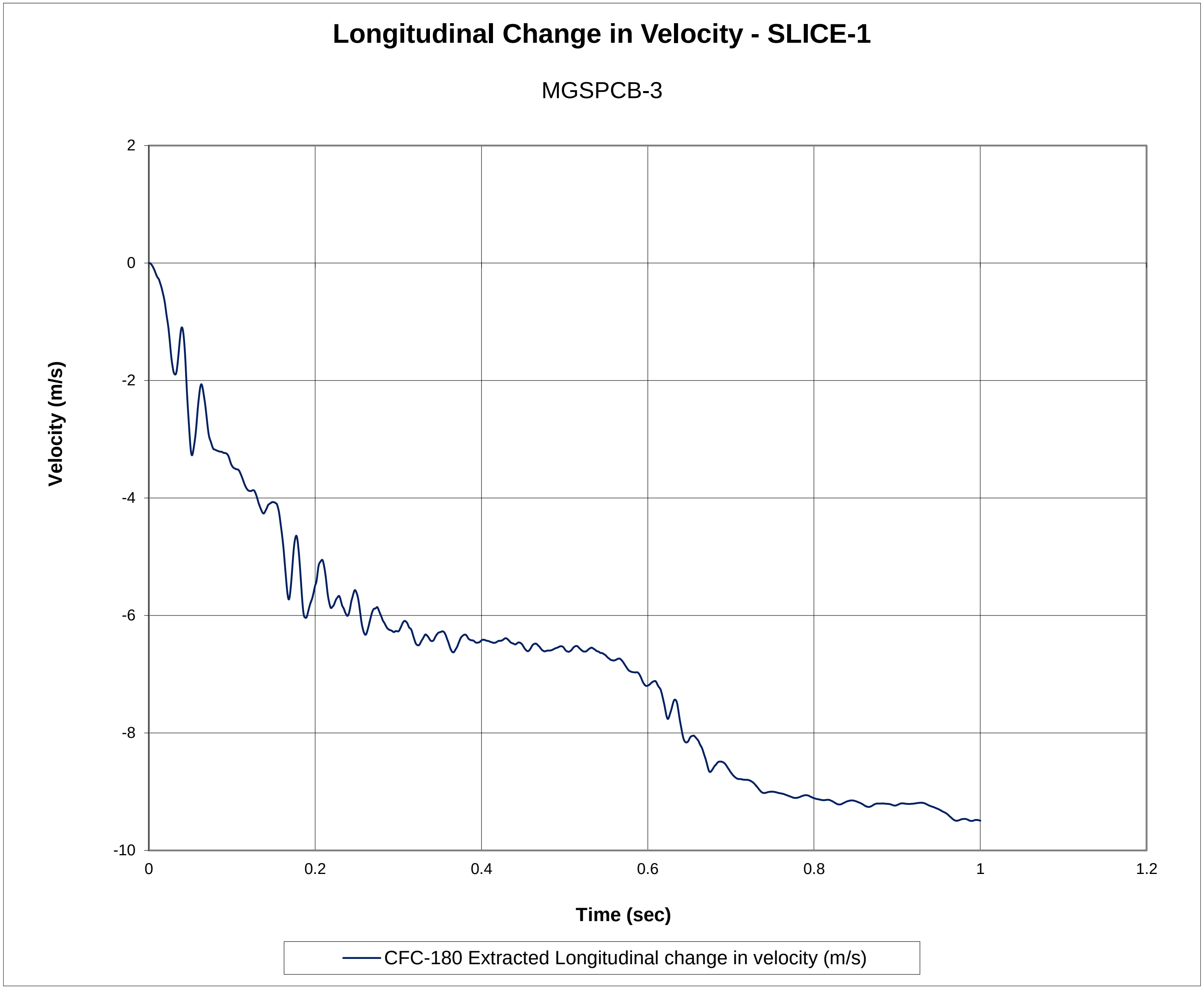


Figure H-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MGSPCB-3

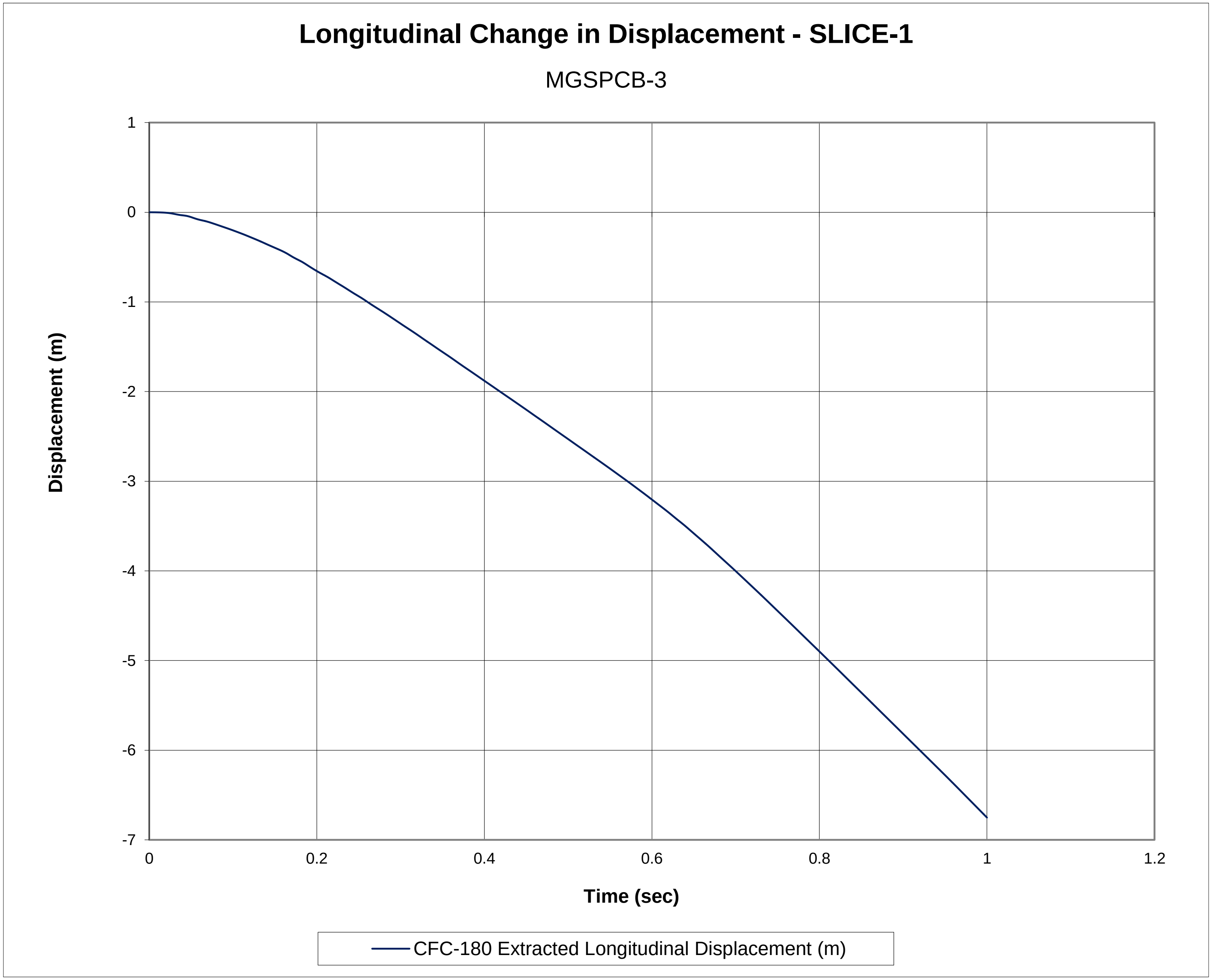


Figure H-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MGSPCB-3

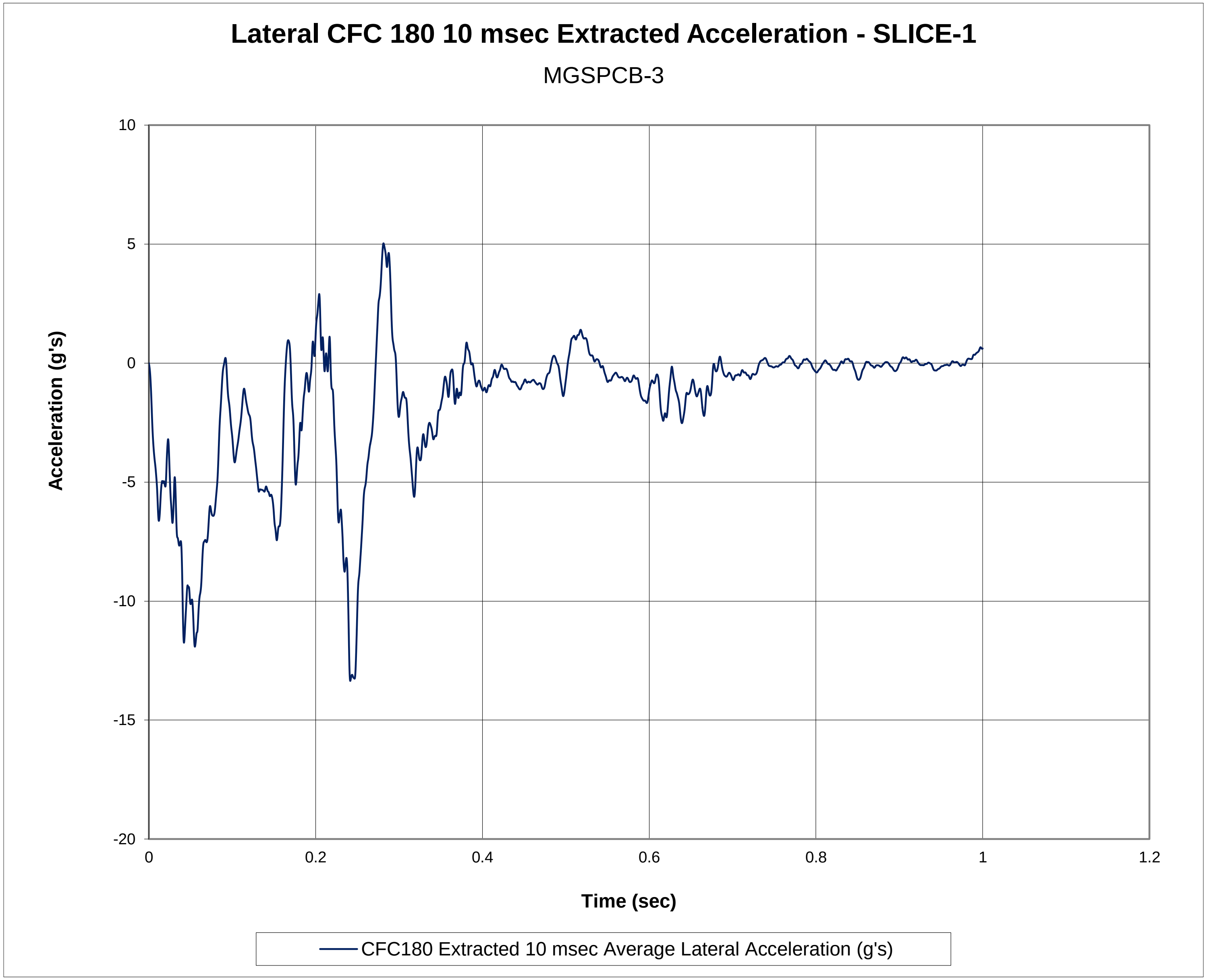


Figure H-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MGSPCB-3

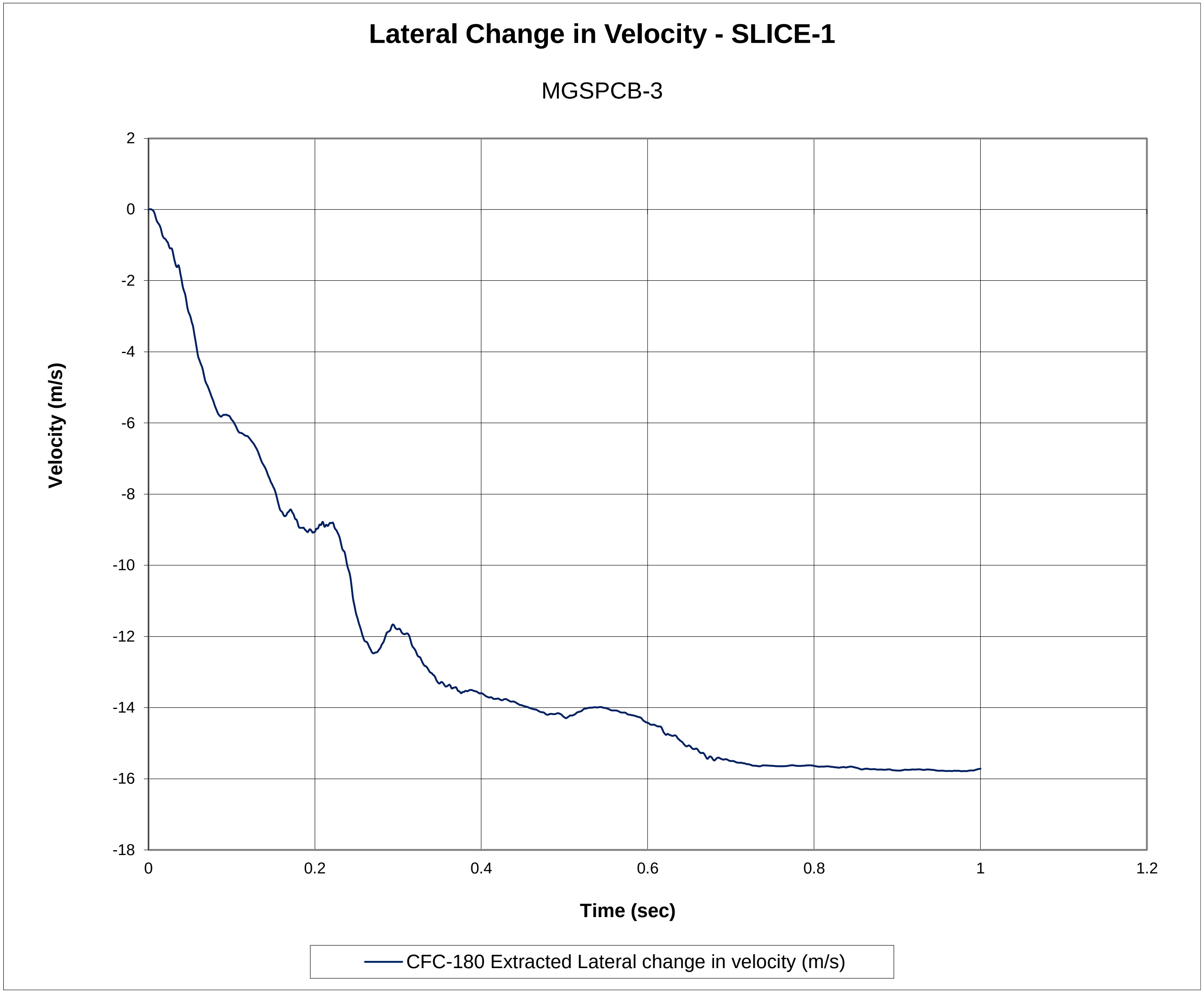


Figure H-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. MGSPCB-3

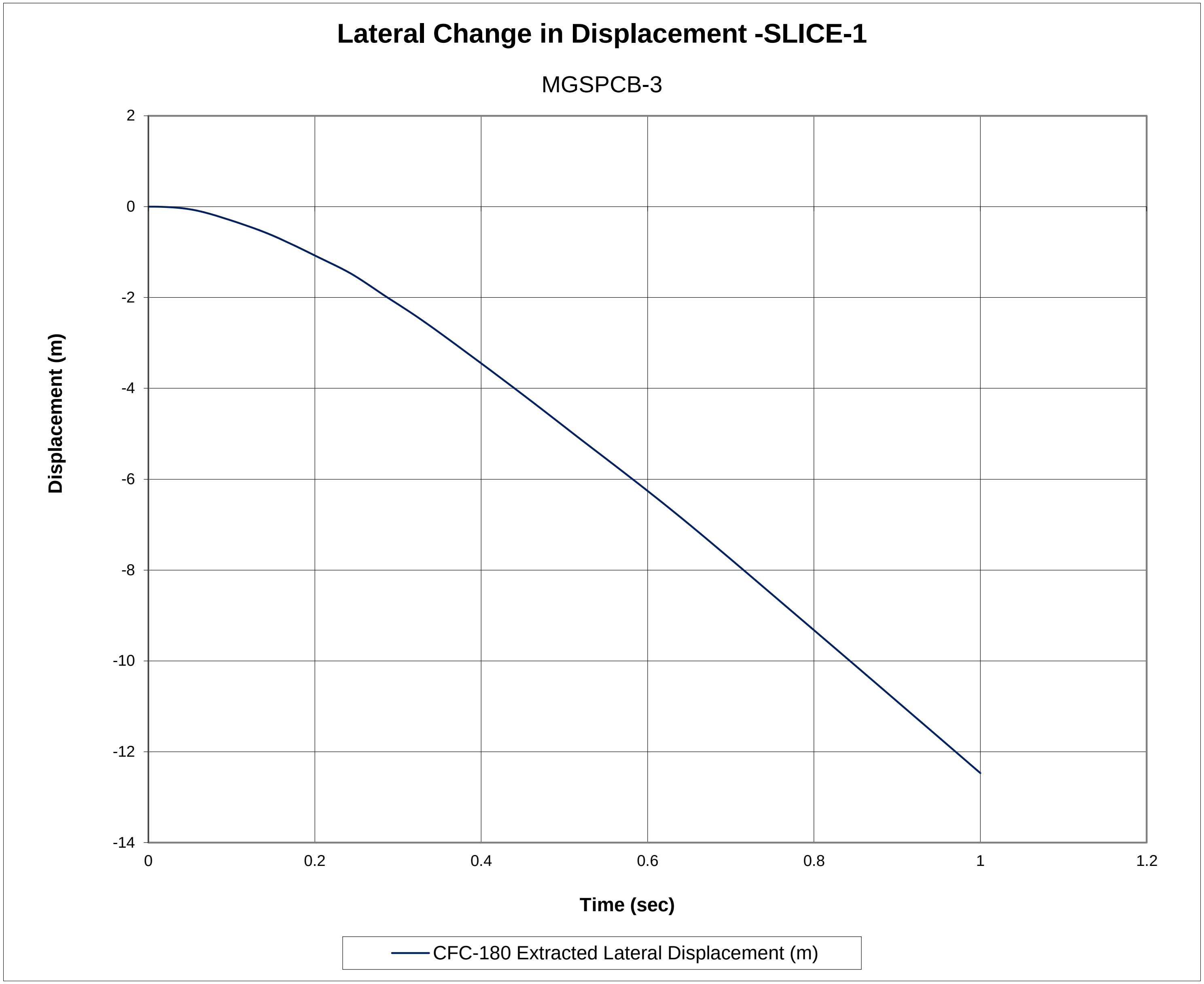


Figure H-6. Lateral Occupant Displacement (SLICE-1), Test No. MGSPCB-3

Figure H-7. Vehicle Angular Displacements (SLICE-1), Test No. MGSPCB-3

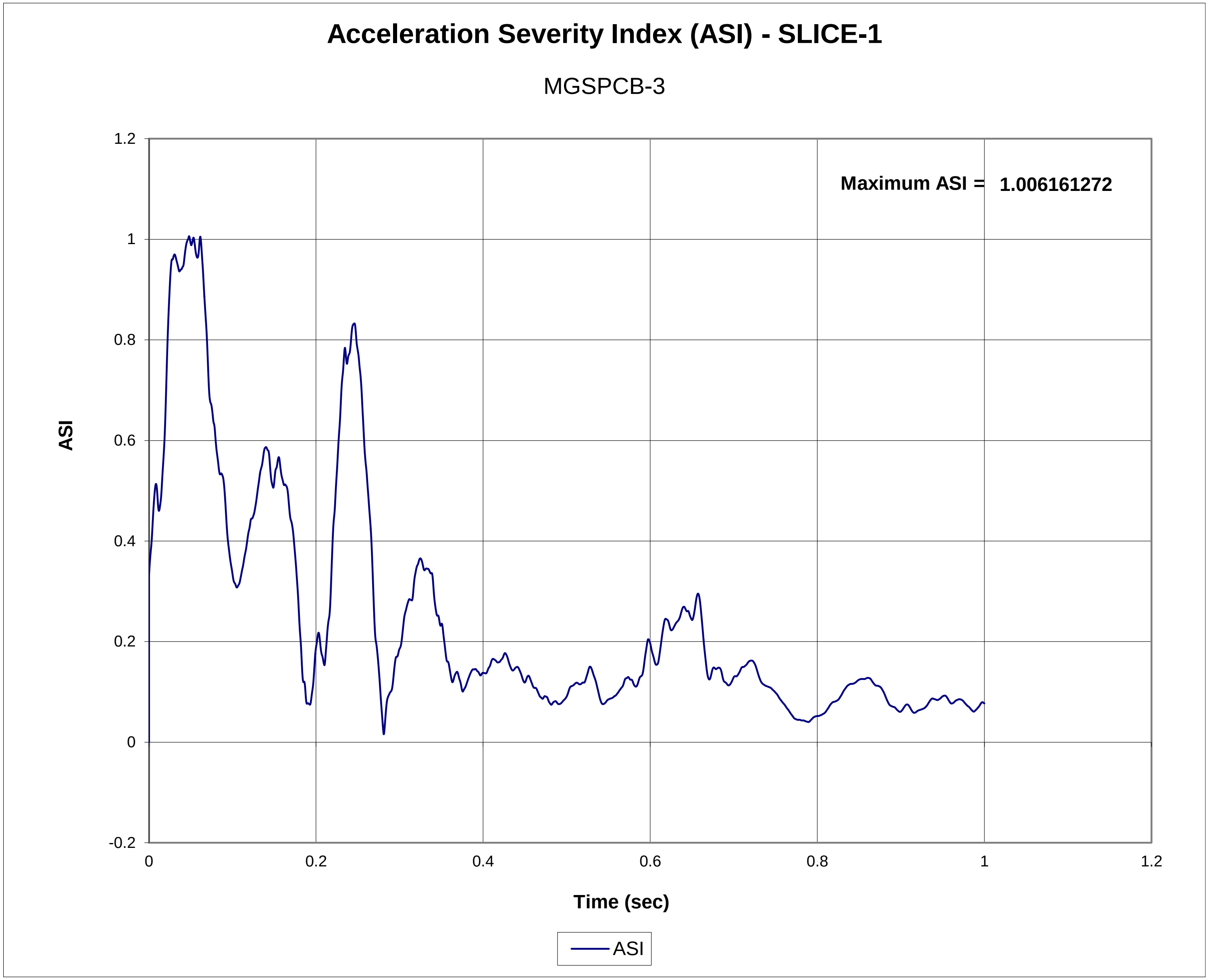


Figure H-8. Acceleration Severity Index (SLICE-1), Test No. MGSPCB-3

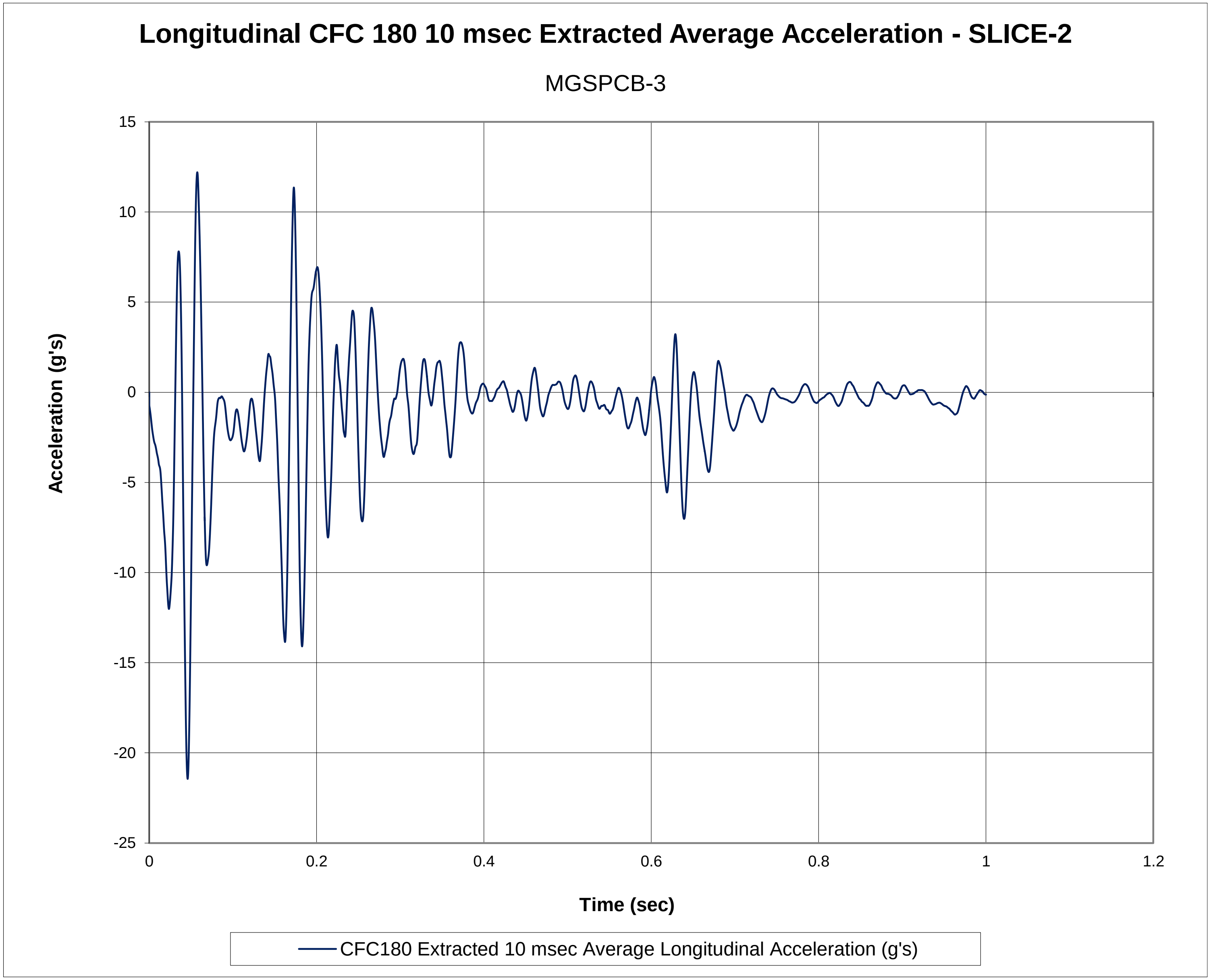


Figure H-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MGSPCB-3

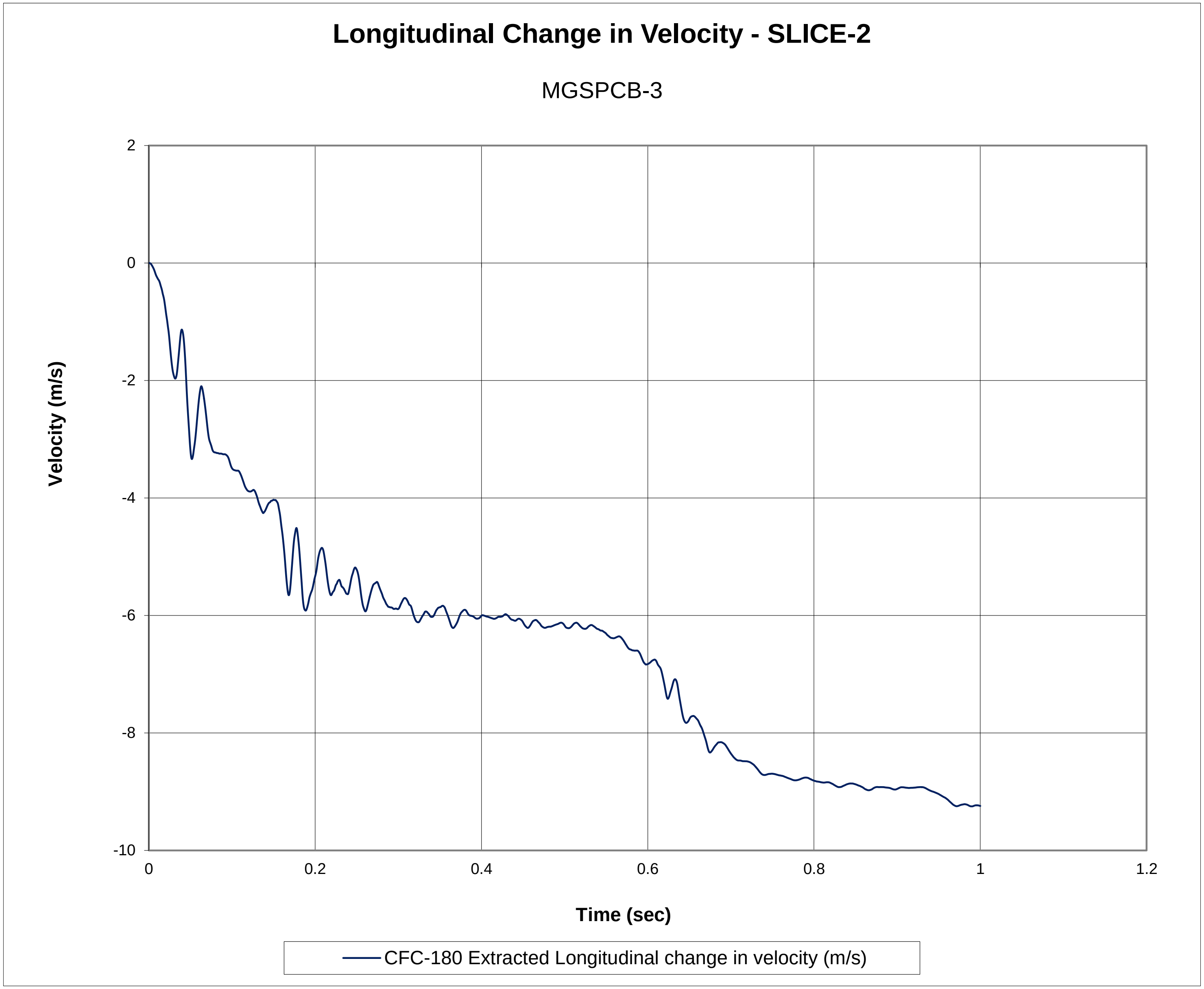


Figure H-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MGSPCB-3

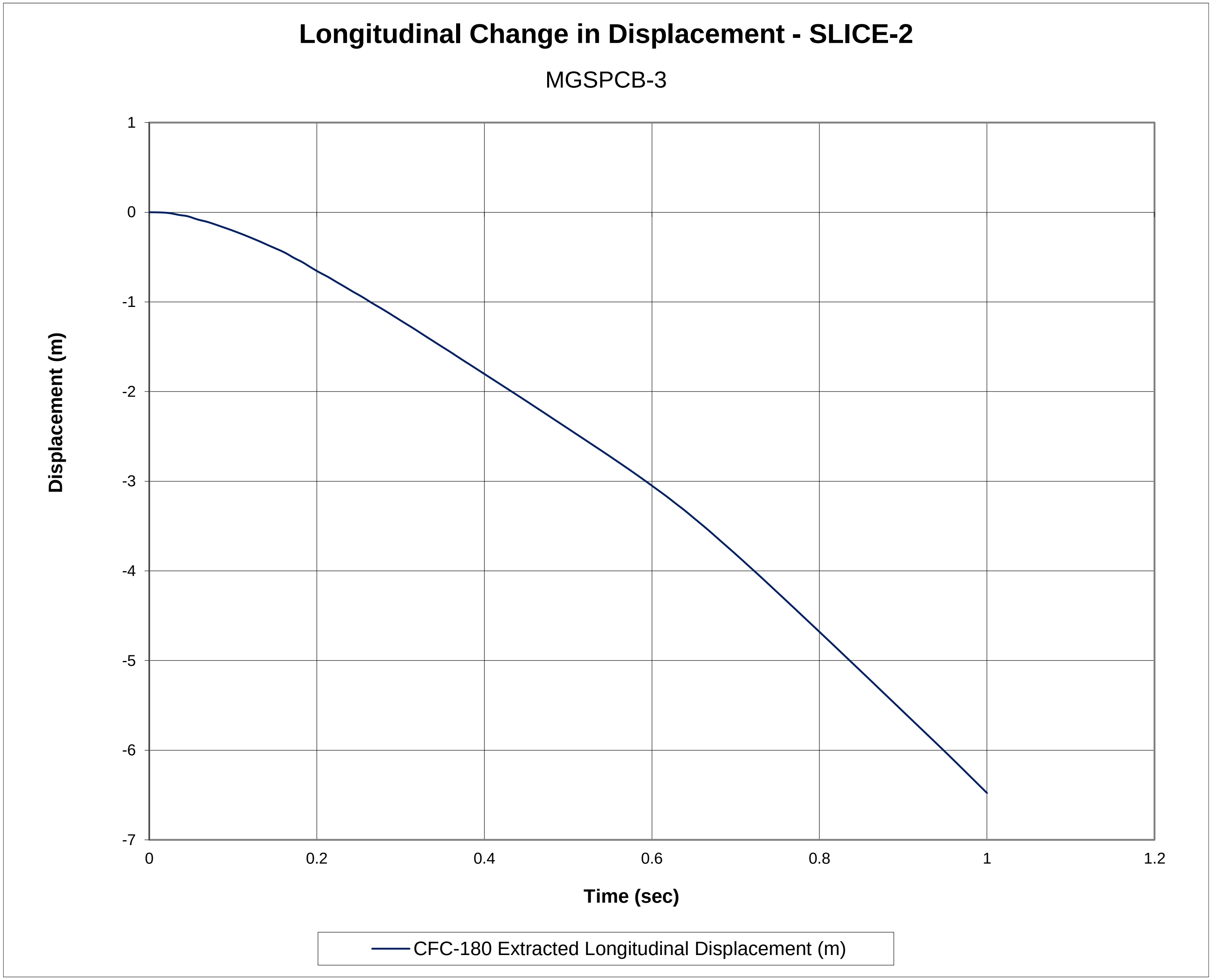


Figure H-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MGSPCB-3

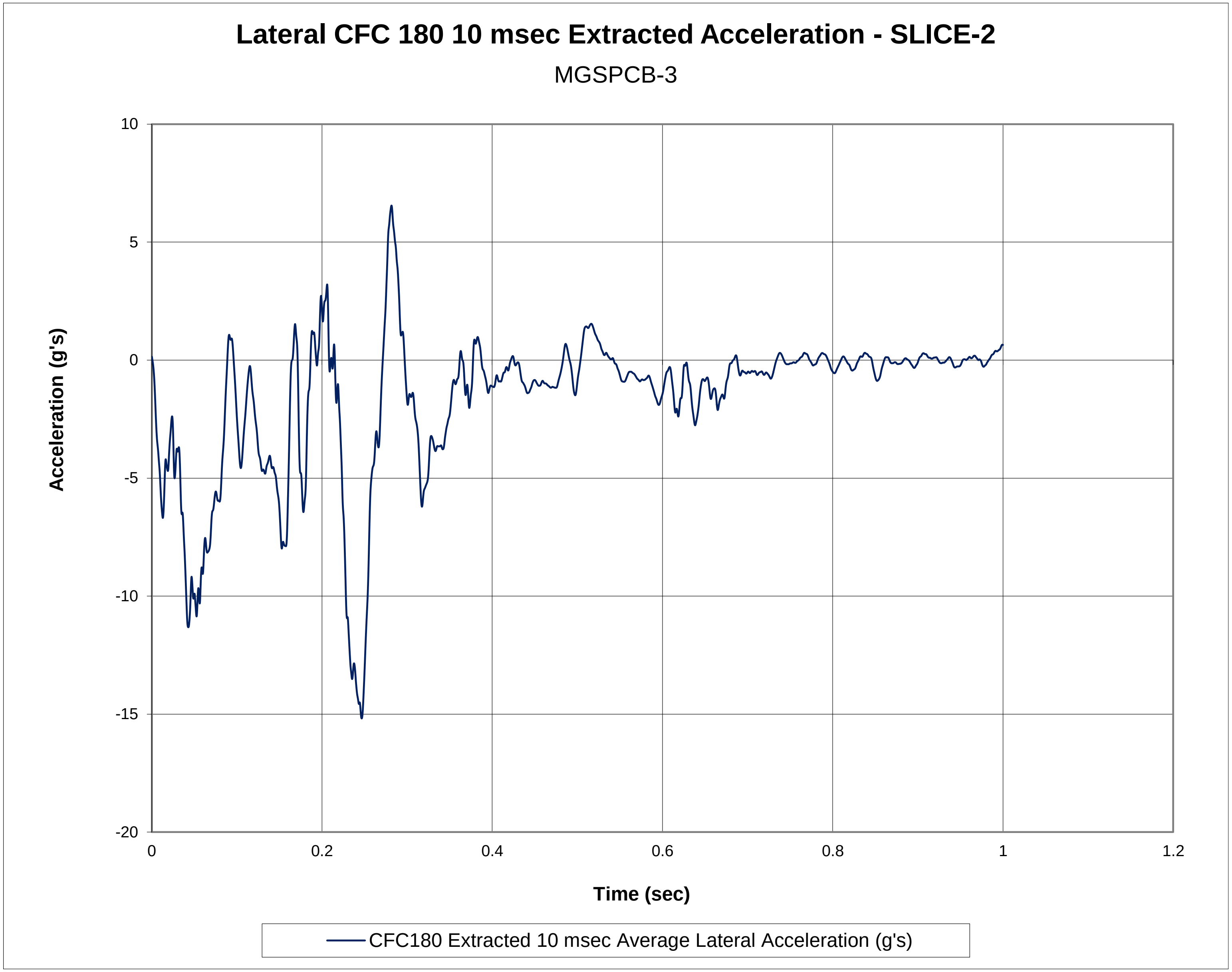


Figure H-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MGSPCB-3

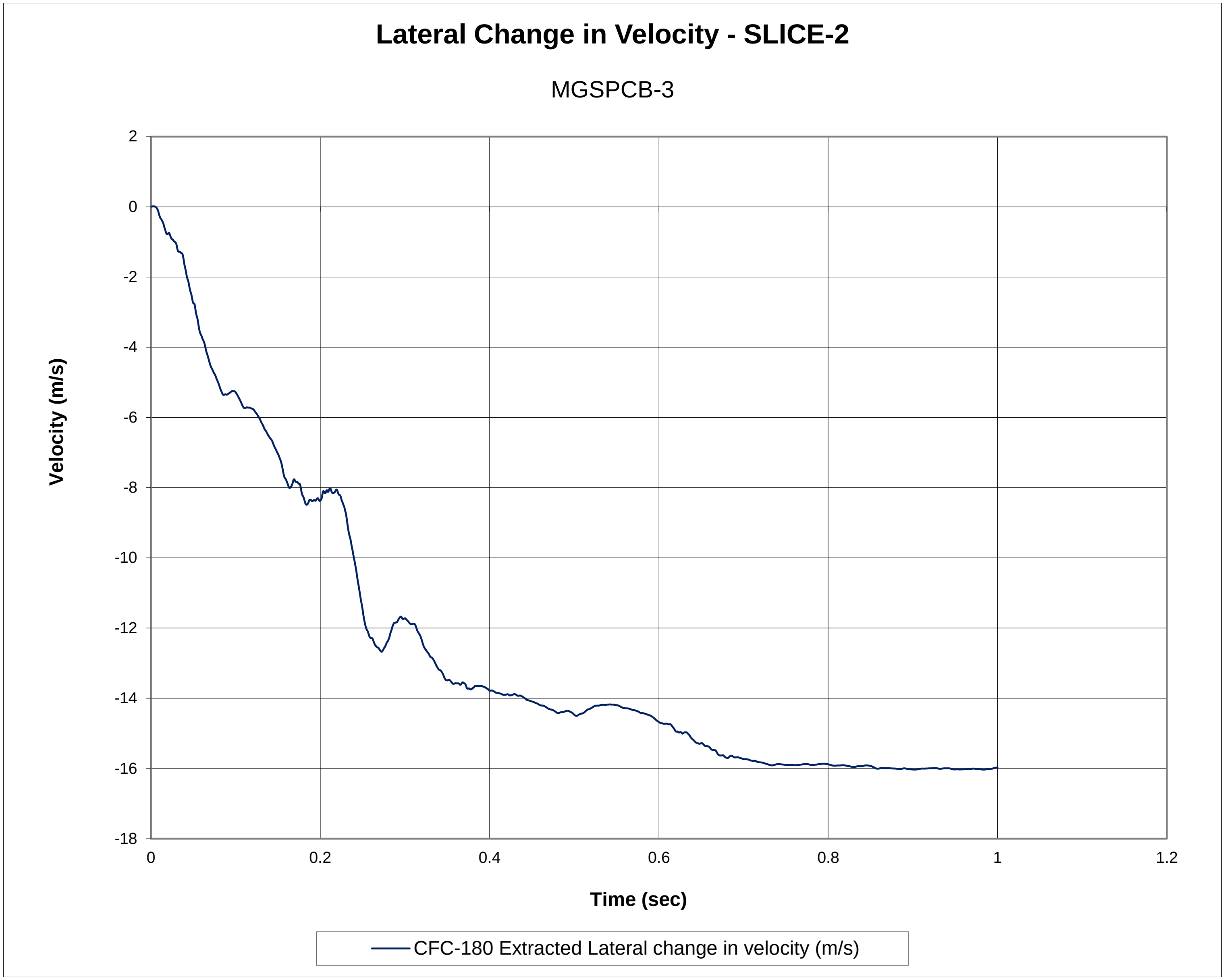


Figure H-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. MGSPCB-3

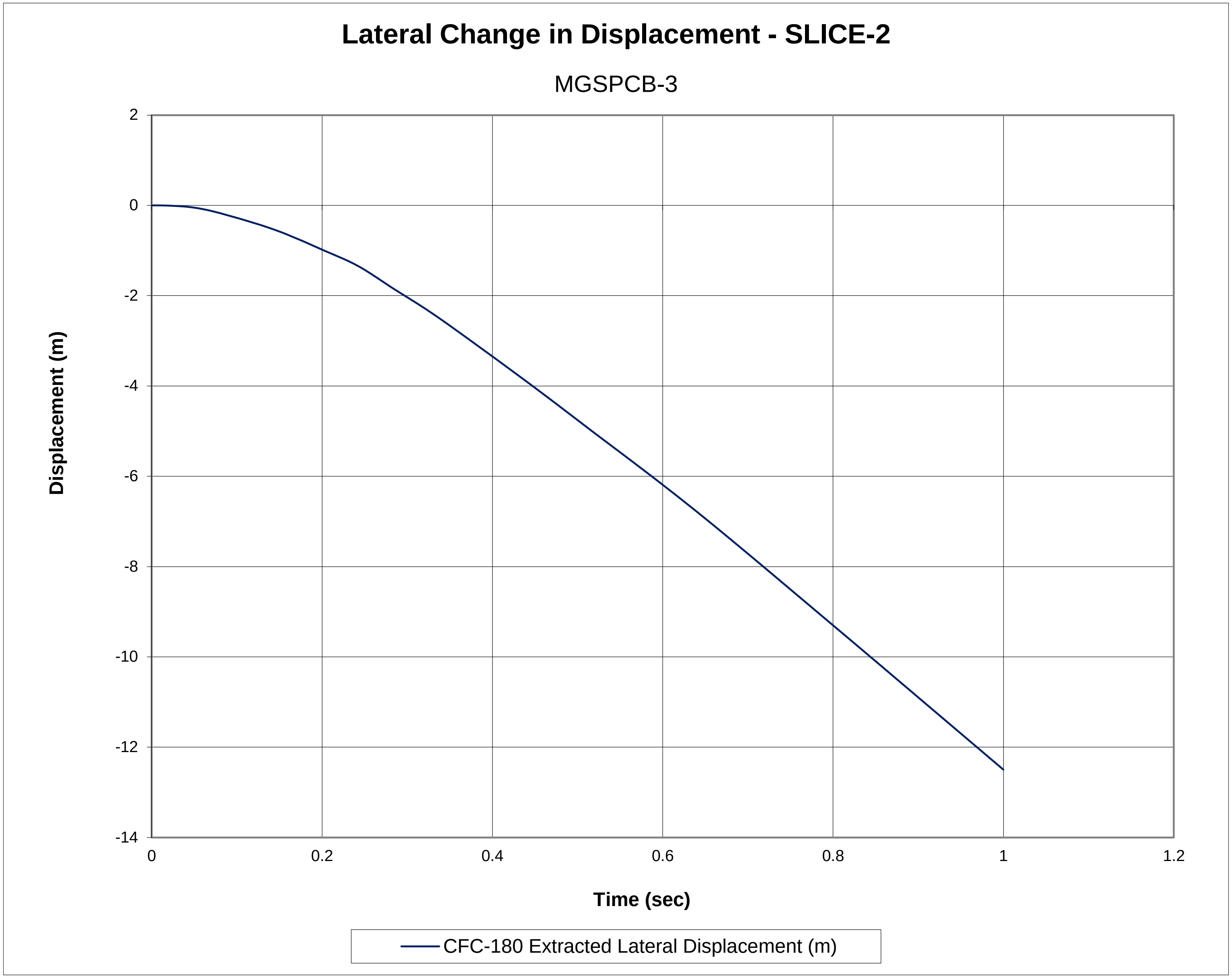


Figure H-14. Lateral Occupant Displacement (SLICE-2), Test No. MGSPCB-3

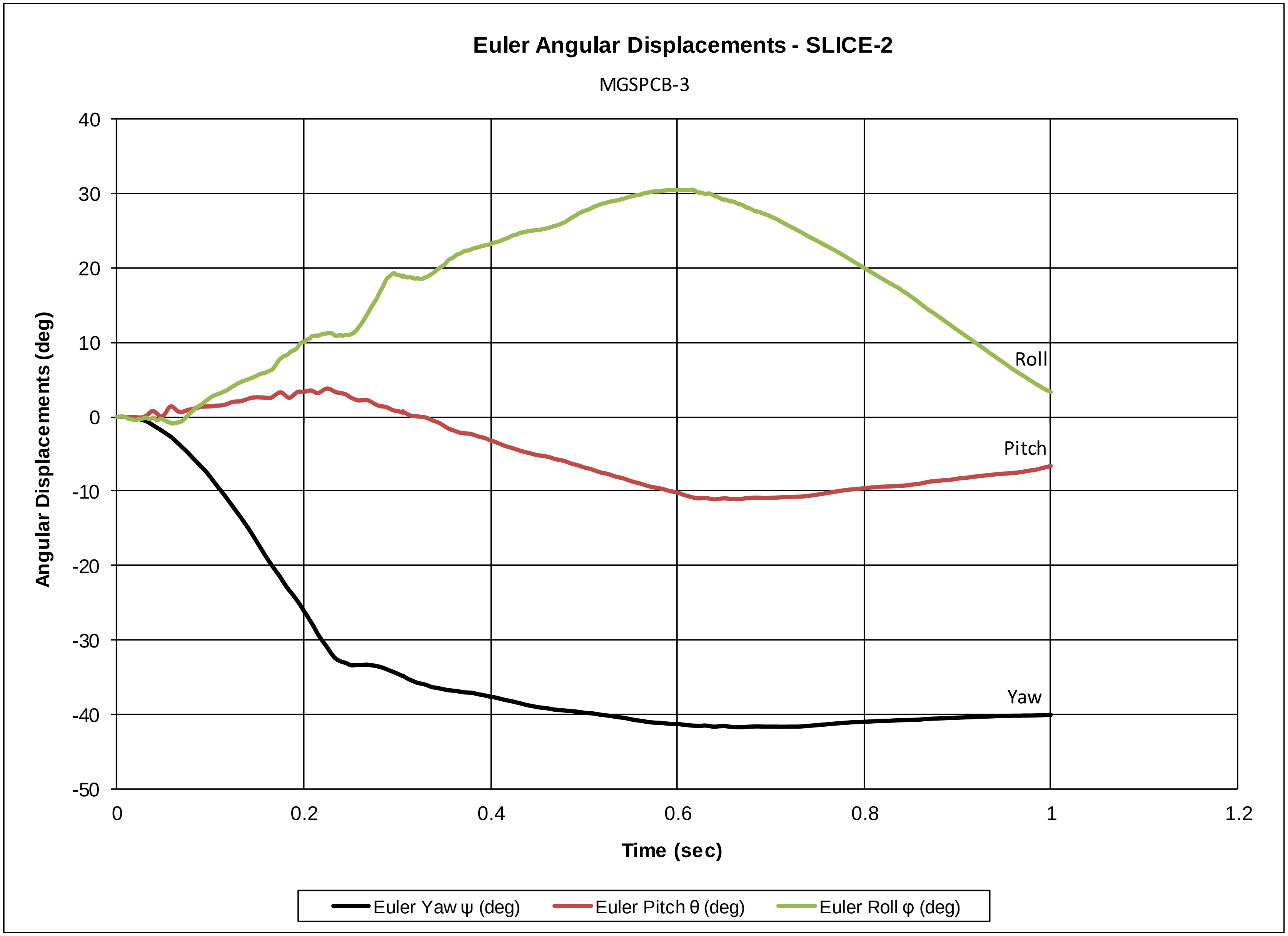


Figure H-15. Vehicle Angular Displacements (SLICE-2), Test No. MGSPCB-3

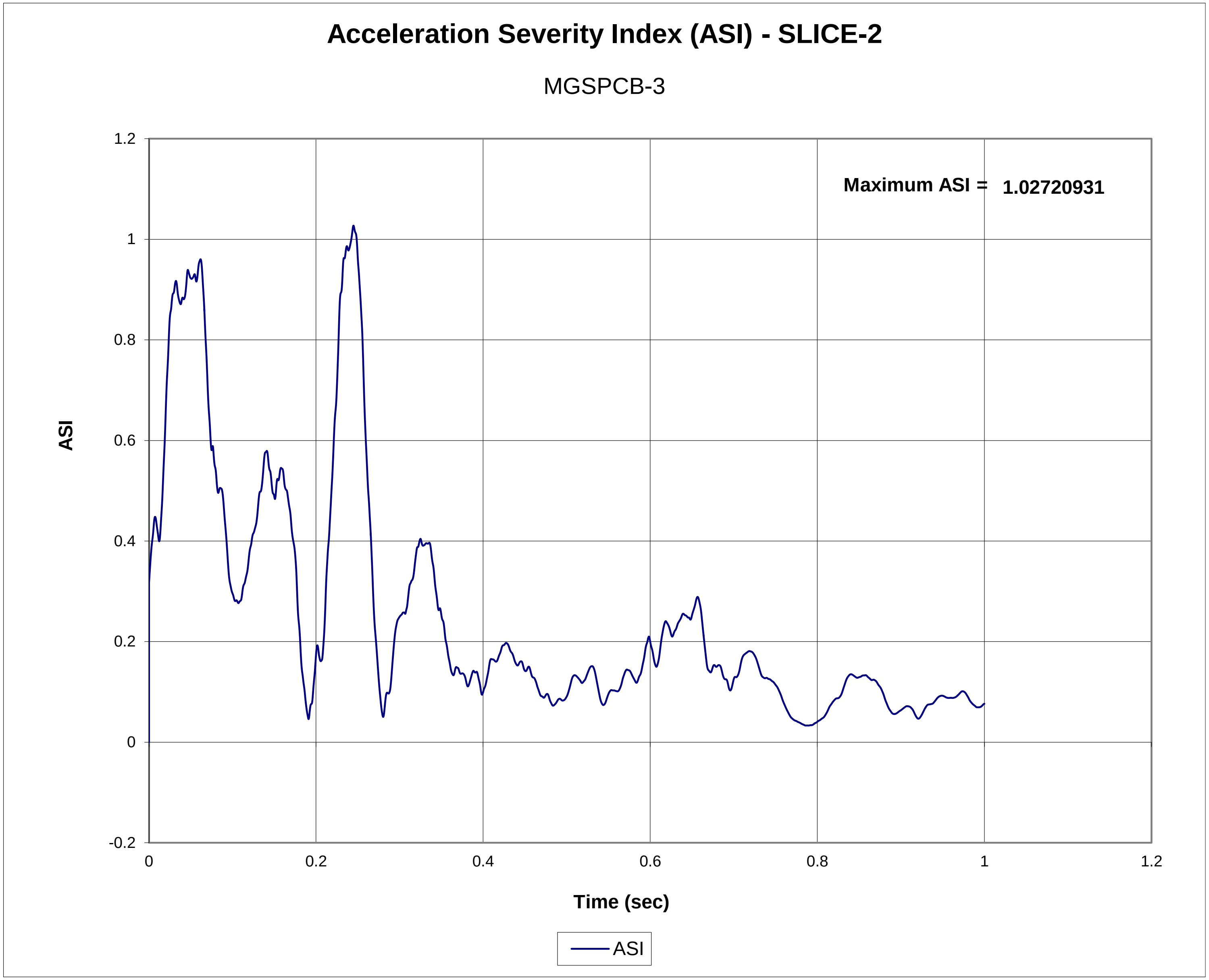


Figure H-16. Acceleration Severity Index (SLICE-2), Test No. MGSPCB-3

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