MASH 2016 Evaluation of a Non-Proprietary Type III Barricade

Final Report – Revision-1
September 2018

SWZDI
Smart Work Zone Deployment Initiative

Sponsored by
Smart Work Zone Deployment Initiative
(TPF-5(295))
Federal Highway Administration
(InTrans Project 18-535)

About SWZDI

Iowa, Kansas, Missouri, and Nebraska created the Midwest States Smart Work Zone Deployment Initiative (SWZDI) 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.

ISU Non-Discrimination Statement

Notice

Quality Assurance Statement

Iowa DOT Statements

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16. Abstract

Several work-zone traffic control devices have not yet been evaluated to the American Association of State Highway and Transportation Officials' (AASHTO's) *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016) safety performance criteria. Devices commonly used by Smart Work Zone Deployment Initiative state sponsors were summarized. A non-proprietary Type III barricade was selected for testing, as no non-proprietary barricades had been evaluated to MASH 2016. The Type III barricade had 8-ft (2.4-m) long plastic barricade panels, a 30-in. x 48-in. (762-mm x 1,219-mm) aluminum sign attached to the top two plastic barricade panels. The 2-in. (51-mm) square legs and 1¾-in. (44-mm) square uprights were 14-gauge perforated square steel tube. The barricade also had two warning lights attached at the top of each upright. The Type III barricade was tested to MASH 2016 test designation no. 3-71 with a 2,426-lb (1,100-kg) small car. One barricade was impacted at a speed of 64.7 mph (104.1 km/h) and at an impact angle of 90 degrees, and the other barricade was impacted at a speed of 61.2 mph (98.5 km/h) and an impact angle of 0 degrees. Both tests successfully met all evaluation criteria in MASH 2016 for test designation no. 3-71.

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Principal Investigator
Jennifer D. Schmidt, Research Assistant Professor
Midwest Roadside Safety Facility – University of Nebraska-Lincoln

Co-Principal Investigator
Mojdeh Asadollahi Pajouh, Assistant Professor
University of Nevada, Las Vegas

Ronald K. Faller, MwRSF Director and Research Professor
Midwest Roadside Safety Facility – University of Nebraska-Lincoln

Research Assistants
Tyler J. Langel and Nathan Asselin

Authors
Jennifer D. Schmidt, Tyler J. Langel, Nathan Asselin, Mojdeh A. Pajouh, and Ronald K. Faller

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A report from
Smart Work Zone Deployment Initiative
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103 / Fax: 515-294-0467
www.intrans.iastate.edu/smartwz/

ISO 17025 LABORATORY
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MASH 2016 EVALUATION OF A NON-PROPRIETARY TYPE III BARRICADE

Submitted by

Jennifer D. Schmidt, Ph.D., P.E.
Research Assistant Professor

Tyler Langel, B.S.M.E.
Former Undergraduate Research Assistant

Nathan Asselin
Undergraduate Research Assistant

Mojdeh Asadollahi Pajouh, Ph.D., P.E.
Assistant Professor, University of Nevada, Las Vegas

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

MIDWEST ROADSIDE SAFETY FACILITY
Nebraska Transportation Center
University of Nebraska-Lincoln

Main Office
Prem S. Paul Research Center at Whittier School
Room 130, 2200 Vine Street
Lincoln, Nebraska 68583-0853
(402) 472-0965

Outdoor Test Site
4630 N.W. 36th Street
Lincoln, Nebraska 68524

Submitted to

SMART WORK ZONE DEPLOYMENT INITIATIVE
Iowa Department of Transportation
800 Lincoln Way
Ames, Iowa 50010

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Page	**Revision**
89	Wheel Well & Toe Pan maximum deformation value corrected to 0.4 in. (10 mm) in to data row of Table 9
123	Figure C-1 replaced due to corrected ΔZ^A column values
124	Figure C-2 replaced due to corrected ΔZ^A column values
133	Figure C-11 replaced due to corrected Maximum Deformation values
134	Figure C-12 replaced due to corrected Maximum Deformation values

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This research was conducted under the Smart Work Zone Deployment Initiative (SWZDI) and Federal Highway Administration (FHWA) Pooled Fund Study TPF-5(295), involving the following state departments of transportation:

- Iowa (lead state)
- Kansas
- Missouri
- Nebraska
- Wisconsin

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UNCERTAINTY OF MEASUREMENT STATEMENT

MwRSF has determined the uncertainty of measurements for several parameters involved in standard full-scale crash 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.

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Dr. Cody S. Stolle, Research Assistant Professor.

EXECUTIVE SUMMARY

The objective of this research effort was to evaluate the performance of a non-proprietary work-zone safety device, such as a work-zone sign support or barricade. The research team made recommendations on the performance and usage of work-zone devices based on the background research in National Cooperative Highway Research Program (NCHRP) Project No. 3-119, a survey sent to the Smart Work Zone Deployment Initiative (SWZDI) state departments of transportation (DOTs), as well as additional background review on past NCHRP Report 350 crash tests. A Type III barricade that is commonly used by SWZDI state DOTs was selected for the full-scale crash testing program. The Type III barricade was evaluated according to the American Association of State Highway and Transportation Officials' (AASHTO's) *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016) Test Level 3 (TL-3) test designation no. 3-71 safety criteria through two full-scale crash tests at 0-degree and 90-degree impact angles.

Test no. WZNP-1 was conducted on a Type III barricade in accordance with MASH 2016 test designation no. 3-71. Two Type III barricades were placed 60 ft (18.3 m) apart on level terrain. During the test, the 1100C small car impacted both barricades. The system readily activated in a predicable manner and allowed the 1100C vehicle to continue traveling without any major obstruction of the windshield. 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 remained upright during and after the collisions. Therefore, test no. WZNP-1 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-71.

The Type III barricade that was tested was non-proprietary and thus the components could be provided by any manufacturer. Each component should have the similar dimensions and material grade as the as-tested system. The barricade rails could vary some in dimension and cross-section appearance but should have similar properties to the panels that were tested.

INTRODUCTION

Background and Problem Statement

Through a project funded jointly through Dicke Safety Products, the Mid-America Transportation Center, and the Smart Work Zone Deployment Initiative (SWZDI) from 2008 to 2010, several work-zone sign stands were evaluated (*1*). These sign stands were crashworthy according to the crash testing and safety performance criteria in National Cooperative Highway Research Program (NCHRP) Report 350 (2). In 2009, the American Association of State Highway and Transportation Officials (AASHTO) implemented an updated standard for the evaluation of roadside hardware (*3*). The new standard, entitled the *Manual for Assessing Safety Hardware* (MASH 2009), improved the criteria for evaluating roadside hardware beyond the previous NCHRP Report 350 standard through updates to test vehicles, test matrices, and impact conditions. However, when NCHRP Report 350 work-zone devices were subjected to the new MASH 2009 crash testing and safety performance criteria, several of the work-zone sign stands produced undesirable results, including windshield and floorboard penetration and excessive windshield and roof deformation. This testing indicated that devices tested under previous NCHRP Report 350 safety performance standards may not perform acceptably with the new MASH safety performance standards.

In an effort to encourage state departments of transportation (DOTs) and hardware developers to advance hardware designs, the Federal Highway Administration (FHWA) and AASHTO collaborated to develop a MASH implementation policy that included sunset dates for various roadside hardware categories. Further, the MASH 2009 safety criteria were also updated in 2016, thus resulting in the MASH 2016 document (*4*). There were no changes to the impact conditions or safety performance criteria for work-zone devices from MASH 2009 to MASH 2016. The new policy by the FHWA and AASHTO required that temporary work-zone devices installed on federal aid roadways after December 31, 2019 are evaluated to MASH 2016.

NCHRP Project 03-119 is currently being conducted to evaluate the in-service safety performance of breakaway sign supports, luminaires, and work-zone devices, and evaluate these devices to MASH 2016 (*5*). This NCHRP Project began with identifying devices, an agency survey, and contact with practitioners to identify current practices related to the use of work-zone traffic control devices. Researchers identified a list of non-proprietary safety work-zone devices in common use as well as insights on safety performance issues associated with each of them. However, it is not likely that very many work-zone traffic control devices will be evaluated under the NCHRP Project. Therefore, there is a need to conduct research for crash testing and evaluating the MASH 2016 crashworthiness performance of non-proprietary work-zone traffic control devices. Successful testing of these devices would provide state DOTs a non-proprietary MASH 2016-tested work-zone device.

Objective

The objective of this research effort was to evaluate the performance of a non-proprietary work-zone safety device, such as a work-zone sign support or barricade. The research team made recommendations on the performance and usage of work-zone devices based on the background research in NCHRP Project 3-119 and selected one that is commonly used by SWZDI state DOTs for full-scale crash testing. The selected device's performance was to be evaluated according to the MASH 2016 Test Level 3 (TL-3) safety criteria through two full-scale crash tests at 0-degree and 90-degree impact angles. In these tests, the selected work-zone device was impacted by an 1100C passenger car at an impact speed of 62 mph (100 km/h), as required by MASH 2016. A summary report was completed detailing the crash testing of a non-proprietary work-zone sign support or barricade as well as the recommendations for safe implementation of the work-zone sign support or barricade.

The research study was directed toward improving the safety and minimizing risk for the motoring public traveling within our nation's work zones and on our highways and roadways. More specifically, this project would address the goal of SWZDI, which is "to develop improved methods and products for addressing safety and mobility in work zones by evaluating new technologies and methods, thereby enhancing safety and efficiency of traffic operations and highway workers. The project is a public partnership between the sponsoring public transportation agencies in several Midwestern States, the FHWA, private technology providers and university transportation researchers."

NCHRP PROJECT 3-119 BACKGROUND

NCHRP Project 3-119 is an ongoing project to evaluate the crash performance of breakaway sign and luminaire supports and crashworthy work-zone traffic control devices that are non-proprietary and commonly used. Several methods were used to determine usage and the likelihood of these devices meeting MASH 2016 evaluation criteria, including a use survey, prior crash testing, and crash data analysis. Then, computer simulations and crash tests would be utilized to determine crashworthiness and/or modifications needed to obtain MASH 2016 crashworthiness.

During NCHRP Project 3-119, a survey was sent to state DOTs, contractors, national agencies, county and city engineers, research facilities, and industry groups to determine the current practices related to the use of work-zone traffic control devices. However, there were several limitations to the survey in regards to non-proprietary work-zone traffic control devices. Most state DOTs allow contractors to choose which devices are utilized as long as they have FHWA eligibility letters and very few state DOTs have an Approved Products List or Qualified Products List for these devices. Thus, they do not know which specific systems are utilized. Additionally, many states use proprietary work-zone sign stands, and some use proprietary barricades. A larger percent of states use non-proprietary barricades than work-zone sign stands. A summary of the survey data on non-proprietary barricades is shown in Table 1.

Table 1. Survey summary of non-proprietary barricades

Barricade Type	System Name	System Origin	Number of States Using System
Type I	Type I Universal Plastic Barricade	Bent Manufacturing Company	3
	Type I Waffle Board Barricade	Bent Manufacturing Company	2
Type II	Type II Universal Plastic Barricade	Bent Manufacturing Company	3
	Type II Waffle Board Barricade	Bent Manufacturing Company	2
	Type II Wood Panel – Metal Leg Barricade	Bent Manufacturing Company	2
Type III	Type III Barricade	Bent Manufacturing Company	3
	Plasticade Telespar Type III Barricade	Plasticade	3
	Illinois L-Channel Type III Barricade	Illinois Approved Vendors	1
	Michigan Type III Barricade	Michigan Approved Vendors	1
	Minnesota Type III Barricade	Minnesota Approved Vendors	1
	Type III Hollow Core Plastic Barricade	N/A	1

Usage data for non-proprietary work-zone sign stands could not be determined, so a list of known non-proprietary work-zone sign stands was collected as is shown in Table 2.

Table 2. Survey summary of non-proprietary work-zone sign stands

System Name (Source)	FHWA Eligibility Letter Nos.
Temporary Sign Stand (Michigan DOT)	WZ-149
4x5 Portable Rigid Panel Sign Support (Michigan DOT)	N/A
Rigid Panel Portable Sign Support (Minnesota DOT)	WZ-133
Large Combination Temporary Support (Minnesota DOT)	N/A
Stop Sign Stand (Minnesota DOT)	N/A
Route Marker Assembly Sign Support (Minnesota DOT)	N/A
24" x 36" and 48" x 36" Work-Zone Speed Limit Sign Support (Minnesota DOT)	N/A
48" x 48" Diamond Panel Work-Zone Sign Support with 5' Mounting Height (Minnesota DOT)	N/A
48" x 48" Diamond Panel Work-Zone Sign Support with 7' Mounting Height (Minnesota DOT)	N/A
Stop Sign Support with 7' Mounting Height (Minnesota DOT)	N/A
H-Footprint Sign Stand (Pennsylvania DOT)	WZ-266
X-Footprint Sign Stand (Pennsylvania DOT)	WZ-266

A safety performance assessment was conducted, which provided a general review of limited accident data for trends, compiled safety performance knowledge and insights from DOT staff, and obtained data from a very limited number of crash reports (e.g., vehicle type, impact point, and crash severity) to supplement opinions. General crash data from eight state DOTs was collected and evaluated over a three- to five-year period. Several factors were to be identified: (1) the frequency of non-proprietary devices not performing as intended in real-world crashes, (2) the number of failures (injuries/fatalities, injury/fatal crashes, unintended system behavior) for specific devices divided by the number of police-reported crashes into specific devices (category, make, model, etc.), and (3) the number of crashes into non-performing specific devices divided by the number of police-reported crashes into specific devices. However, due to the limited scope of this task, this information was not obtained. Thus, only the general frequency of crashes into work-zone devices was determined. The number of device failures, or unsatisfactory performance, could not be determined. However, the number of injuries and fatalities or injury and fatal crashes into general system categories was found, as shown in Table 3. Table 3 contains crash data on luminaire poles, sign supports, and work-zone traffic control devices.

Table 3. Crash data summary on luminaires, sign supports, and work-zone devices

State (Data Years)	Object Struck	Total # of Crashes	Total # of Non-Injury Crashes	Total # of Injury Crashes	Total # of Fatal Crashes
California (2009-2013)		Most Harmful Event			
	Traffic Sign/Sign Post	5932	4581	1286	65
	Light or Signal Pole	3090	2364	714	12
	Other Signs Not Traffic	91	60	28	3
	Temp Barricade, Cones, Etc.	1713	1277	419	17
Indiana (2011-2015)		First Harmful Event			
	Highway Traffic Sign Support	3625	3267	345	13
	Light/Luminaire Support	3434	2980	448	6
	Other Post/Pole or Support	9112	8108	991	13
	Work Zone Maintenance Equipment	400	336	59	5
Kansas (2011-2015)		First Harmful Event			
	Work Zone Signs	43	34	9	0
	Work Zone Barricades	15	10	5	0
North Carolina (2013-2015)		Most Harmful Event (Unit1)			
	Official Highway Sign Breakaway	322	271	50	1
	Official Highway Sign Non-Breakaway	241	200	40	1
	Luminaire Pole Breakaway	21	14	7	0
	Luminaire Pole Non-Breakaway	24	12	12	0
South Dakota (2011-2015)		Most Harmful Event			
	Highway Traffic Sign Post	927	821	102	4
	Light/Luminaire Support	624	491	133	0
	Other Post, Pole, or Support	205	171	34	0
		First Harmful Event			
	Highway Traffic Sign Post	1030	882	143	5
	Light/Luminaire Support	594	457	137	0
	Other Post, Pole, or Support	233	181	50	2
Utah (2011-2015)		Most Harmful Event			
	Traffic Sign Support	1407	1245	160	2
	Utility Pole/Light Support	2529	1713	800	16
	Other Post, Pole, or Support	1354	1063	279	12
		First Harmful Event			
	Traffic Sign Support	1484	1239	238	7
	Utility Pole/Light Support	2274	1566	697	11
	Other Post, Pole, or Support	1327	1029	289	9
Washington (2011-2015)		First Harmful Event			
	Metal/Wood Sign Post	5856	4715	1114	27
	Street Light Pole or Base	3354	2562	781	11
	Temporary Sign, Barricade or Construction Material	332	250	78	4
Wisconsin (2010-2015)		First Harmful Event			
	Traffic Signs	121	107	14	0
	Light Pole	73	57	16	0
	Other Posts	20	17	3	0

N/A = not available

The object struck varied by each state DOT, so related categories were collected. Work-zone traffic control devices were specifically categorized by California, Kansas, and Washington, but these crashes could also contain impacts with other hardware besides work-zone traffic control devices. It is unknown how other state DOTs categorize impacts with these devices.

State DOT accident databases with a focus on non-proprietary devices in common use were collected and evaluated. From the crash data, several general conclusions were drawn:

- In approximately ¼ of the impacts with work-zone signs, the crash reports noted that the crashes occurred due to signs blowing around from the wind. Thus, utilizing signs with more ballast may be necessary to prevent these crashes.
- Crashes into work-zone barricades and signs primarily occurred on Interstate, US, and State routes that had speed limits of between 25 to 35 mph (40 to 56 km/h) or between 55 to 65 mph (89 to 105 km/h). The most common vehicle type associated with crashes into work-zone barricades and signs was passenger cars, followed by pickup trucks.

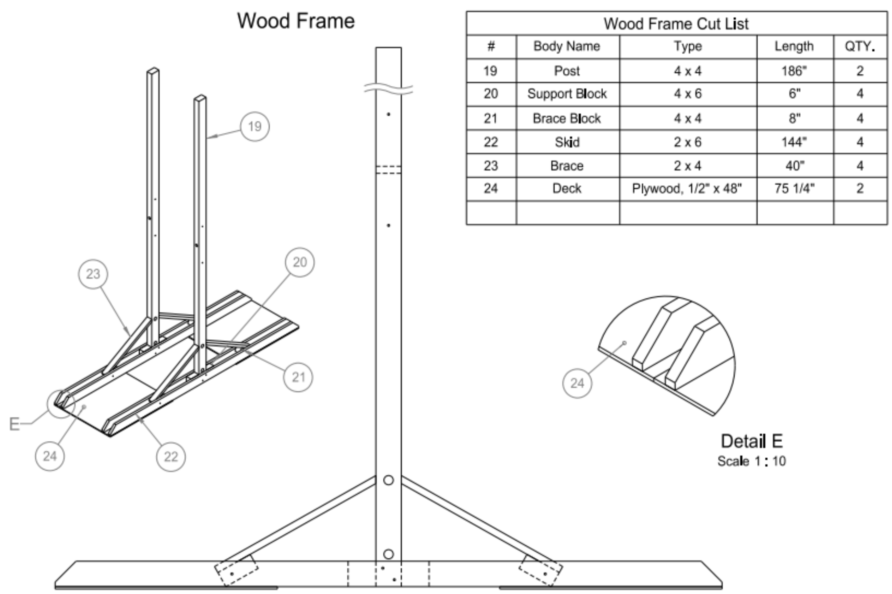
There were several limitations with the crash data that did not allow for more specific conclusions, including type of device impacted and system performance to be determined. Even with the crash reports or reconstructed crashes, this information could not be obtained. Limitations of the state DOT crash data include:

- Not all crash databases recorded all of the desired data.
- It was difficult to discern specific objects impacted. For example, most state DOTs did not code work-zone traffic control devices as a specific Object Struck. One state DOT had work-zone data that discerned if the impact was with a barricade, cone, sign, etc.; however, the manufacturer or specific configuration was unknown. Proprietary versus non-proprietary was not determined.
- Some of the data were coded incorrectly.
- Not all crashes were reported. Therefore, there is likely an under-sampling of property-damage only crashes.
- The full crash reports were obtained for a few cases, but the specific object struck or device performance was still not discernable.
- It was difficult to determine whether vehicle damage or occupant injury actually resulted from the object struck, even if it was the first or most harmful event. This was especially true with the first harmful event. When looking at Kansas crash data where a barricade was impacted as the first harmful event, four incapacitating injuries occurred. However, when reviewing the individual crash reports, the barricades likely did not contribute to any incapacitating injuries. The researchers assumed that the object struck and injury level were directly related, which likely overestimated the number of injuries caused by the safety devices.
- Device performance was not discerned for almost every crash.

SWZDI STATE SURVEY

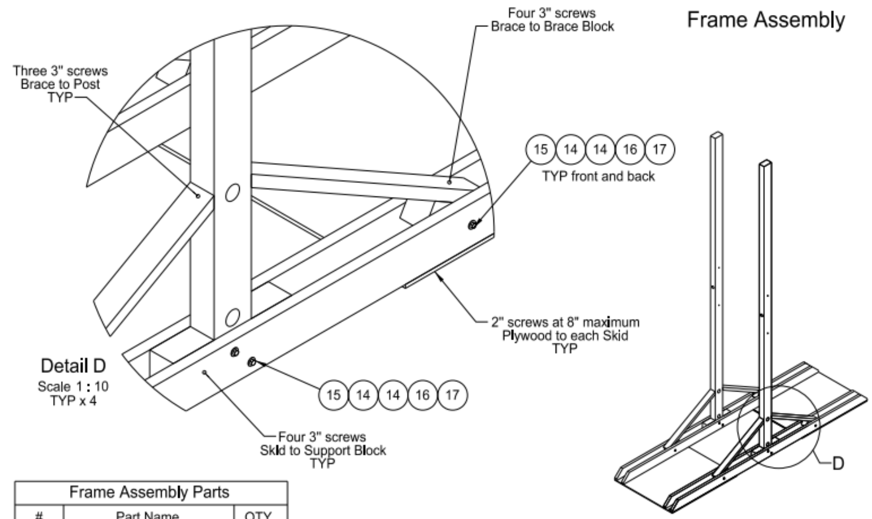
Since the NCHRP Project 3-119 survey did not provide definitive usage information, the SWZDI state DOTs were asked to provide recommendations on work-zone traffic control devices for which MASH 2016 testing would be the most beneficial. Each state was asked to recommend one or two work-zone devices to be tested and updated to meet the new MASH 2016 standard. The project was to focus on work-zone barricades and portable/temporary sign stands that were preferably non-proprietary systems widely used in those states.

Iowa DOT responded with a Type III barricade. Wisconsin responded with a temporary gore sign, similar to what is shown in Figure 1.



Wood Frame Cut List				
#	Body Name	Type	Length	QTY.
19	Post	4 x 4	186"	2
20	Support Block	4 x 6	6"	4
21	Brace Block	4 x 4	8"	4
22	Skid	2 x 6	144"	4
23	Brace	2 x 4	40"	4
24	Deck	Plywood, 1/2" x 48"	75 1/4"	2

6a. All lumber is #2 yellow pine, and lumber and plywood shall be pressure treated for weather and insect resistance (Wolmanized or comparable treatment).



Frame Assembly Parts		
#	Part Name	QTY.
13	Wood Frame	1
14	Washer, 3/8 flat	32
15	Bolt, 3/8 x 7-1/2 hex	16
16	Washer, 3/8 lock	16
17	Nut, 3/8 hex	16
18	Deck Screws as needed*	

*Use Deck Screws or other screws designed for outdoor use. Minimum size #8 for 2" screws and #9 for 3" screws. Drywall screws are not acceptable.

Figure 1. Wisconsin Temporary Gore Sign

Kansas DOT had several recommendations:

- Type III barricades tested with warning lights mounted in various ways (attached directly to the rail, attached directly to the post, attached to a generic metal bracket that is attached to the post, etc.)
- Portable Changeable Message Sign trailers and arrow board trailers
- A-frame signs
- Warning lights on portable signs
- Signs mounted to cones/conical delineators/drums/etc.

Nebraska DOT also had several recommendations:

- Tall perforated square tube sign stand. The stand would be similar to the one in the WZ-266 eligibility letter (*6-7*), as shown in Figure 2, but with two vertical posts, spaced at 30 in. (762 mm) to hold a 48-in. (1,219-mm) diamond sign, not one post as shown. The base could be an H or a box frame.
- Type III barricade attached to sign posts.
- Short perforated steel square tube (PSST) sign stand-similar to WZ-129 eligibility letter (*8*), as shown in Figure 3.
- Sign installation on a Type III barricade. The sign could be a 48-in. (1,219-mm) wide “Road Closed” sign or a 48-in. (1,219-mm) diamond sign.

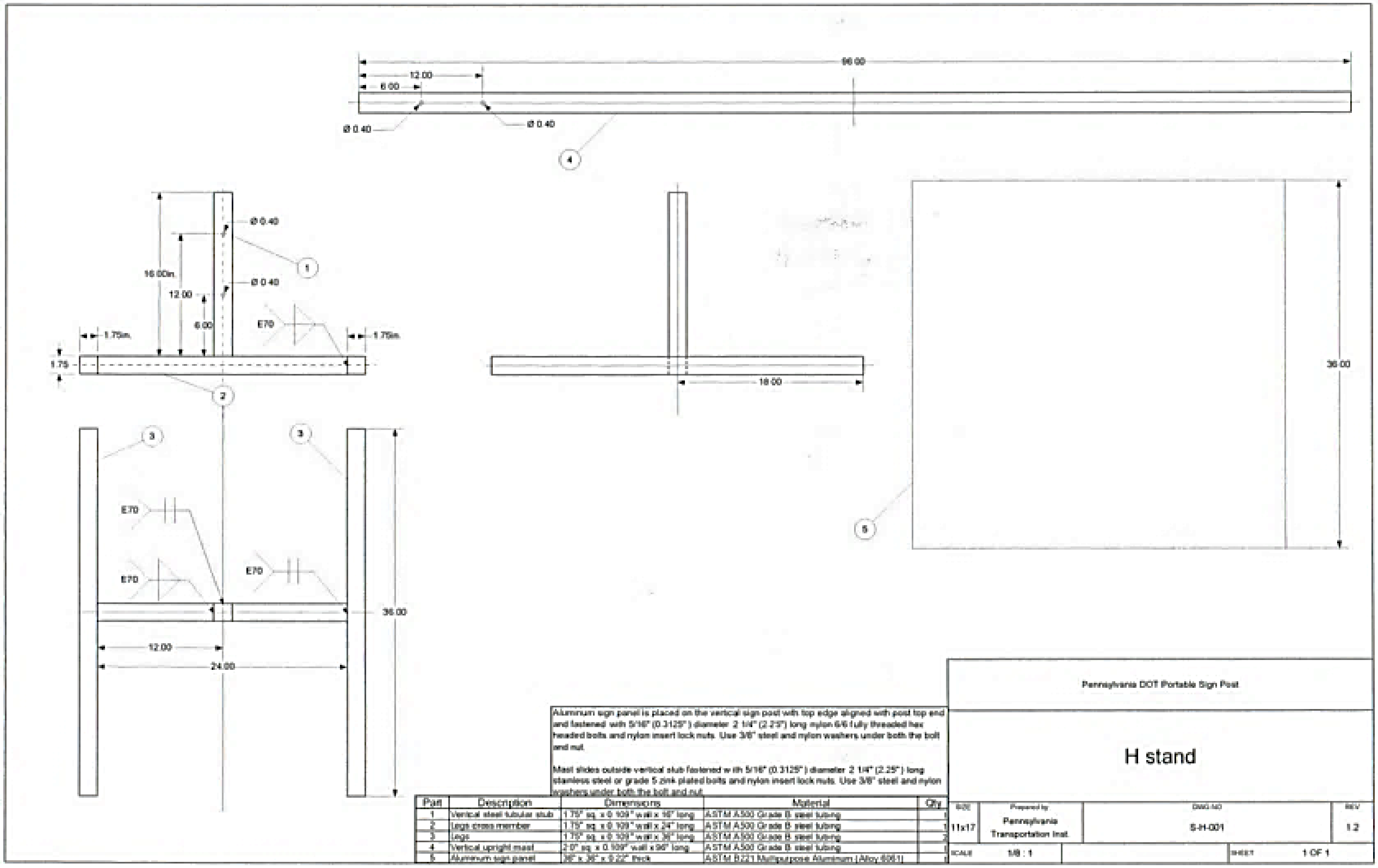


Figure 2. WZ-266 H-Base Sign Stand (*6-7*)

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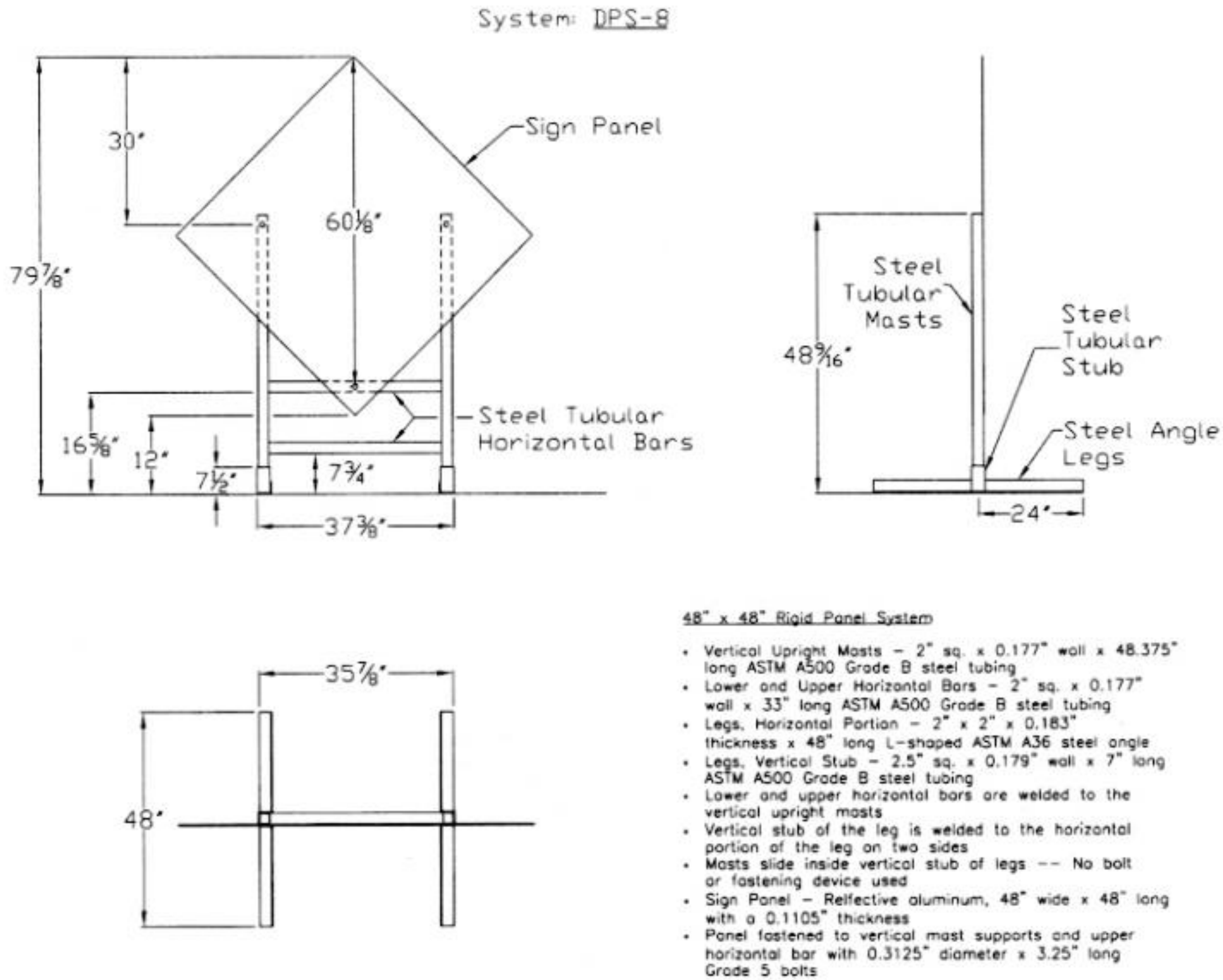

Figure 3. WZ-129 H-Base Sign Stand (*8*)

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There were two general categories that were deemed as needs for the states: (1) Type III barricades and (2) portable signs. Almost all non-proprietary portable signs have been historically made of PSST. Additionally, the Wisconsin temporary gore sign is made of wood. Several non-proprietary Type III barricades have previously been tested to NCHRP Report 350 and include steel angle or PSST legs and uprights. Further background review was desired on these two categories of devices for MASH 2016 evaluation to select a system for testing.

PREVIOUS CRASH TESTING REVIEW

Prior successful NCHRP Report 350 TL-3 crash tests on work-zone signs and barricades were reviewed. The results of the tests and key features of the systems were used to select a system for MASH 2016 full-scale crash testing.

Non-Proprietary Work-Zone Sign Stands

One PSST sign stand was originally tested by Midwest Roadside Safety Facility (MwRSF) in test nos. DPS-8 and DPS-9, as shown in Figure 3, at an impact angle of 0 degrees and 90 degrees, respectively (*8*). The system had two steel angles with a nominal thickness of $^{3}/_{16}$ in. (5 mm) that formed the legs of an H-base assembly system. In addition to the H-base, there were also lower and upper horizontal bars made of 2-in. x 33-in. (51-mm x 838-mm) long square steel tubes with a nominal wall thickness of $^{3}/_{16}$ in. (5 mm). The vertical support of the temporary single sign support consisted of two parts: a 2-in. (51-mm) square tube with a thickness of $^{3}/_{16}$ in. (5 mm) and a length of 48 9/16 in. (1,233 mm), and a 2½-in. (64-mm) square tube with a thickness of $^{3}/_{16}$ in. (5 mm) and a length of 7 in. (178 mm). The vertical portion of the leg was welded to the horizontal portion on two sides. The tubes were nested inside of each other to provide height adjustment to the sign assembly. The masts slid inside the vertical portion of the legs and no bolts or fastening devices were used. A 48-in. x 48-in. x ⅛ in. thick (1,220-mm x 1,220-mm x 3-mm) aluminum diamond-shaped sign was attached to the 2-in. (51-mm) tube with $^{5}/_{16}$-in. (8-mm) Grade 5 bolts. The mounting height to the bottom of the sign blank was 12 in. (305 mm). The system was evaluated with 0-degree and 90-degree orientations and passed all NCHRP Report 350 evaluation criteria.

Several PSST sign stands were originally tested by MwRSF and sponsored by the Minnesota DOT (*9*). One system was successful. In test no. MNS-2, system number 3 had two 1¾-in. x 60-in. (45-mm x 1,520-mm) long telespar steel square steel tubes with a nominal wall thickness of ⅛ in. (3 mm) that formed the legs of an H-base assembly system, as shown in Figure 4.

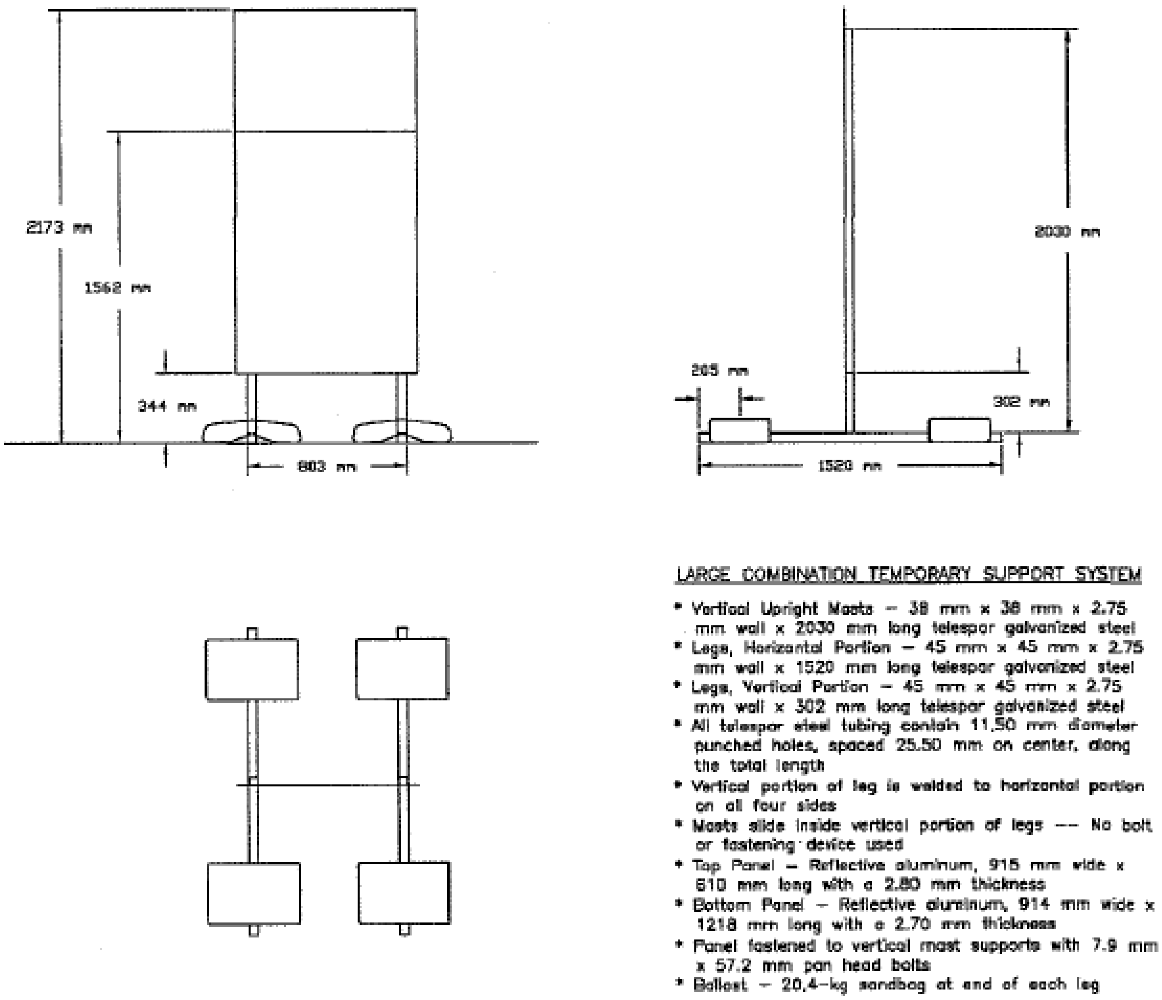

Figure 4. System No. 3 Sign Details, Test MNS-2 (*9*)

The vertical support of the temporary single sign support consisted of two parts: a 1½-in. (38-mm) square tube with a thickness of ⅛ in. (3 mm) and a length of 80 in. (2,030 mm) and a 1¾-in. (45-mm) square tube with a thickness of ⅛ in. (3 mm) and a length of 12 in. (302 mm). The vertical portion of the leg was welded to the horizontal portion on all four sides. The tubes were nested inside of each other to provide height adjustment to the sign assembly. The masts slid inside the vertical portion of the legs and no bolts or fastening devices were used. Two sign panels were attached to the sign stand. The top panel was a 36-in. x 24-in. x ⅛-in. (915-mm x 610-mm x 3-mm) thick aluminum sign. The bottom panel was a 36-in. x 48-in. x ⅛-in. (914-mm x 1,218-mm x 3-mm) thick aluminum sign. The panels were attached to the 1½-in. (38-mm) tube with $^{5}/_{16}$-in. (8-mm) pan head bolts. The mounting height to the bottom of the sign was 14 in. (344 mm). The sign stand was ballasted with a 45-lb (20-kg) sandbag on each leg. The system was evaluated with a 0-degree orientation and passed all NCHRP Report 350 evaluation criteria.

One PSST sign stand was originally tested by MwRSF and sponsored by the Michigan DOT (*10*). In test no. MI-3, system numbers 5 and 6 had two 2-in. x 72-in. (51-mm x 1,829-mm) long telespar steel tubes with a nominal wall thickness of ¼ in. (6 mm) that formed the legs of an H-base assembly system, as shown in Figure 5.

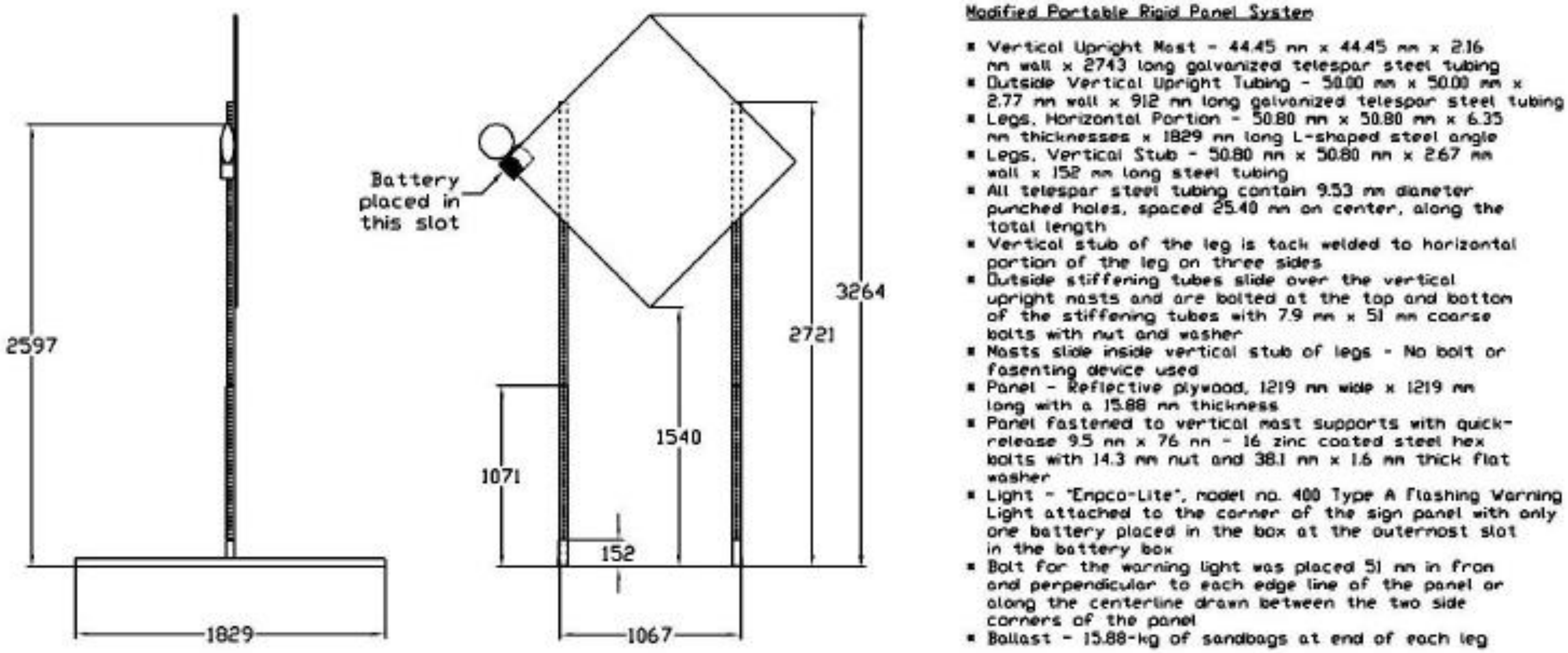

Figure 5. System No. 5 and 6 Sign Details, Test MI-3 (*10*)

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The vertical support of the temporary single sign support consisted of two parts: a 1¾-in. (44-mm) telespar steel square tube with a thickness of $^{1}/_{16}$ in. (2 mm) and a length of 108 in. (2,743 mm) and a 2-in. (51-mm) telespar steel square tube with a thickness of ⅛ in. (2 mm) and a length of 6 in. (152 mm). The outside vertical mast was a 2-in. (51-mm) telespar steel square tube with a thickness of ⅛ in. (3 mm) and a length of 36 in. (912 mm). The vertical portion of the leg was tack welded to the horizontal portion on three sides. The tubes were nested inside of each other to provide height adjustment to the sign assembly. The masts slid inside the vertical portion of the legs and no bolts or fastening devices were used. The sign panel was a 48-in. x 48-in. x ⅝-in. thick (1,219-mm x 1,219-mm x 16-mm) plywood sign. The panel was attached to the upright masts with sixteen ⅜-in. (10-mm) zinc coated steel hex bolts with a $^{9}/_{16}$-in. (14-mm) nut and a 1½-in. x $^{1}/_{16}$-in. (38-mm x 2-mm) flat washer. The mounting height to the bottom of the sign blank was 60 in. (1,524 mm). The sign stand was ballasted with a 35-lb (16-kg) sandbag on each leg. The system was evaluated with 0-degree and 90-degree orientations and passed all NCHRP Report 350 evaluation criteria.

Several PSST sign stands were originally tested by MwRSF and sponsored by the Minnesota DOT (*11*). Seven of the sign stands tested met NCHRP Report 350 standards. The system description and test results for these seven systems are summarized below.

The system in test no. MN1C had two 2-in. x 60-in. (51-mm x 1,524-mm) long telespar steel square steel tubes with a nominal wall thickness of ⅛ in. (3 mm) that formed the legs of an H-base assembly system, as shown in Figure 6.

The vertical support of the temporary single sign support consisted of two parts: a 2¼-in. (57-mm) square tube with a thickness of ⅛ in. (3 mm) and a length of 60 in. (1,524 mm) and a 2½-in. (64-mm) square tube with a thickness of ⅛ in. (3 mm) and a length of 36 in. (914 mm). The tubes were nested inside of each other to provide height adjustment to the sign assembly. The mast slid over the vertical portion of the legs and no bolts or fastening devices were used. The vertical stub on the base was made of a 2-in. (51-mm) steel square tube with a thickness of ⅛ in. (3 mm) and a length of 12 in. (305 mm). The vertical stub portion of the leg was welded to the horizontal portion on all four sides. There was one 30-in. x 30-in. (813-mm x 813-mm) sign panel attached to the sign stand mast with two $^{5}/_{16}$-in. x 3-in. (8-mm x 76-mm) Grade 5 plug bolts. The mounting height to the bottom of the sign blank was 34½ in. (876 mm). The sign stand was ballasted with a 45-lb (20-kg) sandbag on each leg. The test was performed with the sign at 0-degree and 90-degree orientations, and the test passed all NCHRP Report 350 evaluation criteria.

The system in test no. MN2C had two 2-in. x 60-in. (51-mm x 1,524-mm) long telespar steel square steel tubes with a nominal wall thickness of ⅛ in. (3 mm) that formed the legs of an H-base assembly system, as shown in Figure 7.

The vertical support of the temporary single sign support consisted of two parts: a 2¼-in. (57-mm) square tube with a thickness of ⅛ in. (3 mm) and a length of 60 in. (1,524 mm), and a 2½-in. (64-mm) square tube with a thickness of ⅛ in. (3 mm) and a length of 36 in. (914 mm). The tubes were nested inside of each other to provide height adjustment to the sign assembly. The mast slid over the vertical portion of the legs and no bolts or fastening devices were used. The vertical stub on the base was made of a 2-in. (51-mm) steel square tube with a thickness of ⅛ in. (3 mm) and a length of 12 in. (305 mm). The vertical stub portion of the leg was welded to the horizontal portion on all four sides. There were three sign panels attached to the sign stand mast with two $^{5}/_{16}$-in. x 3-in. (8-mm x 76-mm) Grade 5 plug bolts per panel. The mounting height to the bottom of the sign blank was 22⅛ in. (562 mm) and the top height was 74⅛ in. (1,883 mm). The sign stand was ballasted with a 45-lb (20-kg) sandbag on each leg. The test was performed with the sign at 0-degree and 90-degree orientations, and the test passed all NCHRP Report 350 evaluation criteria.

The system in test no. MN3B had two 1½-in. x 60-in. (38-mm x 1,524-mm) long telespar steel square steel tubes with a nominal wall thickness of ⅛ in. (3 mm) that formed the legs of an H-base assembly system, as shown in Figure 8.

The vertical support of the temporary single sign support consisted of two parts: a 1¾-in. (44-mm) square tube with a thickness of ⅛ in. (3 mm) and a length of 92 in. (2,337 mm), and a 2-in. (51-mm) square tube with a thickness of 0.158 in. (4.0 mm) and a length of 36 in. (914 mm). The tubes were nested inside of each other to provide height adjustment to the sign assembly. The masts slid inside the vertical portion of the legs and no bolts or fastening devices were used. The vertical stub on the base was made of a 1½-in. (38-mm) steel square tube with a thickness of ⅛ in. (3 mm) and a length of 11⅞ in. (302 mm). The vertical stub portion of the leg was welded to the horizontal portion on all four sides. There were two sign panels attached to the sign stand masts. The top panel was a 36-in. x 24-in. x ⅛-in. (914-mm x 610-mm x 3-mm) thick aluminum sign. The bottom panel was a 36-in. x 48-in. x ⅛-in. (914-mm x 1219-mm x 3-mm) thick aluminum sign. The panels were attached to the masts with four $^{5}/_{16}$-in. x 2½-in. (8-mm x 64-mm) Grade 5 plug bolts. The mounting height to the bottom of the sign blank was 24⅜ in. (619 mm). The sign stand was ballasted with a 45-lb (20-kg) sandbag on each leg. The test was performed with the sign at 0-degree and 90-degree orientations, and the test passed all NCHRP Report 350 evaluation criteria.

The system in test no. MN5A had two 1½-in. (38-mm) telespar steel square steel tubes with a nominal wall thickness of ⅛ in. (3 mm) that formed the legs of an H-base assembly system, as shown in Figure 9.

Each tube forming the H-base was 60 in. (1,524 mm) long. The vertical support of the temporary single sign support consisted of two parts: a 1¾-in. (44-mm) square tube with a thickness of ⅛ in. (3 mm) and a length of 60 in. (1,524 mm), and a 2-in. (51-mm) square tube with a thickness of ⅛ in. (3 mm) and a length of 36 in. (914 mm). The tubes were nested inside of each other to provide height adjustment to the sign assembly. The masts slid inside the vertical portion of the legs and no bolts or fastening devices were used. The vertical stub on the base was made of a 1½-in. (38-mm) steel square tube with a thickness of ⅛ in. (3 mm) and a length of 11⅞ in. (302 mm). The vertical stub portion of the leg was welded to the horizontal portion on all four sides. The sign panel was a 36-in. x 36-in. x ⅛-in. (914-mm x 914-mm x 3-mm) thick aluminum sign. The panel was attached to the masts with four $^{5}/_{16}$-in. x 2½-in. (8-mm x 64-mm) Grade 5 plug bolts. The mounting height to the bottom of the sign blank was 29⅛ in. (740 mm). The sign stand was ballasted with a 45-lb (20-kg) sandbag on each leg. The test was performed with the sign at a 0-degree orientation, and the test passed all NCHRP Report 350 evaluation criteria.

The system in test no. MN6A had two 1¾-in. (44-mm) telespar steel square steel tubes with a nominal wall thickness of ⅛ in. (3 mm) that formed the legs of an H-base assembly system, as shown in Figure 10.

Each tube forming the H-base was 72 in. (1,829 mm) long. The vertical support of the temporary single sign support consisted of two parts: a 2-in. (51-mm) square tube with a thickness of ⅛ in. (3 mm) and a length of 107⅞ in. (2,740 mm), and a 2¼-in. (57-mm) square tube with a thickness of ⅛ in. (3 mm) and a length of 36 in. (914 mm). The tubes were nested inside of each other to provide height adjustment to the sign assembly. The masts slid inside the vertical portion of the legs and no bolts or fastening devices were used. The vertical stub on the base was made of a 1¾-in. (44-mm) steel square tube with a thickness of ⅛ in. (3 mm) and a length of 12 in. (305 mm). The vertical stub portion of the leg was welded to the horizontal portion on all four sides. The sign panel was a 48-in. x 48-in. x ⅛-in. (1,219-mm x 1,219-mm x 3-mm) thick aluminum sign. The panel was attached to the masts with four $^{5}/_{16}$-in. x 2½-in. (8-mm x 64-mm) Grade 5 plug bolts. The mounting height to the bottom of the sign blank was 69⅛ in. (1,756 mm). The sign stand was ballasted with a 45-lb (20-kg) sandbag on each leg. The test was performed with the sign at 0-degree and 90-degree orientations, and the test passed all NCHRP Report 350 evaluation criteria.

The system in test no. MN7A had two 1¾-in. (44-mm) telespar steel square steel tubes with a nominal wall thickness of ⅛ in. (3 mm) that formed the legs of an H-base assembly system, as shown in Figure 11.

Each tube forming the H-base was 72 in. (1,829 mm) long. The vertical support of the temporary single sign support consisted of two parts: a 2-in. (51-mm) square tube with a thickness of ⅛ in. (3 mm) and a length of 131 in. (3,327 mm), and a 2¼-in. (57-mm) square tube with a thickness of ⅛ in. (3-mm) and a length of 35⅞ in. (911 mm). The tubes were nested inside of each other to provide height adjustment to the sign assembly. The masts slid inside the vertical portion of the legs and no bolts or fastening devices were used. The vertical stub on the base was made of a 1¾-in. (44-mm) steel square tube with a thickness of ⅛ in. (3 mm) and a length of 12 in. (305 mm). The vertical stub portion of the leg was welded to the horizontal portion on all four sides. The sign panel was a 48-in. x 48-in. x ⅛-in. (1,219-mm x 1,219-mm x 3-mm) thick aluminum sign. The panel was attached to the masts with four ⅜-in. x 2¾-in. (10-mm x 70-mm) Grade 5 plug bolts. The mounting height to the bottom of the sign blank was 84 in. (2,134 mm). The sign stand was ballasted with a 45-lb (20-kg) sandbag on each leg. The test was performed with the sign at 0-degree and 90-degree orientations, and the test passed all NCHRP Report 350 evaluation criteria.

The system in test no. MN8A had two 2-in. x 60-in. (51-mm x 1,524-mm) long telespar steel square steel tubes with a nominal wall thickness of ⅛ in. (3 mm) that formed the legs of an H-base assembly system, as shown in Figure 12.

The vertical support of the temporary single sign support consisted of a 1¾-in. (44-mm) square tube with a thickness of ⅛ in. (3 mm) and a length of 110 in. (2,794 mm). The masts slid inside the vertical portion of the legs and no bolts or fastening devices were used. The vertical stub on the base was made of a 2-in. (51-mm) steel square tube with a thickness of ⅛ in. (3 mm) and a length of 12 in. (305 mm). The vertical stub portion of the leg was welded to the horizontal portion on all four sides. The sign panel was a 30-in. x 30-in. x ⅛-in. (762-mm x 762-mm x 3-mm) thick aluminum sign. The panel was attached to the masts with two $^{5}/_{16}$-in. x 2½-in. (8-mm x 64-mm) Grade 5 plug bolts. The mounting height to the bottom of the sign blank was 84⅜ in. (2,143 mm). The sign stand was ballasted with a 45-lb (20-kg) sandbag on each leg. The test was performed with the sign at a 0-degree orientation, and the test passed all NCHRP Report 350 evaluation criteria.

The H-base system described in test no. WZ-266 had two 1¾-in. x 36-in. (44-mm x 914-mm) steel square steel tubes with a nominal wall thickness of ⅛ in. (3 mm) that formed the legs of an H-base assembly system, as shown in Figure 2. The cross member for the base was made of the same tubing but was 24 in. (610 mm) long. The vertical support of the temporary single sign support was a 2-in. (51-mm) square tube with a thickness of ⅛ in. (3 mm) and a length of 96 in. (2,438 mm). The masts slid over the vertical stub portion of the legs. The vertical stub on the base was made of a 1¾-in. (44-mm) steel square tube, with a thickness of ⅛ in. (3 mm) and a length of 16 in. (406 mm). The vertical stub portion of the leg was welded to the horizontal portion on all four sides. The mast was fastened to the vertical stub with $^{5}/_{16}$-in. (8-mm) diameter Grade 5 zinc plated bolts with a length of 2¼ in. (57 mm) and nylon insert lock nuts. In addition, ⅜-in. (10-mm) steel and nylon washers were used under both the bolt and the nut. There was one sign panel attached to the sign stand mast. The panel was a 36-in. x 24-in. x ¼-in. (914-mm x 610-mm x 6-mm) thick aluminum sign. The panels were attached to the masts with four $^{5}/_{16}$-in. x 2¼-in. (8-mm x 57-mm) long nylon fully threaded hex headed bolts and nylon insert nuts. The test was performed with the sign at a 0-degree orientation and the test passed all NCHRP Report 350 evaluation criteria.

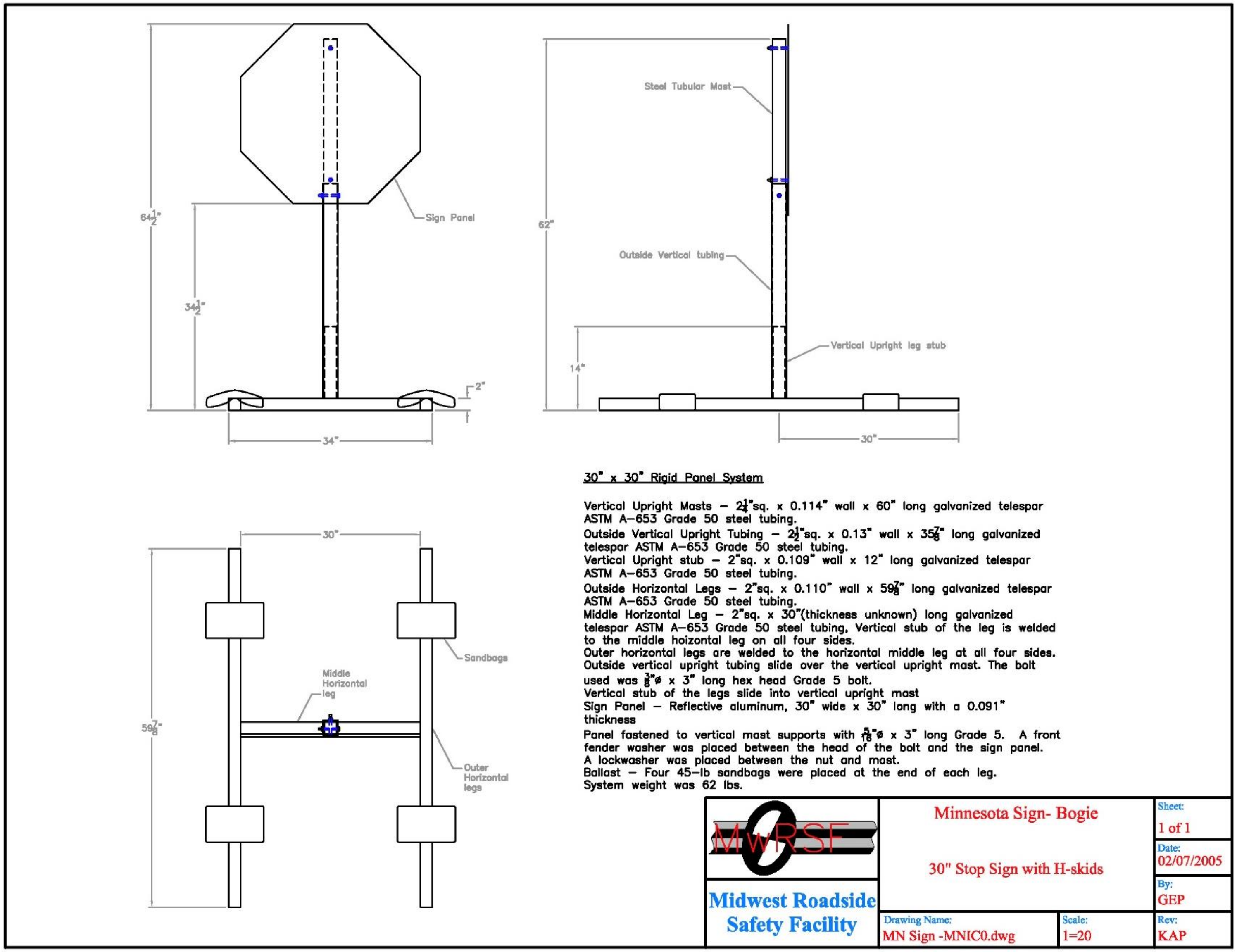

Figure 6. Stop Sign System, Bogie Test No. MN1C0 (*11*)

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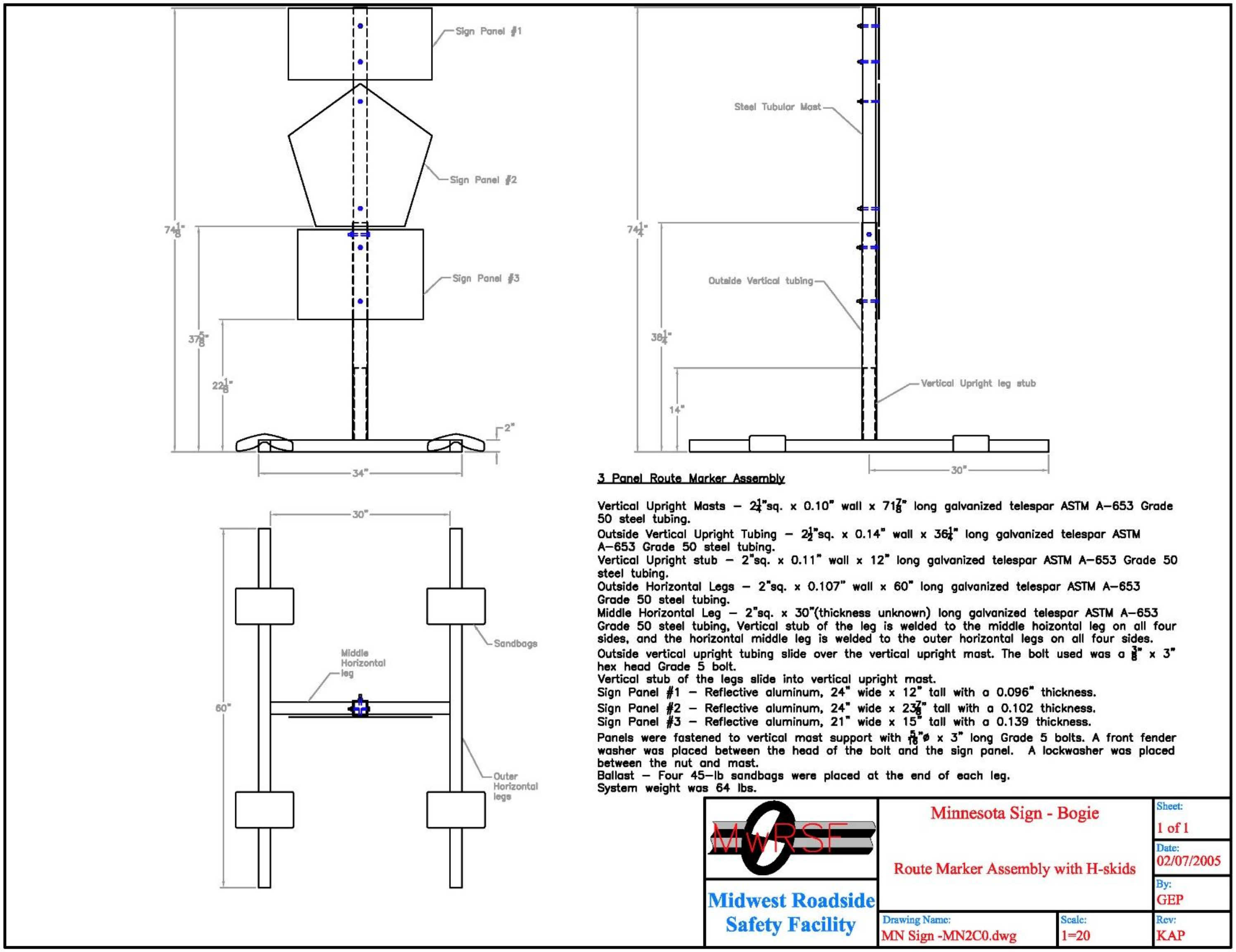

Figure 7. Route Marker Assembly Sign System, Bogie Test No. MN2C0 (*11*)

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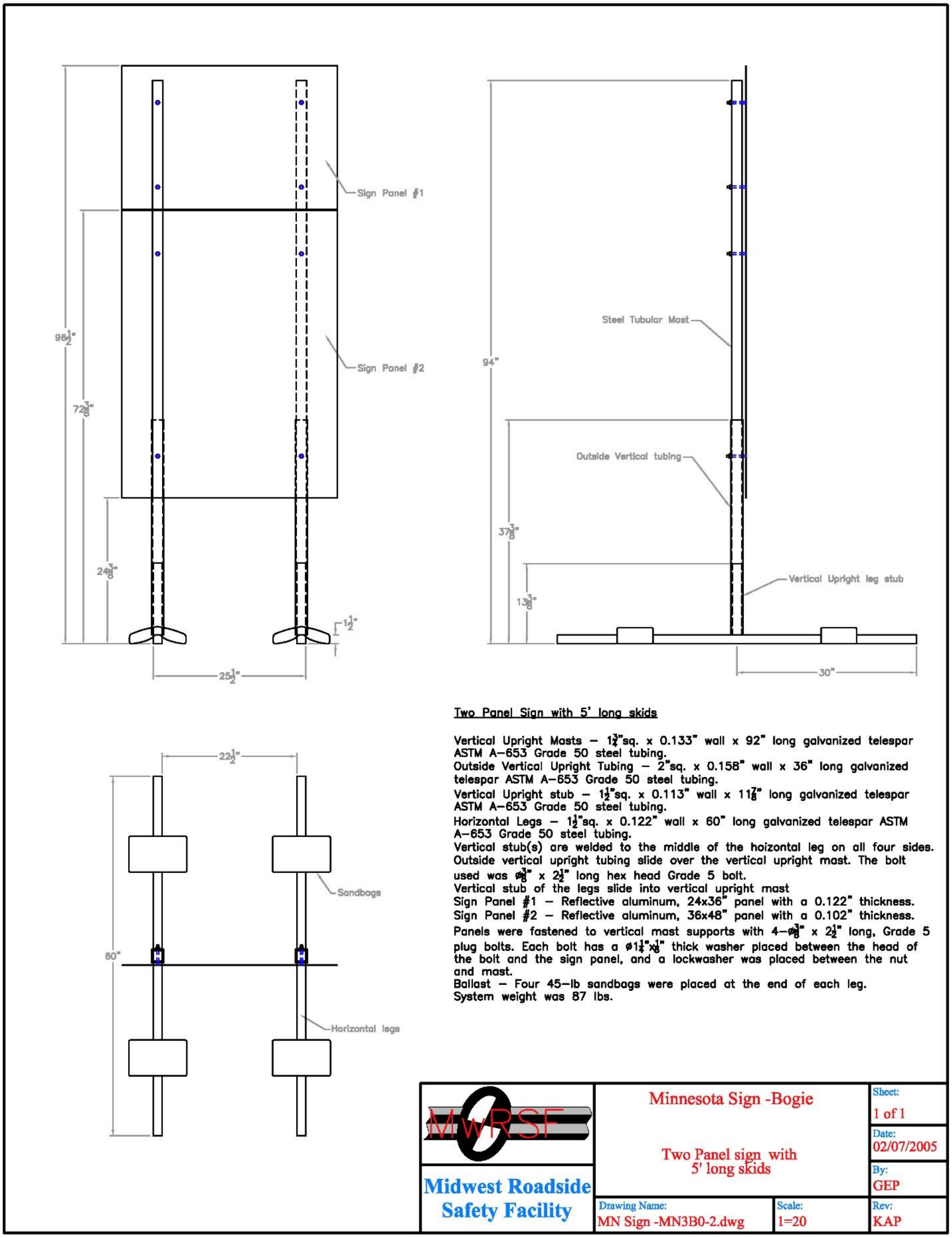

Figure 8. Work-Zone Speed Limit Sign System, Bogie Test No. MN3B0-2 (*11*)

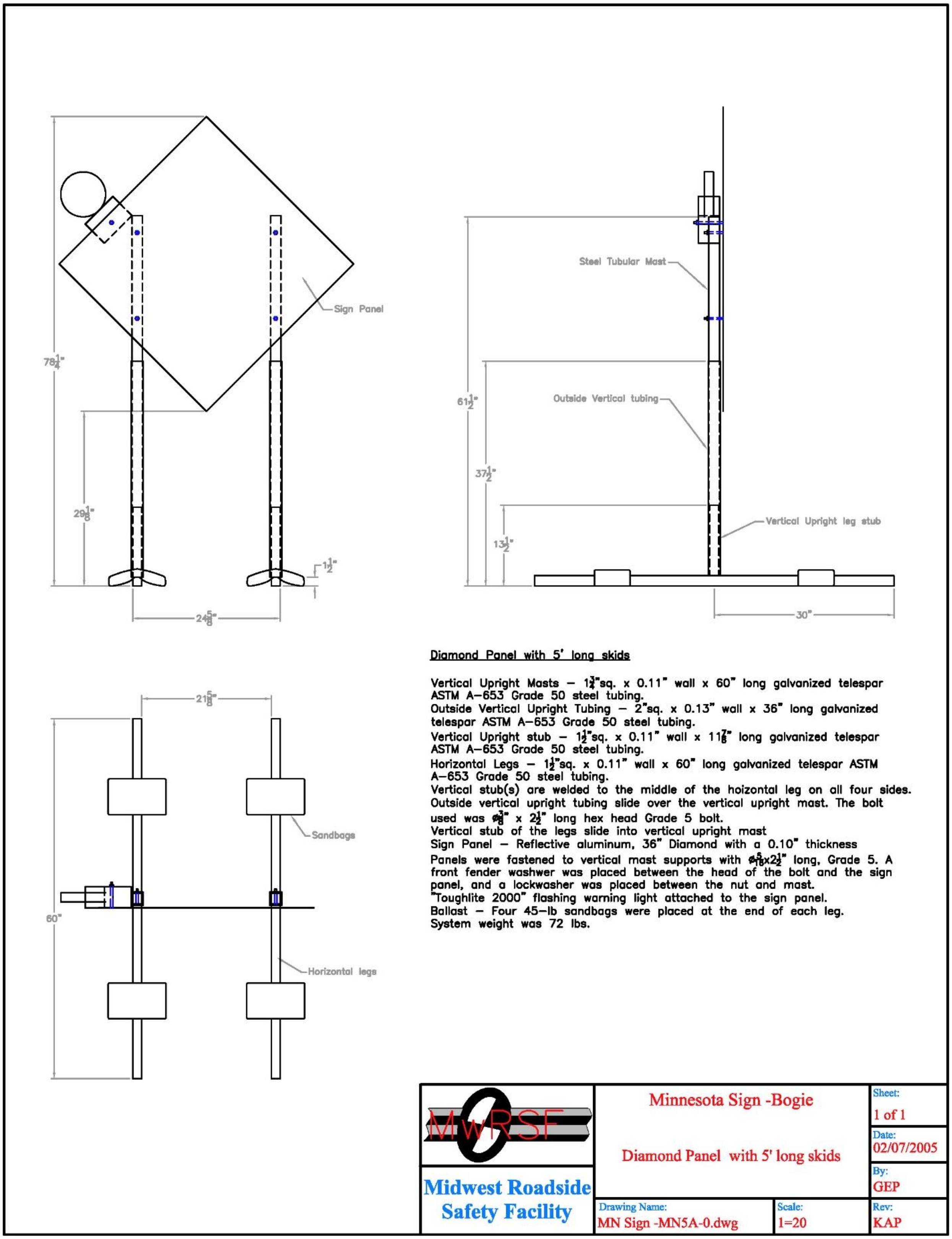

Figure 9. 36-in. (914-mm) Diamond Work-Zone Sign System, Bogie Test No. MN5A0 (*11*)

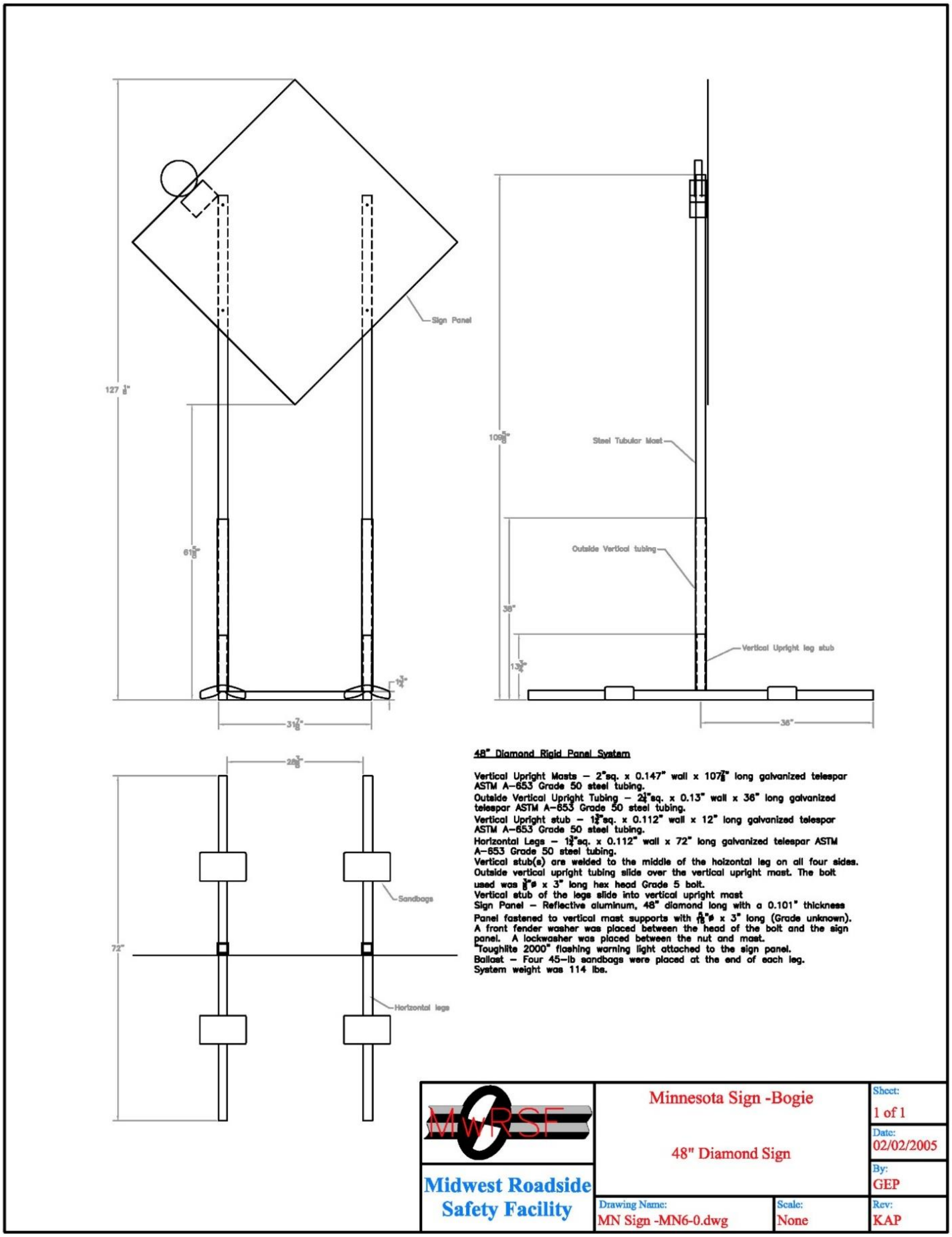

Figure 10. 48-in. (1,219-mm) Diamond Work-Zone Sign System, Bogie Test No. MN6A0 (*11*)

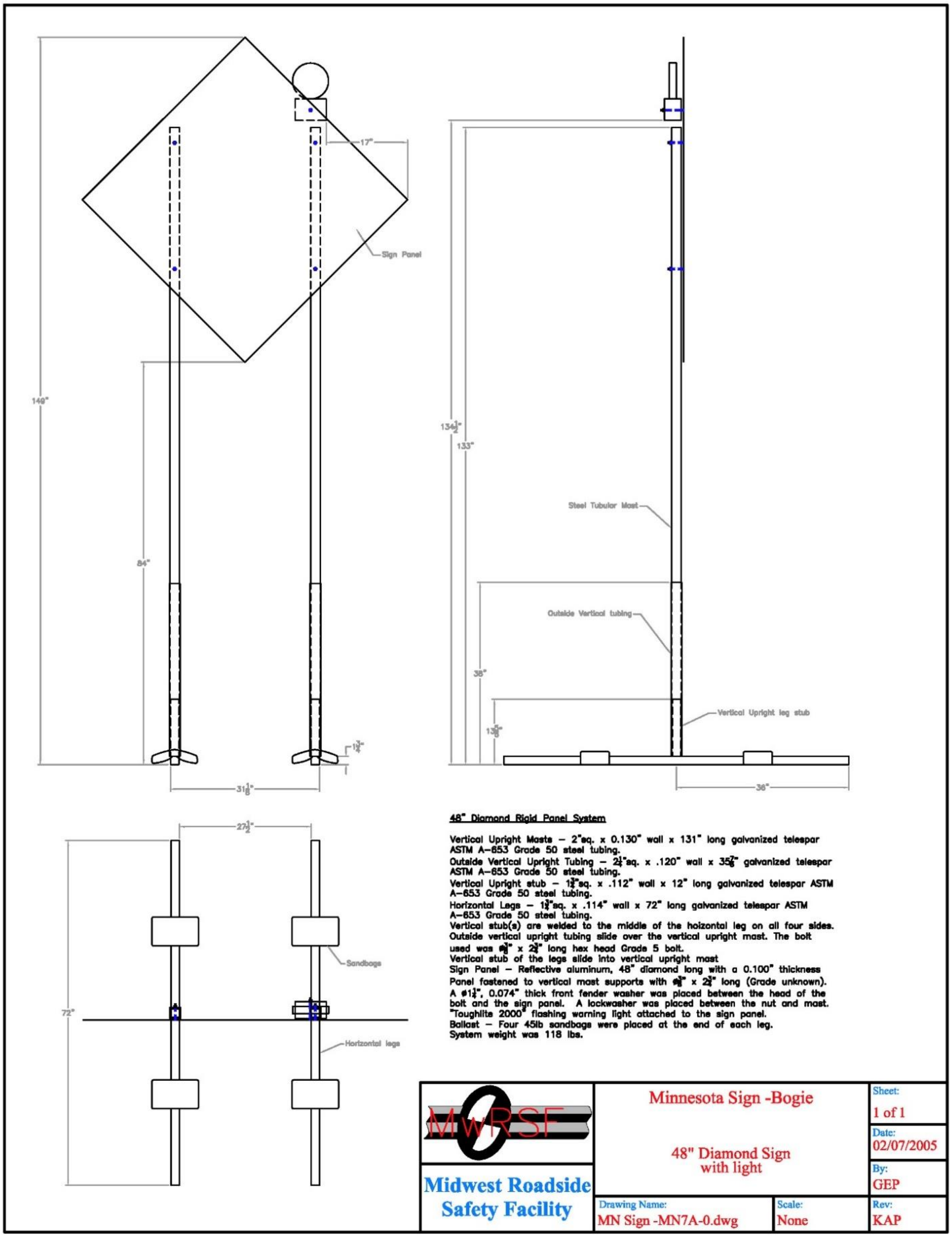

Figure 11. 48-in. (1,219-mm) Diamond Panel Work-Zone Sign System, Bogie Test No. MN7A0 (*11*)

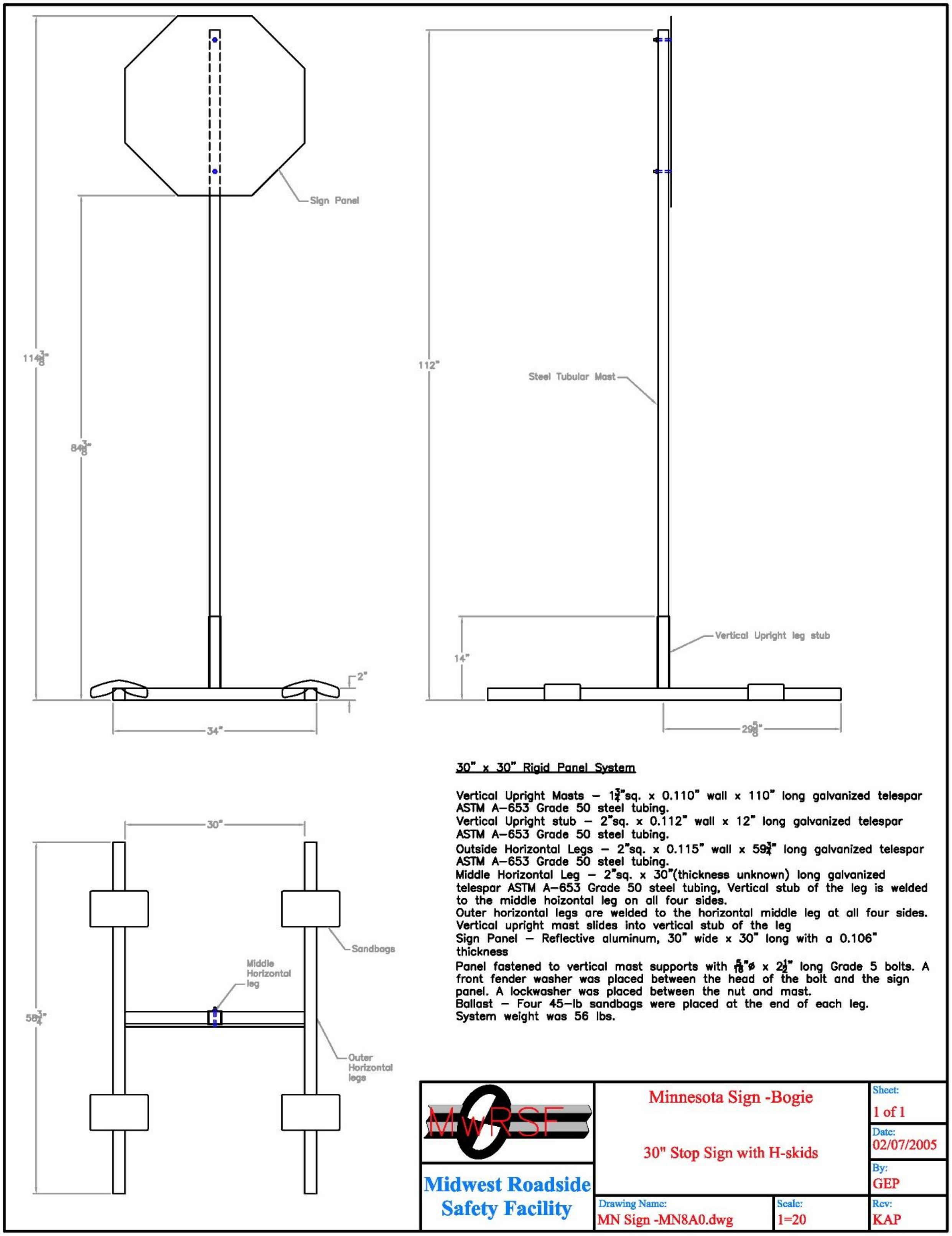

Figure 12. Stop Sign Panel Work-Zone Sign System, Bogie Test No. MN8A0 (*11*)

The Texas DOT sponsored a project conducted by Texas Transportation Institute (TTI) that tested single mast, H-base sign stands with several different nested mast and sign panel connections (*12-13*). All of the sign stands had a 1¾-in. x 12-ga. (44-mm x 3-mm) PSST H-base with two outer legs 48 in. (1,219 mm) in length and one horizontal leg 48 in. (1,219 mm) in length. All sign stands had a single PSST vertical mast fabricated from nested 12-ga. x 1¾-in. (3-mm x 44-mm) and 1½-in. (38-mm) PSST. The lengths, nesting, and splice configurations of these tubes varied between designs. All designs utilized a 36-in. x 36-in. x ⅛-in. (914-mm x 914-mm x 3-mm) aluminum diamond-shaped panel mounted at a 7-ft (2.1-m) height to the bottom of the panel. The connection between the sign panel and mast varied between designs.

Several different connection designs were evaluated with MASH 2009 test designation no. 3-71 with a 90-degree orientation (test nos. 490022-7-1, 490022-7-2, 490022-7-3) (*12*). All three tests were successful. Modifications to the systems were recommended through a FEA effort, and a MASH 2009 test designation no. 3-72 crash test (test no. 490022-7-4) was conducted at a 0 and 90-degree sign stand orientation. This system utilized a telescopic slip connection at a height of 60 in. (1,524 mm) to permit height adjustability, as shown in Figures 13 through 15. The system oriented at 0 degrees successfully passed MASH 2009 test designation no. 3-72 evaluation criteria. However, the system oriented at 90 degrees was unsuccessful due to roof penetration.

Further connection modifications were evaluated (*13*). The mast connection was modified with a shorter overlapped section, as shown in Figures 16 through 18, and evaluated with MASH 2009 test designation no. 3-72 with the system oriented at 90 degrees (test no. 490026-2-1). The system oriented at 90 degrees was unsuccessful due to roof penetration.

The mast connection was modified with a slip connection and the sign panel connection was modified to include fuse plates, designated Option B, as shown in Figures 19 through 21. MASH 2009 test designation no. 3-71 at 0 degrees (test no. 490026-2-6), MASH 2009 test designation no. 3-71 at 90 degrees (test no. 490026-2-4), MASH 2009 test designation no. 3-72 at 0 degrees (test no. 490026-2-8), and MASH 2009 test designation no. 3-72 at 90 degrees (test no. 490026-2-2) were all successful, and the system was recommended for use.

Another option was configured with the mast and sign panel connections at the same location near the bottom of the sign panel, designated Option C, as shown in Figures 22 through 24. MASH 2009 test designation no. 3-71 at 0 degrees (test no. 490026-2-7), MASH 2009 test designation no. 3-71 at 90 degrees (test no. 490026-2-5), MASH 2009 test designation no. 3-72 at 0 degrees (test no. 490026-2-9), and MASH 2009 test designation no. 3-72 at 90 degrees (test no. 490026-2-3) were all successful, and the system was recommended for use. All of these systems appeared to be very similar with slight changes in the mast and sign panel connections, however, they sign panel disengaged very differently, with some resulting in an unsuccessful performance.

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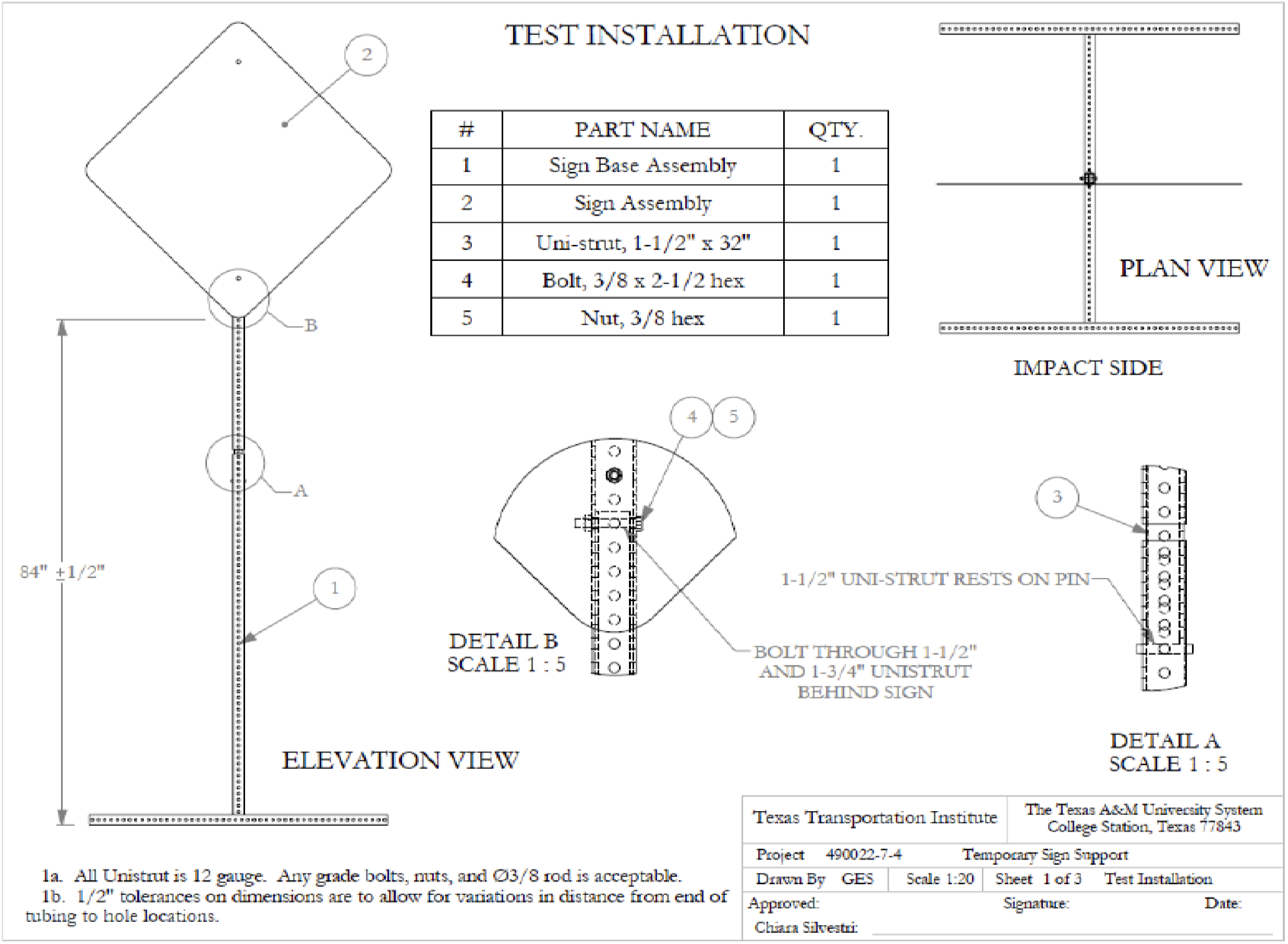

#	PART NAME	QTY.
1	Sign Base Assembly	1
2	Sign Assembly	1
3	Uni-strut, 1-1/2" x 32"	1
4	Bolt, 3/8 x 2-1/2 hex	1
5	Nut, 3/8 hex	1

Figure 13. Temporary Work-Zone Sign Support, Test No. 490022-7-4 (*12*)

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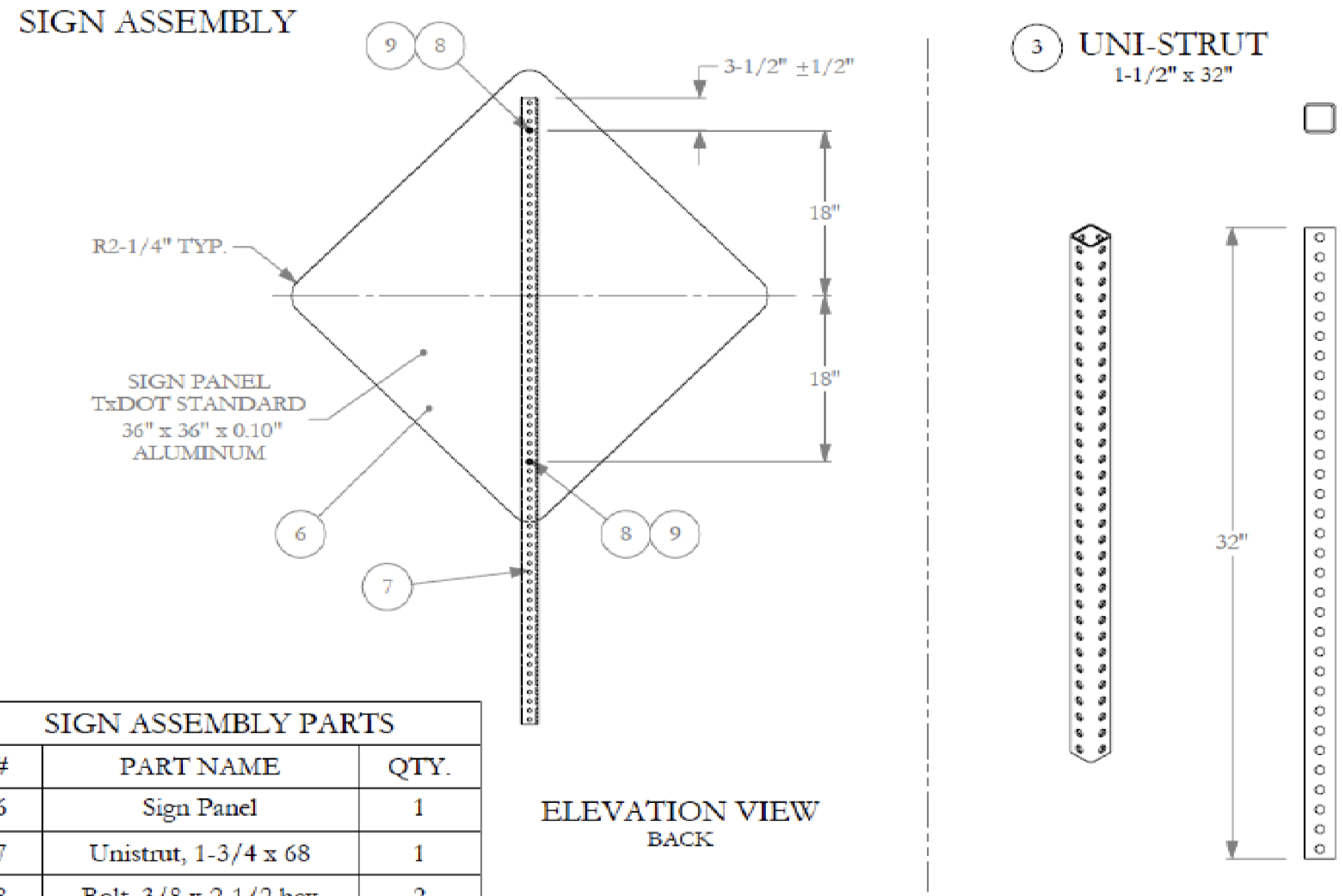

SIGN ASSEMBLY PARTS		
#	PART NAME	QTY.
6	Sign Panel	1
7	Unistrut, 1-3/4 x 68	1
8	Bolt, 3/8 x 2-1/2 hex	2
9	Nut, 3/8 hex	2

2a. 1/2" tolerances on bolt locations are to allow for distance from end of tubing to hole locations.

Texas Transportation Institute		The Texas A&M University System College Station, Texas 77843	
Project 490022-7-4	Temporary Sign Support		2012-05-03
Drawn By GES	No Scale	Sheet 2 of 3	Sign Assembly

Figure 14. Temporary Work-Zone Sign Support, Test No. 490022-7-4 (*12*) (Continued)

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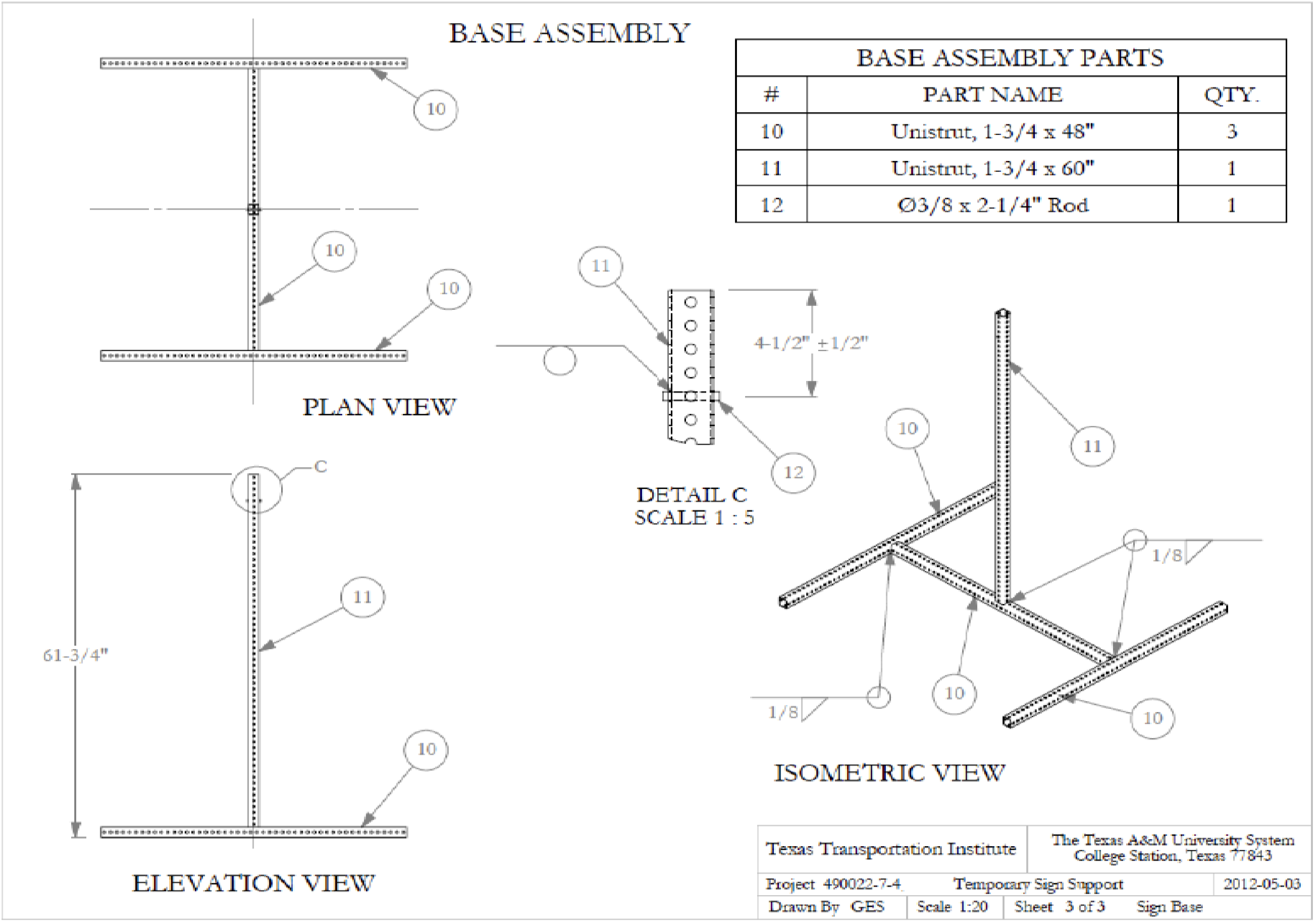

Figure 15. Temporary Work-Zone Sign Support, Test No. 490022-7-4 (*12*) (Continued)

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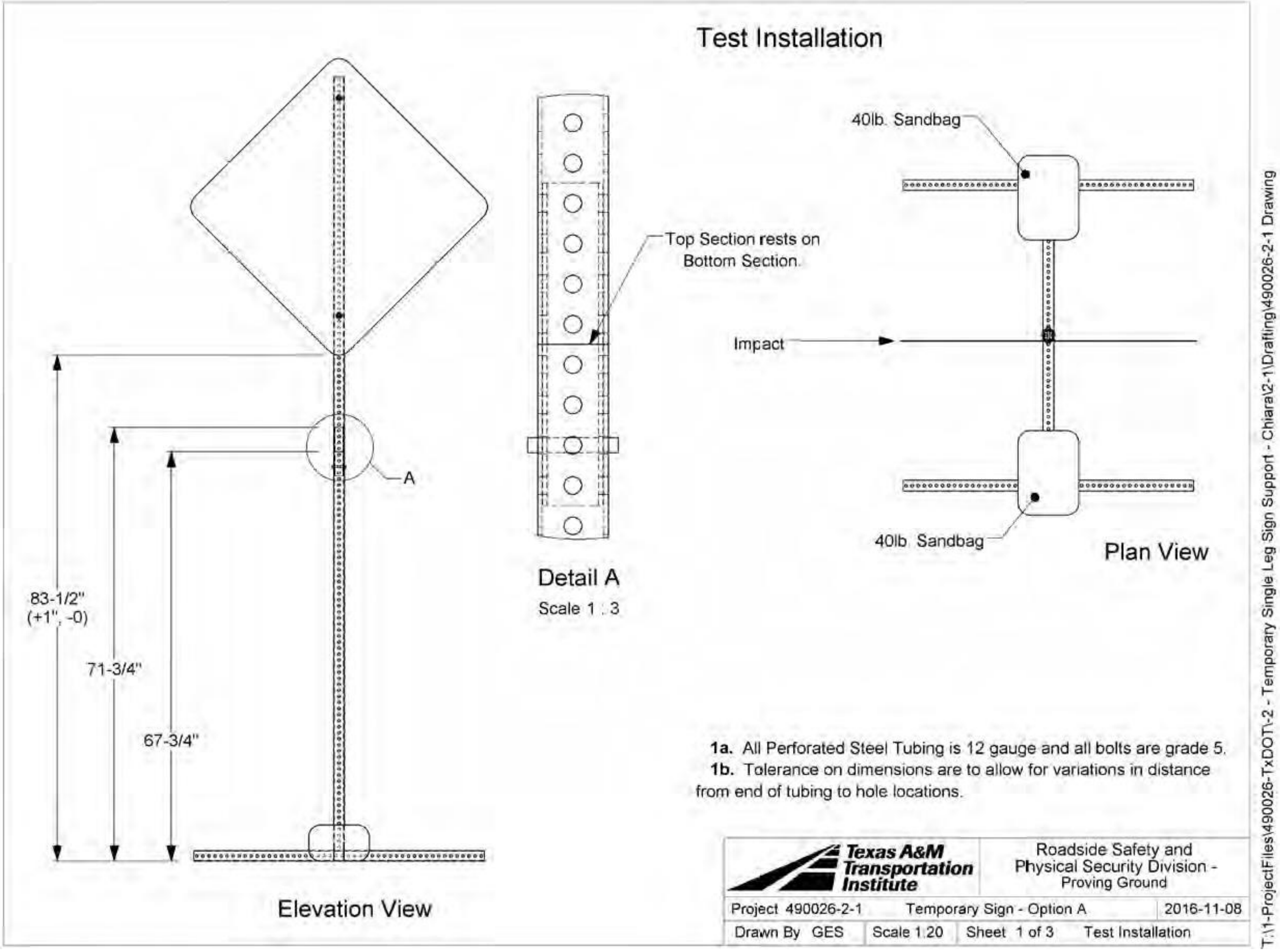

Figure 16. Temporary Work-Zone Sign Support, Test No. 490026-2-1 (*13*)

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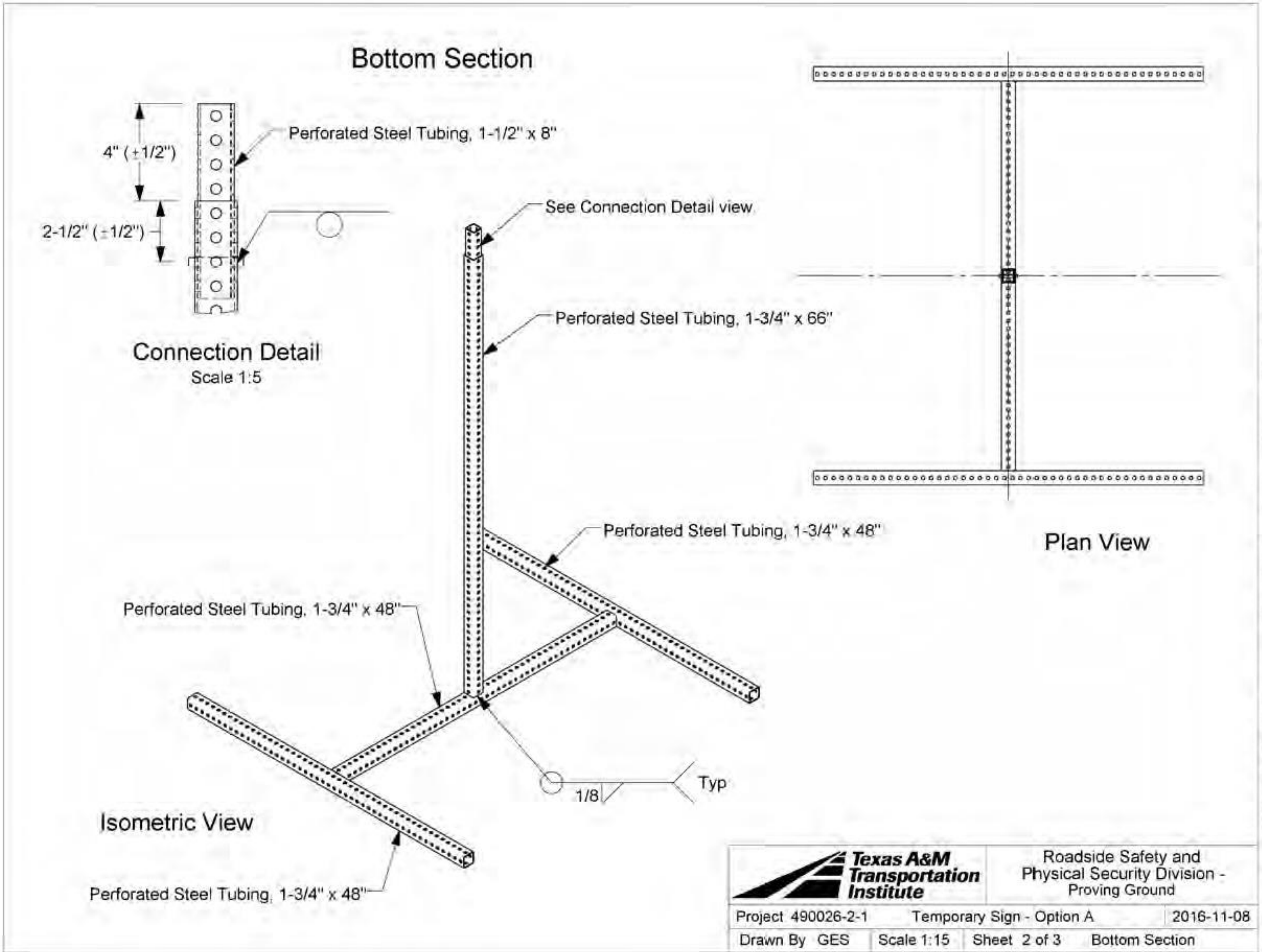

Figure 17. Temporary Work-Zone Sign Support, Test No. 490026-2-1 (*13*) (Continued)

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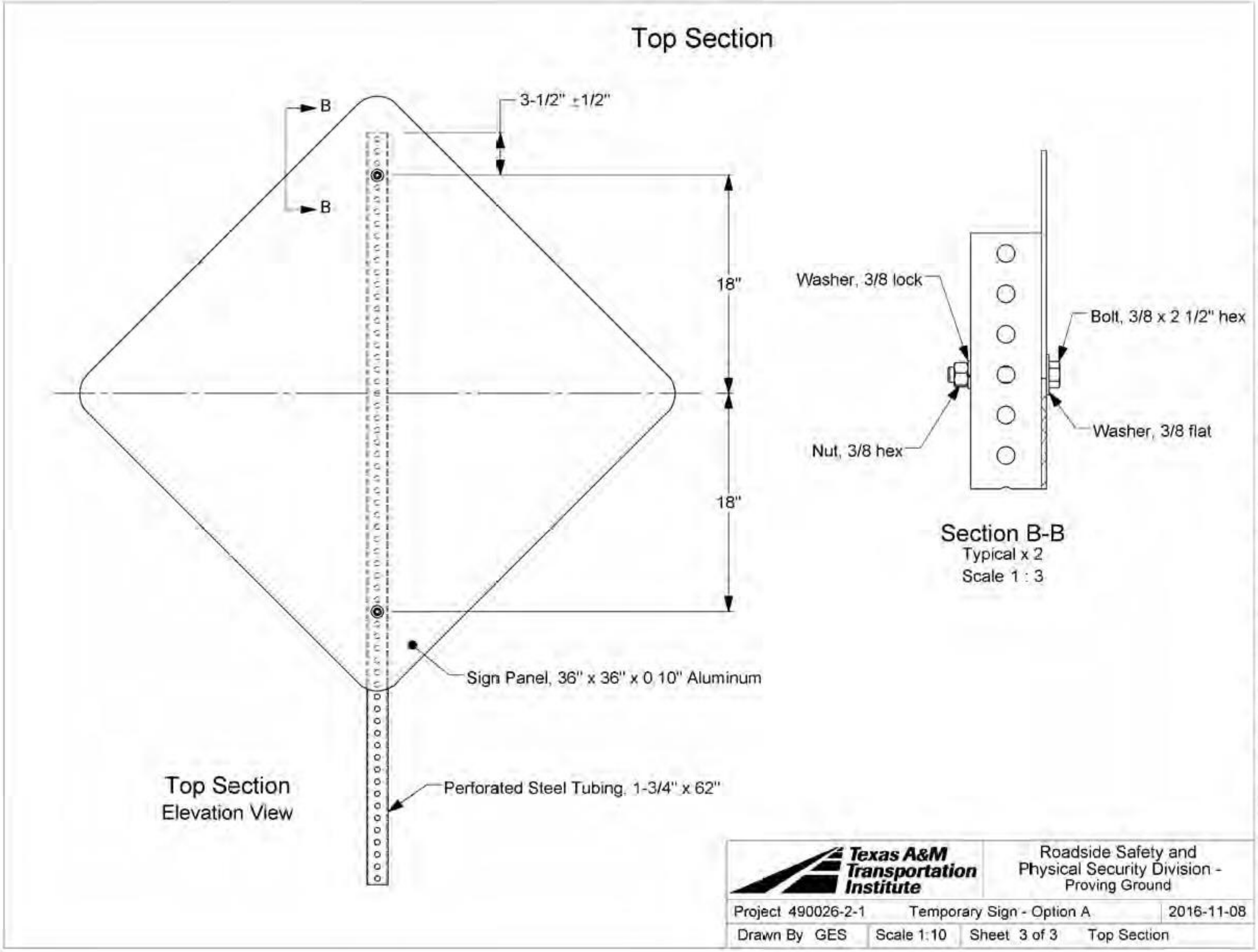

Figure 18. Temporary Work-Zone Sign Support, Test No. 490026-2-1 (*13*) (Continued)

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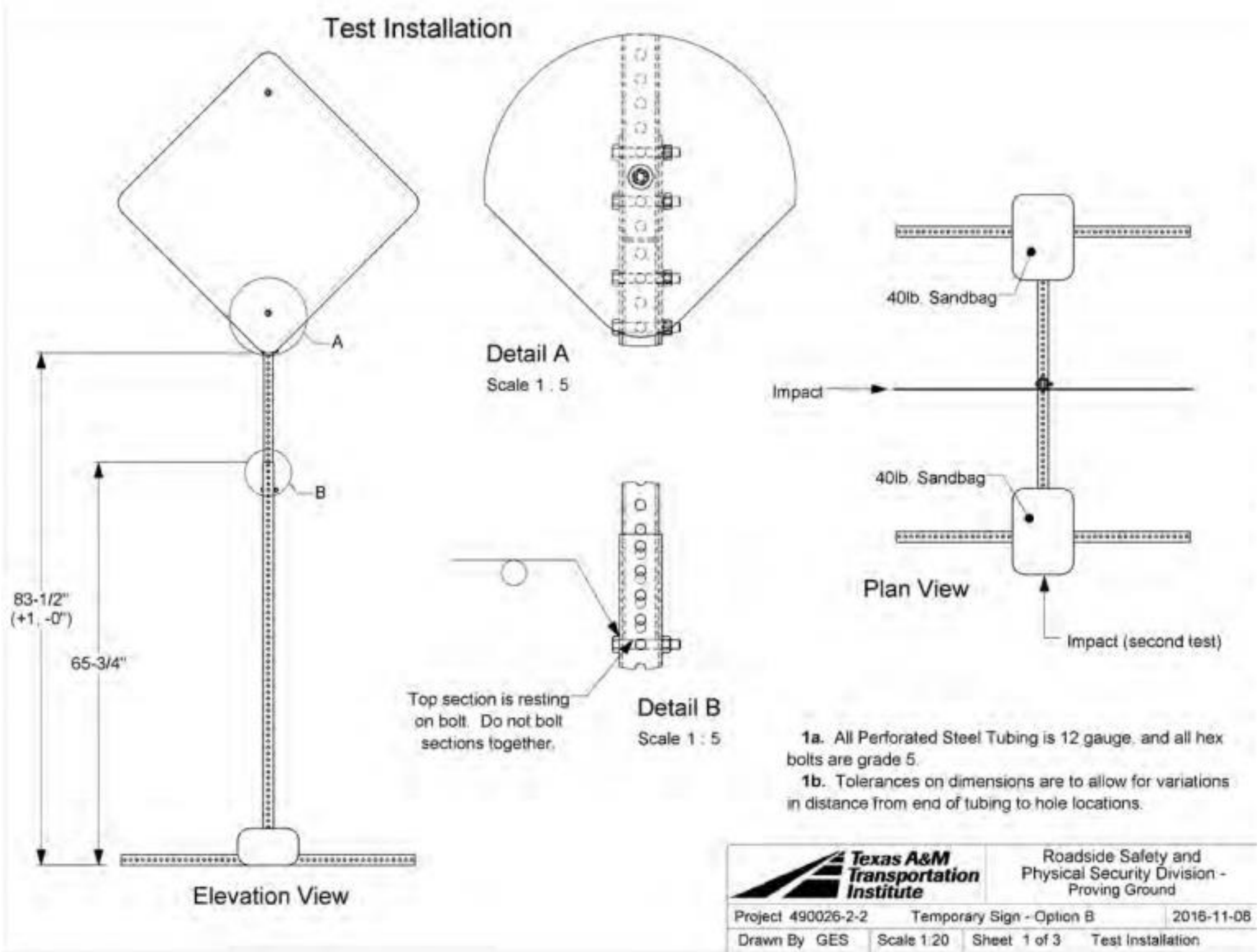

Figure 19. Option B Temporary Work-Zone Sign Support (*13*)

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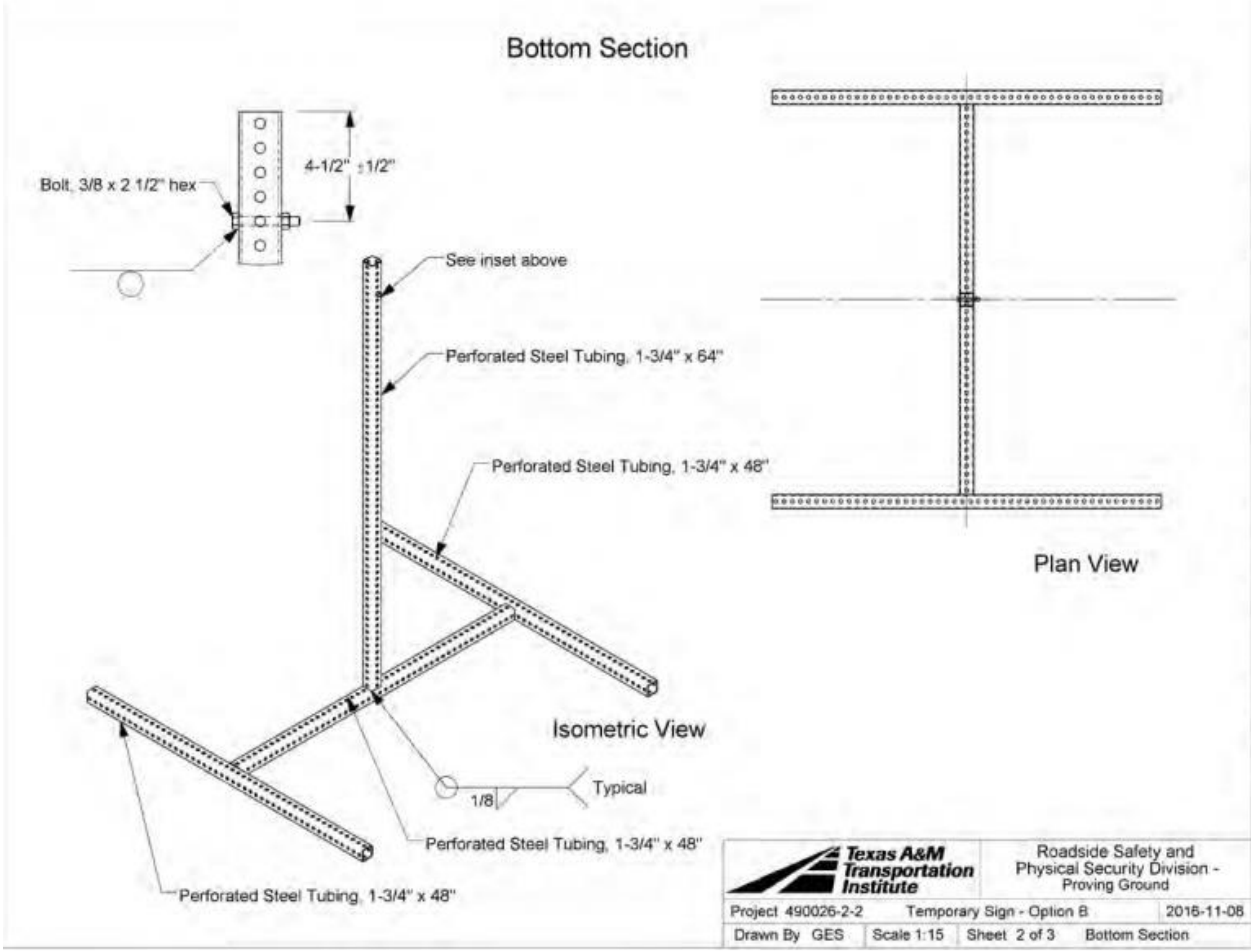

Figure 20. Option B Temporary Work-Zone Sign Support (*13*) (Continued)

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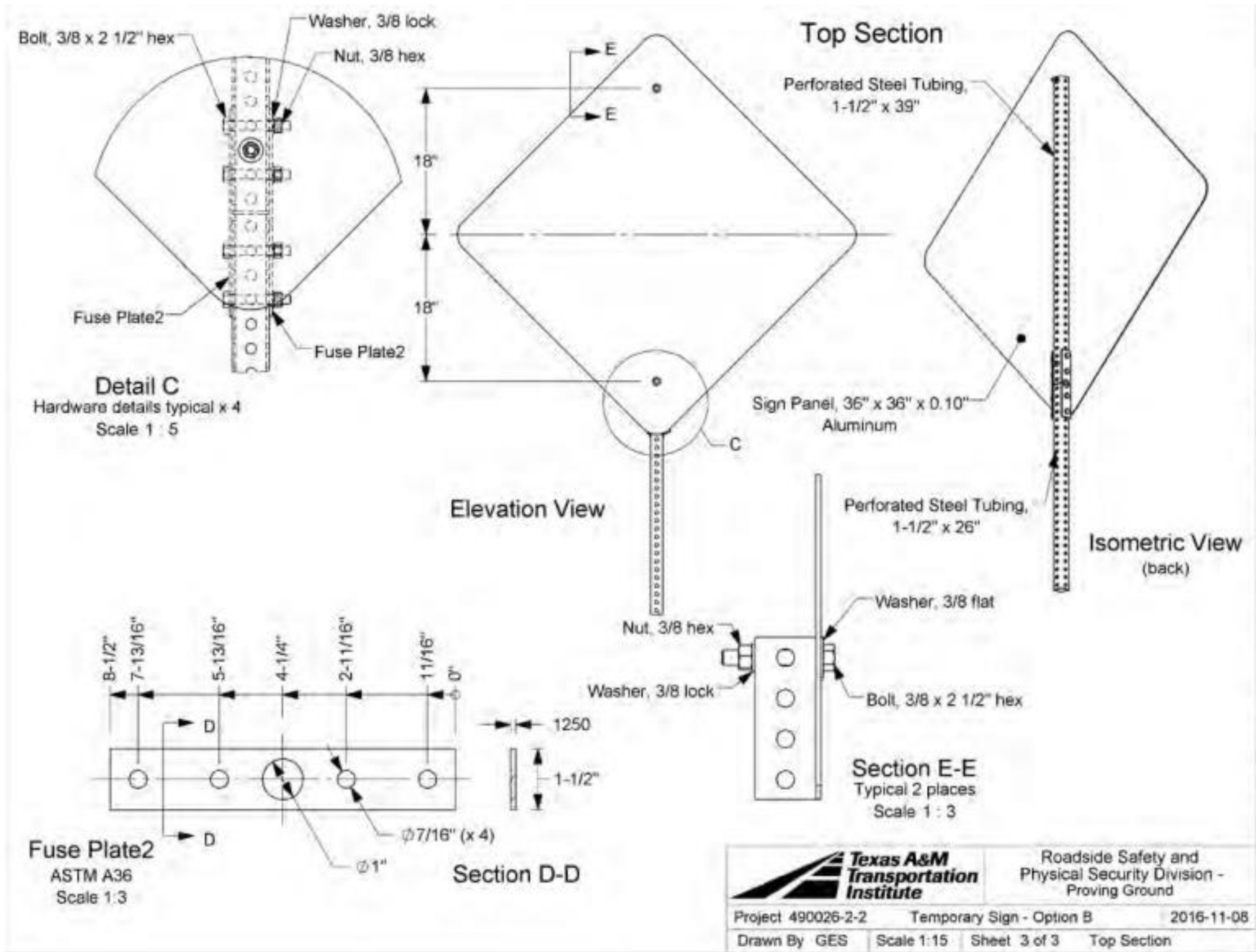

Figure 21. Option B Temporary Work-Zone Sign Support (*13*) (Continued)

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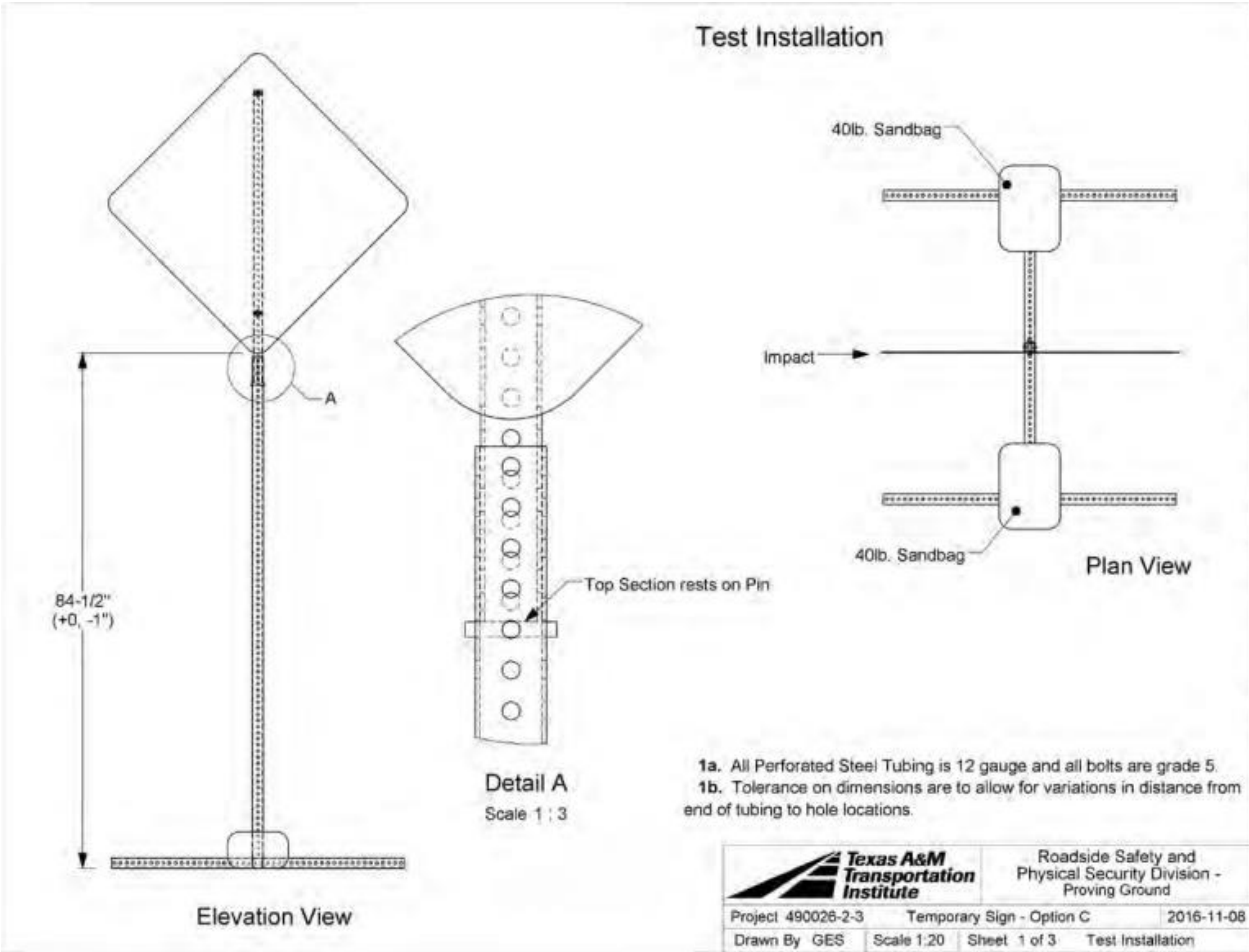

Figure 22. Option C Temporary Work-Zone Sign Support (*13*)

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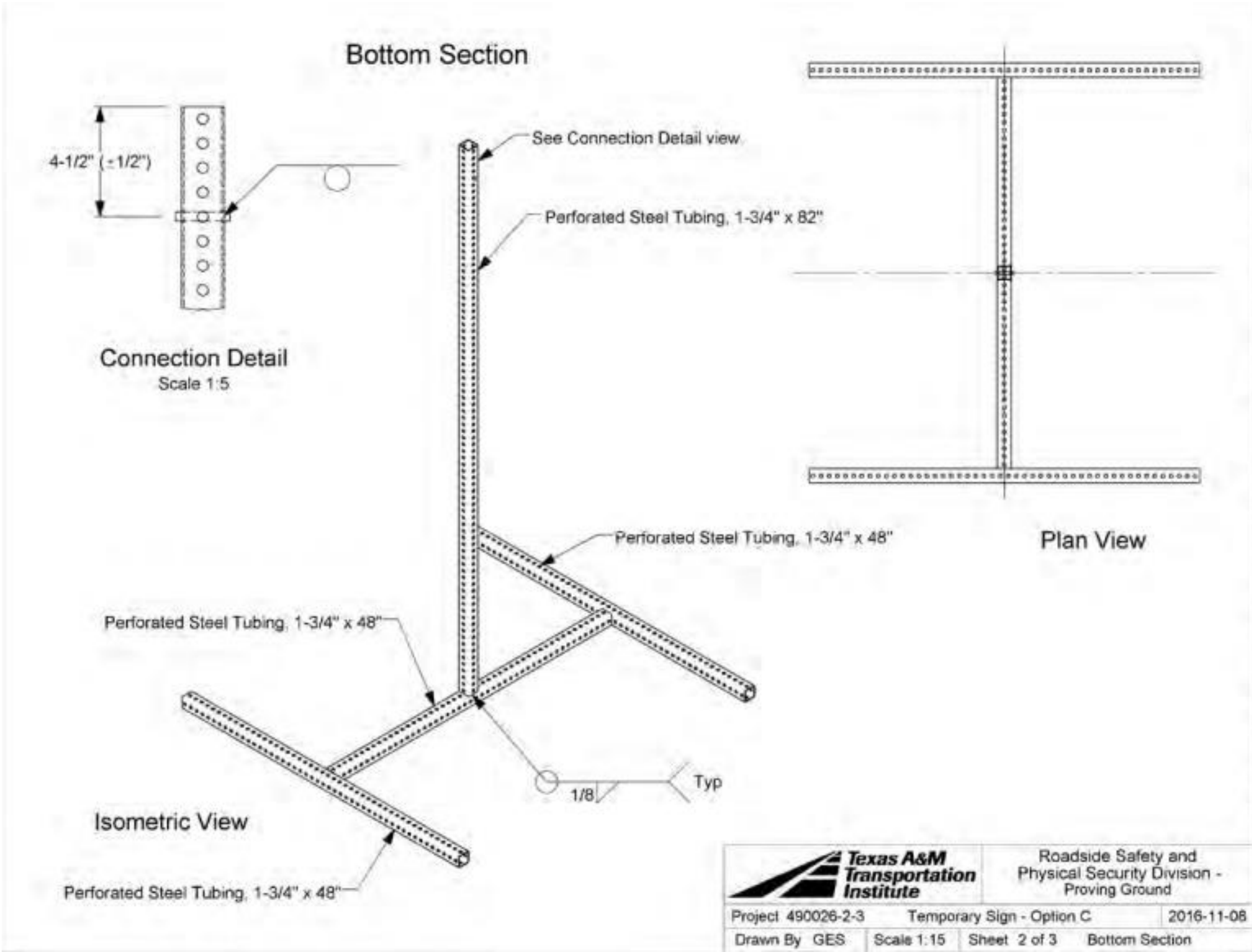

Figure 23. Option C Temporary Work-Zone Sign Support (*13*) (Continued)

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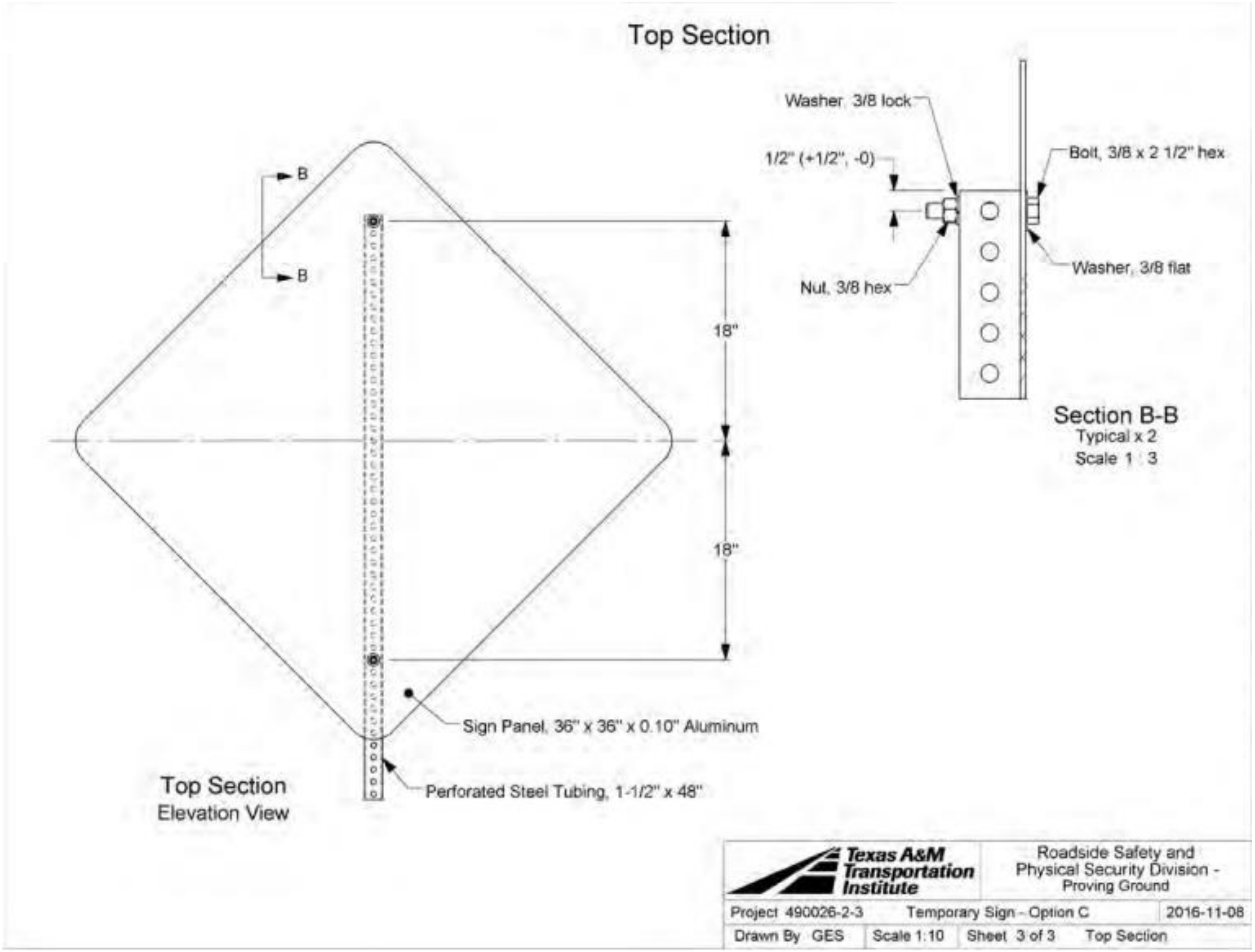

Figure 24. Option C Temporary Work-Zone Sign Support (*13*) (Continued)

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Work-Zone Barricades

Test nos. MNB-1 and MNB-2 were each conducted on aluminum Type III barricades (*14*). Two barricades were impacted for each test, as shown in Figures 25 and 26. All four barricades were similar, but the two barricades impacted in test no. MNB-2 included an aluminum sign panel with reflective material, while the two barricades in test no. MNB-1 did not. The vertical upright masts consisted of 1½-in. x 1½-in. x 5-ft (38-mm x 38-mm x 1.5-m) Telespar ASTM A-653 Grade 50 steel. The horizontal portion of the legs consisted of Telespar ASTM A-653 Grade 50 steel measuring 1¾ in. x 1¾ in. x 5 ft. (44 mm x 44 mm x 1.5 m) and the vertical component of the legs consisted of Telespar ASTM A-653 Grade 50 steel measuring 12 in. (305 mm) in height. The three aluminum panels were 12 ft (3.7 m) long, 7¼ in. (184 mm) wide, and ¾ in. (19 mm) thick. A sign panel was attached for test no. MNB-2 to the top aluminum panel and measured 2½ ft x 4 ft (0.8 m x 1.2 m). Approximately 45-lb (20-kg) sandbags were placed on each end of each leg. All of the impacts on the barricade systems resulted in acceptable safety performance according to NCHRP Report 350.

Test no. MI-2 was conducted on two similar Type III barricades, shown in Figure 27, one impacted at 0 degrees and one impacted at 90 degrees (*10*). The vertical upright masts were composed of 1¾-in. x 1¾-in. x 5-ft (44-mm x 44-mm x 1.5-m) telespar galvanized steel tubing. The horizontal portion of the legs was composed of ASTM A-36 steel measuring 2 in. x 2 in. x 4 ft (51 mm x 51 mm x 1.2 m) and the vertical component of the legs was composed of steel tubing measuring 6 in. (152 mm) in height. The three wood panels were 12 ft (3.7 m) long, 7¼ in. (184 mm) wide, and ¾ in. (19 mm) thick. The diameter of each of the three warning lights on the barrier was 7⅜ in. (187 mm). Approximately 70-lb (32-kg) sandbags were placed on each end of each leg. No sign panel was present. The system performed acceptably to NCHRP Report 350 TL-3 when impacted at 90 degrees, but not at 0 degrees.

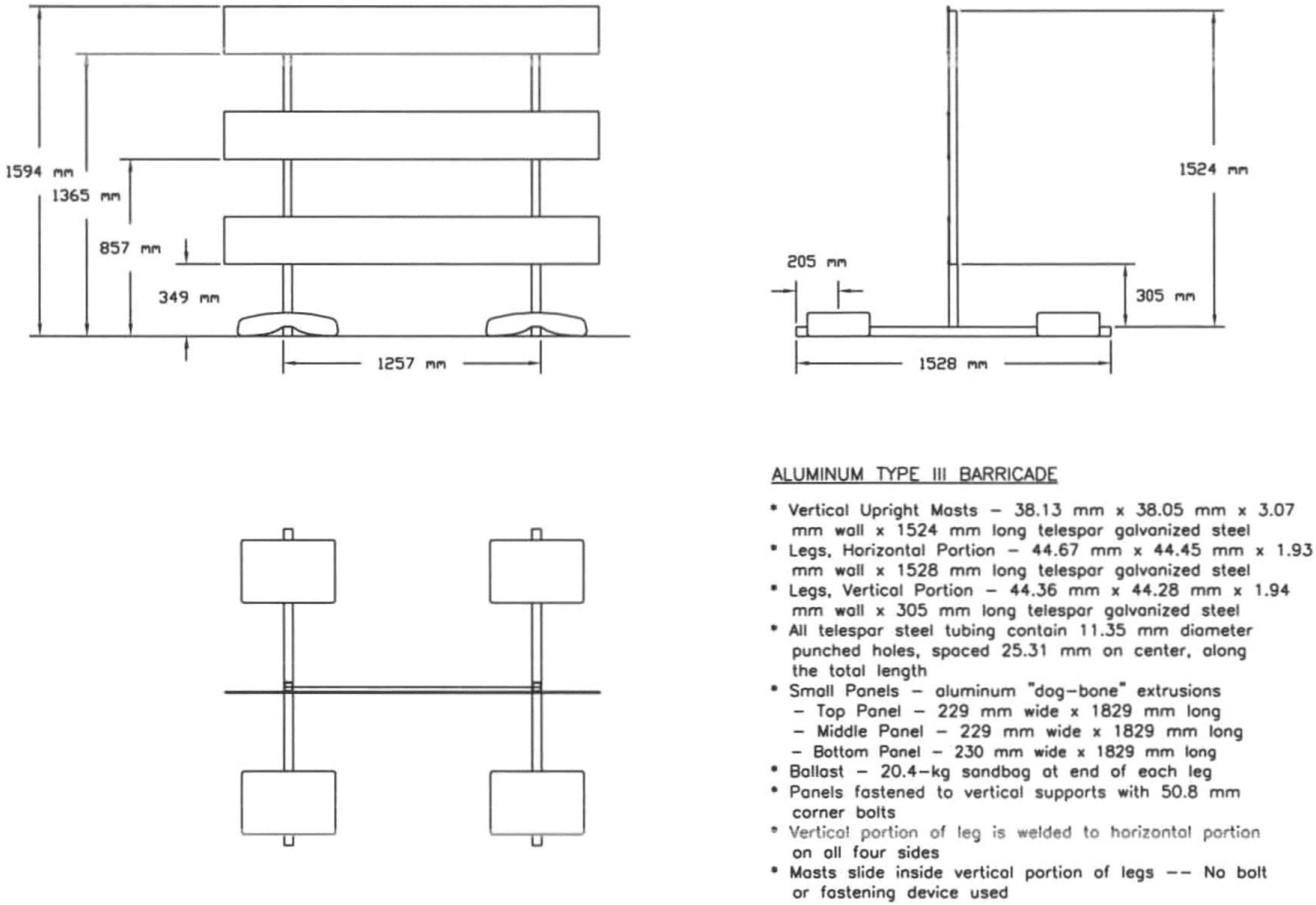

Figure 25. Test No. MNB-1 Type III Barricade (*14*)

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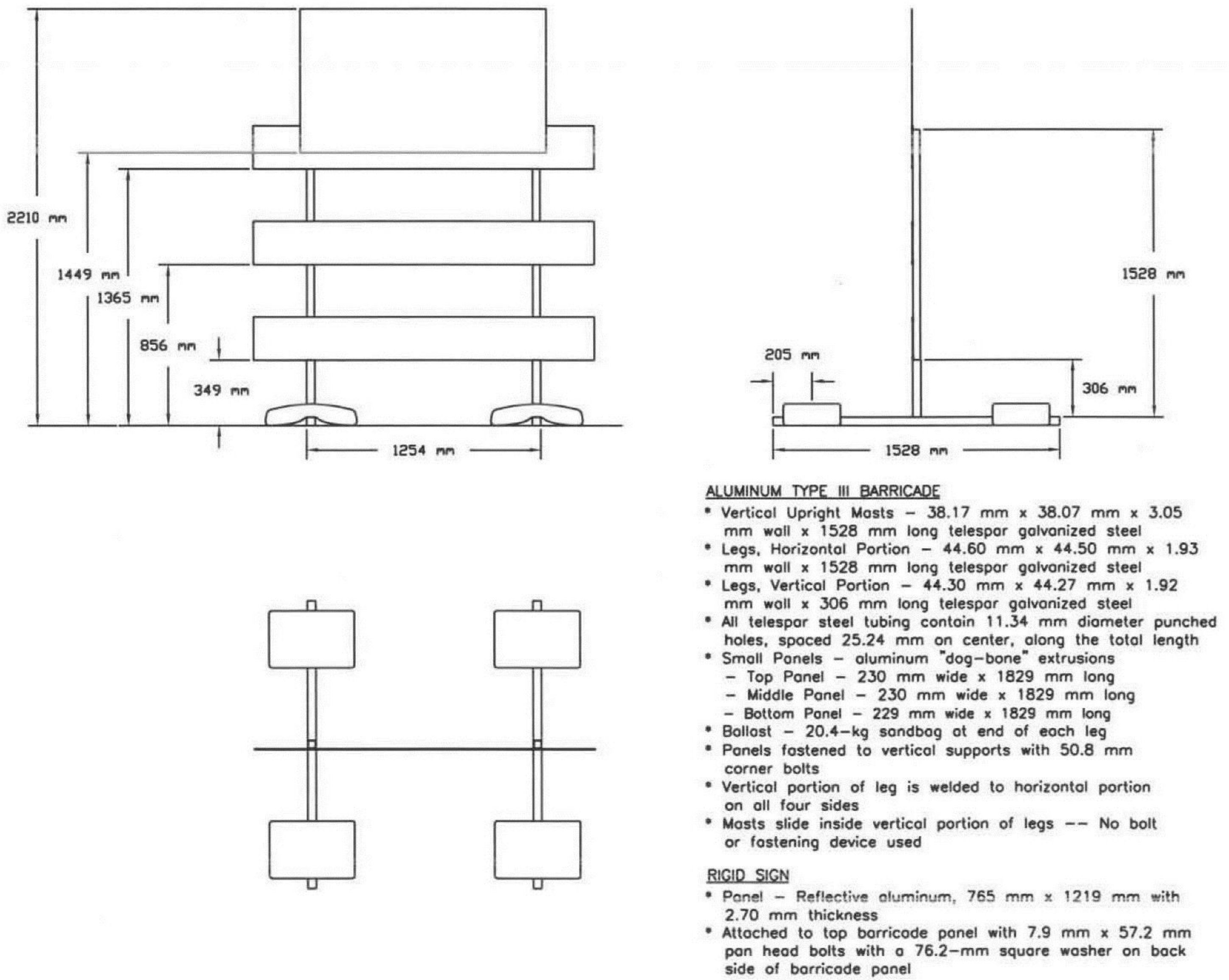

Figure 26. Test No. MNB-2 Type III Barricade (*14*)

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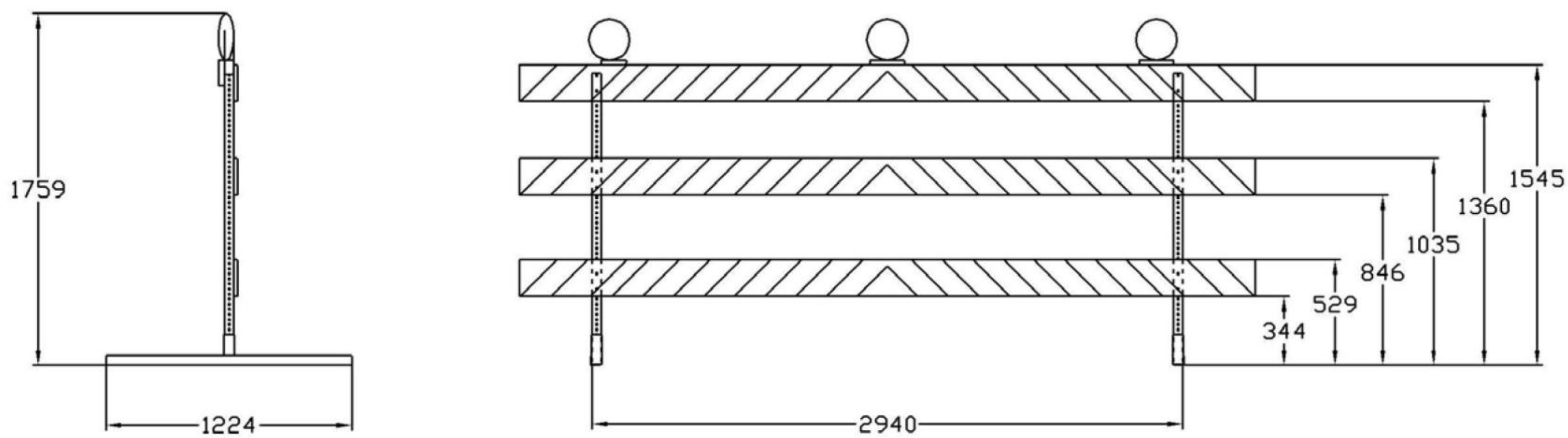

Type III Barricade System

- Vertical Upright Mast - 44.70 mm x 44.96 mm x 2.59 mm wall x 2940 long telespar galvanized steel tubing
- Legs, Horizontal Portion - 50.80 mm x 50.80 mm x 4.69 mm thicknesses x 1222 mm long L-shaped steel angle
- Legs, Vertical Stub - 50.80 mm x 50.80 mm x 2.64 mm wall x 151 mm long steel tubing
- All telespar steel tubing contain 9.53 mm diameter punched holes, spaced 25.40 mm on center, along the total length
- Vertical stub of the leg is tack welded to horizontal portion of the leg on three sides
- Masts slide inside vertical stub of legs - No bolt or fasenting device used
- Top Barricade Panel - Reflective wood, 184 mm wide x 3662 mm long with a 19.05 mm thickness
- Middle Barricade Panel - Reflective wood, 183 mm wide x 3662 mm long with a 19.05 mm thickness
- Bottom Barricade Panel - Reflective wood, 184 mm wide x 3662 mm long with a 19.05 mm thickness
- Panels fastened to vertical mast supports with 9.5 mm x 76 mm 16-hex bolt with 14.3 mm nut and 38.1 mm flat washer
- Lights - Three "Work Safe Supply" Type A Flashing Warning Light attached to the top barricade panel
- Ballast - 31.75-kg of sandbags at end of each leg

Figure 27. Details of MI-2 Type III Barricade (*10*)

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TTI conducted five full-scale crash tests on Type III barricades, test nos. 439107-1, 439107-2, 439107-3, 439107-5, and 439107-12 (*15*). All impact points were centered on the barricade at 0 degrees with a target impact speed of 62.1 mph (100 km/h). The barricade for test no. 439107-1 had two 5-ft (1.5-m) wooden legs, as shown in Figure 28. The vertical posts were supported by a 3-ft (0.9-m) diagonal wooden plank that attached to the end of each leg on one end and to the vertical posts 25 in. (635 mm) from the bottom on the other end. The barricade had three 1-in. (25-mm) thick plywood rail panels that were 4 ft (1.2 m) long and an attached warning light. The barricade was 60 in. (1,524 mm) tall and 12 ft (3.7 m) wide. The system was found to be unacceptable according to NCHRP Report 350, but the researchers believed that the system would have been acceptable without an attached warning light.

The barricade for test no. 439107-2 had two 1¾-in. (44-mm) perforated steel square tube legs with two 12-ga., 1½-in. (38-mm) perforated steel square tube supports, as shown in Figure 29. Each leg was attached to the support with a 4-in. (102-mm) long, 1¾-in. (44-mm) perforated steel square tube sleeve and a ⅜-in. (10-mm) diameter bolt. The barricade had three 1-in. (25-mm) thick plywood rail panels that were 12 ft (3.7 m) long. Three 1-in. (25-mm) thick wooden vertical braces were attached to the wood rail panels. The barricade was 60 in. (1,254 mm) tall and 12 ft (3.7 m) wide. The system was found to be acceptable according to NCHRP Report 350 criteria but was not tested at a 90-degree impact angle.

The barricade for test no. 439107-3 had two 1¾-in. (44-mm) perforated steel square tube legs with two 12-ga., 1½-in. (38-mm) perforated steel square tube supports, as shown in Figure 30. Each leg was attached to the support with a 4-in. (102-mm) long, 1¾-in. (44-mm) perforated steel square tube sleeve and a ⅜-in. (10-mm) diameter bolt. The barricade had three 1-in. (25-mm) thick plywood rail panels that were 4 ft (1.2 m) long. Two 1-in. (25-mm) thick wooden vertical braces were attached to the wood rail panels. The barricade was 60 in. (1,254 mm) tall and 4 ft (1.2 m) wide. The system was found to be acceptable according to NCHRP Report 350 criteria but was not tested at a 90-degree impact angle.

The barricade for test no. 439107-5 had two 5-ft (1.5-m) wooden legs, as shown in Figure 31. Each leg was attached to the support with two ½-in. (13-mm) diameter all-thread bolts. The vertical supports were HyCom fiberglass pipes with a 3 in. (76 mm) diameter. The barricade had six ¾-in. (19-mm) thick hollow plastic panels that were 4 ft (1.2 m) long, separated into three groups of two for a total width of 12 in. (304 mm) and spaced 8 in. (204 mm) apart. The barricade was 58 in. (1,473 mm) tall and 5 ft (1.5 m) wide. The legs were slid into 3-in. (76-mm) wide channels. The system was found to be acceptable according to NCHRP Report 350 criteria but was not tested at a 90-degree impact angle.

The barricade for test no. 439107-12 had two 6-ft (1.8-m) long fiberglass U-channel legs, as shown in Figure 32. Each leg was attached to the vertical support with ⅜-in. (10-mm) diameter carriage bolts and wooden inserts. The vertical supports were fiberglass U-channels measuring 5 ft (1.5 m) in height. The barricade had three ¼-in. (19-mm) thick fiberboard panels that were 4 ft (1.2 m) long. The barricade was 61 in. (1,549 mm) tall and 6 ft (1.8 m) wide. The system was found to be acceptable according to NCHRP Report 350 criteria but was not tested at a 90-degree impact angle.

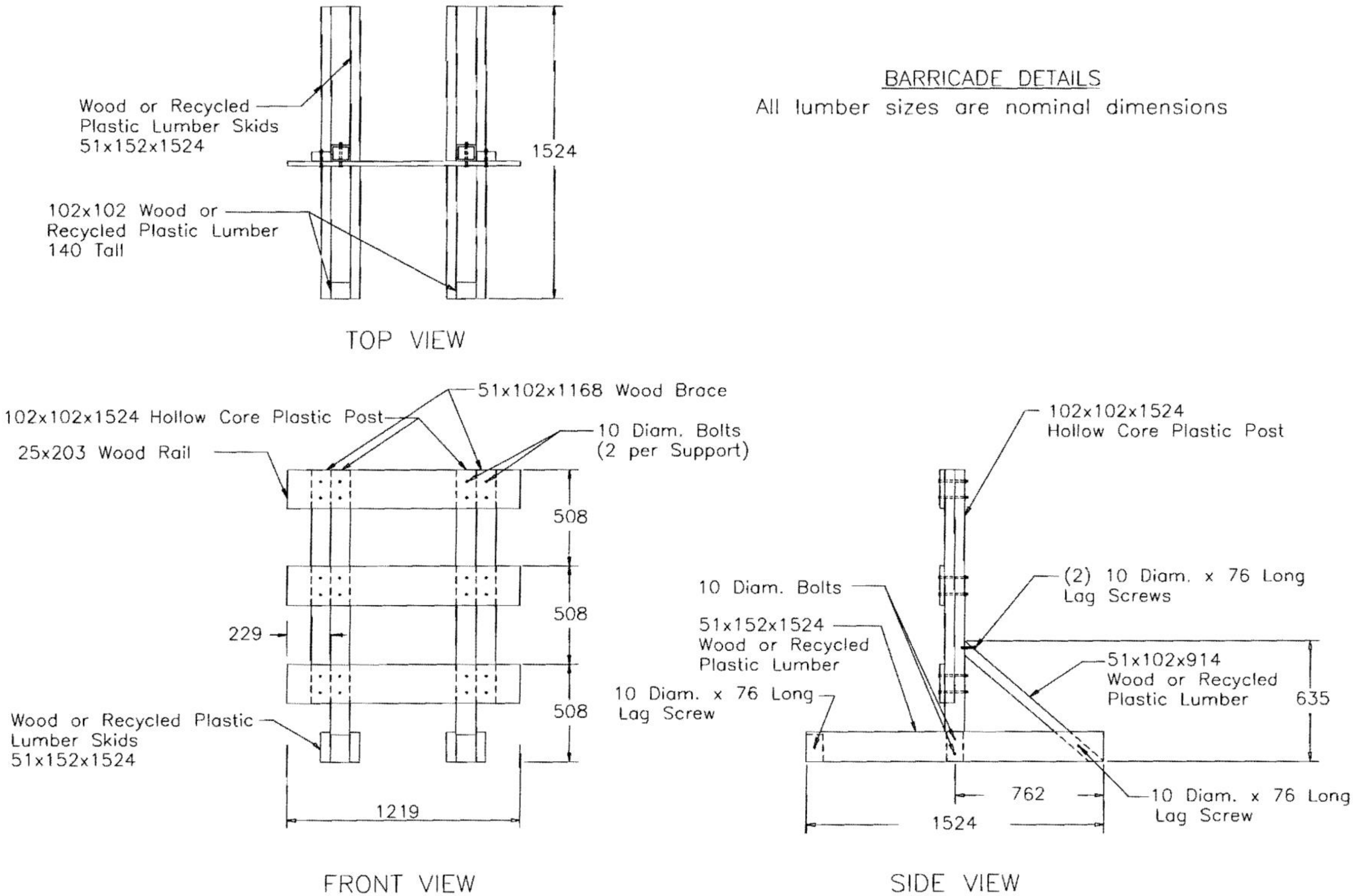

Figure 28. Test No. 439107-1 Type III Barricade (*15*)

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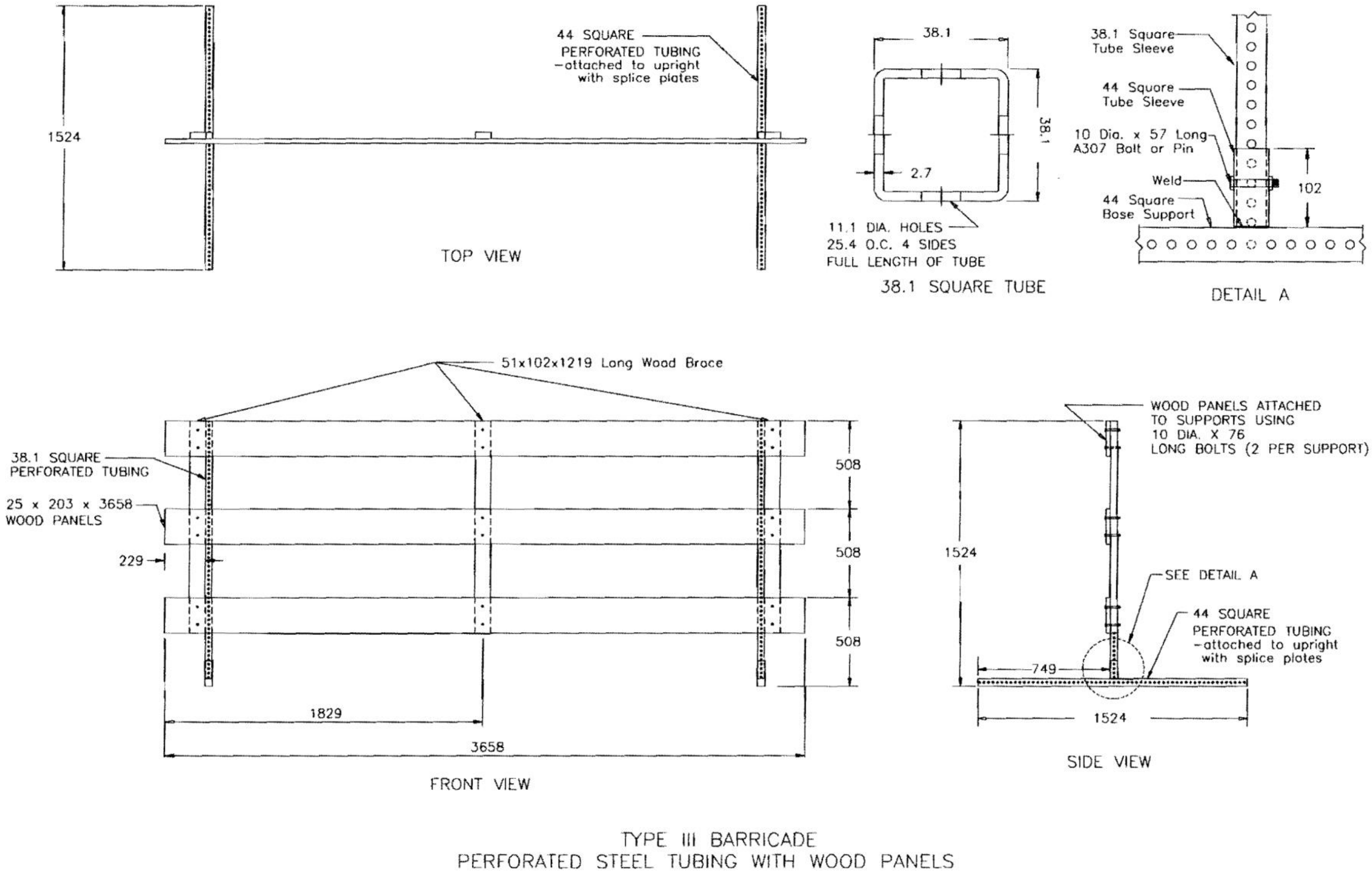

Figure 29. Test No. 439107-2 Type III Barricade (*15*)

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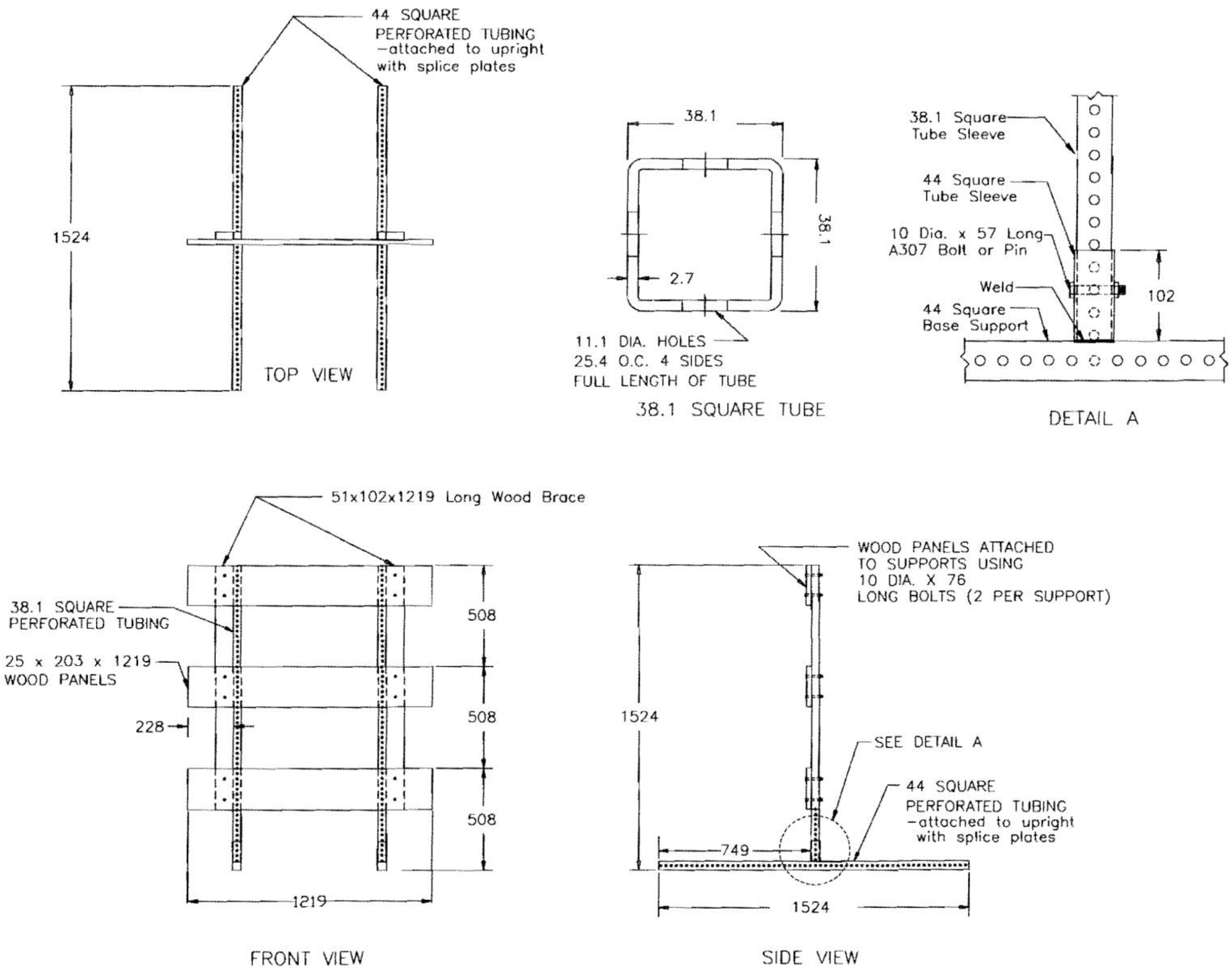

Figure 30. Test No. 439107-3 Type III Barricade (*15*)

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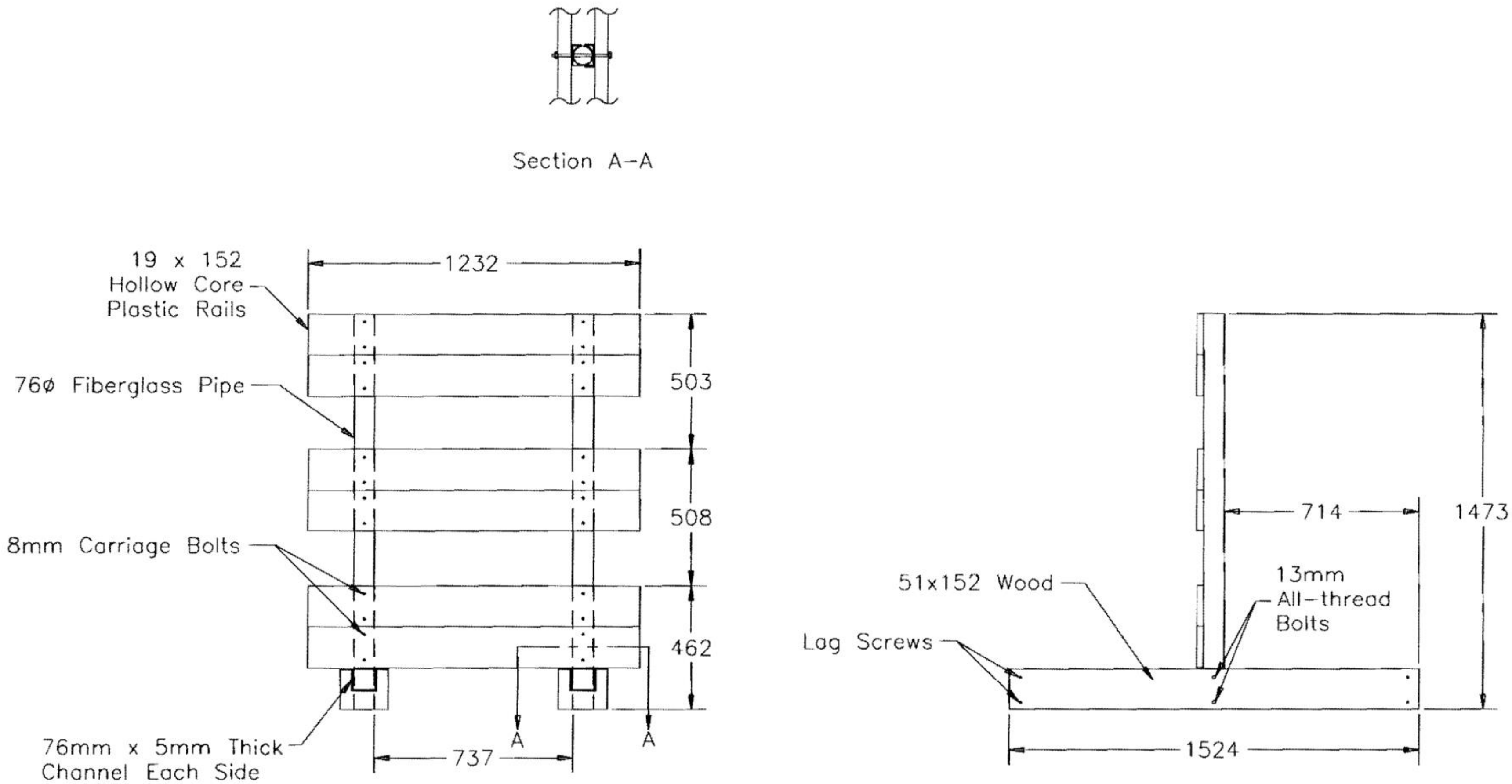

Figure 31. Test No. 439107-5 Type III Barricade (*15*)

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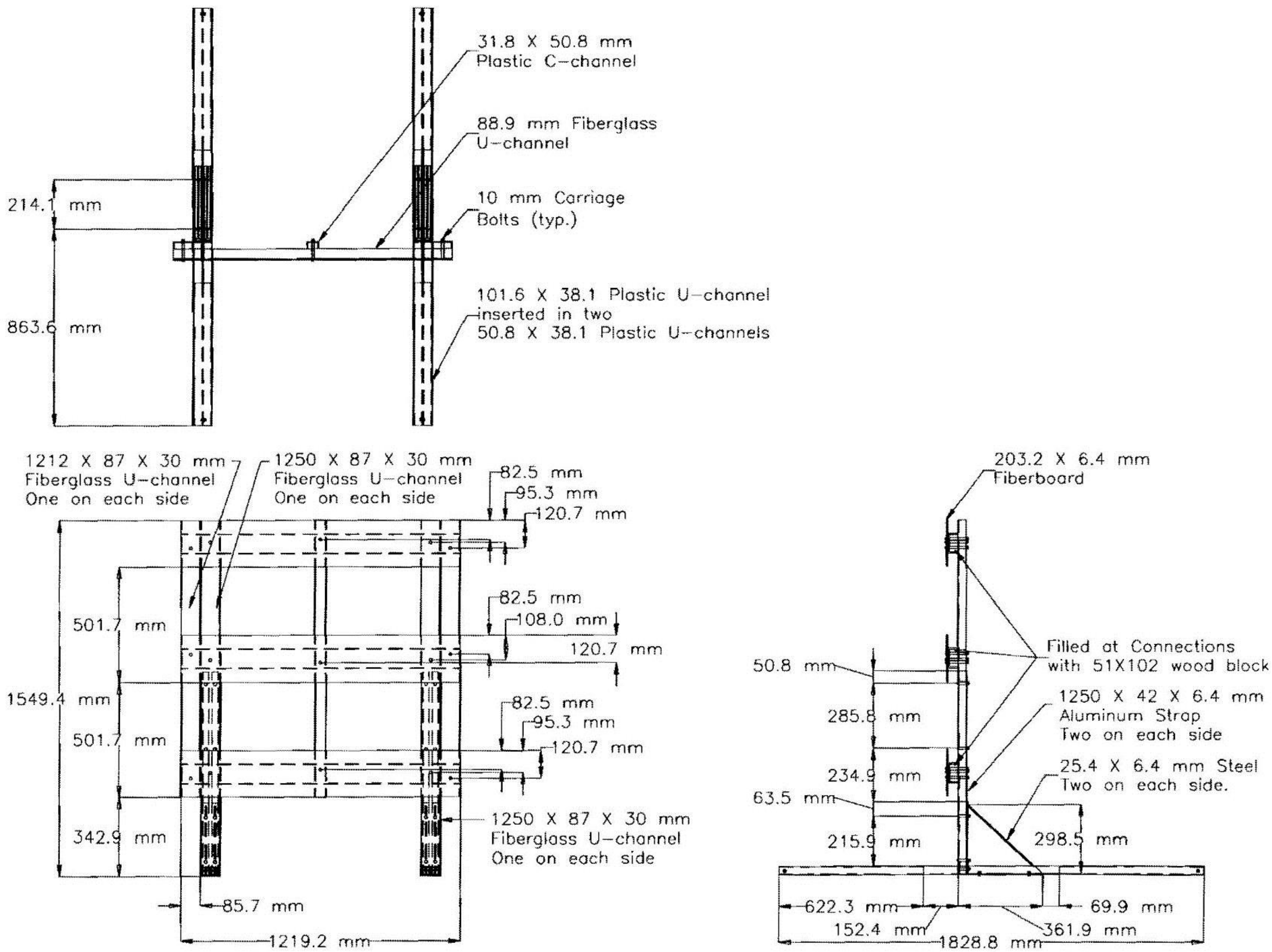

Figure 32. Test No. 439107-12 Type III Barricade (*15*)

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TTI conducted thirteen full-scale crash tests of Type III barricades, test nos. 453360-1, 453360-4, 453880-4, 453790-3, 453880-1, 453880-2, 453790-2, 453790-4, 453880-3, 453790-5, 453880-5, 453880-6, and 453880-7 (*16*). All crash tests were in accordance with guidelines set forth in NCHRP Report 350. The barricade for test no. 453360-1 was supported by two wooden legs with a horizontal portion measuring 5 ft (1,524 mm) in length and no vertical portion, as shown in Figure 33. A 2-in. x 4-in. x 3-ft (51-mm x 102-mm x 914-mm) diagonal wooden plank connected the back end of each leg to its corresponding vertical upright. Four wooden uprights supported three horizontal wooden panels. The two outside uprights were 4 in. x 4 in. x 5 ft (102 mm x 102 mm x 1,524 mm) and the two inside uprights were 2 in. x 4 in. x 4½ ft (51 mm x 102 mm x 1,372 mm). The three wooden panels were 4 ft (1,219 mm) long, 7¼ in. (184 mm) wide, and ¾ in. (19 mm) thick. A 4-ft x 4-ft x ½-in. (1,219-mm x 1,219-mm x 13-mm) diamond-shaped plywood sign panel was attached to the top of the barricade. The overall system height was 8½ ft (2,591 mm). The system was found to be unacceptable according to NCHRP Report 350 criteria when impacted at 0 degrees due to the supports penetrating through the windshield.

The barricade for test no. 453360-4 was supported by two wooden legs with a horizontal portion measuring 5 ft (1,524 mm) in length and no vertical portion, as shown in Figure 34. A 2-in. x 4-in. x 3-ft (51-mm x 102-mm x 914-mm) diagonal wooden plank connected the back end of each leg to its corresponding vertical upright. Four wooden uprights supported three horizontal wooden panels. The two outside uprights were 4 in. x 4 in. x 5 ft (102 mm x 102 mm x 1,524 mm) and the two inside uprights were 2 in. x 4 in. x 4 ft (51 mm x 102 mm x 1,219 mm). The three wooden panels were 4 ft (1,219 mm) long, 7¼ in. (184 mm) wide, and ¾ in. (19 mm) thick. No sign panel was attached to the barricade. The overall system height was 5 ft (1,524 mm). The system was found to be unacceptable according to NCHRP Report 350 criteria when impacted at 0 degrees due to the barricade penetrating through the windshield.

The barricade for test no. 453880-4 was the exact same as the barricade for test no. 453360-4. Note that the only difference between the two tests was that test no. 453880-4 was performed on damp soil while test no. 453360-4 was performed on dry pavement. The system was found to be acceptable according to NCHRP Report 350 criteria when impacted at 0 degrees.

The barricade for test no. 453790-3 was supported by two telespar perforated tube legs with a horizontal portion measuring 5 ft (1,524 mm) in length and vertical splice plates to attach the vertical uprights, as shown in Figure 35. Two telespar perforated tube uprights supported three horizontal plastic hollow core panels. The two uprights were 1½ in. x 1½ in. x 5 ft (38 mm x 38 mm x 1,524 mm). The three plastic panels were 4 ft (1,219 mm) long, 9½ in. (241 mm) wide, and 1½ in. (38 mm) thick. No sign panel was attached to the barricade. The overall system height was 67½ in. (1,715 mm). The system was found to be acceptable according to NCHRP Report 350 criteria when impacted at 0 degrees.

The barricade for test no. 453880-1 was the exact same as the barricade for test no. 453790-3. Note that the only difference between the two tests was that test no. 453880-1 was performed on damp soil while test no. 453790-3 was performed on dry pavement. The system was found to be acceptable according to NCHRP Report 350 criteria when impacted at 0 degrees.

The barricade for test no. 453880-2 was supported by two telespar perforated tube legs with a horizontal portion measuring 5 ft (1,524 mm) in length and vertical splice plates to attach the vertical uprights, as shown in Figure 36. Two telespar perforated tube uprights supported three horizontal wooden panels. The two uprights were 1½ in. x 1½ in. x 5 ft (38 mm x 38 mm x 1,524 mm). The three wooden panels were 4 ft (1,219 mm) long, 7¼ in. (184 mm) wide, and 1 in. (25 mm) thick. No sign panel was attached to the barricade. The overall system height was 5 ft (1,511 mm). The test was performed on damp soil. The system was found to be acceptable according to NCHRP Report 350 criteria when impacted at 0 degrees.

The barricade for test no. 453790-2 was supported by two inverted poly-vinyl U-channel legs with a horizontal portion measuring 3 ft (914 mm) in length and no vertical portion, as shown in Figure 37. Two hollow poly-vinyl uprights supported three horizontal hollow poly-vinyl panels. The two uprights were 5 in. x 5 in. x 5 ft (127 mm x 127 mm x 1,524 mm). The three panels were 4 ft (1,219 mm) long, 5½ in. (140 mm) wide, and 1½ in. (38 mm) thick. No sign panel was attached to the barricade. The overall system height was 5 ft (1,524 mm). The system was found to be acceptable according to NCHRP Report 350 criteria when impacted at 0 degrees.

The barricade for test no. 453790-4 was supported by two wooden legs with a horizontal portion measuring 5 ft (1,524 mm) in length and no vertical portion, as shown in Figure 38. A 2-in. x 4-in. x 3-ft (51-mm x 102-mm x 914-mm) diagonal wooden plank connected the back end of each leg to its corresponding vertical upright. Two recycled plastic uprights supported six horizontal recycled plastic panels. The two uprights were 3.4 in. x 3.4 in. x 5 ft (86 mm x 86 mm x 1,524 mm). The six recycled plastic panels were 4 ft (1,219 mm) long, 3½ in. (89 mm) wide, and ¾ in. (19 mm) thick. No sign panel was attached to the barricade. The overall system height was 5 ft (1,524 mm). The system was found to be acceptable according to NCHRP Report 350 criteria when impacted at 0 degrees.

The barricade for test no. 453880-3 was the exact same as the barricade for test no. 453790-4. Note that the only difference between the two tests was that test no. 453880-3 was performed on damp soil while test no. 453790-4 was performed on dry pavement. The system was found to be acceptable according to NCHRP Report 350 criteria when impacted at 0 degrees.

The barricade for test no. 453790-5 was supported by two recycled plastic legs with a horizontal portion measuring 5 ft (1,524 mm) in length and no vertical portion, as shown in Figure 39. A 1½-in. x 3½-in. x 3-ft (38-mm x 89-mm x 914-mm) diagonal recycled plastic plank connected the back end of each leg to its corresponding vertical upright. Two recycled plastic uprights supported six horizontal recycled plastic panels. The two uprights were 3½ in. x 3½ in. x 5 ft (89 mm x 89 mm x 1,524 mm). The three recycled plastic panels were 4 ft (1,219 mm) long, 3½ in. (89 mm) wide, and ¾ in. (19 mm) thick. No sign panel was attached to the barricade. The overall system height was 5 ft (1,524 mm). The system was found to be unacceptable according to NCHRP Report 350 criteria when impacted at 0 degrees due to the support penetrating through the windshield.

The barricade for test no. 453880-5 was supported by two perforated square tube legs with a horizontal portion measuring 5 ft (1,524 mm) in length and vertical splice plates to attach the vertical uprights, as shown in Figure 40. Four square perforated tube uprights supported three horizontal wooden panels. The two outside uprights were 1½ in. x 1½ in. x 5 ft (38 mm x 38 mm x 1,524 mm) and the two inside uprights were 1½ in. x 1½ in. x 8 ft (38 mm x 38 mm x 2,438 mm). The three wooden panels were 4 ft (1,219 mm) long, 8 in. (203 mm) wide, and 1 in. (25 mm) thick. A 4-ft x 4-ft x 0.1-in. (1,219-mm x 1,219-mm x 3-mm) diamond-shaped aluminum sign panel was attached to the top of the two inside vertical uprights, which extended beyond the top wood panel. The overall system height was 10.8 ft (3,302 mm). The system was found to be unacceptable according to NCHRP Report 350 criteria when impacted at 0 degrees due to the windshield shattering and deformation from sign panel contact. However, the researchers believed that vertical bracing behind the sign panel or lowering the mounting height would perform satisfactorily.

The barricade for test no. 453880-6 was supported by two recycled plastic lumber legs with a horizontal portion measuring 5 ft (1,524 mm) in length and no vertical portion, as shown in Figure 41. A 2-in. x 4-in. x 3-ft (51-mm x 102-mm x 914-mm) diagonal recycled plastic lumber plank connected the back end of each leg to its corresponding vertical upright. Four hollow core plastic uprights supported three horizontal hollow core recycled plastic panels. The two outside uprights were 4 in. x 4 in. x 5 ft (102 mm x 102 mm x 1,524 mm) and the two inside uprights were 4 in. x 4 in. x 8 ft (102 mm x 102 mm x 2,438 mm). The three wooden panels were 4 ft (1,219 mm) long, 8 in. (203 mm) wide, and 1 in. (25 mm) thick. A 4-ft x 4-ft x 0.1-in. (1,219-mm x 1,219-mm x 3-mm) diamond-shaped aluminum sign panel was attached to the top of the barricade. The overall system height was 9 ft (2,743 mm). The system was found to be acceptable according to NCHRP Report 350 criteria when impacted at 0 degrees. Similar to the system in test no. 453880-5, the researchers recommended adding vertical bracing behind the sign panel or lowering the mounting height for a better performance.

The barricade for test no. 453880-7 was supported by two perforated square tube legs with a horizontal portion measuring 5 ft (1,524 mm) in length and vertical splice plates to attach the vertical uprights, as shown in Figure 42. Four square perforated tube uprights supported three horizontal wooden panels. The two outside uprights were 1½ in. x 1½ in. x 5 ft (38 mm x 38 mm x 1,524 mm) and the two inside uprights were 1½ in. x 1½ in. x 8 ft (38 mm x 38 mm x 2,438 mm). The three wooden panels were 4 ft (1,219 mm) long, 8 in. (203 mm) wide, and 1 in. (25 mm) thick. A 4-ft x 4-ft x 0.1-in. (1,219-mm x 1,219-mm x 3-mm) diamond-shaped aluminum sign panel was attached to the top of the two inside vertical uprights, which extended beyond the top wood panel. The bottom 2 in. (51 mm) of the sign were attached to the top wood panel with a 3-in. (76-mm) long, ⅜-in. (10-mm) diameter A307 bolt. The overall system height was 9 ft (2,743 mm). The system was found to be acceptable according to NCHRP Report 350 criteria when impacted at 0 degrees. However, the sign panel attachment mechanism was not recommended for implementation due to the potential hazard from the debris.

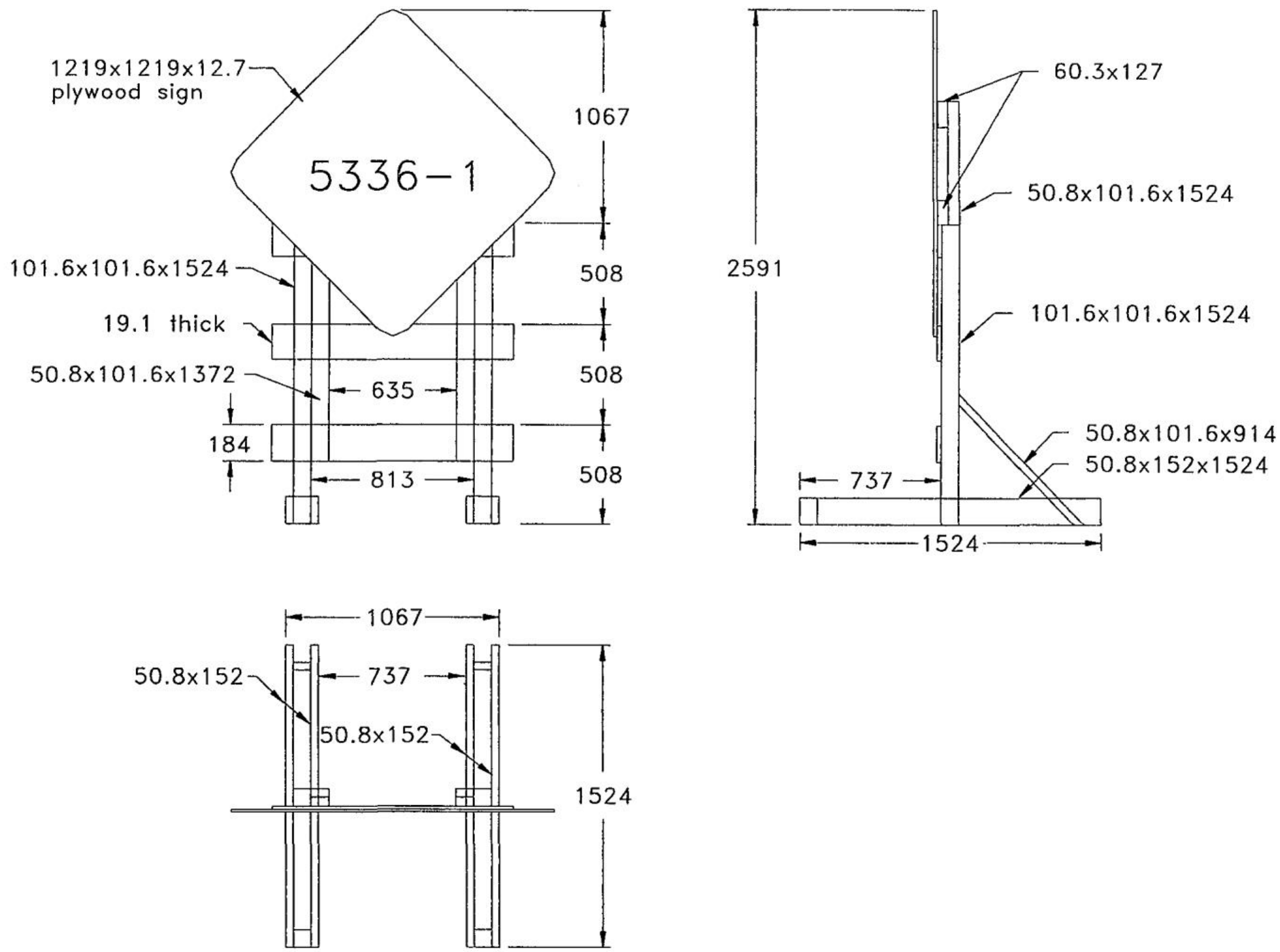

Figure 33. Test No. 453360-1 Type III Barricade (*16*)

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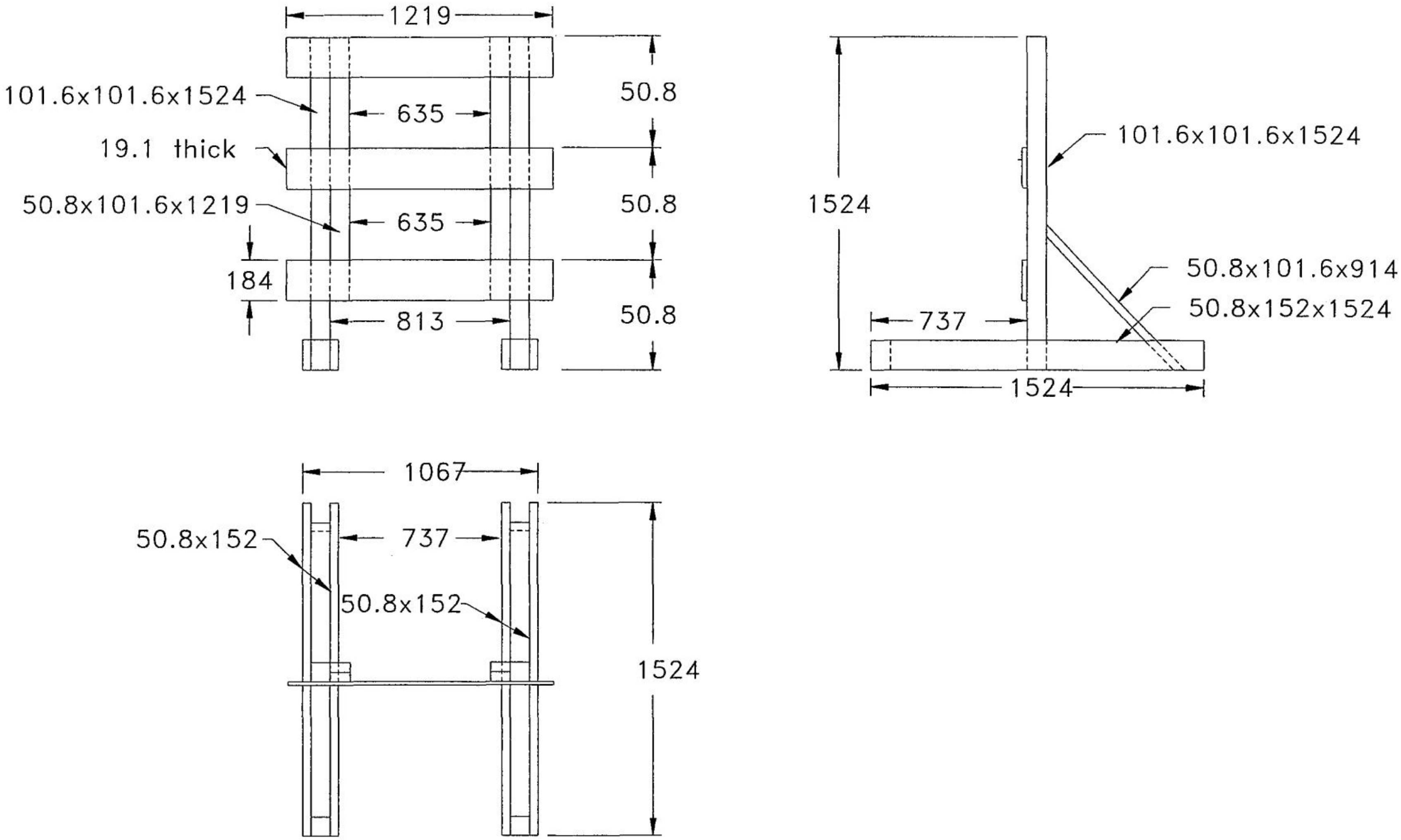

Figure 34. Test Nos. 453360-4 and 453880-4 Type III Barricade (*16*)

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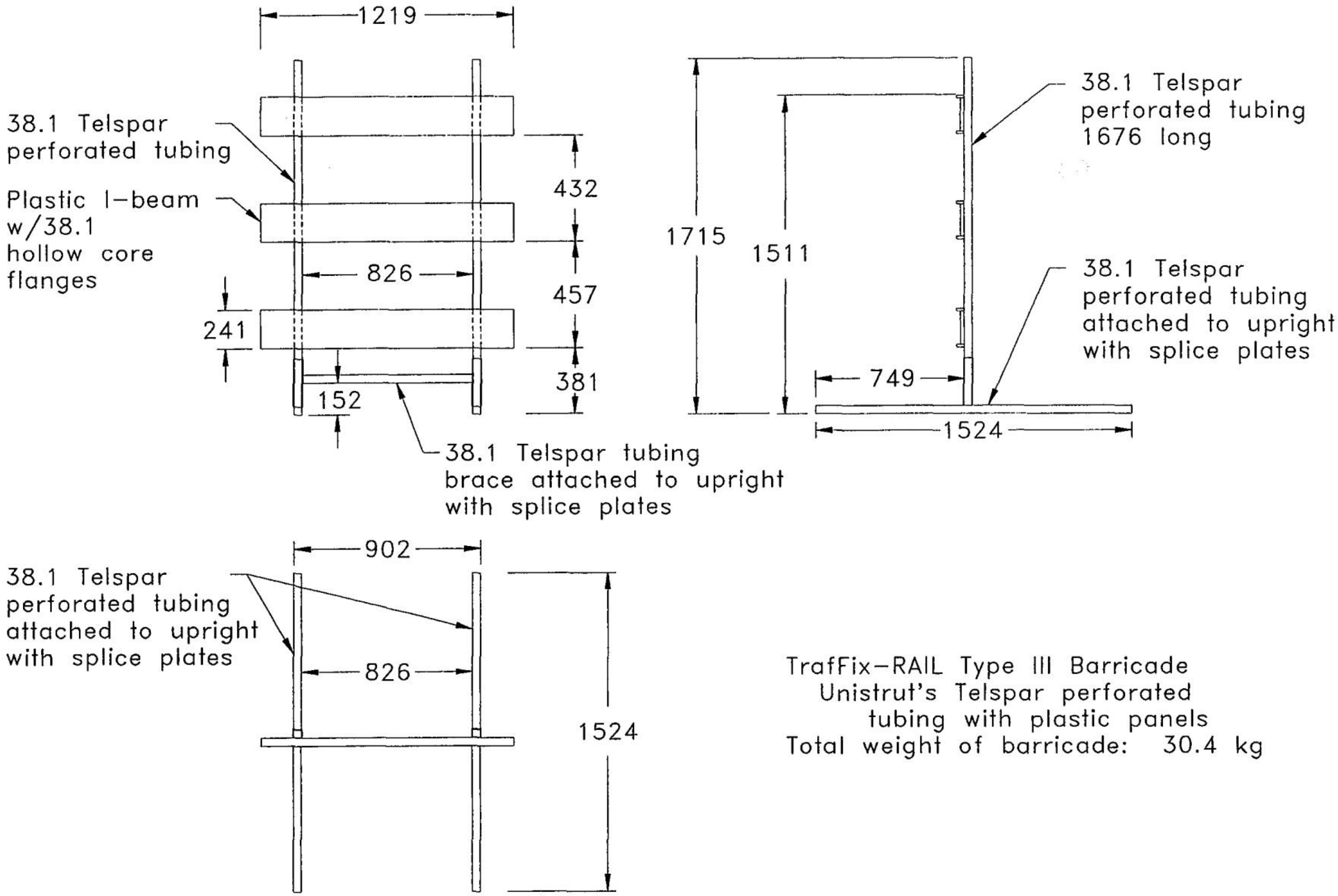

Figure 35. Test Nos. 453790-3 and 453880-1 Type III Barricade (*16*)

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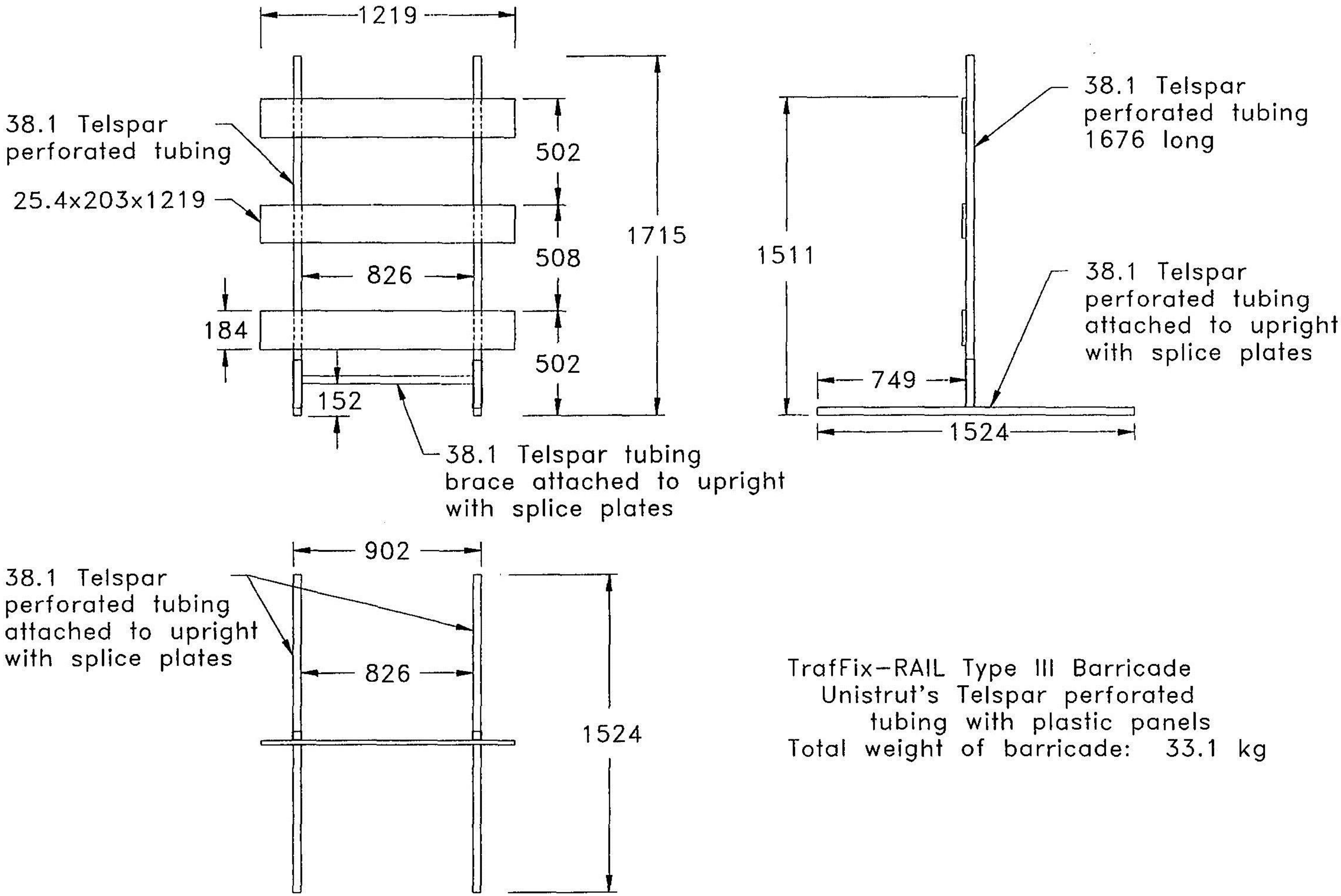

Figure 36. Test No. 453880-2 Type III Barricade (*16*)

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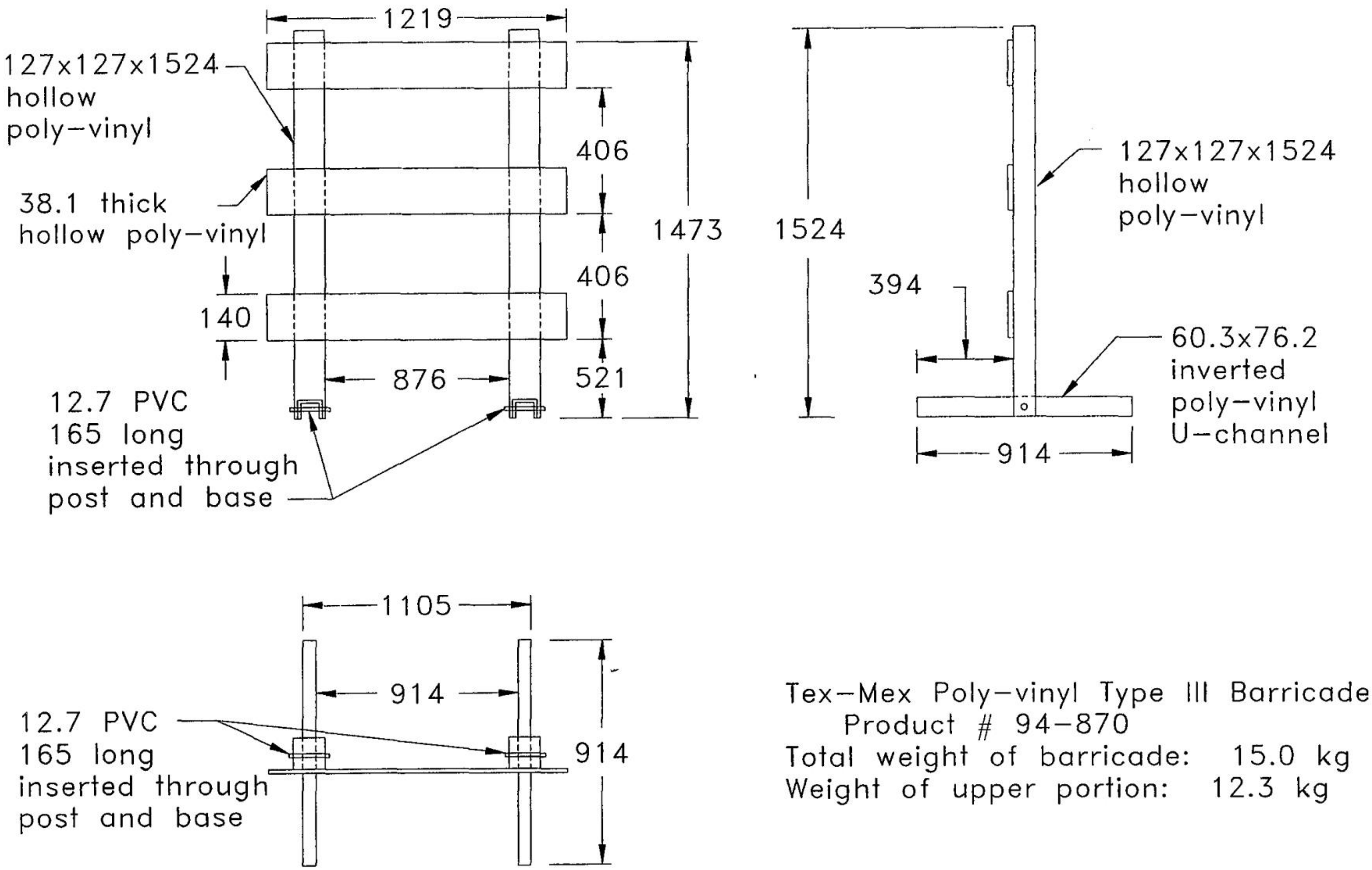

Figure 37. Test No. 453790-2 Type III Barricade (*16*)

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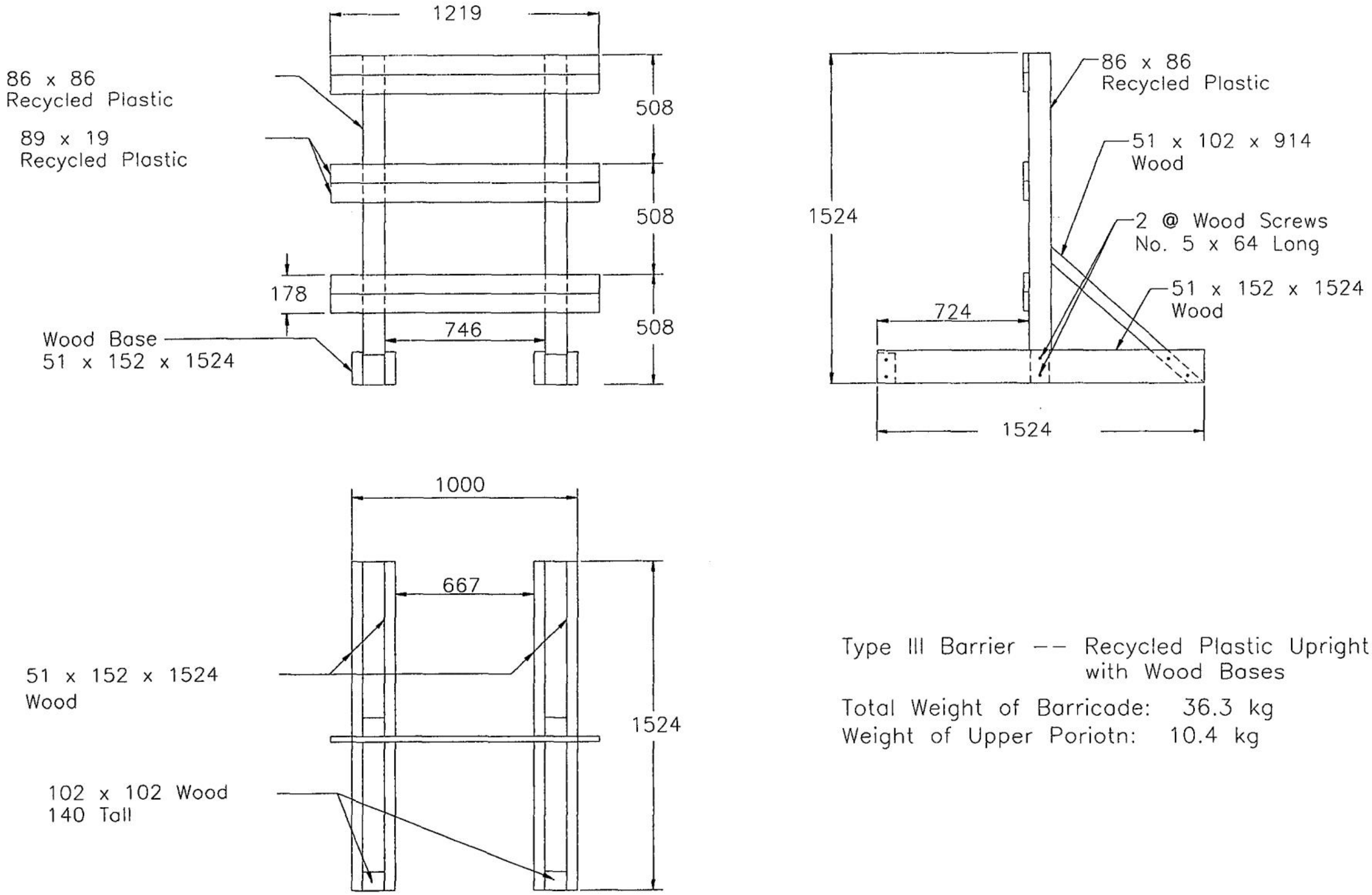

Figure 38. Test Nos. 453790-4 and 453880-3 Type III Barricade (*16*)

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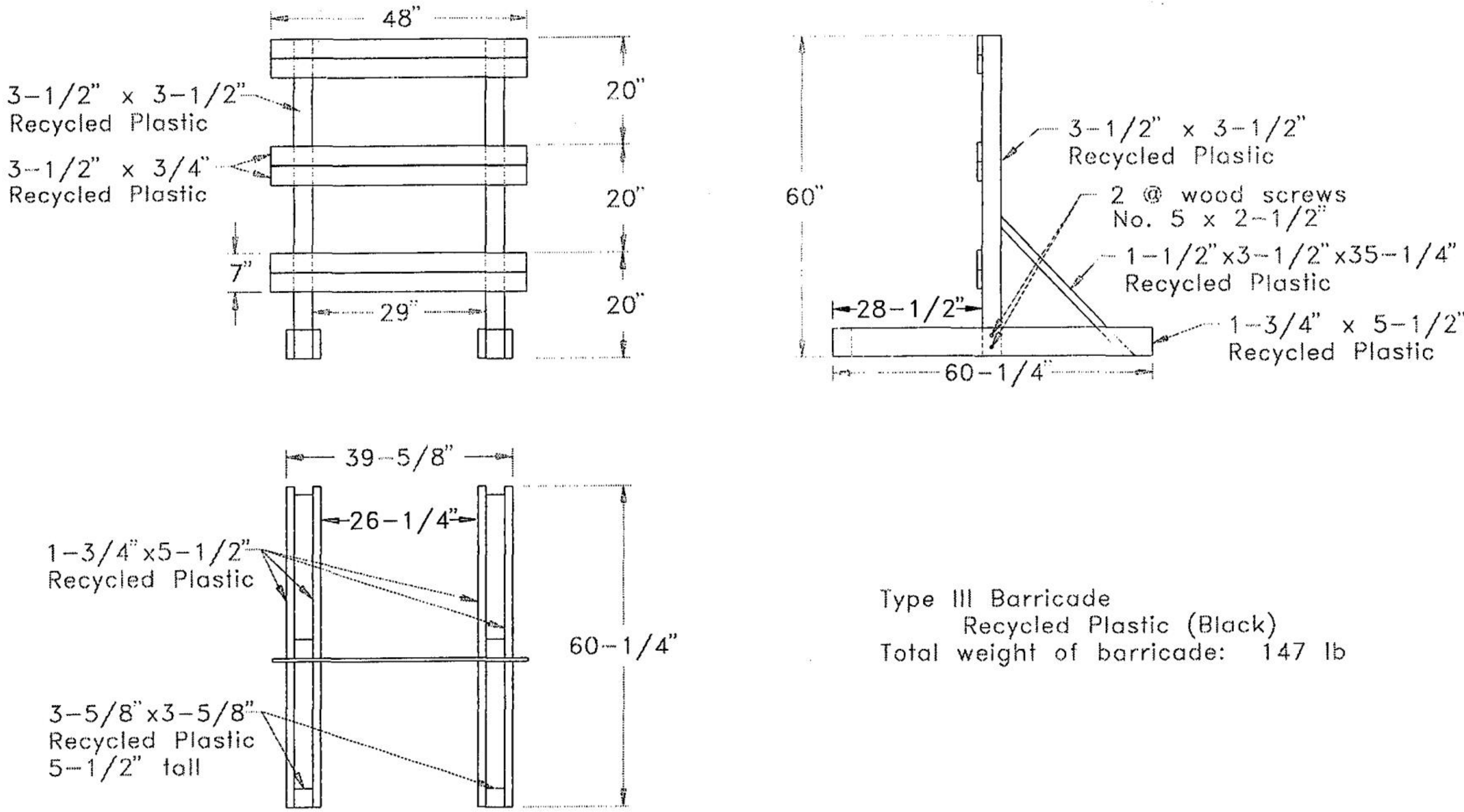

Figure 39. Test No. 453790-5 Type III Barricade (*16*)

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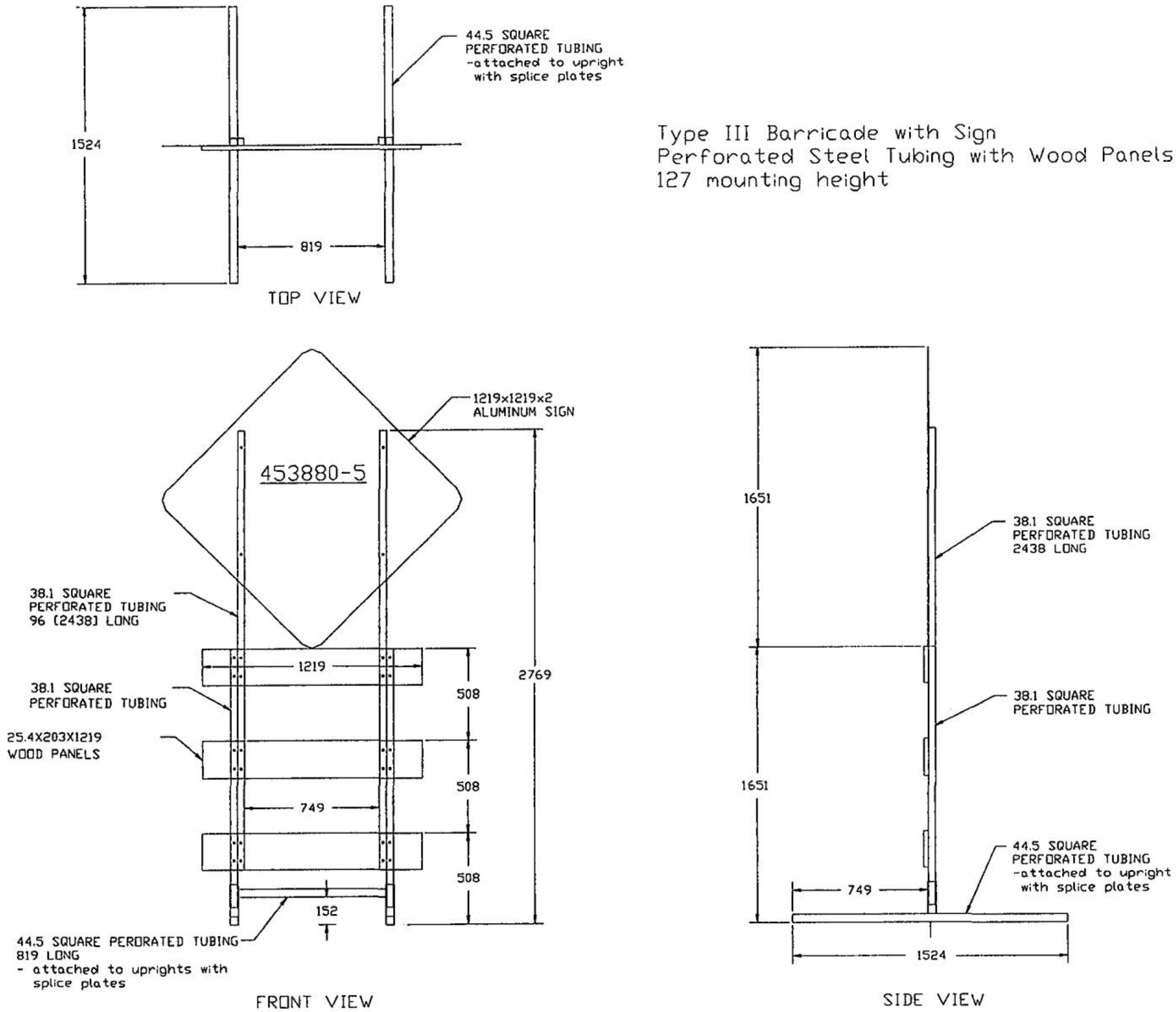

Figure 40. Test No. 453880-5 Type III Barricade (*16*)

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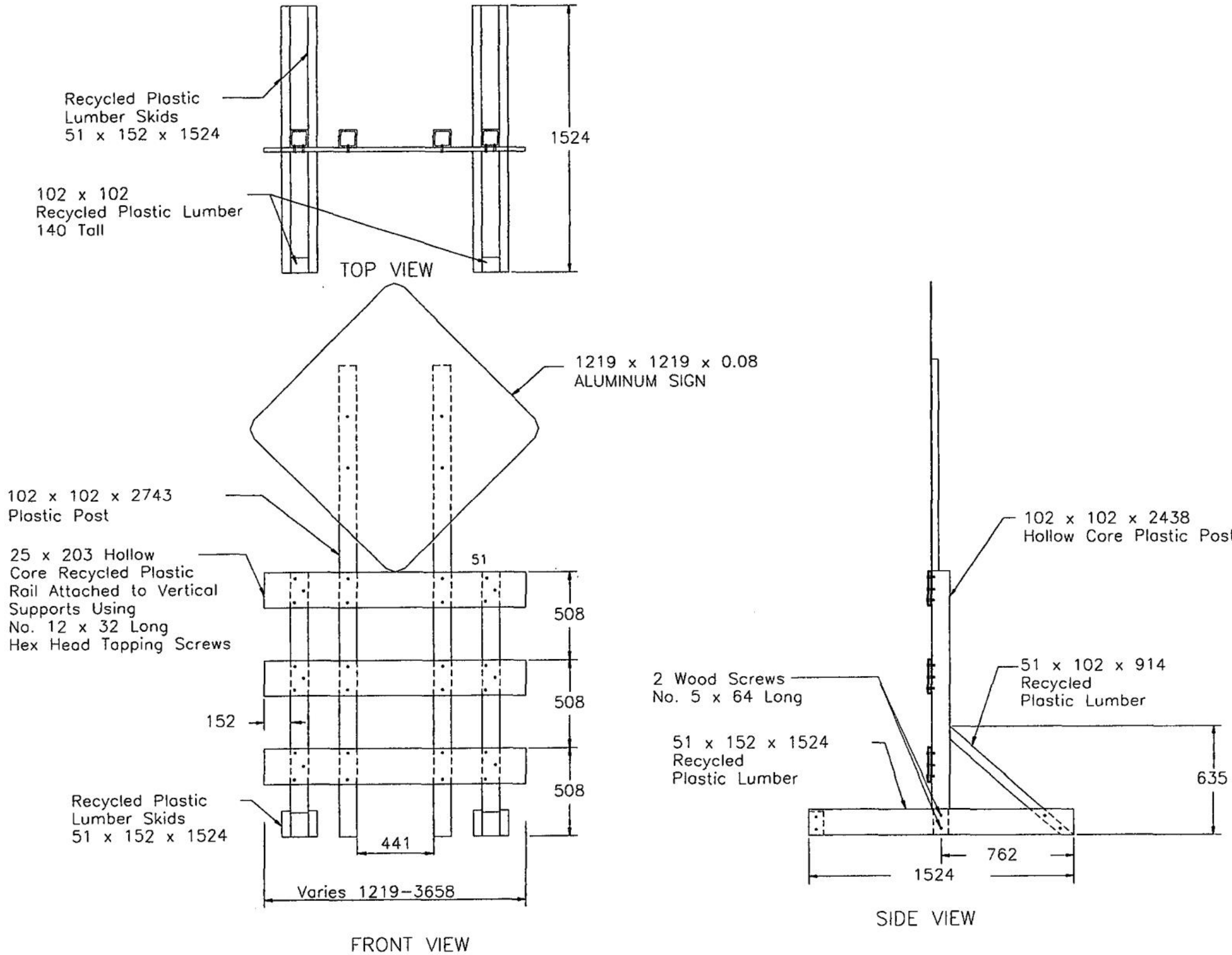

Figure 41. Test No. 453880-6 Type III Barricade (*16*)

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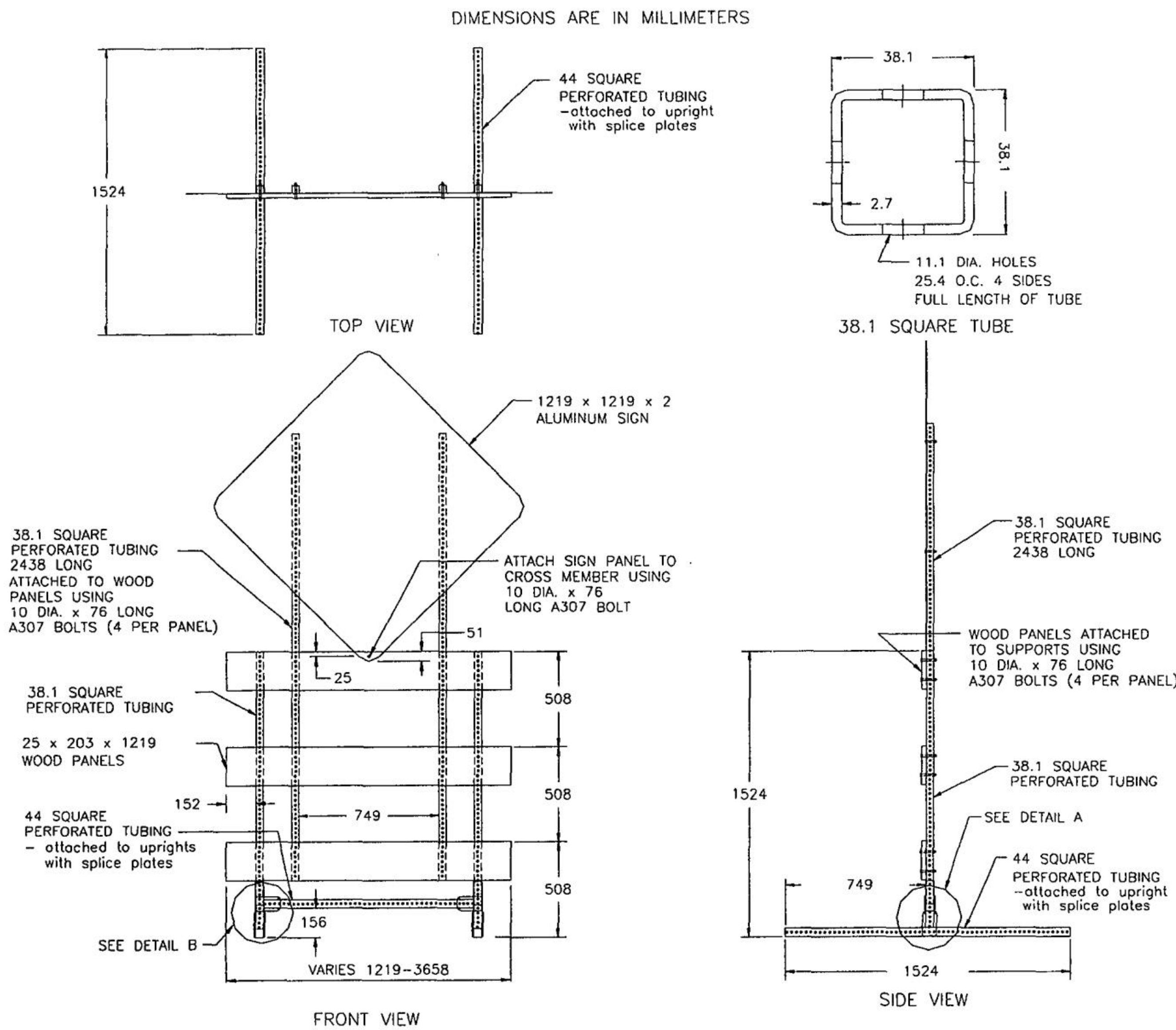

Figure 42. Test No. 453880-7 Type III Barricade (*16*)

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NCHRP Report 553 included four full-scale crash tests of Type III barricades (*17*). No drawings were obtained from the report, but each of the four tests are summarized briefly below. For Test 1, a 6-in. (152-mm) long vertical sleeve fabricated from 1¾-in. (44-mm) square, perforated steel square tubing was welded to the center of each 5-ft (1.5-m) long skid fabricated from the same material. A 1½-in. (38-mm) square x 4-ft – 10-in. (1.5-m) long perforated steel square upright was inserted into the sleeves and connected using a ⅜-in (10-mm) diameter through bolt. Three 1-in. x 8-in. x 8-ft (25-mm x 203-mm x 2.4-m) wooden rails were bolted to 1½-in. (38-mm) square x 4-ft (1.2-m) long perforated steel square braces spaced 4 ft – 3 in. (1.3 m) apart. The top of the upper rail was flush with the ends of the braces, and the center and lower rails were spaced 1 ft – 8 in. (0.51 m) apart from each other. A 4-ft x 4-ft x ½-in. (1.2-m x 1.2-m x 13-mm) plywood sign panel was attached to the face of the rails in a diamond orientation. The bottom corner of the sign panel was mounted flush with the bottom edge of the lower rail, and the top of the sign panel extended approximately 1 ft – 8 in. (0.51 m) above the top edge of the upper rail, or 6 ft – 8 in. (2.0 m) above ground. The system was found to be marginally acceptable according to NCHRP Report 350 criteria at 0-degree and 90-degree impact angles, since the windshield was shattered and had 2 in. (50 mm) of crush.

For Test 2, the design used vertical braces manufactured from standard 2-in. x 4-in. (51-mm x 102-mm) dimensional lumber. The horizontal rails and sign panel were attached to these vertical braces. The 2.5-ft x 5-ft x ½-in. (0.8-m x 1.5-m x 13-mm) rectangular plywood sign panel was mounted at a height of 2.5 ft (0.8 m) above ground. This placed the top of the sign panel flush with the top edge of the upper horizontal rail. The assembled rail and sign panel unit was bolted to the 1½-in. (38-mm) square, perforated steel square tube uprights through the rails and sign panel. The uprights, which were spaced 4.5 ft (1.4 m) apart, telescoped inside a 1¾-in. (44-mm) square, 9¾-in. (248-mm) long, perforated steel square tube sleeve that was welded to 1¾-in. (44-mm) square, perforated steel tube skids. The longer tube sleeves permit telescoping of the uprights to provide adjustability for placement of the barricade on sloping terrain. A Type A warning light was also attached to the top of the left upright. The system was found to be unacceptable according to NCHRP Report 350 criteria due to a small hole in the windshield.

For Test 3, other than the addition of a horizontal brace, the barricade system was identical to the design used in Test 2. The system was found to be acceptable according to NCHRP Report 350 criteria at 0-degree and 90-degree impact angles.

For Test 4, the barricade uprights were 4-in. (102-mm) square hollow-profile plastic lumber (HPPL) manufactured from high-density polyethylene (HDPE). The uprights were bolted between the legs of the 2-in. x 6-in. (51-mm x 152-mm) wood skids in two locations to form a moment connection to resist rotation. Short lengths of the (4-in. [102-mm] square) HPPL were used as spacers at the front and back of the skids. As with the steel frame barricade designs, the 1-in. x 8-in. (25-mm x 203-mm) wooden horizontal rails and 2.5-ft x 5-ft x ½-in (0.8-m x 1.5-m x 13-mm) plywood sign panel were attached to the vertical braces. The vertical braces were fabricated from the same size HPPL used for the barricade uprights. The system was found to be acceptable according to NCHRP Report 350 criteria at 0-degree and 90-degree impact angles.

Skid-Mounted Temporary Sign Stand

TTI conducted two crash tests on a temporary, skid-mounted, wood support sign stand (*18*), similar to Figure 43. For test nos. 467824-1 and 467824-2, the test installation involved an 8-ft (2.4-m) tall × 12-ft (3.7-m) wide extruded aluminum sign panel supported by five 4-in. x 6-in. (102-mm x 152-mm), Grade 2, Southern Yellow Pine wood support posts at a mounting height of 7½ ft (2.3 m) from the ground to the bottom of the sign panel. The mounting height was increased 6 in. (152 mm) beyond the standard mounting height of 7 ft (2.1 m) to provide additional clearance for the pickup truck to pass beneath the sign panel and fractured supports in the event the vehicle climbs on top of the horizontal skids while traversing the system.

Each of the vertical support posts were connected to a pair of 2-in. x 6-in. x 12-ft (51-mm x 152-mm x 3.7-m) long horizontal skids using two ⅜-in. (10-mm) diameter x 7½-in. (191-mm) long A307 hex head bolts. A 2-in. x 6-in. (51-mm x 152-mm) board was secured across the top of the horizontal skids against the front and back sides of the support posts using three 3-in. (76-mm) long, #9 deck screws per skid. A ¾-in. (19-mm) thick, 32-inch (813-mm) wide plywood deck was attached to the top of the skids on their leading and trailing ends to provide a platform for the sand bag ballast. The plywood deck was attached to each skid using 2-in. (51-mm) long, #8 deck screws. Fifty-six 40-lb (18 kg) sand bags were evenly distributed on the front and back plywood decks. The system was tested to MASH 2009 test designation no. 3-70 with an impact speed of 19.1 mph (30.7 km/h) and an impact angle of 0 degrees and was found to be acceptable. The system was tested to MASH 2009 test designation no. 3-71 with an impact speed of 62.1 mph (100.0 km/h) and an impact angle of 0 degrees and was found to be unacceptable due to a longitudinal occupant impact velocity greater than the MASH limit of 16.4 ft/s (5.0 m/s). Design modifications were implemented including tapering the ends of the skids, incorporating weakening holes at the top of the skids and at 23 in. (584 mm) above ground, removing a gusset plate, adding a second diagonal brace, and adjusting the post spacing. Test no. 467824-3 was a repeat of MASH 2009 test designation no. 3-71, and the system was found to be acceptable according the MASH 2009 test designation no. 3-71 criteria at a 0-degree impact angle. Test no. 467824-4 was a MASH 3-72 test, and the system was found to be acceptable according to the MASH 2009 test designation no. 3-72 criteria at a 0-degree impact angle. The Wisconsin skid-mounted sign support is a very similar system and will not be further explored during this project.

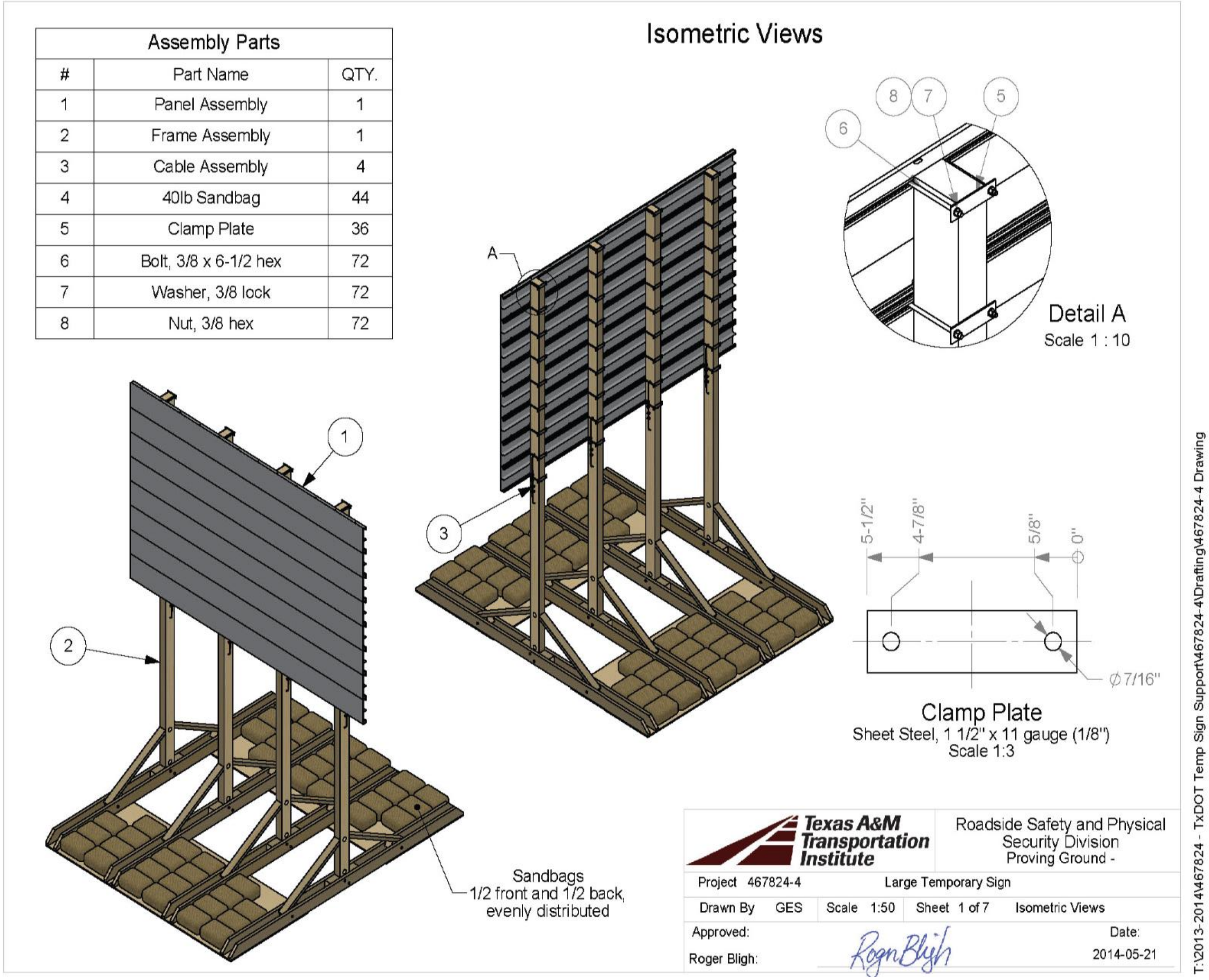

Figure 43. Test Nos. 467824-3 and 467824-4 Type III Barricade (*18*)

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SYSTEM SELECTION AND DESIGN DETAILS

Since some non-proprietary work-zone sign stands have already been tested to MASH 2016, the highest need was determined to be a non-proprietary Type III barricade, none of which had been evaluated to MASH 2016 crash test standards. While several different variations of the systems existed, the final system was designed to be the most useful to the state DOT sponsors.

The test installation consisted of two identical work-zone traffic control devices, as shown in Figures 44 through 51. Photographs of the test installation are shown in Figure 52. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

Each Type III barricade consisted of three horizontal HDPE panels, measuring 96 in. (2,428 mm) in length, with a 48-in. x 30-in. x 0.08-in. (1,219-mm x 762-mm x 2-mm) aluminum sign attached to the top two barricade panels. The barricade panel was targeted to have a cross-sectional dimension of 8 in. (203 mm) x 1 in. (25 mm). However, the dimensions vary between manufacturers, and the supplied barricade panel was 8¼ in. (210 mm) x ¾ in. (19 mm). The barricade panels were attached to two 1¾-in. (44-mm) x 14-ga (1.9-mm) thick PSST uprights, which were inserted into two 2-in. (51-mm) x 14-ga (1.9-mm) thick x 6-in. (152-mm) long vertical stubs that were welded to two legs. The legs were 2-in. (51-mm) x 14-ga (1.9-mm) thick x 60-in. (1,524-mm) long PSST. All PSST used was galvanized ASTM 1011 Grade 50 steel with a minimum yield strength of 60 ksi. A 50-lb (23-kg) sandbag was placed on top of the end of each leg. A warning light was attached to the front of the top barricade panel and upright at both upright locations.

Two identical Type III barricades were evaluated. System A was oriented at 0 degrees, or head-on to the vehicle. System B was oriented at 90 degrees, or end-on to the vehicle. Initial vehicle impact with System A was to occur with a right quarter-point offset from the centerline of the car and initial vehicle impact with System B was to occur with a left quarter-point offset from the centerline of the car, as shown in Figure 44.

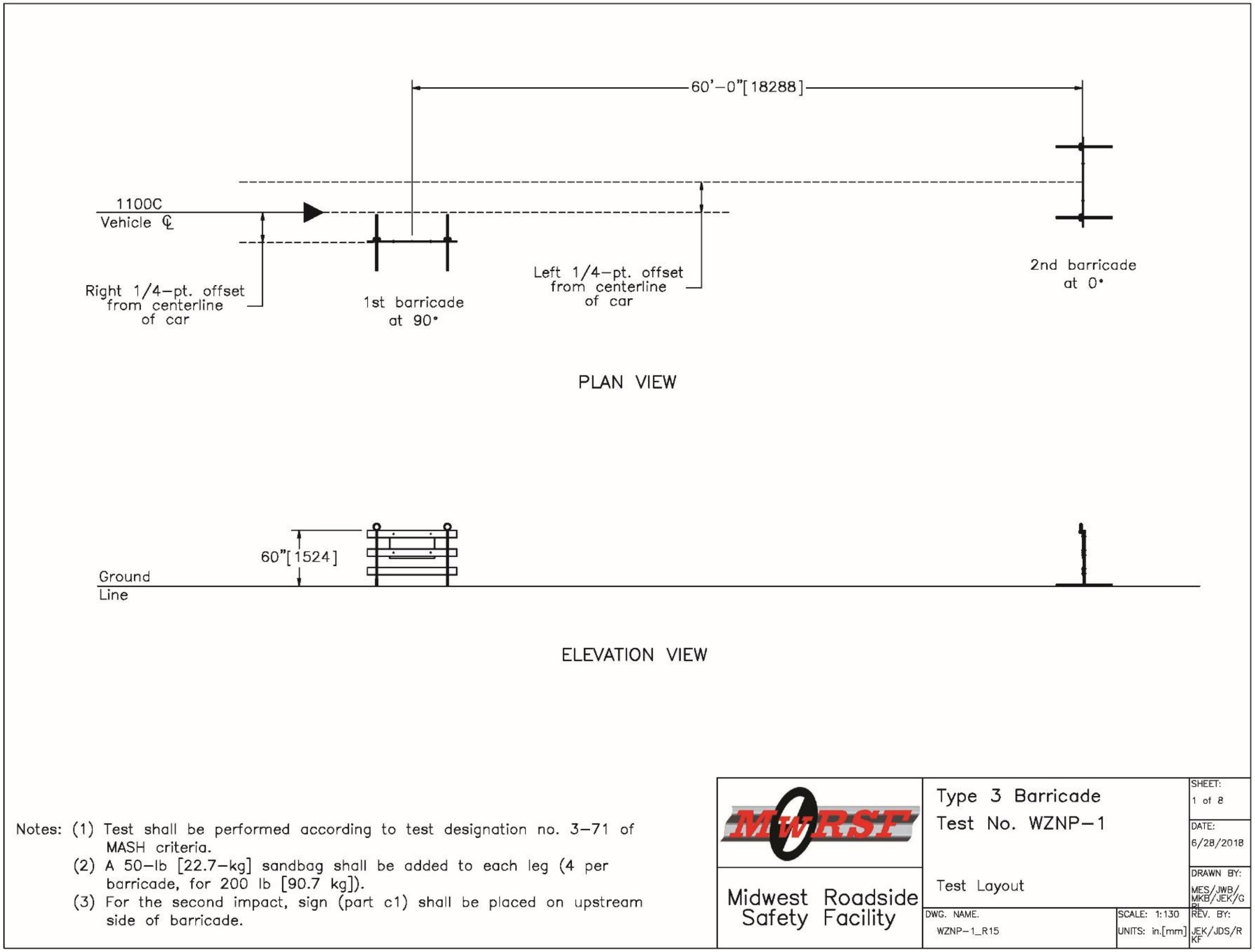
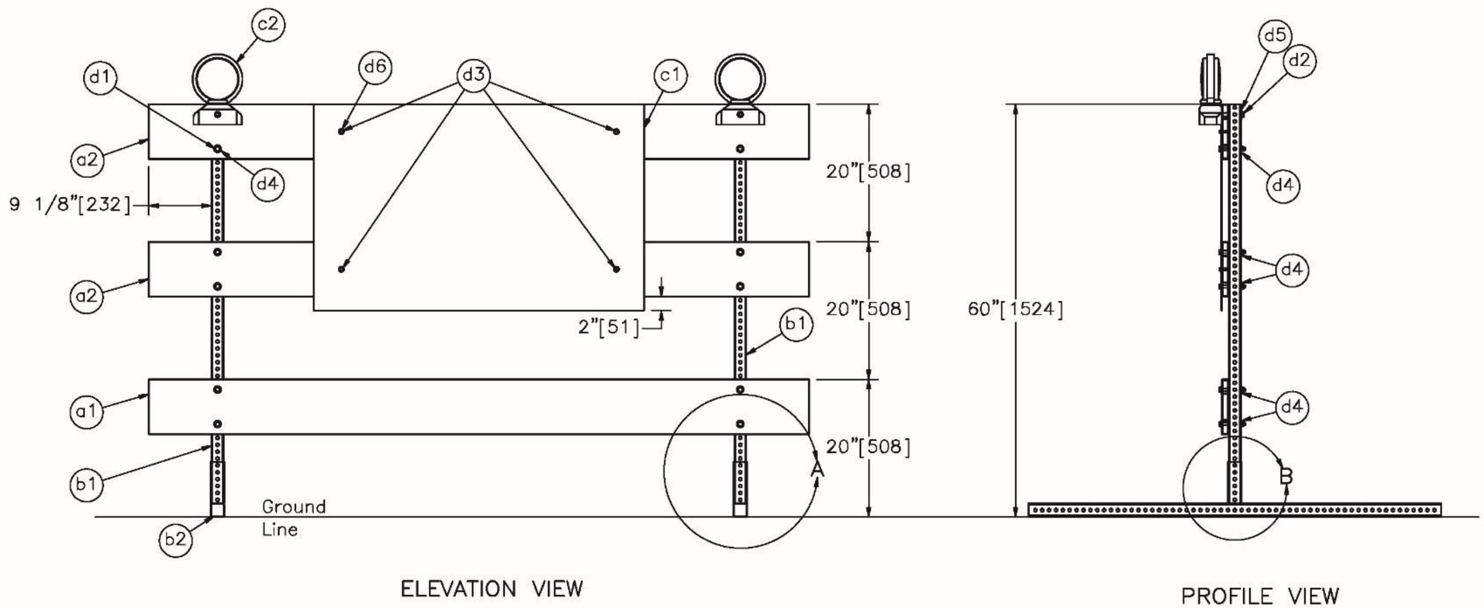


Figure 44. Test Installation Layout, Test No. WZNP-1



Note: (1) Total barricade weight = 61 lb [27.7 kg].
(2) Additional washers (parts d4, d5, and d6) on the opposite side.

MwRSF
Midwest Roadside Safety Facility

Type 3 Barricade
Test No. WZNP-1

Barricade Overview

SHEET: 2 of 8
DATE: 6/28/2018
DRAWN BY: MES/JWB/MKB/JEK/GRL
DWG. NAME. WZNP-1_R15
SCALE: 1:22
UNITS: in.[mm]
REV. BY: JEK/JDS/RKF

Figure 45. Barricade Overview, Test No. WZNP-1

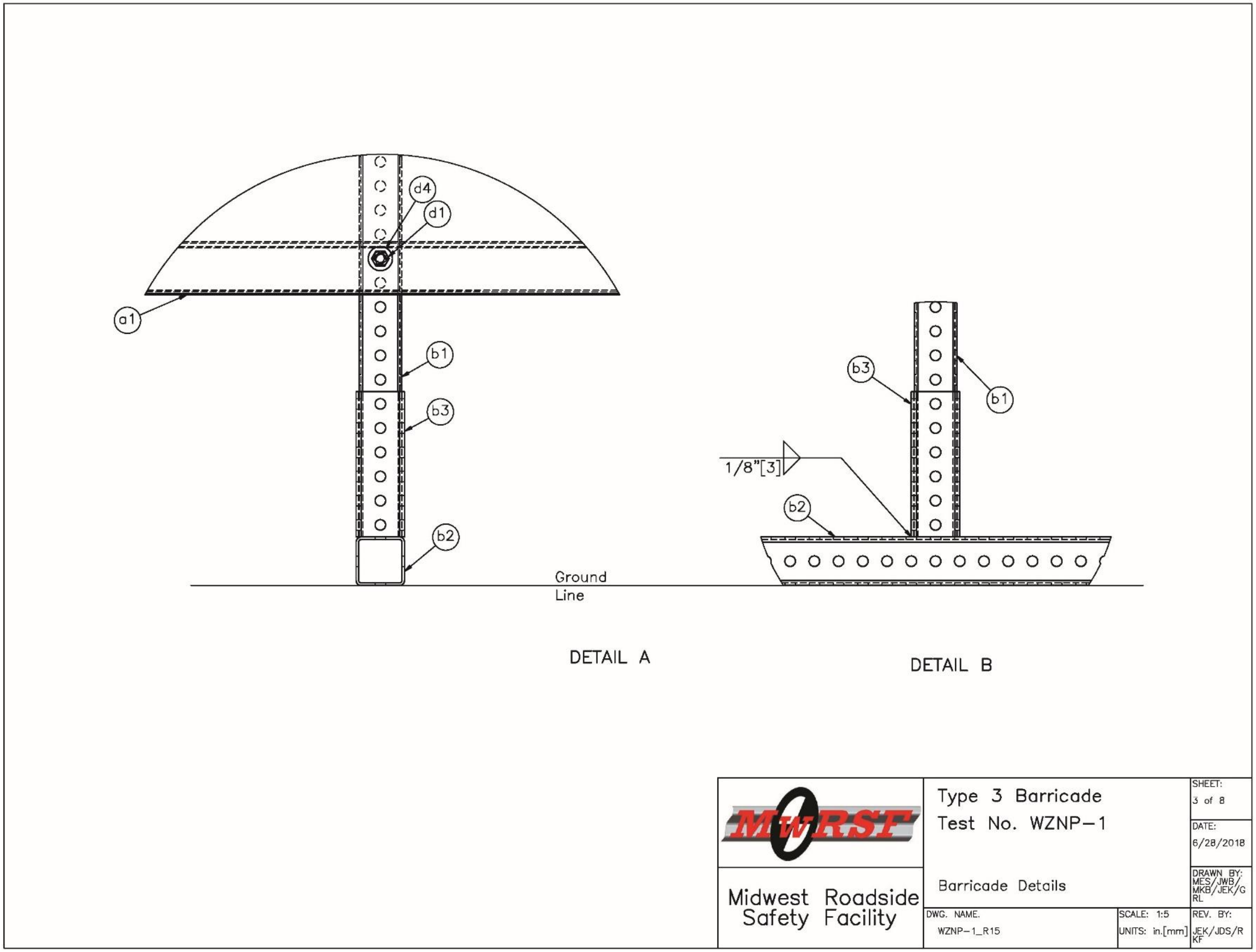


Figure 46. Barricade Details, Test No. WZNP-1

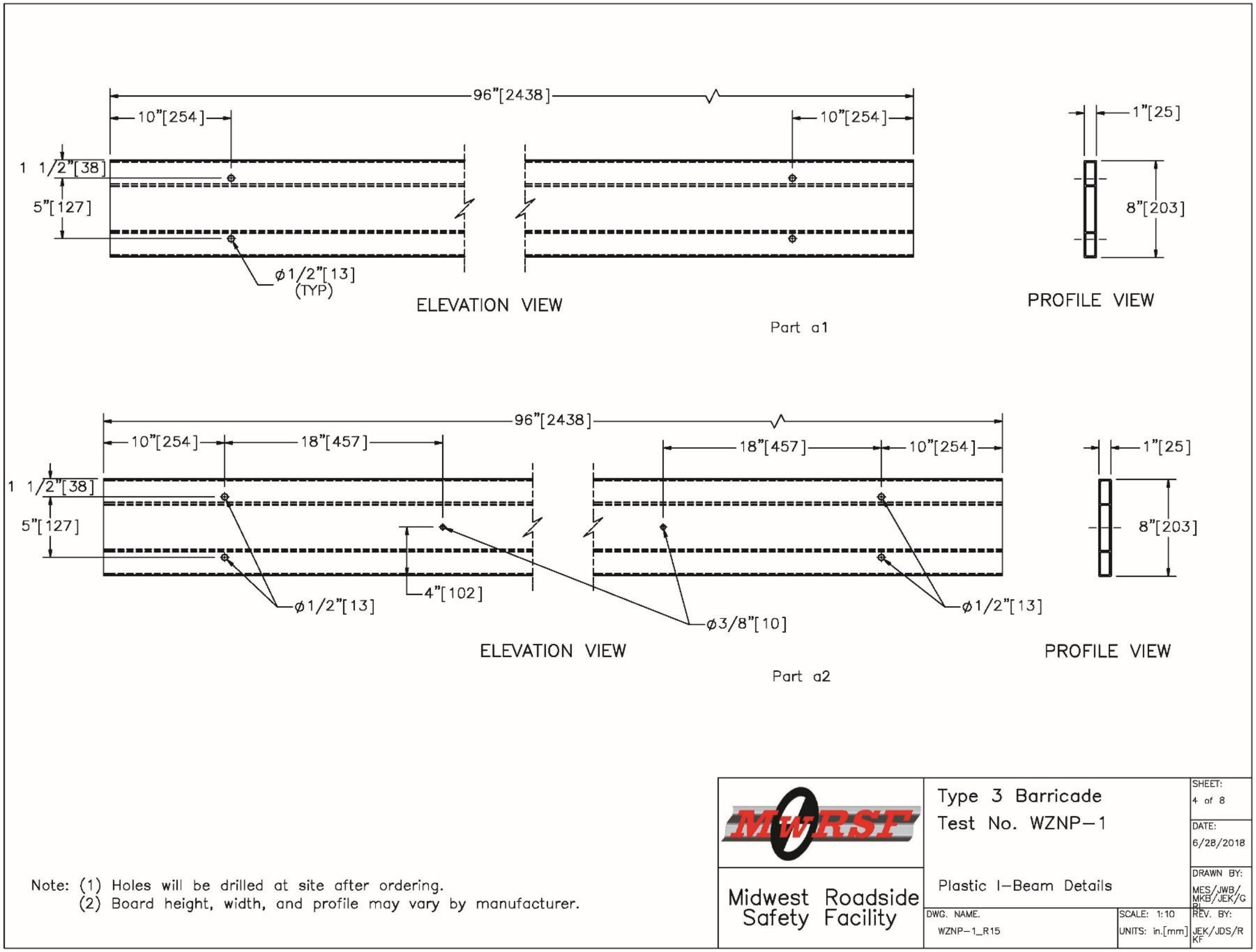


Figure 47. Plastic Beam Details, Test No. WZNP-1

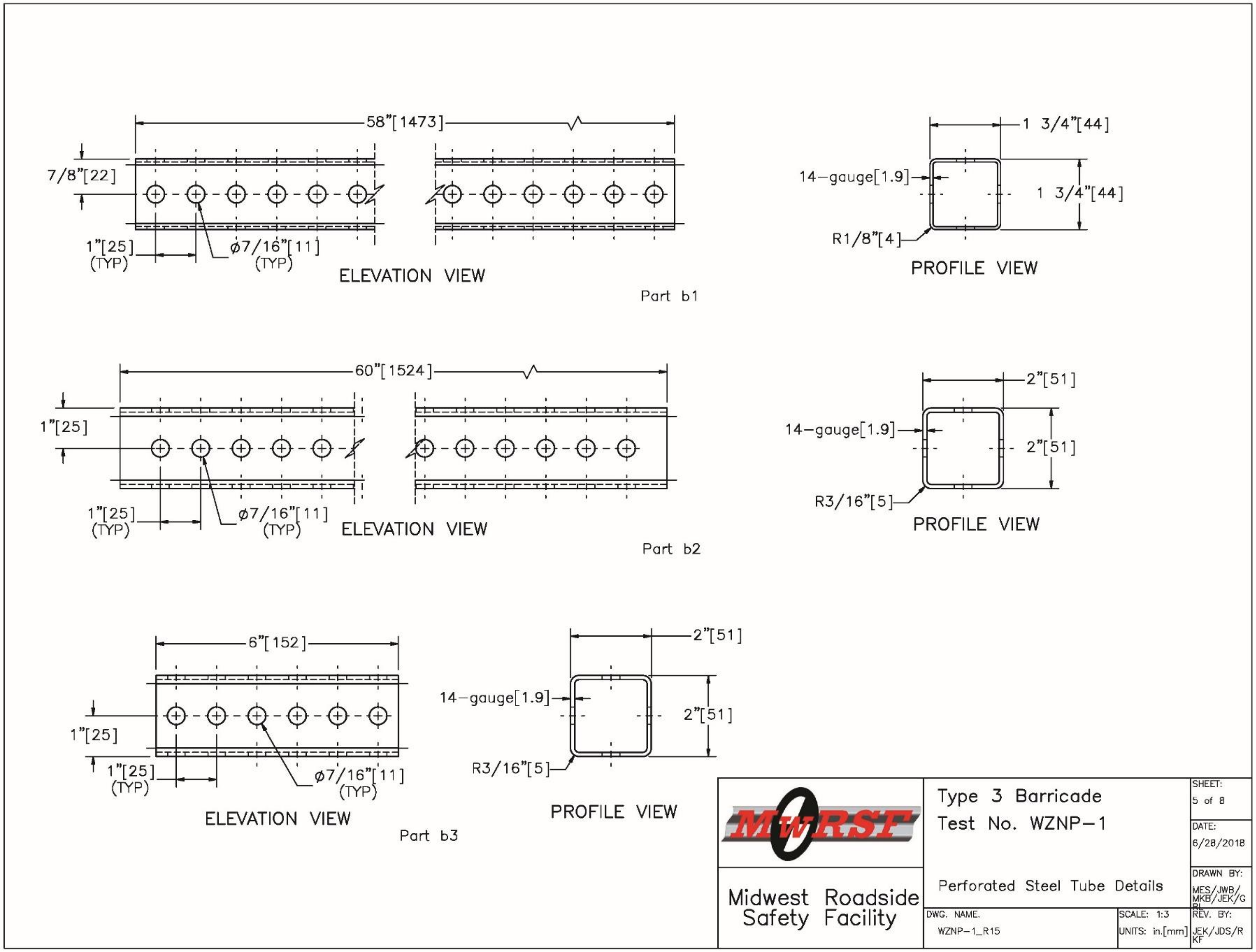


Figure 48. Perforated Steel Tube Details, Test No. WZNP-1

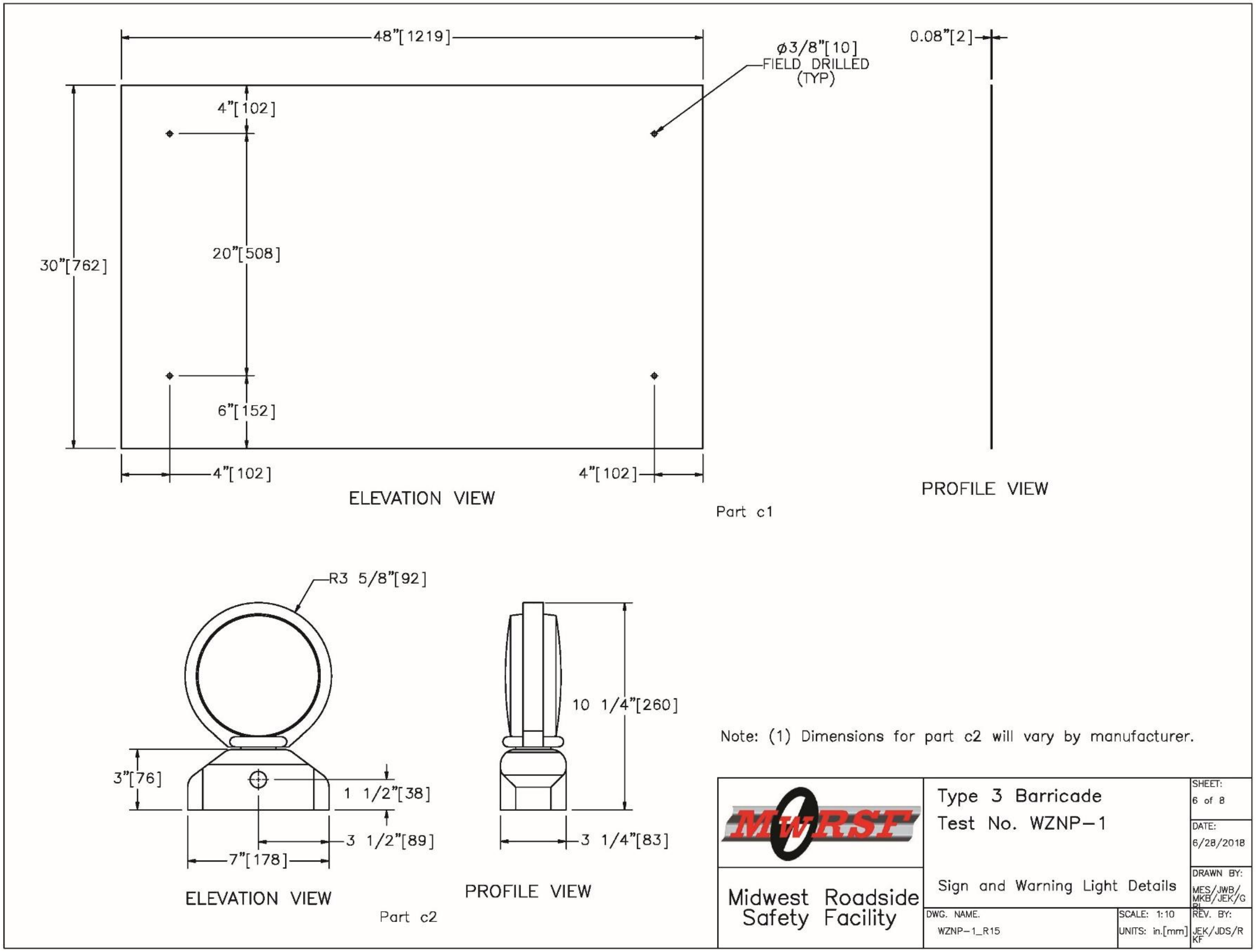
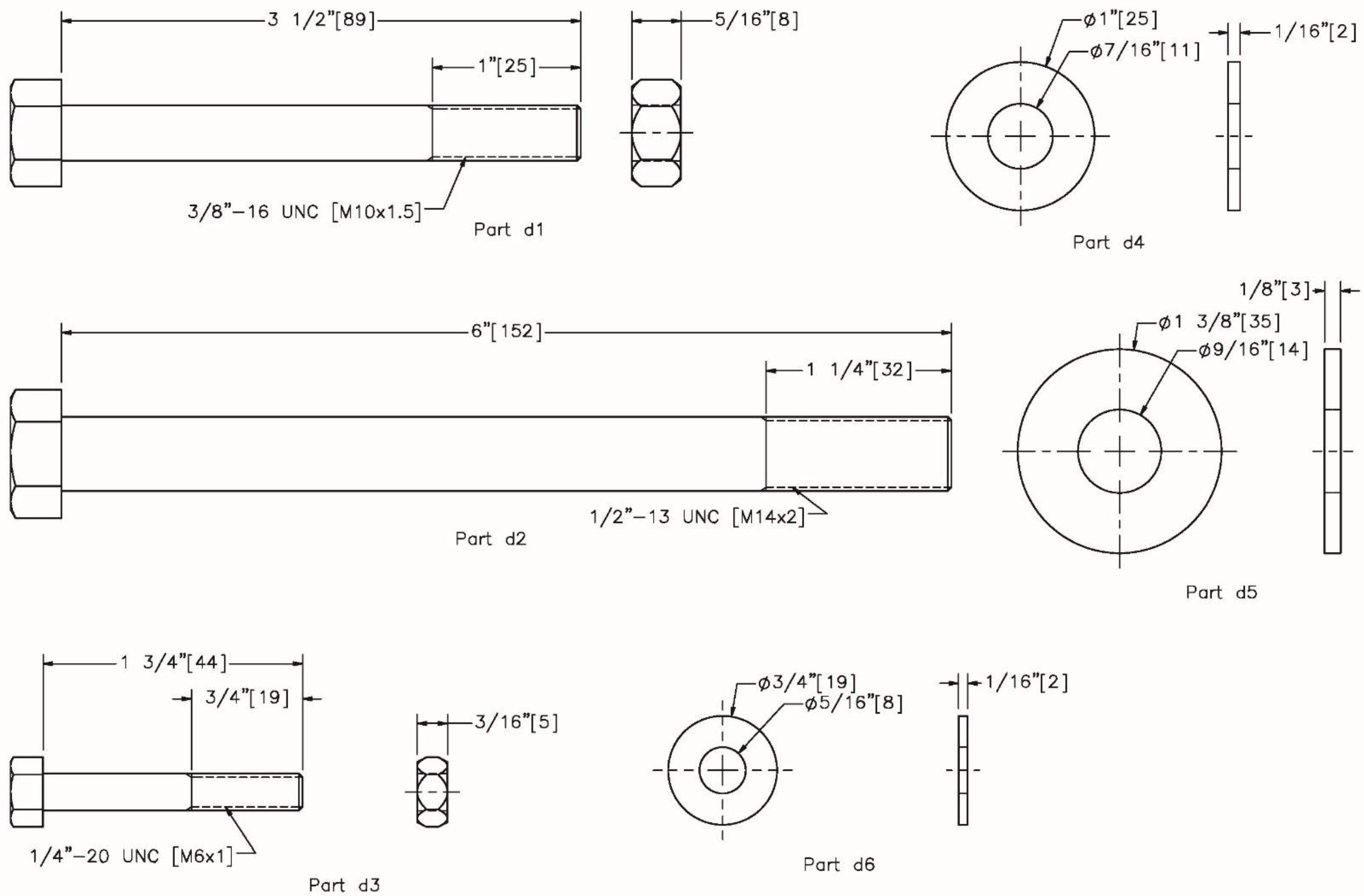


Figure 49. Sign and Warning Light Details, Test No. WZNP-1



MwRSF	Type 3 Barricade Test No. WZNP–1	SHEET: 7 of 8 DATE: 6/28/2018
Midwest Roadside Safety Facility	System Hardware	DRAWN BY: MES/JWB/MKB/JEK/GBL
	DWG. NAME. WZNP–1_R15	SCALE: 1:1 UNITS: in.[mm]	REV. BY: JEK/JDS/RKF

Note: (1) Part d2 length may vary by barricade rail manufacturer and diameter may vary by warning light manufacturer. Hole size in parts a2 and b1 may need to be adjusted to accommodate part d2.

Figure 50. System Hardware, Test No. WZNP-1

Item No.	QTY.	Description	Material Specification	Treatment Specification
a1	2	Plastic Panel, 96" [2,438] Long	High Density Polyethylene	–
a2	4	Plastic Panel, 96" [2,438] Long	High Density Polyethylene	–
b1	4	1 3/4"x1 3/4"x14–gauge [44x44x1.9], 58" [1,473] Long Perforated Square Tubing	ASTM 1011 Gr. 55 Min. yield 60 ksi [414 MPa]	ASTM A653–G90 or AASHTO M–120
b2	4	2"x2"x14–gauge [51x51x1.9], 60" [1,524] Long Perforated Square Tubing	ASTM 1011 Gr. 55 Min. yield 60 ksi [414 MPa]	ASTM A653–G90 or AASHTO M–120
b3	4	2"x2"x14–gauge [51x51x1.9], 6" [152] Long Perforated Square Tubing	ASTM 1011 Gr. 55 Min. yield 60 ksi [414 MPa]	ASTM A653–G90 or AASHTO M–120
c1	2	48"x30"x0.08" [1,219x762x2] Sign with Reflective Sheeting	Aluminum Alloy 5052 or similar	–
c2	4	Warning Light (Type A or C)	As Supplied	–
d1	20	3/8"–16 UNC [M10x1.5], 3 1/2" [89] Long Hex Head Bolt and Lock Nut	Bolt – ASTM A307 Gr. A or equivalent Nut – SAE J995 Gr. 2 or equivalent	Fe/Zn 3AN per ASTM F1941
d2	4	1/2"–13 UNC [M14x2], 6" [152] Long Hex Head Bolt	ASTM A307 Gr. A or equivalent	Fe/Zn 3AN per ASTM F1941
d3	8	1/4"–20 UNC [M6x1], 1 3/4" [44] Long Hex Head Bolt and Lock Nut	Bolt – ASTM A307 Gr. A or equivalent Nut – SAE J995 Gr. 2 or equivalent	Fe/Zn 3AN per ASTM F1941
d4	40	3/8" [10] Dia. Plain Round Washer	Low Carbon Steel	Fe/Zn 3AN per ASTM F1941
d5	4	1/2" [13] Dia. Plain Round Washer	Low Carbon Steel	Fe/Zn 3AN per ASTM F1941
d6	16	1/4" [6] Dia. Plain Round Washer	Low Carbon Steel	Fe/Zn 3AN per ASTM F1941

Note: (1) Part c1 shall have a reflective sheeting.
(2) Parts a1 & a2 will have orange and white striped reflective sheeting on at least one side (sign panel side).

Midwest Roadside Safety Facility

Type 3 Barricade
Test No. WZNP–1

Bill of Materials

SHEET: 8 of 8
DATE: 6/28/2018
DRAWN BY: MES/JWB/MKB/JEK/GRL
DWG. NAME. WZNP–1_R15
SCALE: None
UNITS: in.[mm]
REV. BY: JEK/JDS/RKF

Figure 51. Bill of Materials, Test No. WZNP-1

Figure 52. Test Installation Photographs, Test No. WZNP-1

TEST REQUIREMENTS AND EVALUATION CRITERIA

Test Requirements

Work-zone traffic control devices, such as Type III barricades, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the FHWA for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH 2016 (*4*). Note that there is no difference between MASH 2009 and MASH 2016 for work-zone traffic control devices such as Type III barricades tested in this project. According to TL-3 of MASH 2016, work-zone traffic control devices must be subjected to three full-scale vehicle crash tests, as summarized in Table 4.

Table 4. MASH 2016 TL-3 crash test conditions for work-zone traffic control devices

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight, lb (kg)	Impact Conditions		Evaluation Criteria [1]
				Speed, mph (km/h)	Angle, deg.	
Work-Zone Traffic Control Devices	3-70	1100C	2,425 (1,100)	19 (30)	CIA	B,D,E,F,H,I,N
	3-71	1100C	2,425 (1,100)	62 (100)	CIA	B,D,E,F,H,I,N
	3-72	2270P	5,000 (2,270)	62 (100)	CIA	B,D,E,F,H,I,N

[1] Evaluation criteria explained in Table 5.

It is anticipated that the low-speed test, test no. 3-70, was not required since the Type III barricade weighed less than 220 lb (100 kg). MASH 2016 recommends the high-speed test, test no. 3-71, be conducted both perpendicular to the device (0 degrees) and parallel to the device (90 degrees), as both orientations may occur along roadsides. MwRSF has developed a procedure for testing multiple work-zone traffic control devices in one test run. The selected device was evaluated at two impact angles, 0 degree angle (System A), and 90 degree angle (System B), in one full-scale crash test. The devices were spaced 60 ft (18.3 m) apart and each device impacted at the quarter points on the front bumper. Thus, two MASH 2016 test designation no. 3-71 crash tests occurred at two critical impact angles (CIA). Note, only one of the prescribed full-scale crash tests, test designation no. 3-71, was conducted and reported herein. Test no. 3-72 with a 2270P pickup truck still needs to be conducted for the full crash test matrix to be completed.

Table 5. MASH 2016 evaluation criteria for work-zone traffic control devices

<table>
<tr><th>Appraisal area</th><th colspan="4">Evaluation criteria</th></tr>
<tr><td>Structural Adequacy</td><td>B.</td><td colspan="3">The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td></tr>
<tr><td rowspan="11">Occupant Risk</td><td>D.</td><td colspan="3">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 5.2.2 and Appendix E of MASH 2016.</td></tr>
<tr><td>E.</td><td colspan="3">Detached elements, fragments, or other debris from the test article, or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.</td></tr>
<tr><td>F.</td><td colspan="3">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 rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal</td><td>10 ft/s
(3.0 m/s)</td><td>16 ft/s
(4.9 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g's</td><td>20.49 g's</td></tr>
<tr><td>Post-Impact Vehicular Response</td><td>N.</td><td colspan="3">Vehicle trajectory behind the test article is acceptable.</td></tr>
</table>

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 work-zone traffic control device to break away, fracture, or yield in a predictable manner. 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 5 and defined in greater detail in MASH 2016. The full-scale vehicle crash test documented herein was conducted and reported in accordance with the procedures provided in MASH 2016.

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 2016.

TEST CONDITIONS

Test Facility

The Outdoor Test Site 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.

Vehicle Tow and Guidance System

A reverse-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 second barricade system. A digital speedometer on the tow vehicle increased the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch (*19*) 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 second barricade 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.

Test Vehicles

For test no. WZNP-1, a 2011 Kia Rio was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,320 lb (1,052 kg), 2,426 lb (1,100 kg), and 2,589 lb (1,174 kg), respectively. The test vehicle is shown in Figures 53 and 54, and vehicle dimensions are shown in Figure 55.

Figure 53. Test Vehicle, Test No. WZNP-1

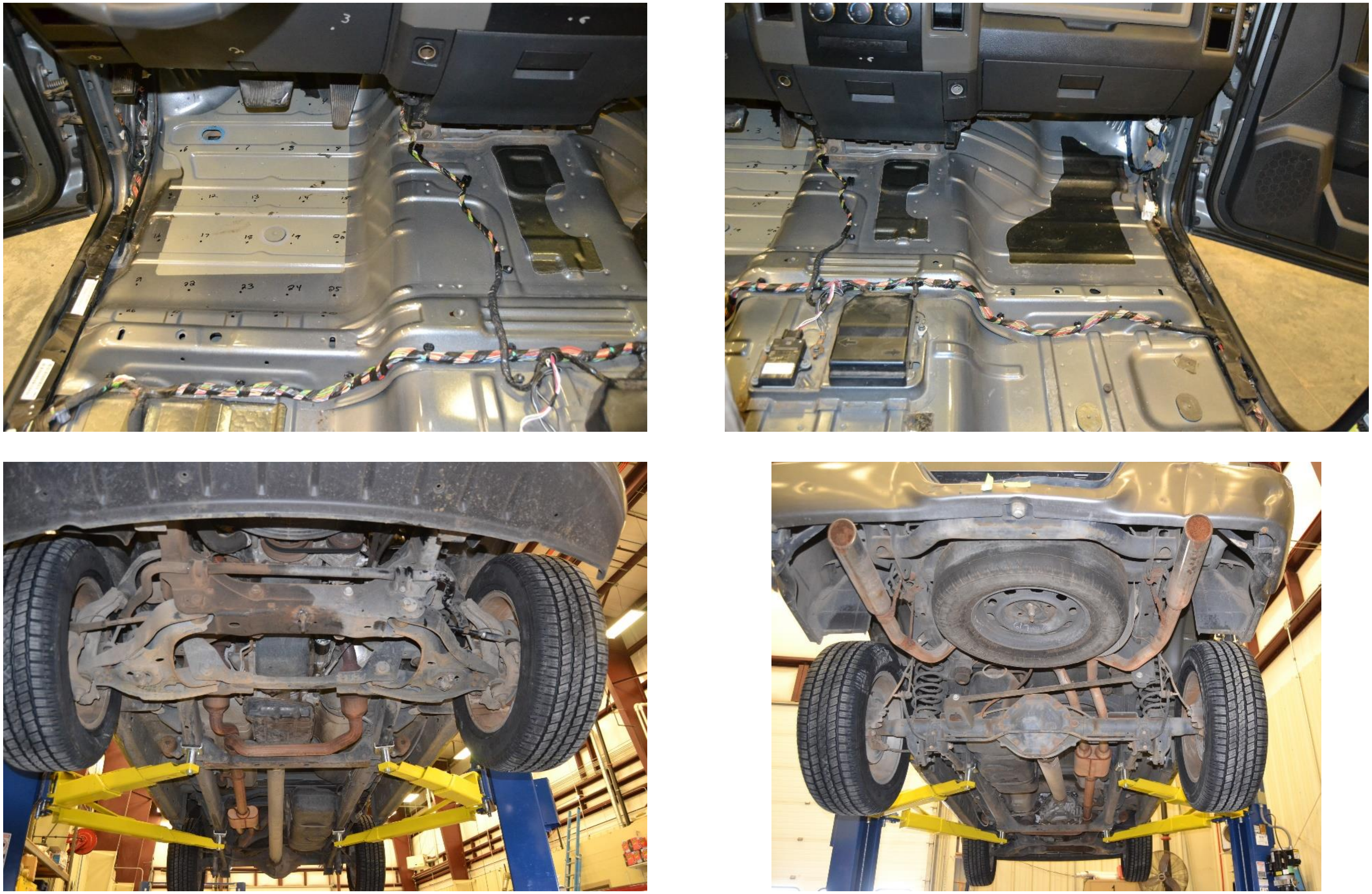
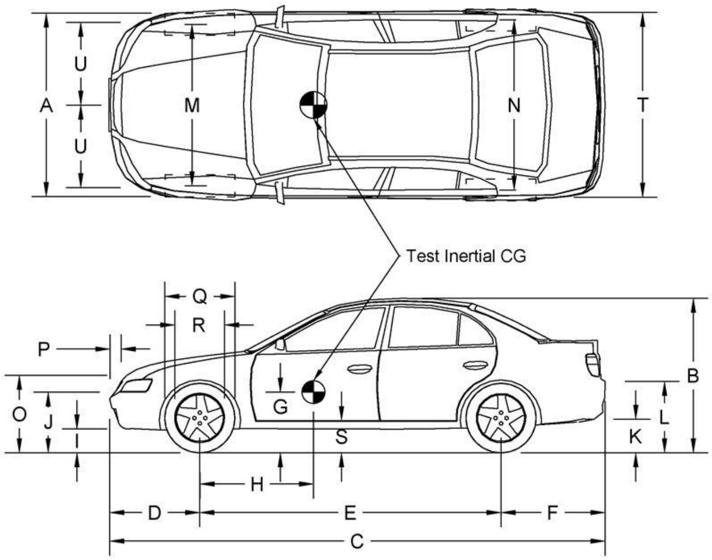


Figure 54. Test Vehicle's Interior Floorboards and Undercarriage

Date:	5/23/2018	Test Name:	WZNP-1	VIN No:	KNADH4A38B6939145
Year:	2011	Make:	KIA	Model:	RIO
Tire Size:	175/70 R14	Tire Inflation Pressure:	32 Psi	Odometer:	80728



Vehicle Geometry - in. (mm)
Target Ranges listed below

A:	65 1/2 (1664) 65±3 (1650±75)	B:	58 1/4 (1480)
C:	167 1/2 (4255) 169±8 (4300±200)	D:	23 1/4 (591) 35±4 (900±100)
E:	98 3/4 (2508) 98±5 (2500±125)	F:	45 1/2 (1156)
G:	22 1/2 (572)	H:	40 1/8 (1019) 39±4 (990±100)
I:	8 1/2 (216)	J:	22 (559)
K:	11 1/5 (284)	I:	7 (178)
M:	57 7/8 (1470) 56±2 (1425±50)	N:	58 (1473) 56±2 (1425±50)
O:	27 3/4 (705) 24±4 (600±100)	P:	4 1/4 (108)
Q:	23 1/2 (597)	R:	15 3/8 (391)
S:	12 (305)	T:	65 1/4 (1657)

U (impact width):	56 (1422)
Top of radiator core support:	29 (737)
Wheel Center Height (Front):	11 3/4 (298)
Wheel Center Height (Rear):	11 3/4 (298)
Wheel Well Clearance (Front):	5 1/4 (133)
Wheel Well Clearance (Rear):	9 3/4 (248)
Bottom Frame Height (Front):	8 (203)
Bottom Frame Height (Rear):	9 1/4 (235)
Engine Type:	4 cyl. Gas
Engine Size:	1.6L
Transmission Type:	Manual
Drive Type:	FWD

Mass Distribution lb (kg)

Gross Static	LF	746 (338)	RF	783 (355)
	LR	524 (238)	RR	536 (243)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	1465 (665)	1441 (654)	1529 (694)
W-rear	855 (388)	985 (447)	1060 (481)
W-total	2320 (1052)	2426 (1100) 2420±55 (1100±25)	2589 (1174) 2585±55 (1175±50)

GVWR Ratings lb

Front	1918
Rear	1874
Total	3638

Surrogate Occupant Data

Type:	Hybrid II
Mass:	163 lb
Seat Position:	Right Front

Note any damage prior to test: None

Figure 55. Vehicle Dimensions, Test No. WZNP-1

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The vertical component of the c.g. for the 1100C vehicle was determined utilizing a procedure published by SAE (*20*). The location of the final c.g. is shown in Figures 55 and 56. Data used to calculate the location of the c.g. and ballast information are shown in Appendix B.

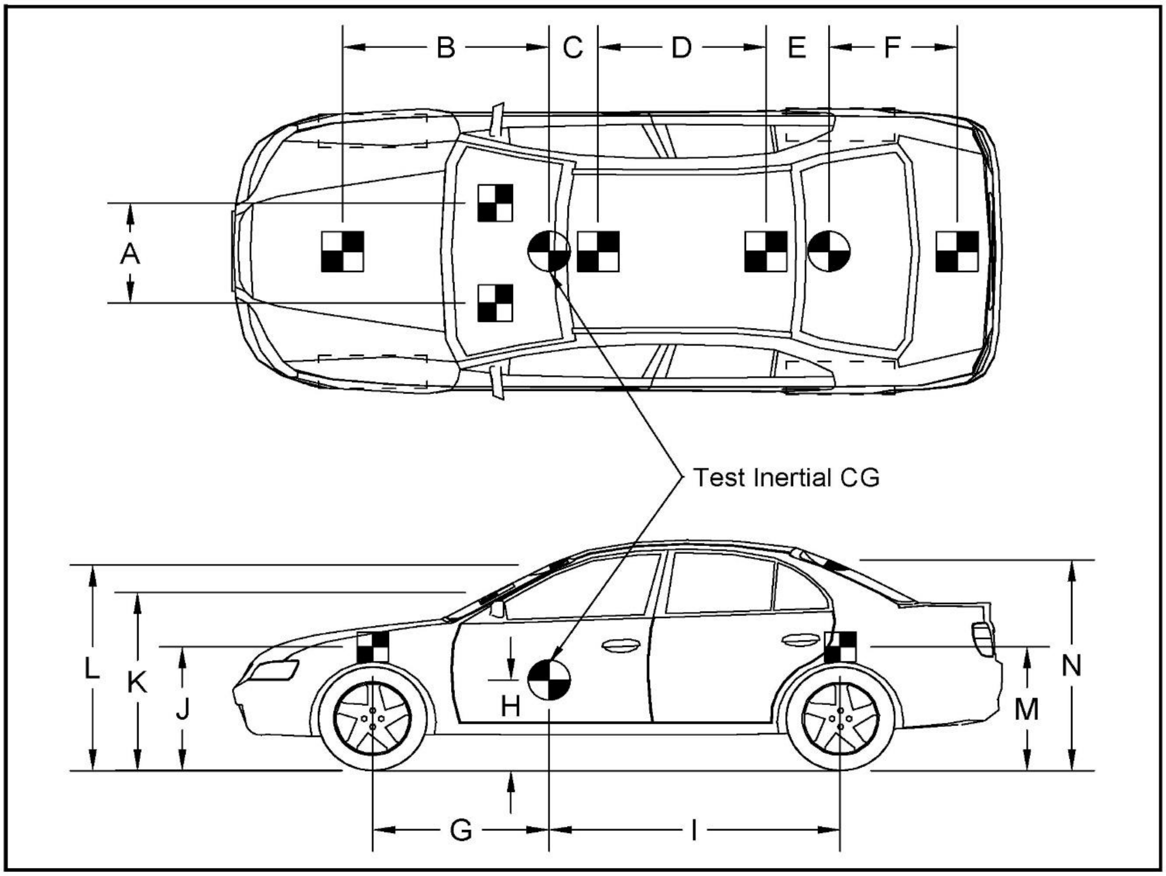
Square, black- and white-checkered targets were placed on the vehicle for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figure 56. Round, checkered targets were placed on the c.g. on the left-side door, the right-side door, and the roof of the vehicle.

The front wheels of the test vehicle were aligned to vehicle standards except the toe-in value was adjusted to zero such that the vehicle would track properly along the guide cable. A 5B flash bulb was mounted under the vehicle's right-side and left-side windshield wiper and was fired by a pressure tape switch mounted at each of the quarter points of the front bumper. The flash bulbs were fired upon initial impact with each 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 the test vehicle, so the vehicle could be brought safely to a stop after the test.

Simulated Occupant

For test no WZNP-1, 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 163 lb (74 kg), was represented by model no. 572, and was manufactured by Android Systems of Carson, California. As recommended by MASH 2016, the dummy was not included in calculating the c.g. location.

Date:	5/23/2018	Test Name:	WZNP-1	VIN:	KNADH4A38B6939145
Year:	2011	Make:	KIA	Model:	RIO



TARGET GEOMETRY-- in. (mm)

A:	23 15/16	(608)	F:	28 1/4	(718)	K:	45 7/8	(1165)
							Windshield Target	
B:	47 1/2	(1207)	G:	40 1/8	(1019)	L:	54 3/4	(1391)
							Front round CG target	
C:	11 1/4	(286)	H:	22 3/8	(568)	M:	29	(737)
D:	32 1/2	(826)	I:	58 3/4	(1492)	N:	54 3/4	(1391)
							Rear Round target	
E:	8 15/16	(227)	J:	29 5/8	(752)			

Figure 56. Target Geometry, Test No. WZNP-1

Data Acquisition Systems

Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both of the accelerometers were mounted near the c.g. of the test vehicle. 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 (*21*).

The two systems, the SLICE-1 and SLICE-2 units, were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The SLICE-2 unit was designated as the primary system. 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.

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 vehicle. 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.

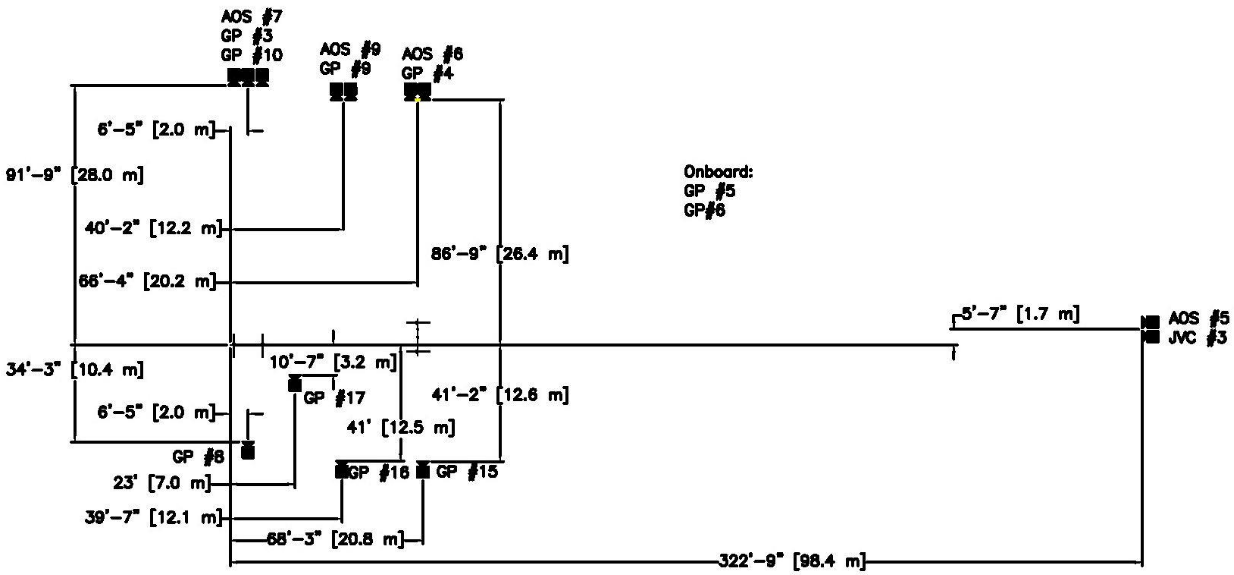
Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the test vehicle before impact. Five retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the side of the 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.

Digital Photography

Four AOS high-speed digital video cameras, ten GoPro digital video cameras, and one JVC digital video camera were utilized to film test no. WZNP-1. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 57.

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 digital still camera was also used to document pre- and post-test conditions for the test.



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-5	AOS X-PRI	500	Telesar 135 mm Fixed	-
AOS-6	AOS X-PRI	500	Sigma 28-70 #1	70
AOS-7	AOS X-PRI	500	Sigma 28-70 #2	70
AOS-9	AOS TRI-VIT 2236	500	KOWA 12 mm Fixed	-
GP-3	GoPro Hero 3+ w/ Cosmicar 12.5mm	120		
GP-4	GoPro Hero 3+ w/ Computar 12.5mm	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	120		
GP-15	GoPro Hero 4	120		
GP-16	GoPro Hero 4	120		
GP-17	GoPro Hero 4	120		
JVC-3	JVC – GZ-MG27u (Everio)	29.97		

Figure 57. Camera Locations, Speeds, and Lens Settings, Test No. WZNP-1

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FULL-SCALE CRASH TEST NO. WZNP-1

Weather Conditions

Test no. WZNP-1 was conducted on May 23, 2018 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 6.

Table 6. Weather conditions, Test No. WZNP-1

Condition	Value
Temperature	88° F
Humidity	43%
Wind Speed	16 mph
Wind Direction	190° from True North
Sky Conditions	Sunny
Visibility	9.94 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.32 in.
Previous 7-Day Precipitation	0.63 in.

Test Description

The 2,426-lb (1,100-kg) small car impacted System A at a speed of 64.7 mph (104.2 km/h) and System B at a speed of 61.2 mph (98.6 km/h). The impact speed of System A was above the velocity range for impact speed according to MASH 2016. However, the higher velocity represents a worst-case scenario and was targeted to be high to insure that the second impact was also within the velocity range. Overhead cameras were not present to verify the impact angles. However, the impact angle appeared to be very close to nominal. A summary of the test results and sequential photographs for both systems are shown in Figures 58 and 59. Additional sequential photographs are shown in Figure 60.

Initial vehicle impact with System A was to occur with a right quarter-point offset from the centerline of the car and initial vehicle impact with System B was to occur with a left quarter-point offset from the centerline of the car, as shown in Figure 61. Although MASH 2016 does not provide specific guidance about how to align the test vehicle and test article, a centerline impact seemed reasonable. However, in order to have two devices impacted in one test run using the previously established method, the systems were aligned with the quarter points of the vehicle to distinguish damage between the two systems. A sequential description of the impact events is contained in Table 7 for System A and Table 8 for System B. The vehicle came to rest 310 ft (94.5 m) downstream and 5 ft – 1 in. (1.5 m) laterally to the left after brakes were applied. The vehicle trajectory and final position are shown in Figures 58, 59, and 62.

Table 7. Sequential description of impact events, System A

TIME (sec)	EVENT
0.000	Vehicle’s front bumper contacted bottom panel of System A.
0.008	Vehicle’s front bumper contacted upstream upright of System A.
0.016	Middle panel detached from the upstream upright on System A. Bottom panel of System A buckled.
0.020	Upstream upright detached from leg on System A.
0.030	Sign on System A contacted vehicle’s hood.
0.036	Sign on System A deformed.
0.044	Top panel of System A contacted vehicle’s hood.
0.054	Top panel of System A contacted vehicle’s windshield.
0.062	Upstream light on System A contacted vehicle’s windshield.
0.066	Bottom panel detached from the downstream upright on System A.
0.088	Vehicle’s front bumper contacted downstream upright of System A.
0.090	Downstream upright detached from leg on System A.
0.120	Sign on System A contacted vehicle’s windshield.
0.140	Vehicle’s windshield cracked.
0.154	System A became airborne.
1.150	System A contacted ground.

Table 8. Sequential description of impact events, System B

TIME (sec)	EVENT
0.000	Vehicle’s front bumper contacted bottom panel of System B at 0.696 seconds after initial impact with System A.
0.004	Vehicle’s front bumper contacted left upright of System B.
0.006	Sign on System B contacted vehicle’s hood, and right upright bent downstream.
0.010	Right upright on System B detached from leg.
0.012	Vehicle’s right headlight contact right upright on System B.
0.024	Middle panel on System B detached from left upright.
0.026	Bottom panel on System B detached from left upright.
0.056	Sign on System B contacted vehicle’s windshield.
0.060	Vehicle’s windshield shattered.
0.078	Sign on System B contacted vehicle’s roof.
0.114	Left upright on System B detached from leg.
0.132	System B became airborne.
1.282	System B contacted ground.

System Damage

Damage to the barricades was moderate, as shown in Figures 63 and 64. System damage consisted of bends and buckles in the uprights and panels, tears in the weighed sandbags, and bolt pullouts.

System A detached from both legs upon impact. The upstream upright had a large buckle approximately 19 in. (483 mm) from the bottom and the downstream upright had a large buckle approximately 13 in. (330 mm) from the bottom. A large bend extended through the entire length of the middle barricade panel. The aluminum sign panel attached to the barricade panels was bent 4 in. (102 mm) on its lower-upstream corner and had a small kink on the lower edge about 13 in. (330 mm) upstream from the downstream edge. The bottom barricade panel was pulled away from its upright bolts and the lower bolts on the sign panel were pulled away from the barricade panel. Both downstream sand bags and the left upstream sand bags were torn open.

System B also detached from both legs upon impact. The front side of the right upright buckled 16 in. (406 mm) from the bottom, where impact occurred. The vertical stub of the right leg had the front weld fractured, was bent downstream, and was fractured along the right-downstream corner along the length of the stub. The top barricade panel was bent 90 degrees about 11 in. (279 mm) from the right edge. Every bolt on the aluminum sign panel, except the bolt in the lower-left corner, was pulled out from the barricade panels and remained attached to the sign. The two sand bags on the right side were torn open.

Vehicle Damage

The damage to the vehicle was minimal, as shown in Figures 65 through Figure 67. After impacting both barricade systems, the car impacted a concrete barrier that was placed downstream from the test, which caused most of the vehicle damage. The maximum occupant compartment deformations are listed in Table 9 along with the deformation limits established in MASH 2016 for various areas of the occupant compartment. A negative value indicates that deformation was outward and not toward the occupant. Note that none of the established MASH 2016 deformation limits were violated. The maximum windshield crush of 0.8 in. (20 mm) was caused by the 0-degree barricade impact (System B) and was located near the left-side A-pillar. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix C.

Table 9. Maximum occupant compartment deformations by location

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH 2016 ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	0.4 (10)	≤ 9 (229)
Floor Pan & Transmission Tunnel	0.2 (5)	≤ 12 (305)
A- and B-Pillars	0.4 (10)	≤ 5 (127)
A- and B-Pillars (Lateral)	0.1 (3)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	0.2 (5)	≤ 12 (305)
Side Door (Above Seat)	0.2 (5)	≤ 9 (229)
Side Door (Below Seat)	0.2 (5)	≤ 12 (305)
Roof	0.1 (3)	≤ 4 (102)
Windshield	0.8 (20)	≤ 3 (76)
Side Window	Intact	No shattering resulting from contact with structural member of test article
Dash	0.8 (20)	NA

NA – Not applicable

Damage to the vehicle consisted of crushing, dents, and detachments. The front bumper was crushed and pushed upward. The hood was folded over on its front lip. The right-front quarter panel was crushed inward near the windshield. A small dent was found near the bottom of the right A-pillar where it meets the right-front quarter panel. Another small dent was found on the left-front quarter panel near the left-front door. A larger dent, measuring 8 in. (203 mm) in length, was located on the left-rear door directly behind the door handle. The left mirror was disengaged from the vehicle. The windshield was cracked across its entirety with localized crush on the lower right side and on the left side adjacent to the A-pillar.

Occupant Risk

The calculated occupant impact velocities (OIVs) in both the longitudinal and lateral directions are shown in Table 10. The maximum 0.010-sec average occupant ridedown accelerations (ORAs) are not available (NA), because the occupant did not move significantly upon impact. Note that the OIVs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 10. Some THIV and PHD values were not significant enough to be recorded. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figures 58 and 59 for Systems A and B, respectively. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix D.

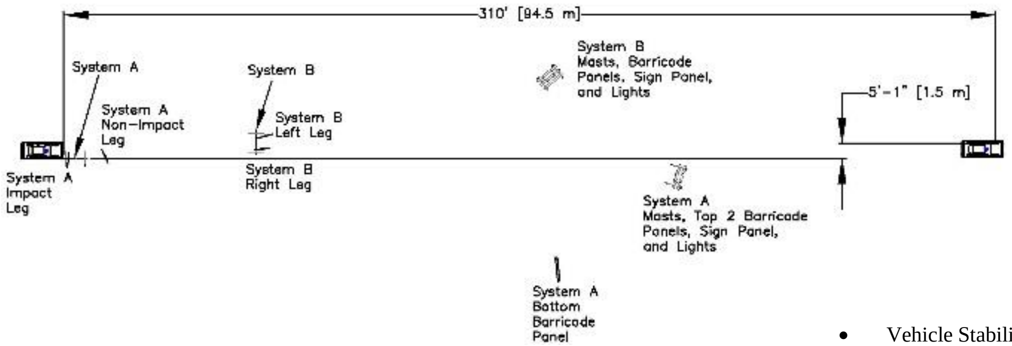
Table 10. Summary of OIV, ORA, THIV, PHD, and ASI values, Test No. WZNP-1

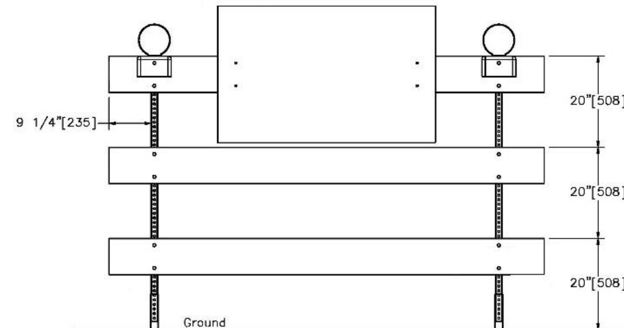
Evaluation Criteria		Transducer				MASH 2016 Limits
		SYSTEM A		SYSTEM B		
		SLICE-1	SLICE-2 (primary)	SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-3.09 (-0.94)	3.04 (-0.93)	-2.38 (-0.73)	-2.13 (-0.65)	±40 (12.2)
	Lateral	-0.08 (-0.02)	-0.14 (-0.04)	0.44 (0.13)	0.22 (0.07)	±40 (12.2)
ORA g's	Longitudinal	NA	NA	NA	NA	±20.49
	Lateral	NA	NA	NA	NA	±20.49
MAX. ANGULAR DISPL. deg.	Roll	-1.9	-1.6	-3.4	-3.3	±75
	Pitch	-0.6	-0.7	0.6	0.6	±75
	Yaw	0.8	0.5	2.1	1.8	not required
THIV ft/s (m/s)		NA	5.38 (1.64)	NA	NA	not required
PHD g's		NA	0.29	NA	NA	not required
ASI		0.10	0.09	0.08	0.07	not required

Discussion

The analysis of the test results for test no. WZNP-1 showed that both systems readily activated in a predicable manner and allow the 1100C vehicle to continue traveling without any major obstruction of the windshield. 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 remained upright during and after the collisions. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix D, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle's trajectory did not violate the bounds of the exit box. Therefore, test no. WZNP-1 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-71.

0.000 sec 0.050 sec 0.100 sec 0.150 sec 0.200 sec



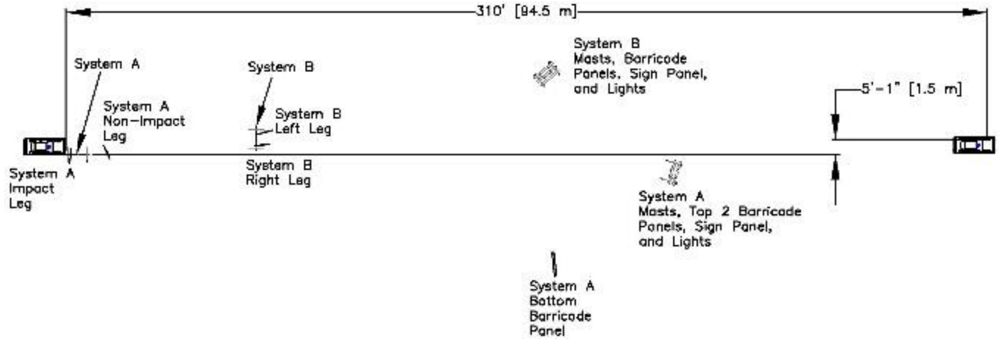


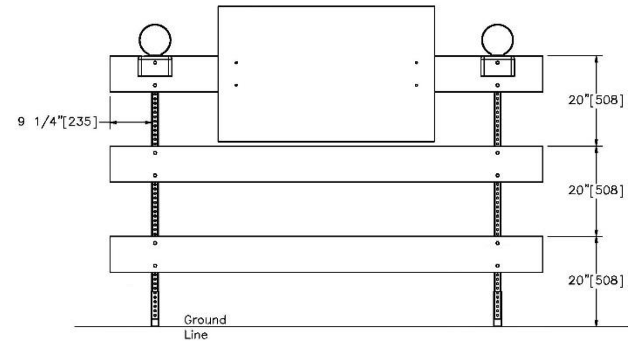
- Test Agency .... MwRSF
- Test Number WZNP-1
- System .... A
- Date 5/23/2018
- MASH 2016 Test Designation No. 3-71
- Test Article .... Type III Barricade
- Key Component – Plastic Barricade Panel
  - Length .... 96 in. (2,438 mm)
  - Width .... 8¼ in. (210 mm)
  - Depth .... ¾ in. (19 mm)
- Key Component – Aluminum Sign
  - Length .... 48 in. (1,219)
  - Width .... 30 in. (762 mm)
  - Depth .... 0.08 in. (2 mm)
- Vehicle Make /Model .... 2011 Kia Rio
  - Curb .... 2,320 lb (1,052 kg)
  - Test Inertial .... 2,426 lb (1,100 kg)
  - Gross Static .... 2,589 lb (1,174 kg)
- Impact Conditions
  - Speed .... 64.7 mph (104.2 km/h)
  - Angle .... 90 deg.
  - Impact Location .... Right quarter-point offset from centerline of car
- Exit Conditions
  - Angle .... 90 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 310 ft (94.5 m) downstream
- Vehicle Damage .... Minimal
  - VDS (*22*) 12-FR-1
  - CDC (*23*) 12FZAN1
  - Maximum Interior Deformation .... 0.8 in. (20 mm)
- Test Article Damage .... Moderate
- Transducer Data

Evaluation Criteria		**Transducer**		**MASH 2016 Limit**
		SLICE-1	**SLICE-2 (primary)**	
OIV ft/s (m/s)	Long.	-3.09 (-0.94)	3.04 (-0.93)	±40 (12.2)
	Lat.	-0.08 (-0.02)	-0.14 (-0.04)	±40 (12.2)
ORA g's	Long.	NA	NA	±20.49
	Lat.	NA	NA	±20.49
MAX ANG. DISP. deg.	Roll	-1.9	-1.6	±75
	Pitch	.0.6	-0.7	±75
	Yaw	0.8	0.5	not required
THIV – ft/s (m/s)		NA	5.38 (1.64)	not required
PHD – g's		NA	0.29	not required
ASI		0.10	0.09	not required

Figure 58. Summary of Test Results and Sequential Photographs –Test No. WZNP-1, System A

0.000 sec | 0.050 sec | 0.100 sec | 0.150 sec | 0.200 sec





- Test Agency .... MwRSF
- Test Number WZNP-1
- System .... B
- Date 5/23/2018
- MASH 2016 Test Designation No. 3-71
- Test Article .... Type III Barricade
- Key Component – Plastic Barricade Panel
  - Length .... 96 in. (2,438 mm)
  - Width .... 8¼ in. (210 mm)
  - Depth .... ¾ in. (19 mm)
- Key Component –Aluminum Sign
  - Length .... 48 in. (1,219)
  - Width .... 30 in. (762 mm)
  - Depth .... 0.08 in. (2 mm)
- Vehicle Make /Model .... 2011 Kia Rio
  - Curb .... 2,320 lb (1,052 kg)
  - Test Inertial .... 2,426 lb (1,100 kg)
  - Gross Static .... 2,589 lb (1,174 kg)
- Impact Conditions
  - Speed .... 61.2 mph (98.6 km/h)
  - Angle .... 0 deg.
  - Impact Location .... Left quarter-point offset from centerline of car
- Exit Conditions
  - Angle .... 0 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 250 ft (76.2 m) downstream
- Vehicle Damage .... Minimal
  - VDS (*22*) 12-FD-1
  - CDC (*23*) 12FYAW1
  - Maximum Interior Deformation .... 0.8 in. (20 mm)
- Test Article Damage .... Moderate
- Transducer Data

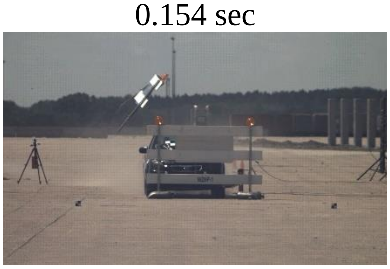
Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1	**SLICE-2 (primary)**	
OIV ft/s (m/s)	Long.	-2.38 (-0.73)	-2.13 (-0.65)	±40 (12.2)
	Lat.	0.44 (0.13)	0.22 (0.07)	±40 (12.2)
ORA g's	Long.	NA	NA	±20.49
	Lat.	NA	NA	±20.49
MAX ANG. DISP. deg.	Roll	-3.4	-3.3	±75
	Pitch	0.6	0.6	±75
	Yaw	2.1	1.8	not required
THIV – ft/s (m/s)		NA	NA	not required
PHD – g's		NA	NA	not required
ASI		0.08	0.07	not required

Figure 59. Summary of Test Results and Sequential Photographs –Test No. WZNP-1, System B

0.000 sec

0.078 sec

0.154 sec



0.698 sec

0.760 sec

0.828 sec

0.000 sec

0.078 sec

0.154 sec

0.698 sec

0.760 sec

0.828 sec

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

Figure 61. Impact Location, Test No. WZNP-1

Figure 62. Vehicle Final Position and Trajectory Marks, Test No. WZNP-1

Figure 63. System Damage –Test No. WZNP-1, System A

Figure 64. System Damage –Test No. WZNP-1, System B

Figure 65. Vehicle Damage, Test No. WZNP-1

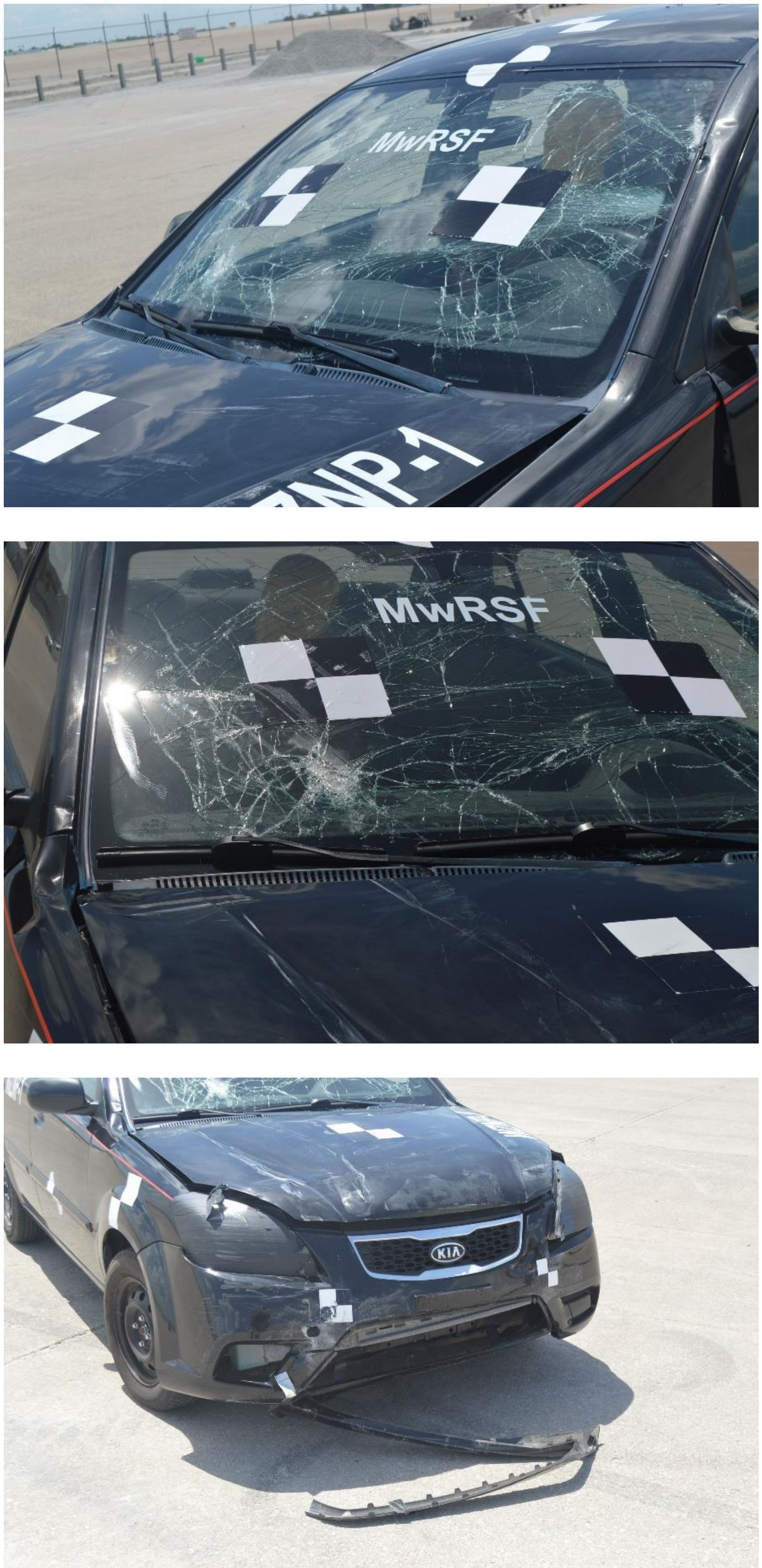


Figure 66. Vehicle Damage, Test No. WZNP-1

Figure 67. Vehicle Damage, Test No. WZNP-1

SUMMARY AND CONCLUSIONS

The objective of this research effort was to evaluate the performance of a non-proprietary work-zone safety device, such as a work-zone sign support or barricade. The research team made recommendations on the performance and usage of work-zone devices based on the background research in NCHRP Project No. 3-119, a survey sent to the SWZDI state DOTs, as well as additional background review on past NCHRP Report 350 crash tests. A Type III barricade that is commonly used by SWZDI state DOTs was selected for the full-scale crash testing program. The Type III barricade was evaluated according to the MASH TL-3 test designation no. 3-71 safety criteria through two full-scale crash tests at 0-degree and 90-degree impact angles.

Test no. WZNP-1 was conducted on a Type III barricade in accordance with MASH 2016 test designation no. 3-71. A summary of the test results is shown in Table 11. Two Type III barricades were placed 60 ft (18.3 m) apart on level terrain with one sandbag on the end of each leg. During the test, the 1100C small car impacted and disengaged both barricades. The systems readily activated in a predicable manner and allowed the 1100C vehicle to continue traveling without any major obstruction of the windshield. 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 remained upright during and after the collisions. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix D, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle’s trajectory did not violate the bounds of the exit box. Therefore, test no. WZNP-1 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-71.

RECOMMENDATIONS

The Type III barricade that was tested was non-proprietary. Thus, the components could be provided by any manufacturer. Each component should have similar dimensions and material grade as the as-tested system. The barricade rails could vary some in dimension and cross-section appearance but should have similar properties to the panels that were tested. It is anticipated that a Type III barricade without an attached aluminum sign panel would perform equivalent to or better than the Type III barricade that was tested with a sign panel. Additionally, the warning lights could be attached on the back side of the barricade.

According to MASH 2016, three full-scale crash tests should be conducted. The low-speed test, MASH 2016 test designation no. 3-70, was not required since the Type III barricade weighed less than 220 lb (100 kg). MASH 2016 test designation no. 3-71 was conducted successfully in this study both perpendicular to the device (0 degrees) and parallel to the device (90 degrees). MASH 2016 test designation no. 3-72 with a 2270P pickup truck is recommended in order for the full crash test matrix to be completed.

Table 11. Summary of safety performance evaluation

Evaluation Factors	**Evaluation Criteria**	**Test No. WZNP-1, System A**	**Test No. WZNP-1, System B**
Structural Adequacy	A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	S	S
Occupant Risk	D. 1. 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.	S	S
	2. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.	S	S
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	S	S
	H. Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits: Occupant Impact Velocity Limits Component: Longitudinal and Lateral; Preferred: 30 ft/s (9.1 m/s); Maximum: 40 ft/s (12.2 m/s)	S	S
	I. The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits: Occupant Ridedown Acceleration Limits Component: Longitudinal and Lateral; Preferred: 15.0 g's; Maximum: 20.49 g's	S	S
MASH 2016 Test Designation No.		3-71 (90 degrees)	3-71 (0 degrees)
Final Evaluation (Pass or Fail)		Pass	Pass

S – Satisfactory, U – Unsatisfactor, NA - Not Applicable

REFERENCES

1. Schmidt, J. D., D. L. Sicking, K. A. Lechtenberg, R. K. Faller, and J. C. Holloway. 2009. *Analysis of Existing Work-Zone Devices with MASH Safety Performance Criteria*. Mid-America Transportation Center, University of Nebraska-Lincoln, Lincoln, NE.
2. Ross, H. E., D. L. Sicking, R. A. Zimmer, and J. D. Michie. 1993. *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features.* National Cooperative Highway Research Program, Washington, DC. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_350-a.pdf.
3. AASHTO. 2009. *Manual for Assessing Safety Hardware (MASH)*. American Association of State Highway and Transportation Officials, Washington, DC.
4. AASHTO. 2016. *Manual for Assessing Safety Hardware (MASH).* Second Edition. American Association of State Highway and Transportation Officials, Washington, DC.
5. Marzougui, D. 2015. NCHRP Project 03-119: Application of MASH Test Criteria to Breakaway Sign and Luminaire Supports and Crashworthy Work-Zone Traffic Control Device. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3857.
6. FHWA. 2002. Low-Height Temporary Rigid Panel Sign Stand. WZ-129. Federal Highway Administration, Washington, DC. https://safety.fhwa.dot.gov/roadway_dept/countermeasures/reduce_crash_severity/workzone/pdf/wz129.pdf.
7. Polivka, K. A., R. K. Faller, J. C. Holloway, J. R. Rohde, and D. L. Sicking. 2002. *Safety Performance Evaluation of Minnesota's Aluminum Work Zone Signs*. Midwest Roadside Safety Facility, University of Nebraska- Lincoln, Lincoln, NE.
8. Polivka, K. A., R. K. Faller, J. C. Holloway, J. R. Rohde, and D. L. Sicking. 2003. *Safety Performance Evaluation of Michigan's Temporary Traffic Control Devices*. Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE.
9. Polivka, K. A., R. K. Faller, J. C. Holloway, and J. R. Rohde. 2007. *Safety Performance Evaluation of Minnesota's Temporary Rigid Panel Sign Stand Systems*. Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE.
10. FHWA. 2008. Portable Sign Stands X and H Bases. WZ-266. Federal Highway Administration, Washington, DC. https://safety.fhwa.dot.gov/roadway_dept/countermeasures/reduce_crash_severity/workzone/pdf/wz266.pdf.
11. Linzell, D. G. and Z. Rado. 2007. *Work Order 7: Portable Sign Crash Test, Numerical Modeling Interim Report*. Pennsylvania Transportation Institute, Pennsylvania State University, University, PA. http://www.dot7.state.pa.us/BPR_PDF_FILES/Documents/Research/Complete%20Projects/Operations/WO%207%20Final%20Report.pdf.
12. Dobrovolny, C. S., D. R. Arrington, R. P. Bligh, and W. L. Menges. 2013. *Development and MASH Full-Scale Crash Testing of a High-Mounting-Height Temporary Single Sign Support with Aluminum Sign.* Texas A&M Transportation Institute, Texas A&M University, College Station, TX. https://static.tti.tamu.edu/tti.tamu.edu/documents/9-1002-12-5.pdf.
13. Dobrovolny, C. S., D. R. Arrington, R. P. Bligh, W. L. Menges, and D. L. Kuhn. 2017. *MASH Evaluation of TXDOT High-Mounting-Height Temporary Work Zone Sign Support System.* Texas A&M Transportation Institute, Texas A&M University, College Station, TX. https://static.tti.tamu.edu/tti.tamu.edu/documents/9-1002-15-8.pdf.

14. Polivka, K. A., R. K. Faller, J. C. Holloway, J. R. Rohde, and D. L. Sicking. 2000. *Safety Performance Evaluation of Minnesota's Aluminum Type III Barricades*. Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, NE.
15. Mak, K. K., R. P. Bligh, and W. L. Menges. 1997. *Evaluation of Work Zone Barricades*. Texas Transportation Institute, Texas A&M University, College Station, TX. https://static.tti.tamu.edu/tti.tamu.edu/documents/3910-S.pdf.
16. Mak, K. K., R. P. Bligh, and W. L. Menges. 1996 *Evaluation of Work Zone Barricades and Temporary Sign Supports*. Texas Transportation Institute, Texas A&M University, College Station, TX, and Texas Department of Transportation, Austin, TX. https://static.tti.tamu.edu/tti.tamu.edu/documents/5388-1F.pdf.
17. Bligh, R. P., W. L. Menges, and R. R. Haug. 2006. *NCHRP Report 553: Crashworthy Work-Zone Traffic Control Devices*. National Cooperative Highway Research Program, Washington DC. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_553.pdf.
18. Bligh, R. P., D. R. Arrington, W. L. Menges, and D. L. Kuhn. 2014. *Skid-Mounted Support System for Temporary Guide Signs*. Texas A&M Transportation Institute, Texas A&M University, College Station, TX. https://static.tti.tamu.edu/tti.tamu.edu/documents/0-6782-2.pdf.
19. SAE. 2007. *Instrumentation for Impact Test–Part 1–Electronic Instrumentation*. Society of Automotive Engineers International, Warrendale, PA.
20. Hinch, J., T. L. Yang, and R. Owings. 1986. *Guidance Systems for Vehicle Testing*. ENSCO, Inc., Falls Church, VA.
21. MacInnis, D., W. Cliff, and K. Ising. 1997. *A Comparison of the Moment of Inertia Estimation Techniques for Vehicle Dynamics Simulation*. SAE Technical Paper 970951. Society of Automotive Engineers International, Warrendale, PA.
22. National Safety Council 1971. *Vehicle Damage Scale for Traffic Investigators*. Second Edition. Traffic Accident Data Project, National Safety Council, Chicago, IL.
23. SAE. 1980. *Collision Deformation Classification–Recommended Practice (J224) March 1980*. Society of Automotive Engineers International, Warrendale, PA.

APPENDIX A. MATERIAL SPECIFICATIONS, MILL CERTIFICATES, AND CERTIFICATES OF CONFORMANCE

Table A.1. Bill of Materials, Test No. WZNP-1

Item No.	Description	Material Specification	Reference
a1	Plastic Panel, 96" [2,438] Long	Petrothene LR734001	Technical Data Sheet
a2	Plastic Panel, 96" [2,438] Long	Petrothene LR734001	Technical Data Sheet
b1	1 1/2" x 1 1/2" x 12-gauge [38x38x2.7], 58 1/4" [1,480] Long Perforated Square Tubing	ASTM 1011 Gr. 50	Coil#144948 H#C83245
b2	1 3/4" x 1 3/4" x 14-gauge [44x44x1.9], 60" [1,524] Long Perforated Square Tubing	ASTM 1011 Gr. 50	Coil#148057 H#C83841
b3	1 3/4" x 1 3/4" x 14-gauge [44x44x1.9], 6" [152] Long Perforated Square Tubing	ASTM 1011 Gr. 50	Coil#148057 H#C83841
c1	48" x 30" x 0.08" [1,219 x 762 x 2] Sign with Reflective Sheeting	Aluminum Alloy 5052	COC
c2	Warning Light (Type A or C)	As Supplied	Fastenal COC
d1	3/8"-16 UNC [M10x1.5], 3 1/2" [89] Long Hex Head Bolt and Lock Nut	Bolt - ASTM A307 Gr. A or equivalent Nut - SAE J995 Gr. 2 or equivalent	Bolt: P#11117 Nut: H#321605150
d2	1/2"-13 UNC [M14x2], 6" [152] Long Hex Head Bolt	ASTM A307 Gr. A or equivalent	P#11225
d3	1/4"-20 UNC [M6x1], 1 3/4" [44] Long Hex Head Bolt and Lock Nut	Bolt - ASTM A307 Gr. A or equivalent Nut - SAE J995 Gr. 2 or equivalent	Bolt: P#11010 Nut: H#321706450
d4	3/8" [10] Dia. Plain Round Washer	Low Carbon Steel	P#1133008
d5	1/2" [13] Dia. Plain Round Washer	Low Carbon Steel	P#1133012
d6	1/4" [6] Dia. Plain Round Washer	Low Carbon Steel	P#1133004

September 19, 2018
MwRSF Report No. TRP-03-394-18 Revision-1

Product Comparison

PROSPECTOR®
www.ulprospector.com

Technical Data

Product Description	
Petrothene® LR734001	Petrothene LR734001 is a high density polyethylene resin that exhibits good stiffness and environmental stress crack resistance. Typical applications include bottles for household chemicals, food products, and personal care products.
PRIMATOP® HDPE 003955P	Phillips Process Hexene Copolymer

General	Petrothene® LR734001	PRIMATOP® HDPE 003955P
Manufacturer / Supplier	- LyondellBasell Industries	- Amco Polymers
Generic Symbol	- HDPE	- HDPE
Material Status	- Commercial: Active	- Commercial: Active
Literature [1]	- Processing - Mold Shrink (English) - Processing - Polyolefin Injection Molding Guide (English) - Technical Datasheet (English)	- Technical Datasheet
UL Yellow Card [2]	- E62552-100622145	--
Search for UL Yellow Card	- LyondellBasell Industries - Petrothene®	- Amco Polymers
Availability	- North America	- North America
Features	- Good ESCR (Stress Crack Resist.) - Good Processability - Good Stiffness	- Copolymer - Food Contact Acceptable - Hexene Comonomer - High ESCR (Stress Crack Resist.) - High Stiffness
Uses	- Bottles - Packaging - Rigid Packaging	- Blow Molding Applications - Sheet
Agency Ratings	--	- FDA 21 CFR 177.1520
Processing Method	- Extrusion Blow Molding	- Blow Molding - Sheet Extrusion - Thermoforming

Physical	Petrothene® LR734001	PRIMATOP® HDPE 003955P	Unit	Test Method
Density				ASTM D1505
-- [4]	0.953	--	g/cm³	
--	--	0.955	g/cm³	
Melt Mass-Flow Rate (MFR) (190°C/2.16 kg)	0.38	0.35	g/10 min	ASTM D1238
Environmental Stress-Cracking Resistance (ESCR)				
F50	--	35.0	hr	ASTM D1693B
100% Igepal, F50	--	45.0	hr	ASTM D1693A
100% Igepal, F50	25.0	--	hr	ASTM D1693B

Mechanical	Petrothene® LR734001	PRIMATOP® HDPE 003955P	Unit	Test Method
Tensile Strength				ASTM D638
Yield [5]	--	4000	psi	
Yield	4000	--	psi	
Tensile Elongation				ASTM D638
Break	> 500	--	%	
Break [5]	--	> 600	%	
Flexural Modulus				ASTM D790
--	--	200000	psi	
1% Secant	176000	--	psi	

1 of 2

Form No. TDS-29304-119304-en
Document Created: Monday, April 30, 2018

Figure A-1. Plastic Panel Material Certificate, Test No. WZNP-1

allied TUBE & CONDUIT A PART OF atkore

ALLIED TUBE & CONDUIT PRODUCT CERTIFICATION

1.75" 14ga.

A01	A02 TYPE OF DOCUMENT	A03 DOC NO.		A06 CUSTOMER
ALLIED TUBE & CONDUIT 16100 S. LATHROP AVE HARVEY, IL 60426	PRODUCT TEST REPORT AS PER ASTM A500; TEST METHOD AS PER ASTM A370	ALLIED MTR NO. 0039833		M61014 ATC/TELESPAR

A07 CUSTOMER ORDER	PRODUCT DATE	PART NO.	DIAMETER	GAGE	THICKNESS	B06 MARKINGS
	9/14/17	695983 TEL-SQ PGAL/H 1.750 14 289.750	1.750	14	.083	

B01 PRODUCT: STEEL TUBING	B02 SPECIFICATION: 60 MIN YIELD	B03 Made and Manufactured in the USA	TUBE MECHANICAL TEST

B07	B16	STEEL GRADE:	A1011GR55			CHEMICAL COMPOSITION %									C11	C12	C13
		C71	C73	C74	C75	C72	C76	C82	C80	C81	C79	C78	C77	C83		CEV	YIELD STR	TENSILE STR	El in 2"
COIL NO.	HEAT NO.	C	Mn	P	S	Si	Al	Cu	Ni	Cr	Mo	V	Cb	Ti	N	%	KSI	KSI	%
144948	C83245	.22	.85	.009	.002	.040	.035	.150	.050	.070	.020	.001	.002			.392	65.6	77.4	12.0

Z01 TERMS AND CONDITIONS OF THE SALE	Z05 CERTIFICATIONS	Z04	Z02/Z03
WE HEREBY CERTIFY THAT THE ABOVE MENTIONED MATERIAL HAS BEEN DELIVERED IN ACCORDANCE WITH THE TERMS OF THE ORDER	QS-SYSTEM:ISO 9001:2008	ALLIED TUBE & CONDUIT 16100 S. LATHROP AVE HARVEY, IL 60426 USA	METLAB Giulio Scartozzi Signature: Giulio Scartozzi ALLIEDMTR-REV 00

Figure A-2. Square Tubing Material Certificate, Test No. WZNP-1

September 19, 2018
MwRSF Report No. TRP-03-394-18 Revision-1

allied TUBE & CONDUIT A PART OF atkore

ALLIED TUBE & CONDUIT PRODUCT CERTIFICATION

2.00" 14GA.

A01	A02 TYPE OF DOCUMENT	A03 DOC NO.	A06 CUSTOMER
ALLIED TUBE & CONDUIT 16100 S. LATHROP AVE HARVEY, IL 60426	PRODUCT TEST REPORT AS PER ASTM A500; TEST METHOD AS PER ASTM A370	ALLIED MTR NO. 0039705	M61014 ATC/TELESPAR

A07 CUSTOMER ORDER	PRODUCT DATE	PART NO.	DIAMETER	GAGE	THICKNESS	B06 MARKINGS
	10/25/17	695799 TEL-SQ PGAL/H 2.000 14 289.750	2.000	14	.083	

B01 PRODUCT: STEEL TUBING	B02 SPECIFICATION: 60 MIN YIELD	B03 Made and Manufactured in the USA

STEEL GRADE: A1011GR55

B07 COIL NO.	B16 HEAT NO.	C71 C	C73 Mn	C74 P	C75 S	C72 Si	C76 Al	C82 Cu	C80 Ni	C81 Cr	C79 Mo	C78 V	C77 Cb	C83 Ti	N	CEV %	C11 YIELD STR KSI	C12 TENSILE STR KSI	C13 El in 2" %
148057	C83841	.21	.84	.008	.004	.020	.035	.160	.050	.070	.020	.001	.001			.382	61.5	74.0	13.1

CHEMICAL COMPOSITION % — TUBE MECHANICAL TEST

Z01 TERMS AND CONDITIONS OF THE SALE	Z05 CERTIFICATIONS	Z04	Z02/Z03
WE HEREBY CERTIFY THAT THE ABOVE MENTIONED MATERIAL HAS BEEN DELIVERED IN ACCORDANCE WITH THE TERMS OF THE ORDER	QS-SYSTEM:ISO 9001:2008	ALLIED TUBE & CONDUIT 16100 S. LATHROP AVE HARVEY, IL 60426 USA	METLAB Giulio Scartozzi Signature: Giulio Scartozzi ALLIEDMTR-REV 00

Figure A-3. Square Tubing Material Certificate, Test No. WZNP-1

September 19, 2018
MwRSF Report No. TRP-03-394-18 Revision-1

SmartSign

RoadTrafficSign
A SmartSign Store
300 Cadman Plaza West, ste 1303
Brooklyn NY 11201
Phone: 1-800-952-1457

5/15/18

CERTIFICATE OF COMPLIANCE

SmartSign hereby certifies that all materials supplied against purchase order number RTS-129064 / PO: WBS# 26-1113-0106-001 shipped on 4/06/18 conforms to the material and/or manufacturing specifications as called on this said purchase order without exceptions.

Item #
X-R11-2

QTY: 2 signs

Description:
Road Closed Engineer Grade Reflective Aluminum Sign, 80 mil

Sincerely,

Tahyna Colon
Call Center Manager
tahyna@smartsign.com
800-952-1457 x 7140

Figure A-4. Sign Certificate of Conformance, Test No. WZNP-1

FASTENAL®

Certificate of Compliance

Sold To:

UNL TRANSPORTATION

Purchase Order:

Job: SWZDI Type III Barricade - WZN

Invoice Date: 04/25/2018

THIS IS TO CERTIFY THAT WE HAVE SUPPLIED YOU WITH THE FOLLOWING PARTS.
THESE PARTS WERE PURCHASED TO THE FOLLOWING SPECIFICATIONS.

4 PCS 7" 3V D-Cell Polycarbonate Flashing or Steady Barricade Light SUPPLIED UNDER OUR TRACE NUMBER llne35292 AND UNDER PART NUMBER 1076058

This is to certify that the above document is true and accurate to the best of my knowledge.

Fastenal Account Representative Signature

Printed Name

Date

Please check current revision to avoid using obsolete copies.

This document was printed on 04/25/2018 and was current at that time.

Fastenal Store Location/Address

3201 N. 23rd Street STE 1
LINCOLN, NE 68521
Phone #: (402)476-7900
Fax #: 402/476-7958

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Figure A-5. Warning Light Certificate of Compliance, Test No. WZNP-1

CERTIFIED MATERIAL TEST REPORT
FOR ASTM A307, GRADE A - MACHINE BOLTS

FACTORY: IFI & MORGAN LTD. REPORT DATE:2015/9/22
ADDRESS: No.583-28, Chang'an North Road, Wuyuan Town, Haiyan, Zhejiang, China
MANUFACTURE DATE:2015/8/20

CUSTOMER: FASTENAL MFG LOT NUMBER:M-2015HT147-4
SAMPE SIZE: ACC. TO ASME B18.18 CATEGORY 2-2011; ASTM F1470-12 TABLE 3
MANU QTY: 28850 PCS SHIPPED QTY: 28800 PCS
SIZE: 3/8-16X3 1/2 ZP CR3+
HEADMARKS: 307A PLUS NY PO NUMBER:110180103
PART NO: 11117

STEEL PROPERTIES:
MATERIAL TYPE:Q195 HEAT NUMBER: 715030679

CHEMISTRY SPEC:	C %*100	Mn%*100	P %*1000	S %*1000
Grade A ASTM A307-12	0.29max	1.20 max	0.04max	0.15max
TEST:	0.06	0. 31	0.017	0.019

DIMENSIONAL INSPECTIONS Unit:inch SPECIFICATION: ASME B18.2.1 - 2012

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
**********************	***********************************	*******************	********	********
VISUAL	ASTM F788-2013	PASSED	29	0
THREAD	ASME B1.1-2003,3A GO,2A NOGO	PASSED	15	0
WIDTH A/F	0.544-0.562	0.548-0.558	4	0
WIDTH A/C	0.620-0.650	0.630-0.642	4	0
HEAD HEIGHT	0.226-0.268	0.234-0.261	4	0
BODY DIA.	0.360-0.388	0.369-0.373	4	0
THREAD LENGTH	1.00Min	1.012-1.124	15	0
LENGTH	3.440-3.540	3.458-3.523	15	0

MECHANICAL PROPERTIES: SPECIFICATION: ASTM A307 - 14e1 GR.A

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
********************	*****************	******************	*****************	********	********
CORE HARDNESS :	ASTM F606-2014	69-100 HRB	76-80 HRB	4	0
WEDGE TENSILE:	ASTM F606-2014	Min 60 KSI	65-69 KSI	4	0

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
COATINGS OF ZINC		SPECIFIATION: ASTM F1941/F1941M-2015 Fe/Zn 3AN			
Coating thickness	ASTM B568-98(2014)	Min 3 μm	4-5 μm	4	0
SALT SPRAY TEST	ASTM B117-11	6 Hr no white rust,12 Hr no red rust	Passed	4	0

ZINC ELECTROPLATING WITH TRIVALENT CHROMATE(CR+3) IN COMPLIANCE WITH ROHS REQUTREMENTS.

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.
Maker's ISO 9001:2015 SGS Certificate # HK04/0105

IFI & MORGAN LTD. 检验专用章 QUALITY CONTROL

(SIGNATURE OF Q.A. LAB MGR.)
(NAME OF MANUFACTURER)

Figure A-6. Hex Bolt Material Certificate, Test No. WZNP-1

ISO/TS 16949
BUREAU VERITAS
Certification

GEM-YEAR TESTING LABORATORY

CERTIFICATE OF INSPECTION

MANUFACTURER GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR
ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA

Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2018/05/09

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 210115915
COMMODITY : NYLON INSERT NUT GR-A
SIZE : 3/8-16 NC
LOT NO : 1N1680060
SHIP QUANTITY : 150,000 PCS
LOT QUANTITY 378,534 PCS
HEADMARKS : GENIUS SYMBOL
MANUFACTURE DATE : 2016/09/06
COUNTRY OF ORIGIN : CHINA

PACKING NO : GEM161201020
INVOICE NO : GEM/FNL-161213ED
PART NO : 1137024
SAMPLING PLAN :
ASME B18.18-2011(Category.2)/ASTM F1470-2012
HEAT NO : 321605150
MATERIAL : ML08
FINISH : Fe/Zn 3AN ASTM F1941/F1941M-2016

PERCENTAGE COMPOSITION OF CHEMISTRY:ACCORDING TO IFI 100/107 GR-A

Chemistry	AL%	C%	MN%	P%	S%	SI%
Spec. : MIN.						
MAX.		0.5800		0.1300	0.2300	
Test Value	0.0380	0.0800	0.4300	0.0130	0.0040	0.0600

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME B18.16.6-2014

SAMPLED BY : LXQING

INSPECTIONS ITEM	SAMPLE	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
WIDTH ACROSS CORNERS	6 PCS	Min. 0.6220 inch	0.6250-0.6290 inch	6	0
THICKNESS	6 PCS	0.4380-0.4680 inch	0.4410-0.4640 inch	6	0
WIDTH ACROSS FLATS	6 PCS	0.5510-0.5640 inch	0.5540-0.5610 inch	6	0
SURFACE DISCONTINUITIES	29 PCS	ASTM F812-2012	PASSED	29	0
THREAD	15 PCS	GAGING SYSTEM 21	PASSED	15	0

MECHANICAL PROPERTIES : ACCORDING TO IFI 100/107 GR-A

SAMPLED BY : GDAN LIAN

INSPECTIONS ITEM	SAMPLE	TEST METHOD	REF	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS	15 PCS	ASTM F606-2014		Max.104 HRB	86-87 HRB	15	0
PROOF LOAD	5 PCS	ASTM F606-2014		Min. 7,000 LBF	OK	5	0
PLATING THICKNESS(μm)	29 PCS	ASTM B568-1998		>=3	3.21-5	29	0
SALT SPRAY TEST	15 PCS	ASTM B117-16		6 HOURS NO WHITE RUST, 12 HOURS NO RED RUST	OK	15	0

WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY .WHICH ACCREDITED BY ISO/IEC17025(CERTIFICATE NUMBER:3358.01)
WE CERTIFY THAT THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH THE REQUIREMENTS OF THE ORDER

Quality Supervisor: [signature]

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Figure A-7. Lock Nut Material Certificate, Test No. WZNP-1

CERTIFIED MATERIAL TEST REPORT
FOR ASTM A307, GRADE A - MACHINE BOLTS

FACTORY: IFI & MORGAN LTD. REPORT DATE:2016/7/28
ADDRESS: No.583-28, Chang'an North Road, Wuyuan Town, Haiyan, Zhejiang, China
MANUFACTURE DATE:2016/6/23

CUSTOMER: FASTENAL MFG LOT NUMBER:M-2016HT258-6
SAMPE SIZE: ACC. TO ASME B18.18 CATEGORY 2-2011; ASTM F1470-12 TABLE 3
MANU QTY: 2200PCS SHIPPED QTY: 2160 PCS
SIZE: 1/2-13X6 ZP CR3+
HEADMARKS: 307A PLUS NY PO NUMBER:110206398
PART NO: 11225

STEEL PROPERTIES:
MATERIAL TYPE:Q195 HEAT NUMBER: 616030871

CHEMISTRY SPEC:	C %*100	Mn%*100	P %*1000	S %*1000
Grade A ASTM A307-12	0.29max	1.20 max	0.04max	0.15max
TEST:	0.06	0. 28	0.021	0.006

DIMENSIONAL INSPECTIONS Unit:inch SPECIFICATION: ASME B18.2.1 - 2012

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
**********************	***********************************	******************	********	********
VISUAL	ASTM F788-2013	PASSED	18	0
THREAD	ASME B1.1-2003,3A GO,2A NOGO	PASSED	13	0
WIDTH A/F	0.725-0.750	0.738-0.745	3	0
WIDTH A/C	0.826-0.866	0.829-0.857	3	0
HEAD HEIGHT	0.302-0.364	0.311-0.360	3	0
BODY DIA.	0.482-0.515	0.488-0.502	3	0
THREAD LENGTH	1.25Min	1.258-1.264	13	0
LENGTH	5.900-6.080	5.914-6.047	13	0

MECHANICAL PROPERTIES: SPECIFICATION: ASTM A307 - 14e1 GR.A

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
********************	*****************	*****************	*****************	********	********
CORE HARDNESS :	ASTM F606/F606M-2016	69-100 HRB	76-80 HRB	4	0
WEDGE TENSILE:	ASTM F606/F606M-2016	Min 60 KSI	65-69 KSI	4	0

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
COATINGS OF ZINC		SPECIFIATION: ASTM F1941/F1941M-2015 Fc/Zn 3AN			
Coating thickness	ASTM B568-98(2014)	Min 3 μm	4-5 μm	4	0
SALT SPRAY TEST	ASTM B117-2016	6 Hr no white rust,12 Hr no red rust	Passed	4	0

ZINC ELECTROPLATING WITH TRIVALENT CHROMATE(CR+3) IN COMPLIANCE WITH ROHS REQUTREMENTS.

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

Maker's ISO 9001:2015 SGS Certificate # HK04/0105

IFI & MORGAN LTD. 检验专用章 QUALITY CONTROL

(SIGNATURE OF Q.A. LAB MGR.)
(NAME OF MANUFACTURER)

Figure A-8. Hex Bolt Material Certificate, Test No. WZNP-1

ISO/TS 16949 BUREAU VERITAS Certification

GEM-YEAR TESTING LABORATORY
CERTIFICATE OF INSPECTION

MANUFACTURER : GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA

Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2018/05/10

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 180147058
COMMODITY : HEX MACHINE BOLT GR-A
SIZE : 1/4-20X1-3/4 NC
LOT NO : 1B17B2527
SHIP QUANTITY : 27,200 PCS
LOT QUANTITY 29,001 PCS
HEADMARKS : CYI & 307A
MANUFACTURE DATE : 2017/12/08
COUNTRY OF ORIGIN : CHINA

PACKING NO : GEM171221011
INVOICE NO : GEM/FNL-180103ED
PART NO : 11010
SAMPLING PLAN : ASME B18.18-2011(Category.2)/ASTM F1470-2012
HEAT NO : 17104786-3
MATERIAL : X1008A
FINISH : Fe/Zn 3AN ASTM F1941/F1941M-2016

PERCENTAGE COMPOSITION OF CHEMISTRY:ACCORDING TO ASTM A307-2014

Chemistry	AL%	C%	MN%	P%	S%	SI%
Spec. : MIN.						
MAX.		0.3300	1.2500	0.0410		
Test Value	0.0300	0.0900	0.3000	0.0110	0.0090	0.0300

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME B18.2.1-2012

SAMPLED BY : ZHANG HUI JING

INSPECTIONS ITEM	SAMPLE	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
THREAD LENGTH	15PCS	0.7500 inch	0.8780-0.8800 inch	15	0
MAJOR DIAMETER	15PCS	0.2410-0.2490 inch	0.2450-0.2460 inch	15	0
BODY DIAMETER	4PCS	0.2370-0.2600 inch	0.2450-0.2460 inch	4	0
WIDTH ACROSS CORNERS	4PCS	0.4840-0.5050 inch	0.4890-0.4910 inch	4	0
HEIGHT	4PCS	0.1500-0.1880 inch	0.1560-0.1570 inch	4	0
NOMINAL LENGTH	15PCS	1.7100-1.7700 inch	1.7310-1.7340 inch	15	0
WIDTH ACROSS FLATS	4PCS	0.4250-0.4380 inch	0.4310-0.4310 inch	4	0
SURFACE DISCONTINUITIES	29PCS	ASTM F788-2013	PASSED	29	0
THREAD	15PCS	ASME B1.1-2003 3A GO 2A NOGO	PASSED	15	0

MECHANICAL PROPERTIES : ACCORDING TO ASTM A307-2014

SAMPLED BY : GDAN LIAN

INSPECTIONS ITEM	SAMPLE	TEST METHOD	REF	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS	15 PCS	ASTM F606-2016		Max. 100 HRB	76-78 HRB	15	0
TENSILE STRENGTH	4 PCS	ASTM F606-2016		Min. 60 KSI	67-70 KSI	4	0
PLATING THICKNESS(μm)	29 PCS	ASTM B568-1998		>=3	3.06-3.6	29	0
SALT SPRAY TEST	15 PCS	ASTM B117-16		6 HOURS NO WHITE RUST, 12 HOURS NO RED RUST	OK	15	0

WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY .WHICH ACCREDITED BY ISO/IEC17025(CERTIFICATE NUMBER:3358.01)
WE CERTIFY THAT THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH THE REQUIREMENTS OF THE ORDER

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Figure A-9. Hex Bolt Material Certificate, Test No. WZNP-1

ISO/TS 16949 BUREAU VERITAS Certification

GEM-YEAR TESTING LABORATORY

CERTIFICATE OF INSPECTION

MANUFACTURER GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA

Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2018/05/09

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 210142206
COMMODITY : NYLON INSERT NUT GR-A
SIZE : 1/4-20 NC
LOT NO : 1N1780821
SHIP QUANTITY : 360,000 PCS
LOT QUANTITY 1,205.425 PCS
HEADMARKS : GENIUS SYMBOL
MANUFACTURE DATE : 2017/10/11
COUNTRY OF ORIGIN : CHINA

PACKING NO : GEM171130003
INVOICE NO : GEM/FNL-171213ED-2
PART NO : 1137018
SAMPLING PLAN :
ASME B18.18-2011(Category.2)/ASTM F1470-2012
HEAT NO : 321706450
MATERIAL : ML08
FINISH : Fe/Zn 3AN ASTM F1941/F1941M-2016

PERCENTAGE COMPOSITION OF CHEMISTRY:ACCORDING TO ASTM A563-2015

Chemistry	AL%	C%	MN%	P%	S%	SI%
Spec. : MIN.						
MAX.		0.5800		0.1300	0.2300	
Test Value	0.0290	0.0600	0.4200	0.0190	0.0050	0.0400

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME B18.16.6-2014

SAMPLED BY : WDANDAN

INSPECTIONS ITEM	SAMPLE	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
WIDTH ACROSS CORNERS	7PCS	Min.0.4850 in.ch	0.4940-0.4960 in.ch	7	0
THICKNESS	7PCS	0.2980-0.3260 in.ch	0.3150-0.3170 in.ch	7	0
WIDTH ACROSS FLATS	7PCS	0.4290-0.4370 in.ch	0.4350-0.4360 in.ch	7	0
SURFACE DISCONTINUITIES	29PCS	ASTM F812-2012	PASSED	29	0
THREAD	15PCS	GAGING SYSTEM 21	PASSED	15	0

MECHANICAL PROPERTIES : ACCORDING TO IFI 100/107 GR-A

SAMPLED BY : PAN LU

INSPECTIONS ITEM	SAMPLE	TEST METHOD	REF	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS	15 PCS	ASTM F606-2014		Max.100HRB	85-88 HRB	15	0
PROOF LOAD	7 PCS	ASTM F606-2014		Min.2,900 LBF	OK	7	0
PLATING THICKNESS(μm)	29 PCS	ASTM B568-1998		>=3	3.1-3.88	29	0
SALT SPRAY TEST	15 PCS	ASTM B117-16		6 HOURS NO WHITE RUST, 12 HOURS NO RED RUST	OK	15	0

WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY .WHICH ACCREDITED BY ISO/IEC17025(CERTIFICATE NUMBER:3358.01)
WE CERTIFY THAT THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH THE REQUIREMENTS OF THE ORDER

Quality Supervisor:

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Figure A-10. Lock Nut Material Certificate, Test No. WZNP-1

TEST REPORT

USS FLAT WASHER, ZP

CUSTOMER:	DATE: **2017-11-10**
PO NUMBER: **480006320**	MFG LOT NUMBER: **M-SWE0412056-3**
SIZE: **3/8**	PART NO: **1133008**
HEADMARKS:	QNTY: **157,500 PCS**

DIMENSIONAL INSPECTIONS — SPECIFICATION: **ASME B18.21.1(2009)**

CHARACTERISTICS		SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*********************		***********************************	******************	********	********
APPEARANCE		**ASTM F788-07**	**PASSED**	**100**	**0**
OUTSIDE DIA		**0.993-1.030**	**0.999-1.002**	**8**	**0**
INSIDE DIA		**0.433-0.453**	**0.446-0.448**	**8**	**0**
THICKNESS		**0.064-0.104**	**0.069-0.071**	**8**	**0**
ZINC PLATED	**ASTM F1941/F1941M FE/ZN 3AN**	**Min 3 μm**	**3.9-4.4 μm**	**8**	**0**
Salt Spray test result	**ASTM B117**	**Min 6 hrs No White Rust**	**Pass**	**8**	**0**

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DAIA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

MFG ISO 9001:2015 SGS Certificate # HK04/0105

IFI & MORGAN LTD. 检验专用章 QUANLITY CONTROL

(SIGNATURE OF Q.A. LAB MGR.)
(NAME OF MANUFACTURER)

IFI & MORGAN LTD. ***ADDRESS: Chang'an North Road, Wuyuan Town, Haiyan, Zhejiang, China***

Figure A-11. Flat Washer Material Certificate, Test No. WZNP-1

CERTIFIED MATERIAL TEST REPORT
FOR USS FLAT WASHERS ZP

FACTORY: IFI & Morgan Ltd REPORT DATE: 2018-05-09
ADDRESS: Chang'an North Road, Wuyuan Town, Haiyan,Zhejiang, China
MANUFACTURE DATE:
CUSTOMER:
MFG LOT NUMBER:

SAMPLING PLAN PER ASME B18.18-11 PO NUMBER: 480006818
SIZE: USS 1/2 ZP QNTY(Lot size): 26250PCS
HEADMARKS: NO MARK PART NO: 1133012

DIMENSIONAL INSPECTIONS SPECIFICATION: ASTM B18.21.1-2011

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*********************	***********************************	******************	********	********
APPEARANCE	ASTM F844	PASSED	100	0
OUTSIDE DIA	1.368-1.405	1.370-1.378	10	0
INSIDE DIA	0.557-0.577	0.567-0.575	10	0
THICKNESS	0.086-0.132	0.086-0.102	10	0

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*********************	******************	******************	*****************	********	********
ZINC PLATED	ASTM F1941	Min 3 um	3-4um	8	0

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.
MFG ISO9002 CERTIFICATE NO. HK04/0105

IFI & MORGAN LTD.
检验专用章
QUANLITY CONTROL

(SIGNATURE OF Q.A. LAB MGR.)
(NAME OF MANUFACTURER)

Figure A-12. Flat Washer Material Certificate, Test No. WZNP-1

TEST REPORT

USS FLAT WASHER, ZP

CUSTOMER:	DATE: **2018-11-12**
PO NUMBER: **110243322**	MFG LOT NUMBER: **M-SWE0412056-1**
SIZE: **1/4**	PART NO: **1133004**
HEADMARKS:	QNTY: **540,000 PCS**

DIMENSIONAL INSPECTIONS — SPECIFICATION: **ASME B18.21.1(2009)**

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
**********************	************************************	*******************	********	********
APPEARANCE	**ASTM F788-07**	**PASSED**	**100**	**0**
OUTSIDE DIA	**0.727-0.749**	**0.730-0.732**	**8**	**0**
INSIDE DIA	**0.307-0.327**	**0.321-0.323**	**8**	**0**
THICKNESS	**0.051-0.080**	**0.053-0.056**	**8**	**0**

ZINC PLATED	**ASTM F1941/F1941M FE/ZN 3AN**	**Min 3 µm**	**3.6-4.1 µm**	**8**	**0**
Salt Spray test result	**ASTM B117**	**Min 6 hrs No White Rust**	**Pass**	**8**	**0**

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION.
WE CERTIFY THAT THIS DAIA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.
MFG ISO 9001:2015 SGS Certificate # HK04/0105

IFI & MORGAN LTD. 检验专用章 QUANLITY CONTROL

(SIGNATURE OF Q.A. LAB MGR.)
(NAME OF MANUFACTURER)

IFI & MORGAN LTD. ***ADDRESS: Chang'an North Road, Wuyuan Town, Haiyan, Zhejiang, China***

Figure A-13. Flat Washer Material Certificate, Test No. WZNP-1

APPENDIX B. VEHICLE CENTER OF GRAVITY DETERMINATION

Date:	5/23/2018	Test Name:	WZNP-1	VIN:	KNADH4A38B6939145
Year:	2011	Make:	KIA	Model:	RIO

Vehicle CG Determination

	Vehicle Equipment	Weight (lb.)
+	Unballasted Car (Curb)	2320
+	Hub	19
+	Brake activation cylinder & frame	7
+	Pneumatic tank (Nitrogen)	22
+	Strobe/Brake Battery	5
+	Brake Receiver/Wires	5
+	CG Plate including DAS	13
-	Battery	-31
-	Oil	-6
-	Interior	-63
-	Fuel	-22
-	Coolant	-6
-	Washer fluid	-7
+	Water Ballast (In Fuel Tank)	95
+	Onboard Supplemental Battery	0
	Trunk	55

Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle

Estimated Total Weight (lb.) 2406

Vehicle Dimensions for C.G. Calculations

Wheel Base:	98 3/4	in.	Front Track Width:	57 7/8	in.
Roof Height:	58 1/4	in.	Rear Track Width:	58	in.

Center of Gravity	1100C MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb.)	2420 ± 55	2426	6.0
Longitudinal CG (in.)	39 ± 4	40.094291	1.09429
Lateral CG (in.)	NA	-0.358229	NA
Vertical CG (in.)	NA	22.50	NA

Note: Long. CG is measured from front axle of test vehicle

Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb.)

	Left	Right
Front	737	728
Rear	430	425

FRONT	1465	lb.
REAR	855	lb.
TOTAL	2320	lb.

TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	729	712
Rear	499	486

FRONT	1441	lb.
REAR	985	lb.
TOTAL	2426	lb.

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

APPENDIX C. VEHICLE DEFORMATION RECORDS

Date: 5/23/2018 Test Name: WZNP-1 VIN: KNADH4A38B6939145
Year: 2011 Make: KIA Model: RIO

VEHICLE DEFORMATION
FLOOR PAN - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX^A (in.)	ΔY^A (in.)	ΔZ^A (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	62.6	19.9	4.8	62.5	20.0	4.7	0.0	-0.1	0.1	0.1	0.1	X, Z
	2	63.0	24.1	4.3	62.9	24.1	4.2	0.0	0.0	0.1	0.1	0.1	X, Z
	3	63.2	27.5	4.1	63.1	27.6	4.0	0.0	0.0	0.1	0.1	0.1	X, Z
	4	63.2	31.5	3.9	63.2	31.5	3.8	0.0	-0.1	0.1	0.1	0.1	X, Z
	5	61.7	33.9	2.1	61.6	33.9	2.0	0.1	0.0	0.1	0.1	0.1	X, Z
	6	59.6	19.4	6.6	59.6	19.4	6.6	0.0	0.0	0.0	0.1	0.1	X, Z
	7	59.9	24.1	6.2	59.9	24.1	6.1	0.0	0.0	0.1	0.1	0.1	X, Z
	8	60.3	28.0	5.8	60.2	28.0	5.8	0.1	0.0	0.1	0.1	0.1	X, Z
	9	60.3	31.7	5.7	60.3	31.8	5.7	0.1	-0.1	0.1	0.1	0.1	X, Z
	10	59.7	35.0	4.9	59.6	35.0	4.7	0.1	0.0	0.2	0.2	0.2	X, Z
FLOOR PAN (Z)	11	56.9	19.8	7.9	56.9	19.7	7.9	0.0	0.0	0.0	0.1	0.0	Z
	12	56.7	24.6	7.8	56.8	24.5	7.8	0.0	0.1	0.0	0.1	0.0	Z
	13	56.9	28.2	7.4	56.8	28.1	7.4	0.1	0.1	0.0	0.1	0.0	Z
	14	56.7	32.3	7.7	56.7	32.2	7.7	0.0	0.1	0.0	0.1	0.0	Z
	15	56.7	35.3	7.6	56.7	35.3	7.6	0.0	0.1	0.0	0.1	0.0	Z
	16	53.5	19.4	7.8	53.5	19.4	7.8	0.0	0.0	0.0	0.0	0.0	Z
	17	53.4	24.3	8.0	53.4	24.2	8.0	0.0	0.1	0.0	0.1	0.0	Z
	18	53.5	28.0	7.8	53.5	27.9	7.8	0.0	0.0	0.0	0.1	0.0	Z
	19	53.0	32.2	8.0	53.1	32.1	8.0	-0.1	0.1	0.0	0.1	0.0	Z
	20	52.5	35.4	8.0	52.5	35.4	8.0	0.0	0.0	0.0	0.0	0.0	Z
	21	48.4	19.1	8.4	48.4	19.1	8.4	0.0	0.0	0.0	0.0	0.0	Z
	22	49.0	23.2	8.5	49.0	23.3	8.5	0.0	-0.1	0.0	0.1	0.0	Z
	23	49.3	27.7	7.9	49.2	27.8	8.0	0.1	0.0	-0.1	0.1	-0.1	Z
	24	49.2	31.7	8.0	49.2	31.7	8.0	0.0	0.0	0.0	0.1	0.0	Z
	25	49.4	35.5	8.4	49.4	35.5	8.4	0.0	0.0	0.0	0.0	0.0	Z
	26	45.1	18.9	8.4	45.0	18.9	8.5	0.1	0.0	0.0	0.1	0.0	Z
	27	45.3	23.1	8.7	45.2	23.1	8.7	0.0	0.0	0.0	0.0	0.0	Z
	28	45.9	27.5	8.0	45.9	27.6	8.1	0.0	0.0	-0.2	0.2	-0.2	Z
	29	45.9	31.5	8.0	45.8	31.4	8.1	0.1	0.1	0.0	0.1	0.0	Z
	30	46.1	35.6	8.6	46.1	35.7	8.7	0.0	0.0	0.0	0.1	0.0	Z

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If no direction listed, then no intrusion is recorded, and Crush will be 0.

Pretest Floor Pan

Posttest Floor Pan

Figure C-1. Floor Pan Deformation Data – Set 1 (Right), Test No. WZNP-1

Date: 5/23/2018 Test Name: WZNP-1 VIN: KNADH4A38B6939145
Year: 2011 Make: KIA Model: RIO

VEHICLE DEFORMATION
FLOOR PAN - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	62.3	-28.6	0.8	62.2	-28.5	0.6	0.1	0.1	0.3	0.3	0.3	X, Z
	2	65.3	-24.5	2.3	65.1	-24.6	2.0	0.2	-0.1	0.3	0.4	0.4	X, Z
	3	65.6	-19.4	3.4	65.6	-19.4	3.1	0.1	0.0	0.3	0.3	0.3	X, Z
	4	65.4	-15.7	3.5	65.3	-15.7	3.2	0.1	-0.1	0.2	0.3	0.3	X, Z
	5	64.9	-12.1	3.8	64.9	-12.1	3.6	0.0	-0.1	0.3	0.3	0.3	X, Z
	6	61.3	-26.8	6.0	61.2	-26.8	5.8	0.1	0.0	0.2	0.2	0.2	X, Z
	7	61.4	-24.8	5.9	61.3	-24.8	5.7	0.1	0.0	0.2	0.2	0.2	X, Z
	8	61.4	-19.9	6.0	61.3	-19.9	5.7	0.1	-0.1	0.2	0.2	0.2	X, Z
	9	61.0	-16.8	6.2	61.0	-16.9	5.9	0.0	-0.1	0.2	0.2	0.2	Z
	10	61.2	-12.1	6.1	61.2	-12.2	5.9	0.0	-0.1	0.2	0.2	0.2	X, Z
FLOOR PAN (Z)	11	58.6	-26.3	7.6	58.4	-26.4	7.5	0.1	-0.1	0.1	0.2	0.1	Z
	12	58.4	-24.6	7.5	58.4	-24.6	7.4	0.0	-0.1	0.1	0.2	0.1	Z
	13	58.5	-20.1	7.6	58.5	-20.2	7.4	0.0	0.0	0.2	0.2	0.2	Z
	14	58.5	-17.1	7.6	58.5	-17.1	7.4	0.0	-0.1	0.2	0.2	0.2	Z
	15	58.5	-12.0	7.4	58.5	-12.1	7.3	-0.1	-0.1	0.2	0.2	0.2	Z
	16	54.1	-29.6	8.0	54.0	-29.7	7.8	0.1	-0.1	0.1	0.2	0.1	Z
	17	53.8	-26.6	8.1	53.7	-26.7	7.9	0.0	-0.1	0.2	0.2	0.2	Z
	18	53.8	-22.9	7.9	53.8	-23.0	7.8	0.0	-0.1	0.1	0.2	0.1	Z
	19	54.0	-18.4	8.0	54.0	-18.4	7.8	0.0	0.0	0.1	0.1	0.1	Z
	20	54.2	-13.3	7.7	54.2	-13.4	7.6	0.0	-0.1	0.2	0.2	0.2	Z
	21	50.4	-29.9	8.3	50.3	-30.0	8.2	0.1	-0.1	0.1	0.2	0.1	Z
	22	50.1	-26.5	8.5	50.0	-26.6	8.3	0.1	-0.1	0.2	0.2	0.2	Z
	23	50.1	-22.9	8.0	50.1	-23.0	7.9	0.1	-0.1	0.1	0.2	0.1	Z
	24	50.5	-18.2	8.0	50.5	-18.3	7.8	0.0	-0.1	0.2	0.2	0.2	Z
	25	51.1	-12.9	8.4	51.1	-12.9	8.3	0.0	0.0	0.1	0.1	0.1	Z
	26	47.6	-30.1	8.4	47.5	-30.2	8.2	0.0	-0.1	0.2	0.2	0.2	Z
	27	47.7	-26.4	8.5	47.7	-26.5	8.3	0.1	-0.1	0.2	0.2	0.2	Z
	28	47.5	-22.8	8.0	47.4	-22.8	8.0	0.0	0.0	0.1	0.1	0.1	Z
	29	47.3	-17.8	8.1	47.3	-17.9	7.9	0.0	-0.1	0.1	0.2	0.1	Z
	30	47.7	-12.6	8.5	47.7	-12.7	8.5	0.0	-0.1	0.1	0.2	0.1	Z

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If no direction listed, then no intrusion is recorded, and Crush will be 0.

Pretest Floor Pan

Posttest Floor Pan

Figure C-2. Floor Pan Deformation Data – Set 2 (Left), Test No. WZNP-1

Date: 5/23/2018 | Test Name: WZNP-1 | VIN: KNADH4A38B6939145
Year: 2011 | Make: KIA | Model: RIO

VEHICLE DEFORMATION
INTERIOR CRUSH - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	49.4	-6.8	-20.8	49.4	-6.7	-20.7	0.0	0.0	0.1	0.1	0.1	X, Y, Z
	2	46.9	-20.0	-23.4	47.0	-19.9	-23.3	-0.1	0.1	0.1	0.2	0.2	X, Y, Z
	3	50.0	-29.8	-20.0	50.1	-29.7	-19.9	-0.1	0.0	0.0	0.1	0.1	X, Y, Z
	4	44.4	-7.4	-13.1	44.5	-7.3	-13.1	-0.1	0.1	0.0	0.1	0.1	X, Y, Z
	5	bad data	bad data	bad data	bad data	bad data	bad data	bad data	bad data	bad data	bad data	bad data	X, Y, Z
	6	47.0	-30.7	-14.5	47.1	-30.7	-14.4	-0.1	0.1	0.1	0.1	0.1	X, Y, Z
SIDE PANEL (Y)	7	54.2	-33.0	-0.1	54.1	-33.0	-0.1	0.1	0.0	0.0	0.1	0.0	Y
	8	59.0	-32.9	-3.3	59.0	-32.9	-3.3	0.0	0.0	0.0	0.0	0.0	Y
	9	59.4	-33.0	-1.0	59.4	-33.0	-0.9	0.0	0.0	0.0	0.0	0.0	Y
IMPACT SIDE DOOR (Y)	10	48.6	-34.4	-15.8	48.7	-34.3	-15.7	-0.1	0.0	0.0	0.1	0.0	Y
	11	36.5	-35.3	-13.7	36.6	-35.2	-13.7	-0.1	0.0	0.0	0.1	0.0	Y
	12	21.9	-34.8	-17.3	22.1	-34.8	-17.3	-0.1	0.0	0.0	0.1	0.0	Y
	13	46.5	-34.3	-6.1	46.5	-34.3	-6.1	0.0	0.0	0.0	0.0	0.0	Y
	14	34.8	-35.1	-0.4	34.8	-35.1	-0.4	0.0	0.0	0.0	0.0	0.0	Y
	15	25.0	-34.8	-2.4	25.1	-34.8	-2.5	0.0	0.0	-0.1	0.1	0.0	Y
ROOF - (Z)	16	34.8	-8.0	-35.4	35.1	-7.9	-35.3	-0.2	0.1	0.1	0.2	0.1	Z
	17	35.0	-12.1	-35.3	35.1	-12.0	-35.3	-0.1	0.1	0.0	0.2	0.0	Z
	18	34.8	-16.0	-35.2	34.9	-15.8	-35.2	-0.1	0.2	0.0	0.2	0.0	Z
	19	34.5	-20.2	-35.0	34.6	-20.1	-35.0	-0.1	0.2	0.0	0.2	0.0	Z
	20	34.1	-24.5	-34.8	34.2	-24.4	-34.9	-0.1	0.1	-0.1	0.2	-0.1	Z
	21	32.4	-7.9	-36.7	32.6	-7.8	-36.7	-0.1	0.1	0.0	0.2	0.0	Z
	22	32.2	-12.1	-36.5	32.4	-11.9	-36.5	-0.2	0.1	0.0	0.2	0.0	Z
	23	31.9	-16.0	-36.5	32.1	-15.8	-36.4	-0.2	0.2	0.1	0.3	0.1	Z
	24	31.5	-20.2	-36.4	31.7	-20.1	-36.4	-0.2	0.1	0.0	0.2	0.0	Z
	25	31.0	-24.2	-36.2	31.2	-24.0	-36.2	-0.2	0.2	-0.1	0.3	-0.1	Z
	26	29.4	-7.9	-38.3	29.5	-7.7	-38.3	-0.1	0.1	0.0	0.2	0.0	Z
	27	29.5	-11.8	-38.2	29.7	-11.6	-38.2	-0.1	0.1	0.0	0.2	0.0	Z
	28	29.2	-15.6	-38.1	29.5	-15.4	-38.1	-0.2	0.2	0.0	0.3	0.0	Z
	29	29.1	-19.9	-37.9	29.3	-19.7	-37.9	-0.2	0.2	0.0	0.3	0.0	Z
	30	28.1	-23.4	-37.8	28.3	-23.3	-37.8	-0.2	0.2	0.0	0.3	0.0	Z
A-PILLAR Maximum (X, Y, Z)	31	53.8	-31.7	-23.0	54.0	-31.6	-22.9	-0.2	0.1	0.0	0.2	0.1	Y, Z
	32	50.8	-31.2	-24.8	50.9	-31.1	-24.7	-0.1	0.1	0.1	0.2	0.1	Y, Z
	33	47.4	-30.5	-27.0	47.5	-30.4	-27.0	-0.2	0.1	0.0	0.2	0.1	Y
	34	43.9	-29.8	-28.9	44.0	-29.6	-28.9	-0.1	0.1	0.0	0.2	0.1	Y
	35	40.9	-29.2	-30.4	41.1	-29.0	-30.4	-0.1	0.1	0.0	0.2	0.1	Y
	36	37.6	-28.5	-32.0	37.7	-28.4	-32.0	-0.1	0.1	0.0	0.2	0.1	Y
A-PILLAR Lateral (Y)	31	53.8	-31.7	-23.0	54.0	-31.6	-22.9	-0.2	0.1	0.0	0.2	0.1	Y
	32	50.8	-31.2	-24.8	50.9	-31.1	-24.7	-0.1	0.1	0.1	0.2	0.1	Y
	33	47.4	-30.5	-27.0	47.5	-30.4	-27.0	-0.2	0.1	0.0	0.2	0.1	Y
	34	43.9	-29.8	-28.9	44.0	-29.6	-28.9	-0.1	0.1	0.0	0.2	0.1	Y
	35	40.9	-29.2	-30.4	41.1	-29.0	-30.4	-0.1	0.1	0.0	0.2	0.1	Y
	36	37.6	-28.5	-32.0	37.7	-28.4	-32.0	-0.1	0.1	0.0	0.2	0.1	Y
B-PILLAR Maximum (X, Y, Z)	37	14.3	-27.8	-34.4	14.3	-27.6	-34.5	0.0	0.1	-0.1	0.2	0.1	Y
	38	15.0	-29.1	-32.4	15.1	-29.0	-32.5	-0.1	0.1	-0.1	0.2	0.1	Y
	39	15.4	-30.0	-30.5	15.6	-29.9	-30.6	-0.2	0.1	-0.1	0.2	0.1	Y
	40	15.9	-30.7	-28.8	16.1	-30.6	-28.8	-0.1	0.1	-0.1	0.2	0.1	Y
B-PILLAR Lateral (Y)	37	14.3	-27.8	-34.4	14.3	-27.6	-34.5	0.0	0.1	-0.1	0.2	0.1	Y
	38	15.0	-29.1	-32.4	15.1	-29.0	-32.5	-0.1	0.1	-0.1	0.2	0.1	Y
	39	15.4	-30.0	-30.5	15.6	-29.9	-30.6	-0.2	0.1	-0.1	0.2	0.1	Y
	40	15.9	-30.7	-28.8	16.1	-30.6	-28.8	-0.1	0.1	-0.1	0.2	0.1	Y

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If no direction listed, then no intrusion is recorded, and Crush will be 0.

Figure C-3. Occupant Compartment Deformation Data – Set 1 (Left), Test No. WZNP-1

Date: 5/23/2018 Test Name: WZNP-1 VIN: KNADH4A38B6939145

Year: 2011 Make: KIA Model: RIO

VEHICLE DEFORMATION
INTERIOR CRUSH - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	48.8	13.8	-20.3	48.5	14.0	-21.0	0.3	-0.2	-0.7	0.8	0.8	X, Y, Z
	2	48.9	23.6	-20.2	48.6	23.8	-20.8	0.3	-0.2	-0.6	0.7	0.7	X, Y, Z
	3	48.9	33.8	-19.7	48.7	34.0	-20.3	0.3	-0.2	-0.6	0.7	0.7	X, Y, Z
	4	43.5	13.3	-12.7	43.4	13.5	-13.3	0.2	-0.2	-0.6	0.7	0.7	X, Y, Z
	5	46.2	23.5	-13.6	46.1	23.6	-14.2	0.1	-0.1	-0.6	0.7	0.7	X, Y, Z
	6	45.7	34.0	-13.9	45.5	34.2	-14.5	0.1	-0.2	-0.6	0.6	0.6	X, Y, Z
SIDE PANEL (Y)	7	52.3	39.5	1.7	52.4	39.6	1.2	-0.1	-0.1	-0.6	0.6	-0.1	Y
	8	57.1	39.6	-2.0	57.2	39.7	-2.7	-0.1	-0.1	-0.7	0.7	-0.1	Y
	9	57.3	39.8	2.0	57.5	39.9	1.2	-0.1	-0.1	-0.7	0.8	-0.1	Y
IMPACT SIDE DOOR (Y)	10	45.9	40.4	-15.6	45.8	40.5	-16.0	0.1	-0.1	-0.4	0.5	-0.1	Y
	11	33.6	40.2	-14.7	33.4	40.4	-15.0	0.2	-0.2	-0.3	0.4	-0.2	Y
	12	20.6	39.5	-15.0	20.5	39.7	-15.2	0.1	-0.2	-0.2	0.3	-0.2	Y
	13	47.3	40.4	-5.8	47.3	40.5	-6.4	0.0	-0.1	-0.6	0.6	-0.1	Y
	14	34.6	40.8	-1.0	34.7	41.0	-1.4	-0.1	-0.2	-0.3	0.4	-0.2	Y
	15	23.3	39.7	-1.7	23.3	39.8	-1.9	0.0	-0.2	-0.2	0.2	-0.2	Y
ROOF - (Z)	16	34.5	13.0	-35.1	34.0	13.2	-35.6	0.5	-0.2	-0.4	0.6	-0.4	Z
	17	34.5	17.4	-35.0	34.0	17.5	-35.4	0.5	-0.2	-0.4	0.7	-0.4	Z
	18	34.4	21.6	-34.9	33.9	21.8	-35.3	0.5	-0.2	-0.4	0.7	-0.4	Z
	19	33.6	26.3	-34.7	33.2	26.5	-35.1	0.4	-0.2	-0.4	0.6	-0.4	Z
	20	32.8	30.6	-34.5	32.3	30.9	-34.9	0.5	-0.2	-0.4	0.7	-0.4	Z
	21	32.3	12.6	-36.3	31.8	12.9	-36.7	0.5	-0.3	-0.4	0.7	-0.4	Z
	22	31.8	16.7	-36.5	31.3	16.9	-36.8	0.5	-0.2	-0.3	0.6	-0.3	Z
	23	31.3	20.9	-36.4	30.9	21.1	-36.8	0.5	-0.2	-0.4	0.6	-0.4	Z
	24	30.7	25.4	-36.4	30.2	25.6	-36.7	0.5	-0.2	-0.3	0.6	-0.3	Z
	25	29.9	29.7	-36.0	29.4	29.9	-36.3	0.4	-0.2	-0.3	0.5	-0.3	Z
	26	29.0	12.3	-38.1	28.4	12.5	-38.4	0.6	-0.2	-0.4	0.7	-0.4	Z
	27	28.8	16.1	-38.1	28.2	16.4	-38.4	0.5	-0.3	-0.3	0.7	-0.3	Z
	28	28.3	20.1	-38.0	27.8	20.3	-38.4	0.5	-0.2	-0.3	0.6	-0.3	Z
	29	27.8	24.9	-37.8	27.3	25.2	-38.1	0.5	-0.3	-0.3	0.7	-0.3	Z
	30	27.0	28.6	-37.6	26.4	28.9	-37.9	0.5	-0.3	-0.3	0.7	-0.3	Z
A-PILLAR Maximum (X, Y, Z)	31	52.3	38.2	-22.2	52.1	38.3	-22.9	0.2	-0.2	-0.7	0.7	0.2	X
	32	47.9	37.1	-25.3	47.6	37.3	-25.8	0.3	-0.2	-0.5	0.7	0.3	X
	33	44.5	36.1	-27.5	44.1	36.3	-28.0	0.3	-0.2	-0.5	0.6	0.3	X
	34	40.9	35.2	-29.5	40.5	35.4	-30.0	0.4	-0.2	-0.5	0.7	0.4	X
	35	38.0	34.4	-31.1	37.6	34.6	-31.5	0.4	-0.2	-0.4	0.6	0.4	X
	36	34.6	33.5	-32.6	34.3	33.7	-33.0	0.4	-0.2	-0.4	0.6	0.4	X
A-PILLAR Lateral (Y)	31	52.3	38.2	-22.2	52.1	38.3	-22.9	0.2	-0.2	-0.7	0.7	-0.2	Y
	32	47.9	37.1	-25.3	47.6	37.3	-25.8	0.3	-0.2	-0.5	0.7	-0.2	Y
	33	44.5	36.1	-27.5	44.1	36.3	-28.0	0.3	-0.2	-0.5	0.6	-0.2	Y
	34	40.9	35.2	-29.5	40.5	35.4	-30.0	0.4	-0.2	-0.5	0.7	-0.2	Y
	35	38.0	34.4	-31.1	37.6	34.6	-31.5	0.4	-0.2	-0.4	0.6	-0.2	Y
	36	34.6	33.5	-32.6	34.3	33.7	-33.0	0.4	-0.2	-0.4	0.6	-0.2	Y
B-PILLAR Maximum (X, Y, Z)	37	13.4	32.0	-34.6	13.1	32.2	-34.7	0.3	-0.2	-0.1	0.4	0.3	X
	38	13.9	33.5	-32.3	13.6	33.7	-32.4	0.3	-0.2	-0.1	0.4	0.3	X
	39	14.4	34.7	-29.7	14.2	34.9	-29.8	0.3	-0.3	-0.1	0.4	0.3	X
	40	14.9	35.6	-27.5	14.7	35.8	-27.5	0.2	-0.2	-0.1	0.3	0.2	X
B-PILLAR Lateral (Y)	37	13.4	32.0	-34.6	13.1	32.2	-34.7	0.3	-0.2	-0.1	0.4	-0.2	Y
	38	13.9	33.5	-32.3	13.6	33.7	-32.4	0.3	-0.2	-0.1	0.4	-0.2	Y
	39	14.4	34.7	-29.7	14.2	34.9	-29.8	0.3	-0.3	-0.1	0.4	-0.3	Y
	40	14.9	35.6	-27.5	14.7	35.8	-27.5	0.2	-0.2	-0.1	0.3	-0.2	Y

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If no direction listed, then no intrusion is recorded, and Crush will be 0.

Figure C-4. Occupant Compartment Deformation Data – Set 1 (Right), Test No. WZNP-1

Date: 5/23/2018 Test Name: WZNP-1 VIN: KNADH4A38B6939145
Year: 2011 Make: KIA Model: RIO

VEHICLE DEFORMATION
INTERIOR CRUSH - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	49.4	-6.6	-20.8	49.4	-6.7	-20.7	-0.1	-0.1	0.1	0.2	0.2	X, Y, Z
	2	46.8	-19.8	-23.4	47.0	-19.9	-23.3	-0.1	-0.1	0.1	0.2	0.2	X, Y, Z
	3	50.0	-29.6	-20.0	50.1	-29.7	-19.9	-0.1	-0.1	0.0	0.2	0.2	X, Y, Z
	4	44.4	-7.2	-13.1	44.5	-7.3	-13.1	-0.1	-0.1	0.1	0.2	0.2	X, Y, Z
	5	bad data	bad data	bad data	bad data	bad data	bad data	bad data	bad data	bad data	bad data	bad data	X, Y, Z
	6	47.0	-30.5	-14.5	47.1	-30.7	-14.4	-0.1	-0.1	0.1	0.2	0.2	X, Y, Z
SIDE PANEL (Y)	7	54.2	-32.8	-0.1	54.1	-33.0	-0.1	0.1	-0.2	0.0	0.2	-0.2	Y
	8	59.0	-32.7	-3.3	59.0	-32.9	-3.3	0.0	-0.2	0.0	0.2	-0.2	Y
	9	59.4	-32.8	-1.0	59.4	-33.0	-0.9	0.0	-0.2	0.1	0.2	-0.2	Y
IMPACT SIDE DOOR (Y)	10	48.5	-34.2	-15.8	48.7	-34.3	-15.7	-0.1	-0.2	0.0	0.2	-0.2	Y
	11	36.5	-35.1	-13.7	36.6	-35.2	-13.7	-0.1	-0.2	-0.1	0.2	-0.2	Y
	12	21.9	-34.6	-17.3	22.1	-34.8	-17.3	-0.1	-0.2	0.0	0.2	-0.2	Y
	13	46.4	-34.1	-6.1	46.5	-34.3	-6.1	0.0	-0.2	0.0	0.2	-0.2	Y
	14	34.8	-34.9	-0.4	34.8	-35.1	-0.4	0.0	-0.2	0.0	0.2	-0.2	Y
	15	25.0	-34.5	-2.4	25.1	-34.8	-2.5	-0.1	-0.2	-0.1	0.3	-0.2	Y
ROOF - (Z)	16	34.8	-7.8	-35.4	35.1	-7.9	-35.3	-0.3	-0.1	0.1	0.3	0.1	Z
	17	34.9	-11.9	-35.3	35.1	-12.0	-35.3	-0.2	0.0	0.0	0.2	0.0	Z
	18	34.7	-15.8	-35.2	34.9	-15.8	-35.2	-0.2	0.0	0.0	0.2	0.0	Z
	19	34.4	-20.1	-35.0	34.6	-20.1	-35.0	-0.2	0.0	0.0	0.2	0.0	Z
	20	34.1	-24.3	-34.8	34.2	-24.4	-34.9	-0.1	0.0	-0.1	0.2	-0.1	Z
	21	32.4	-7.7	-36.7	32.6	-7.8	-36.7	-0.2	0.0	0.0	0.2	0.0	Z
	22	32.2	-11.9	-36.5	32.4	-11.9	-36.5	-0.2	-0.1	0.0	0.2	0.0	Z
	23	31.9	-15.9	-36.5	32.1	-15.8	-36.4	-0.3	0.0	0.1	0.3	0.1	Z
	24	31.5	-20.1	-36.4	31.7	-20.1	-36.4	-0.2	0.0	0.0	0.2	0.0	Z
	25	31.0	-24.0	-36.2	31.2	-24.0	-36.2	-0.2	0.0	-0.1	0.2	-0.1	Z
	26	29.3	-7.7	-38.3	29.5	-7.7	-38.3	-0.2	0.0	0.0	0.2	0.0	Z
	27	29.5	-11.6	-38.2	29.7	-11.6	-38.2	-0.2	0.0	0.0	0.2	0.0	Z
	28	29.2	-15.4	-38.1	29.5	-15.4	-38.1	-0.3	0.0	0.0	0.3	0.0	Z
	29	29.0	-19.8	-37.9	29.3	-19.7	-37.9	-0.2	0.0	0.0	0.2	0.0	Z
	30	28.1	-23.2	-37.8	28.3	-23.3	-37.8	-0.3	0.0	0.0	0.3	0.0	Z
A-PILLAR Maximum (X, Y, Z)	31	53.8	-31.5	-23.0	54.0	-31.6	-22.9	-0.2	-0.1	0.0	0.2	0.0	Z
	32	50.7	-31.0	-24.8	50.9	-31.1	-24.7	-0.2	-0.1	0.1	0.2	0.1	Z
	33	47.3	-30.3	-27.0	47.5	-30.4	-27.0	-0.2	0.0	0.0	0.2	0.0	Z
	34	43.9	-29.6	-28.9	44.0	-29.6	-28.9	-0.1	0.0	0.0	0.1	0.0	Z
	35	40.9	-29.0	-30.4	41.1	-29.0	-30.4	-0.2	0.0	0.0	0.2	0.0	
	36	37.6	-28.3	-32.0	37.7	-28.4	-32.0	-0.2	-0.1	0.0	0.2	0.0	
A-PILLAR Lateral (Y)	31	53.8	-31.5	-23.0	54.0	-31.6	-22.9	-0.2	-0.1	0.0	0.2	-0.1	Y
	32	50.7	-31.0	-24.8	50.9	-31.1	-24.7	-0.2	-0.1	0.1	0.2	-0.1	Y
	33	47.3	-30.3	-27.0	47.5	-30.4	-27.0	-0.2	0.0	0.0	0.2	0.0	Y
	34	43.9	-29.6	-28.9	44.0	-29.6	-28.9	-0.1	0.0	0.0	0.1	0.0	Y
	35	40.9	-29.0	-30.4	41.1	-29.0	-30.4	-0.2	0.0	0.0	0.2	0.0	Y
	36	37.6	-28.3	-32.0	37.7	-28.4	-32.0	-0.2	-0.1	0.0	0.2	-0.1	Y
B-PILLAR Maximum (X, Y, Z)	37	14.3	-27.6	-34.4	14.3	-27.6	-34.5	-0.1	-0.1	-0.1	0.2	0.0	
	38	15.0	-28.9	-32.3	15.1	-29.0	-32.5	-0.2	-0.1	-0.1	0.2	0.0	
	39	15.4	-29.8	-30.5	15.6	-29.9	-30.6	-0.2	-0.1	-0.1	0.3	0.0	
	40	15.9	-30.6	-28.7	16.1	-30.6	-28.8	-0.2	-0.1	-0.1	0.2	0.0	
B-PILLAR Lateral (Y)	37	14.3	-27.6	-34.4	14.3	-27.6	-34.5	-0.1	-0.1	-0.1	0.2	-0.1	Y
	38	15.0	-28.9	-32.3	15.1	-29.0	-32.5	-0.2	-0.1	-0.1	0.2	-0.1	Y
	39	15.4	-29.8	-30.5	15.6	-29.9	-30.6	-0.2	-0.1	-0.1	0.3	-0.1	Y
	40	15.9	-30.6	-28.7	16.1	-30.6	-28.8	-0.2	-0.1	-0.1	0.2	-0.1	Y

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If no direction listed, then no intrusion is recorded, and Crush will be 0.

Figure C-5. Occupant Compartment Deformation Data – Set 2 (Left), Test No. WZNP-1

Date: 5/23/2018 Test Name: WZNP-1 VIN: KNADH4A38B6939145
Year: 2011 Make: KIA Model: RIO

VEHICLE DEFORMATION
INTERIOR CRUSH - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	49.2	-4.9	-20.8	49.1	-4.9	-20.9	0.0	-0.1	-0.1	0.1	0.1	X, Y, Z
	2	49.6	4.9	-20.6	49.6	4.8	-20.6	0.0	0.1	0.0	0.1	0.1	X, Y, Z
	3	50.0	15.1	-20.0	50.0	15.0	-19.9	0.1	0.1	0.1	0.1	0.1	X, Y, Z
	4	44.0	-5.3	-13.2	44.0	-5.4	-13.2	0.0	-0.1	-0.1	0.1	0.1	X, Y, Z
	5	47.0	4.9	-14.0	47.0	4.7	-14.0	0.0	0.2	-0.1	0.2	0.2	X, Y, Z
	6	46.9	15.4	-14.1	46.8	15.3	-14.1	0.0	0.1	0.0	0.1	0.1	X, Y, Z
SIDE PANEL (Y)	7	53.9	20.4	1.5	53.9	20.2	1.7	0.0	0.2	0.2	0.3	0.2	Y
	8	58.7	20.4	-2.3	58.7	20.2	-2.3	0.0	0.2	0.1	0.2	0.2	Y
	9	59.0	20.5	1.6	59.0	20.2	1.7	0.0	0.2	0.1	0.2	0.2	Y
IMPACT SIDE DOOR (Y)	10	47.3	21.7	-15.7	47.3	21.6	-15.5	0.0	0.2	0.2	0.3	0.2	Y
	11	35.0	22.0	-14.7	35.0	21.9	-14.5	0.1	0.2	0.1	0.2	0.2	Y
	12	22.0	21.7	-14.8	22.0	21.6	-14.8	0.0	0.2	0.0	0.2	0.2	Y
	13	48.9	21.5	-6.0	48.9	21.3	-5.9	0.0	0.2	0.1	0.2	0.2	Y
	14	36.2	22.4	-1.0	36.2	22.2	-0.9	0.0	0.2	0.1	0.3	0.2	Y
	15	24.9	21.7	-1.5	24.8	21.4	-1.4	0.1	0.2	0.1	0.3	0.2	Y
ROOF - (Z)	16	34.6	-4.9	-35.5	34.6	-5.0	-35.5	0.0	-0.1	-0.1	0.1	-0.1	Z
	17	34.8	-0.6	-35.3	34.8	-0.7	-35.3	0.0	-0.1	0.0	0.1	0.0	Z
	18	34.8	3.7	-35.1	34.8	3.7	-35.1	0.0	0.0	0.0	0.1	0.0	Z
	19	34.2	8.4	-34.9	34.2	8.3	-34.9	0.0	0.0	0.0	0.1	0.0	Z
	20	33.6	12.8	-34.6	33.5	12.7	-34.5	0.0	0.0	0.0	0.1	0.0	Z
	21	32.4	-5.2	-36.6	32.4	-5.2	-36.7	0.0	0.0	-0.1	0.1	-0.1	Z
	22	32.0	-1.1	-36.7	32.1	-1.1	-36.7	0.0	-0.1	0.0	0.1	0.0	Z
	23	31.7	3.1	-36.6	31.7	3.1	-36.6	0.0	0.0	0.0	0.0	0.0	Z
	24	31.2	7.6	-36.5	31.2	7.6	-36.4	0.0	0.0	0.1	0.1	0.1	Z
	25	30.6	11.9	-36.1	30.6	11.8	-36.0	0.0	0.1	0.1	0.1	0.1	Z
	26	29.0	-5.4	-38.3	29.0	-5.5	-38.4	0.1	-0.1	-0.1	0.1	-0.1	Z
	27	29.0	-1.6	-38.3	29.0	-1.5	-38.3	0.0	0.0	0.0	0.1	0.0	Z
	28	28.6	2.5	-38.2	28.6	2.4	-38.2	0.0	0.1	0.0	0.1	0.0	Z
	29	28.4	7.3	-37.9	28.3	7.3	-37.9	0.0	0.0	0.0	0.0	0.0	Z
	30	27.6	11.0	-37.7	27.6	11.0	-37.6	0.0	0.0	0.0	0.1	0.0	Z
A-PILLAR Maximum (X, Y, Z)	31	53.5	19.4	-22.5	53.6	19.3	-22.5	0.0	0.1	0.0	0.1	0.1	Y, Z
	32	49.1	18.5	-25.5	49.0	18.4	-25.4	0.1	0.1	0.1	0.2	0.2	X, Y, Z
	33	45.5	17.7	-27.7	45.5	17.6	-27.6	0.0	0.0	0.1	0.1	0.1	X, Y, Z
	34	41.9	16.9	-29.6	41.9	16.9	-29.6	0.0	0.1	0.0	0.1	0.1	X, Y, Z
	35	39.0	16.2	-31.2	39.0	16.2	-31.1	0.0	0.0	0.1	0.1	0.1	X, Y, Z
	36	35.6	15.5	-32.7	35.6	15.5	-32.7	0.0	0.0	0.0	0.1	0.1	Y, Z
A-PILLAR Lateral (Y)	31	53.5	19.4	-22.5	53.6	19.3	-22.5	0.0	0.1	0.0	0.1	0.1	Y
	32	49.1	18.5	-25.5	49.0	18.4	-25.4	0.1	0.1	0.1	0.2	0.1	Y
	33	45.5	17.7	-27.7	45.5	17.6	-27.6	0.0	0.0	0.1	0.1	0.0	Y
	34	41.9	16.9	-29.6	41.9	16.9	-29.6	0.0	0.1	0.0	0.1	0.1	Y
	35	39.0	16.2	-31.2	39.0	16.2	-31.1	0.0	0.0	0.1	0.1	0.0	Y
	36	35.6	15.5	-32.7	35.6	15.5	-32.7	0.0	0.0	0.0	0.1	0.0	Y
B-PILLAR Maximum (X, Y, Z)	37	14.3	14.8	-34.3	14.4	14.7	-34.4	-0.1	0.1	0.0	0.2	0.1	Y
	38	14.9	16.2	-32.0	14.9	16.1	-32.0	-0.1	0.1	0.0	0.1	0.1	Y, Z
	39	15.5	17.4	-29.4	15.5	17.3	-29.4	-0.1	0.1	0.1	0.1	0.1	Y, Z
	40	16.0	18.2	-27.2	16.1	18.1	-27.1	-0.1	0.1	0.1	0.2	0.1	Y, Z
B-PILLAR Lateral (Y)	37	14.3	14.8	-34.3	14.4	14.7	-34.4	-0.1	0.1	0.0	0.2	0.1	Y
	38	14.9	16.2	-32.0	14.9	16.1	-32.0	-0.1	0.1	0.0	0.1	0.1	Y
	39	15.5	17.4	-29.4	15.5	17.3	-29.4	-0.1	0.1	0.1	0.1	0.1	Y
	40	16.0	18.2	-27.2	16.1	18.1	-27.1	-0.1	0.1	0.1	0.2	0.1	Y

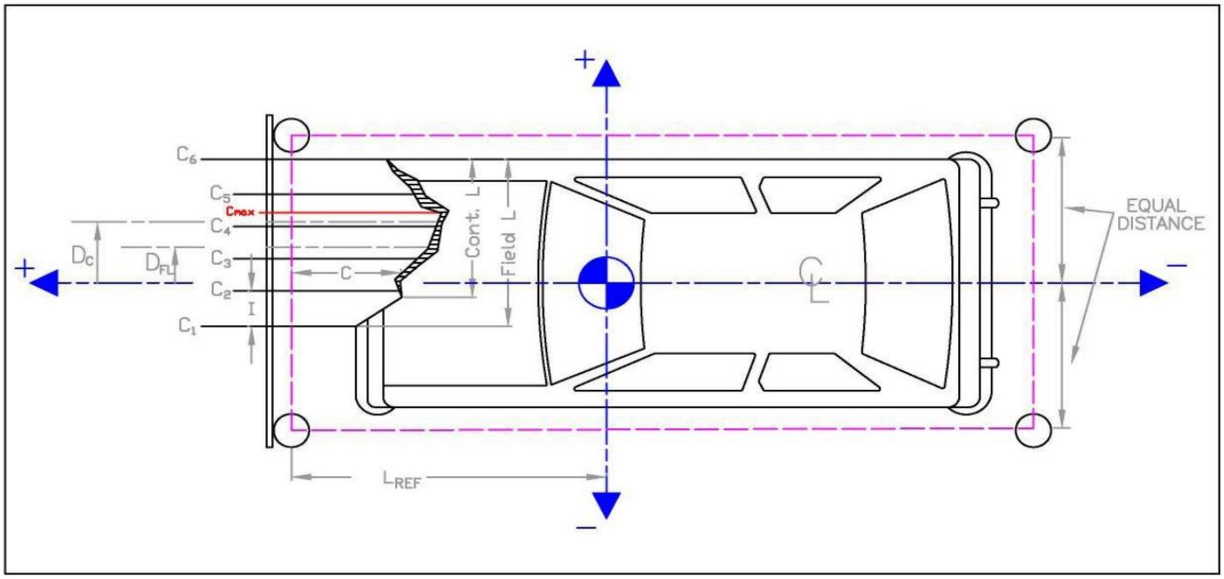
[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If no direction listed, then no intrusion is recorded, and Crush will be 0.

Figure C-6. Occupant Compartment Deformation Data – Set 2 (Right), Test No. WZNP-1

Date:	6/1/2018	Test Name:	WZNP-1	VIN:	KNADH4A38B6939145
Year:	2011	Make:	KIA	Model:	RIO



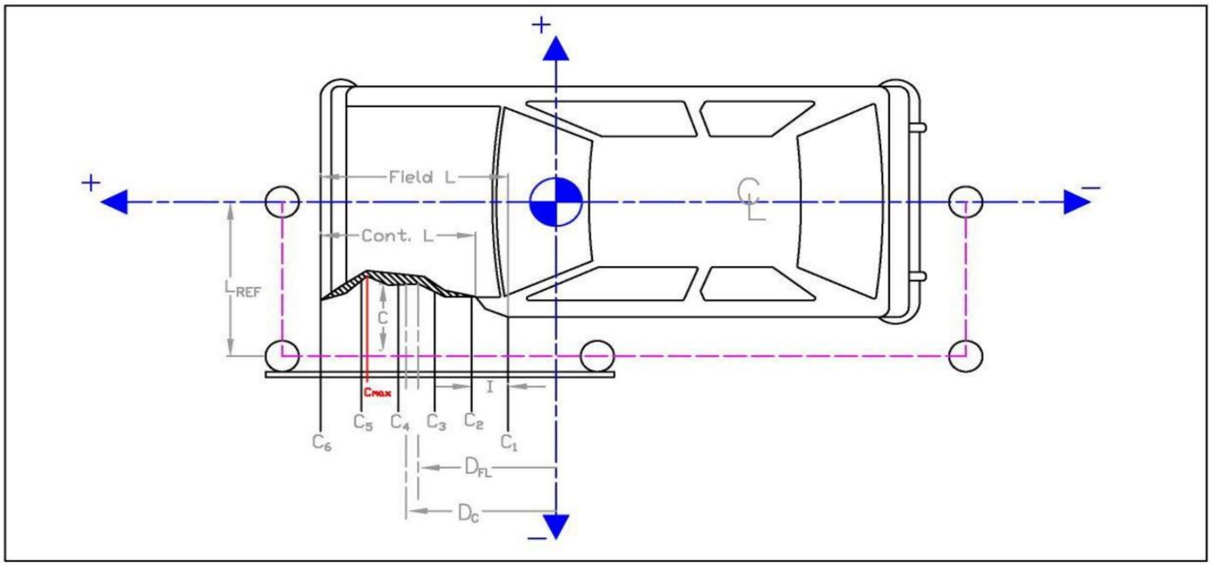
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	103	(2616)
Total Width of Vehicle:	65 1/2	(1664)
Width of contact and induced crush - Field L:	65 1/2	(1664)
Crush measurement spacing interval (L/5) - I:	13 1/8	(333)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	65 1/2	(1664)
Distance from center of vehicle to center of contact 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 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	na	NA	-32 3/4	-(832)	24	(610)	24 1/8	(613)	NA	NA
C_2	34 1/2	(876)	-19 5/8	-(498)	8 1/2	(216)			1 7/8	(48)
C_3	32 1/2	(826)	-6 1/2	-(165)	6 1/8	(156)			2 1/4	(57)
C_4	31 1/2	(800)	6 5/8	(168)	6 1/8	(156)			1 1/4	(32)
C_5	32 3/8	(822)	19 3/4	(502)	8 1/2	(216)			- 1/4	-(6)
C_6	37 5/8	(956)	32 7/8	(835)	24	(610)			-10 1/2	-(267)
C_{MAX}	36	(914)	-23 1/2	-(597)	10 1/8	(257)			1 3/4	(44)

Figure C-7. Exterior Vehicle Crush (NASS) - Front, Test No. WZNP-1

Date:	6/1/2018	Test Name:	WZNP-1	VIN:	KNADH4A38B6939145
Year:	2011	Make:	KIA	Model:	RIO



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	56 1/2	(1435)
Total Vehicle Length:	167 1/2	(4255)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	1 7/8	(48)
Width of contact and induced crush - Field L:	48 3/4	(1238)
Crush measurement spacing interval (L/5) - I:	9 3/4	(248)
Distance from vehicle c.g. to center of Field L - D_{FL}:	46 3/8	(1178)
Width of Contact Damage:	16	(406)
Distance from vehicle c.g. to center of contact damage - D_C:	61 1/4	(1556)

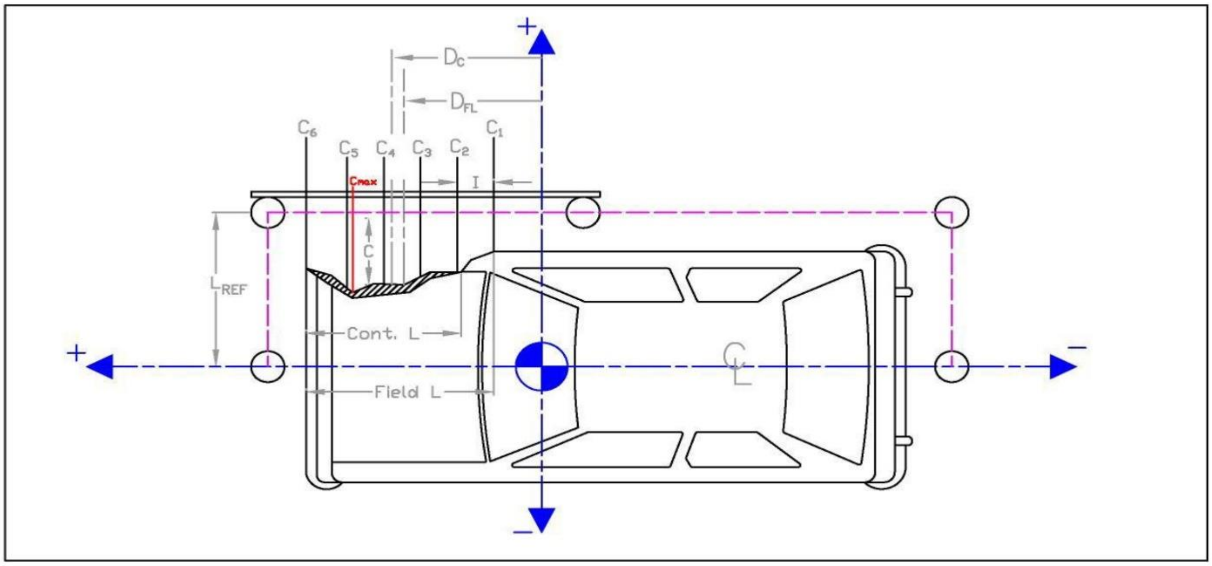
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been removed)
NOTE: All values must be filled out above before crush measurements are filled out.

	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	24 1/8	(613)	22	(559)	3 1/4	(83)	20 1/2	(521)	3/8	(10)
C_2	23 3/4	(603)	31 3/4	(806)	3 1/4	(83)			0	()
C_3	na	NA	41 1/2	(1054)	3 1/4	(83)			NA	NA
C_4	23 1/4	(591)	51 1/4	(1302)	5 3/8	(137)			-2 5/8	-(67)
C_5	25 1/2	(648)	61	(1549)	14 1/2	(368)			-9 1/2	-(241)
C_6	30 1/8	(765)	70 3/4	(1797)	21 3/4	(552)			-12 1/8	-(308)
C_{MAX}	25 1/4	(641)	23	(584)	3 1/4	(83)			1 1/2	(38)

Figure C-8. Exterior Vehicle Crush (NASS) - Left, Test No. WZNP-1

Date: 6/1/2018 Test Name: WZNP-1 VIN: KNADH4A38B6939145

Year: 2011 Make: KIA Model: RIO



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	46 1/4	(1175)
Total Vehicle Length:	167 1/2	(4255)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	1 7/8	(48)
Width of contact and induced crush - Field L:	48 3/4	(1238)
Crush measurement spacing interval (L/5) - I:	9 3/4	(248)
Distance from vehicle c.g. to center of Field L - D_{FL}:	46 3/8	(1178)
Width of Contact Damage:	9	(229)
Distance from vehicle c.g. to center of contact damage - D_C:	66 1/4	(1683)

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	13	(330)	22	(559)	3 1/4	(83)	10 1/4	(260)	- 1/2	-(13)
C_2	12 3/4	(324)	31 3/4	(806)	3 1/4	(83)			- 3/4	-(19)
C_3	na	NA	41 1/2	(1054)	3 1/4	(83)			NA	NA
C_4	12 7/8	(327)	51 1/4	(1302)	5 3/8	(137)			-2 3/4	-(70)
C_5	15	(381)	61	(1549)	14 1/2	(368)			-9 3/4	-(248)
C_6	na	NA	70 3/4	(1797)	21 3/4	(552)			NA	NA
C_{MAX}	12 7/8	(327)	52	(1321)	5 5/8	(143)			-3	-(76)

Figure C-9. Exterior Vehicle Crush (NASS) - Right, Test No. WZNP-1

Date:	5/23/2018	Test Name:	WZNP-1	VIN:	KNADH4A38B6939145
Year:	2011	Make:	KIA	Model:	RIO

VEHICLE DEFORMATION

WINDSHIELD

	POINT	Vertical Reference Length[A]	Vertical Reference Side[B] (Top or Bottom)	Lateral Referece Length[C]	Lateral Reference Side[B] (Driver or Pass.)	Examplar Vehicle Measurement	Test Vehicle Measurment	Crush[D] (in.)
WINDSHIELD	1	9	Top	9	Passenger	5 5/8	5.5	-0.125
	2	3.25	Top	32.25	Passenger	5 1/2	5.5	0
	3	8.5	Top	43	Passenger	6	6.75	0.75
	4	18.5	Top	5.25	Passenger	5 3/4	5.875	0.125
	5	27	Top	12	Passenger	5	5.25	0.25

[A] Length to vertical reference, typically the top or bottom of the windshield frame.
[B] C Side of windshield frame, top, bottom, passenger, or driver, in which the reference was measured from.
[C] Length to lateral referene either the driver or passenger side windshield frame.
[D] Crush is the difference between the test vehcile and examplar vehicle that is the intrusion of the windshield deformation. The intrusion is perpendicular to the plane of the windshield which is a resultant of the X & Z directions.

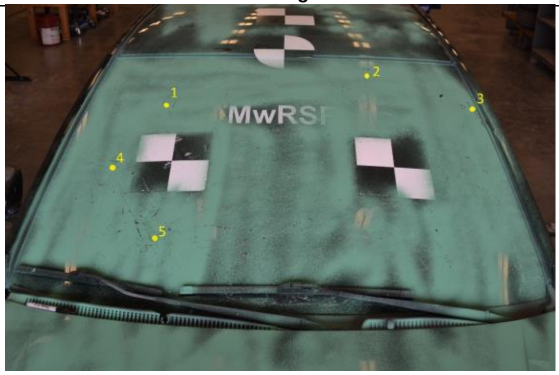
Examplar Vehicle Description

Year:	2009	Make:	Kia	Model:	Rio sedan	VIN:	KNADE223X96522874

Windshield Deformation Notes:

The windshield was 3D scanned with the FARO hand held scanner both pre and post test.

Test Vehicle Damaged Windshield



Examplar Vehicle Windshield

Figure C-10. Windshield Damage, Test No. WZNP-1

Date: 5/23/2018 Test Name: WZNP-1 VIN: KNADH4A38B6939145
Year: 2011 Make: KIA Model: RIO

Reference Set 1				Reference Set 2			
Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]	Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]
Roof	0.1	≤ 4	Z	Roof	0.1	≤ 4	Z
Windshield[D]	0.8	≤ 3	X, Z	Windshield[D]	NA	≤ 3	X, Z
A-Pillar Maximum	0.1	≤ 5	X	A-Pillar Maximum	0.1	≤ 5	X, Y, Z
A-Pillar Lateral	0.1	≤ 3	Y	A-Pillar Lateral	0.0	≤ 3	Y
B-Pillar Maximum	0.1	≤ 5	X	B-Pillar Maximum	0.0	≤ 5	Y
B-Pillar Lateral	0.1	≤ 3	Y	B-Pillar Lateral	-0.1	≤ 3	Y
Toe Pan - Wheel Well	0.0	≤ 9	X, Z	Toe Pan - Wheel Well	0.4	≤ 9	X, Z
Side Front Panel	0.0	≤ 12	Y	Side Front Panel	-0.2	≤ 12	Y
Side Door (above seat)	0.0	≤ 9	Y	Side Door (above seat)	-0.2	≤ 9	Y
Side Door (below seat)	0.0	≤ 12	Y	Side Door (below seat)	-0.2	≤ 12	Y
Floor Pan	0.0	≤ 12	Z	Floor Pan	0.2	≤ 12	Z
Dash - no MASH requirement	0.2	NA	X, Y, Z	Dash - no MASH requirement	0.2	NA	X, Y, Z

[A] Items highlighted in red do not meet MASH allowable deformations.

[B] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[C] For Toe Pan - Wheel Well the direction of defromation may include X and Z direction. For A-Pillar Maximum and B-Pillar Maximum the direction of deformation may include X, Y, and Z directions. The direction of deformation for Toe Pan -Wheel Well, A-Pillar Maximum, and B-Pillar Maximum only include components where the deformation is positive and intruding into the occupant compartment.

[D] If deformation is observered for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

Notes on vehicle interior crush:

The windshield was 3D scanned with the FARO handheld scanner both pre and post test.
Set 1 of floor pan and toe pan measurements was Bad Data and was not used.

Figure C-11. Maximum Occupant Compartment Deformations - Left, Test No. WZNP-1

Date: 5/23/2018 Test Name: WZNP-1 VIN: KNADH4A38B6939145
Year: 2011 Make: KIA Model: RIO

Reference Set 1				Reference Set 2			
Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]	Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]
Roof	-0.3	≤ 4	Z	Roof	0.1	≤ 4	Z
Windshield[D]	0.3	≤ 3	X, Z	Windshield[D]	NA	≤ 3	X, Z
A-Pillar Maximum	0.4	≤ 5	X	A-Pillar Maximum	0.2	≤ 5	X, Y, Z
A-Pillar Lateral	-0.2	≤ 3	Y	A-Pillar Lateral	0.1	≤ 3	Y
B-Pillar Maximum	0.3	≤ 5	X	B-Pillar Maximum	0.1	≤ 5	Y
B-Pillar Lateral	-0.2	≤ 3	Y	B-Pillar Lateral	0.1	≤ 3	Y
Toe Pan - Wheel Well	0.2	≤ 9	X, Z	Toe Pan - Wheel Well	0.0	≤ 9	X
Side Front Panel	-0.1	≤ 12	Y	Side Front Panel	0.2	≤ 12	Y
Side Door (above seat)	-0.1	≤ 9	Y	Side Door (above seat)	0.2	≤ 9	Y
Side Door (below seat)	-0.1	≤ 12	Y	Side Door (below seat)	0.2	≤ 12	Y
Floor Pan	0.0	≤ 12	Z	Floor Pan	0.0	≤ 12	Z
Dash - no MASH requirement	0.8	NA	X, Y, Z	Dash - no MASH requirement	0.8	NA	X, Y, Z

[A] Items highlighted in red do not meet MASH allowable deformations.

[B] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[C] For Toe Pan - Wheel Well the direction of defromation may include X and Z direction. For A-Pillar Maximum and B-Pillar Maximum the direction of deformation may include X, Y, and Z directions. The direction of deformation for Toe Pan -Wheel Well, A-Pillar Maximum, and B-Pillar Maximum only include components where the deformation is positive and intruding into the occupant compartment.

[D] If deformation is observered for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

Notes on vehicle interior crush:

The windshield was 3D scanned with the FARO handheld scanner both pre and post test.
Set 2 of floor pan and toe pan measurements was Bad Data and was not used.

Figure C-12. Maximum Occupant Compartment Deformations - Right, Test No. WZNP-1

APPENDIX D. ACCELEROMETER AND RATE TRANSDUCER DATA PLOTS, TEST NO. WZNP-1

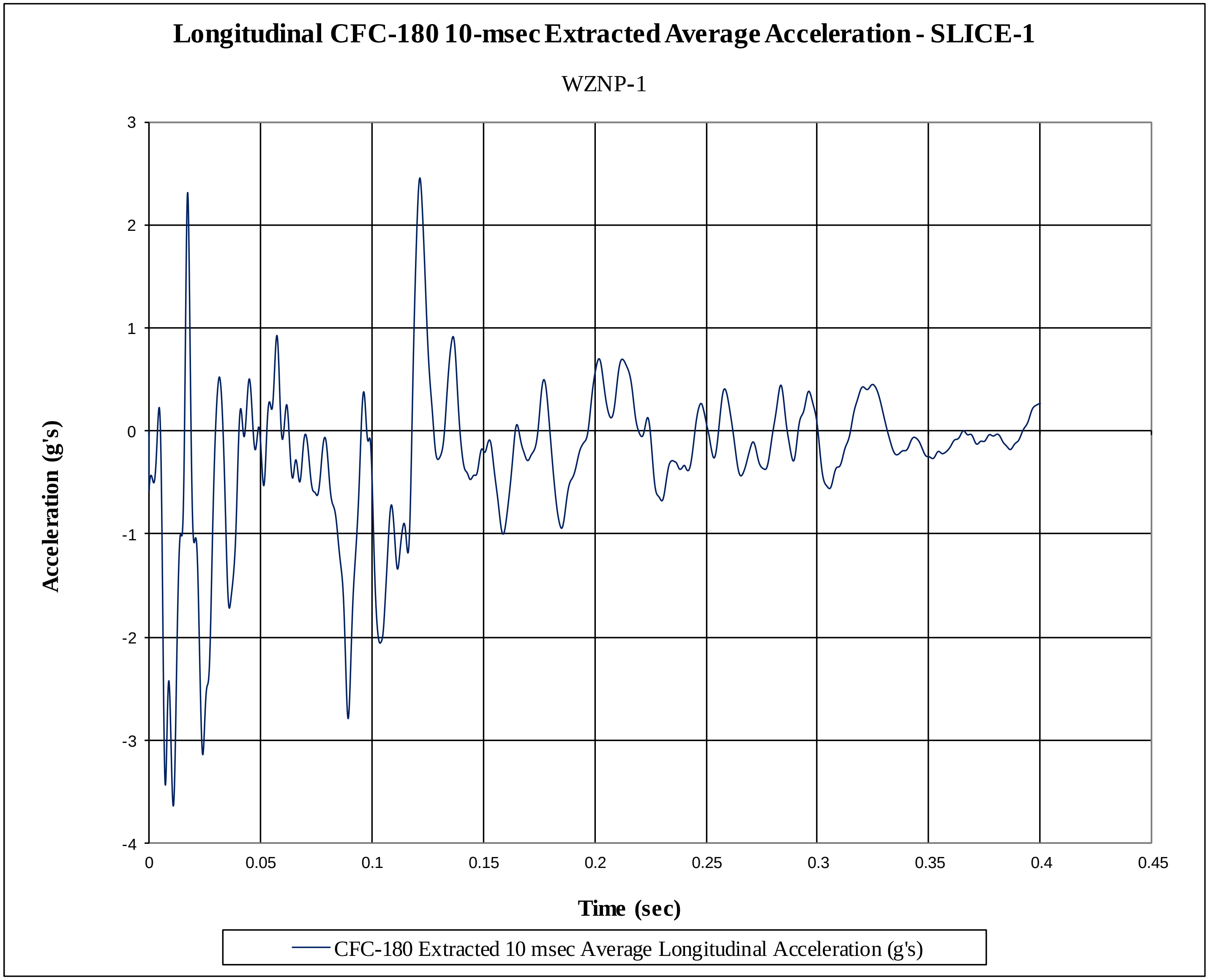


Figure D-1. System A – 10-ms Average Longitudinal Acceleration (SLICE-1), Test No. WZNP-1

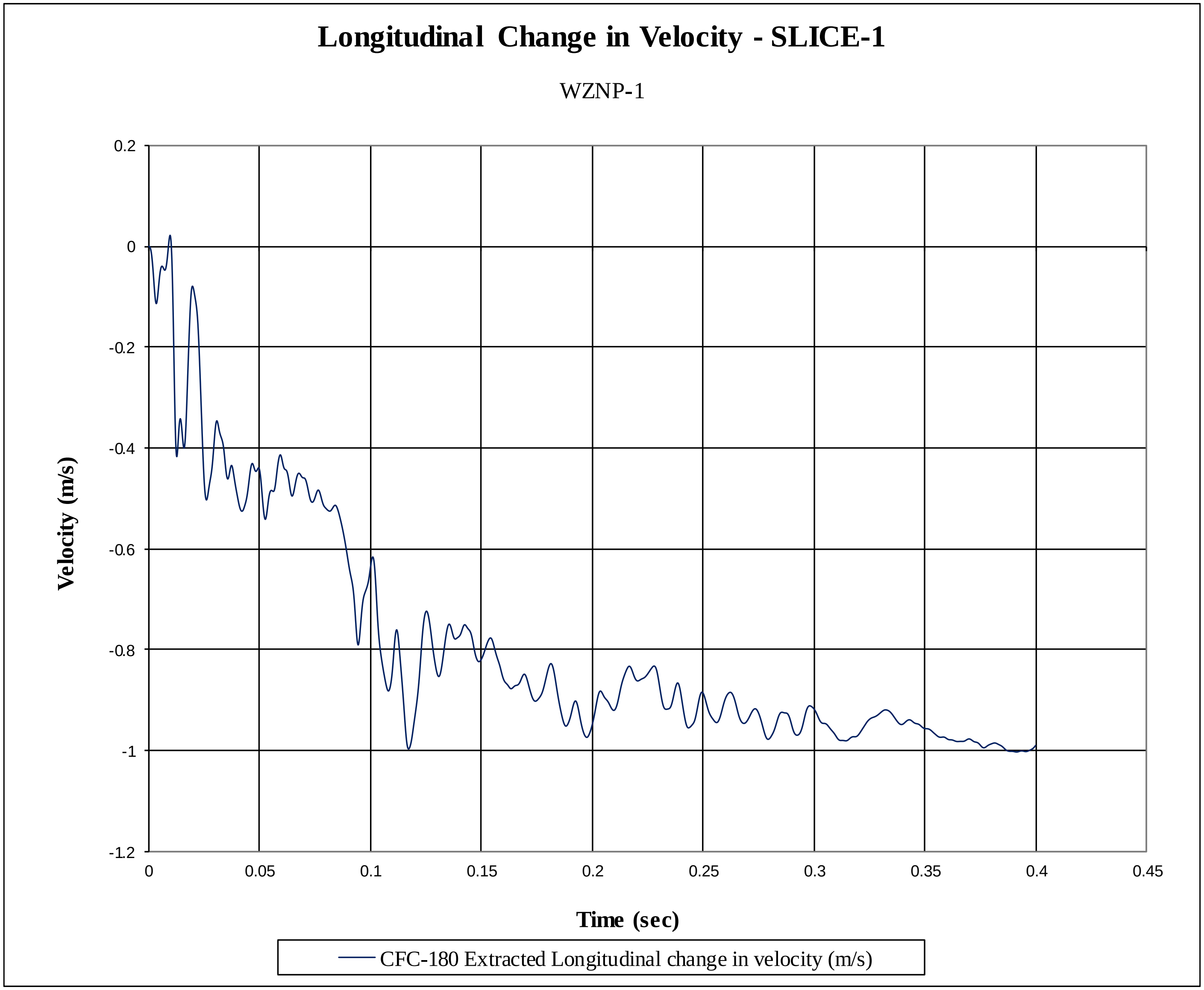


Figure D-2. System A – Longitudinal Occupant Impact Velocity (SLICE-1), Test No. WZNP-1

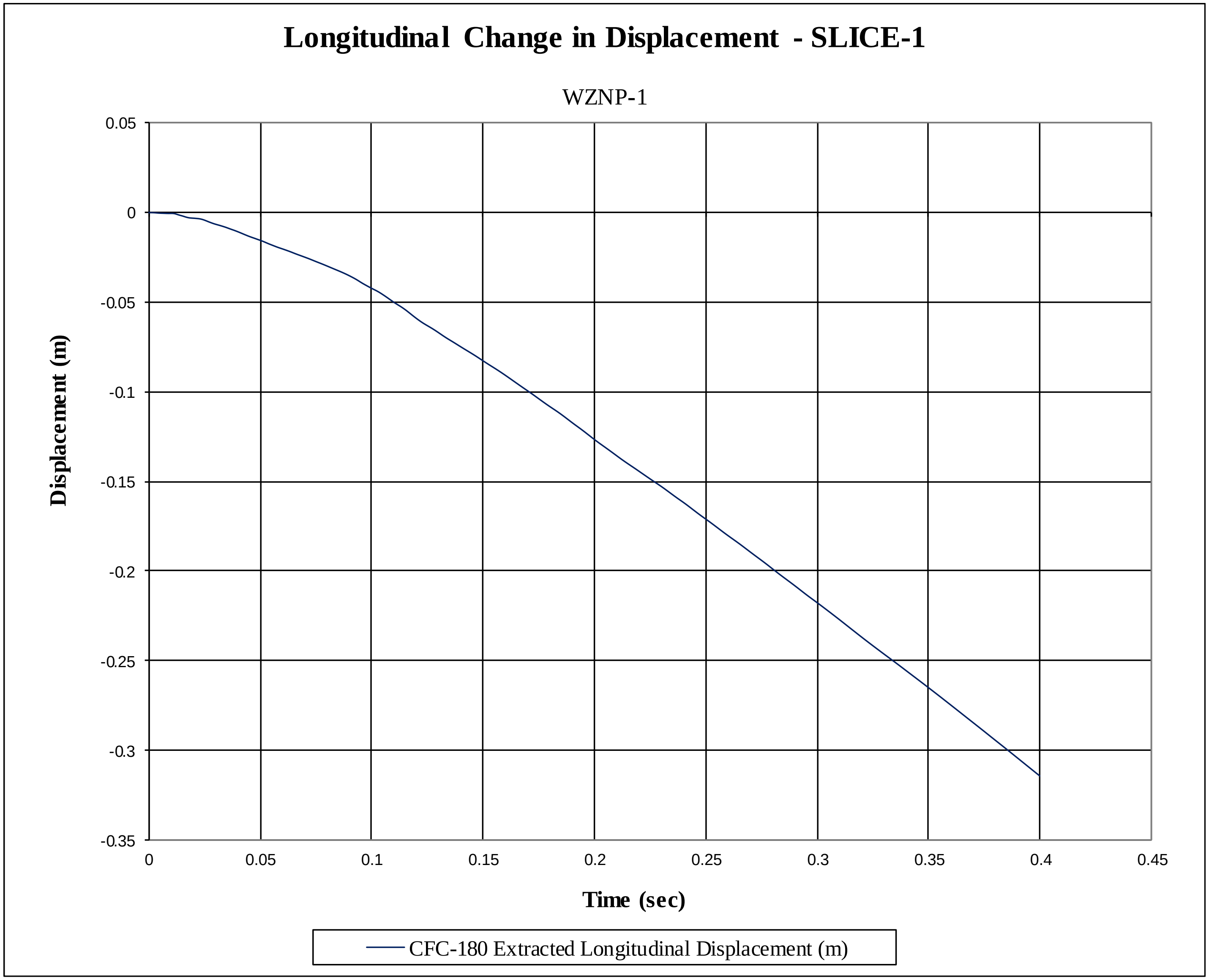


Figure D-3. System A – Longitudinal Occupant Displacement (SLICE-1), Test No. WZNP-1

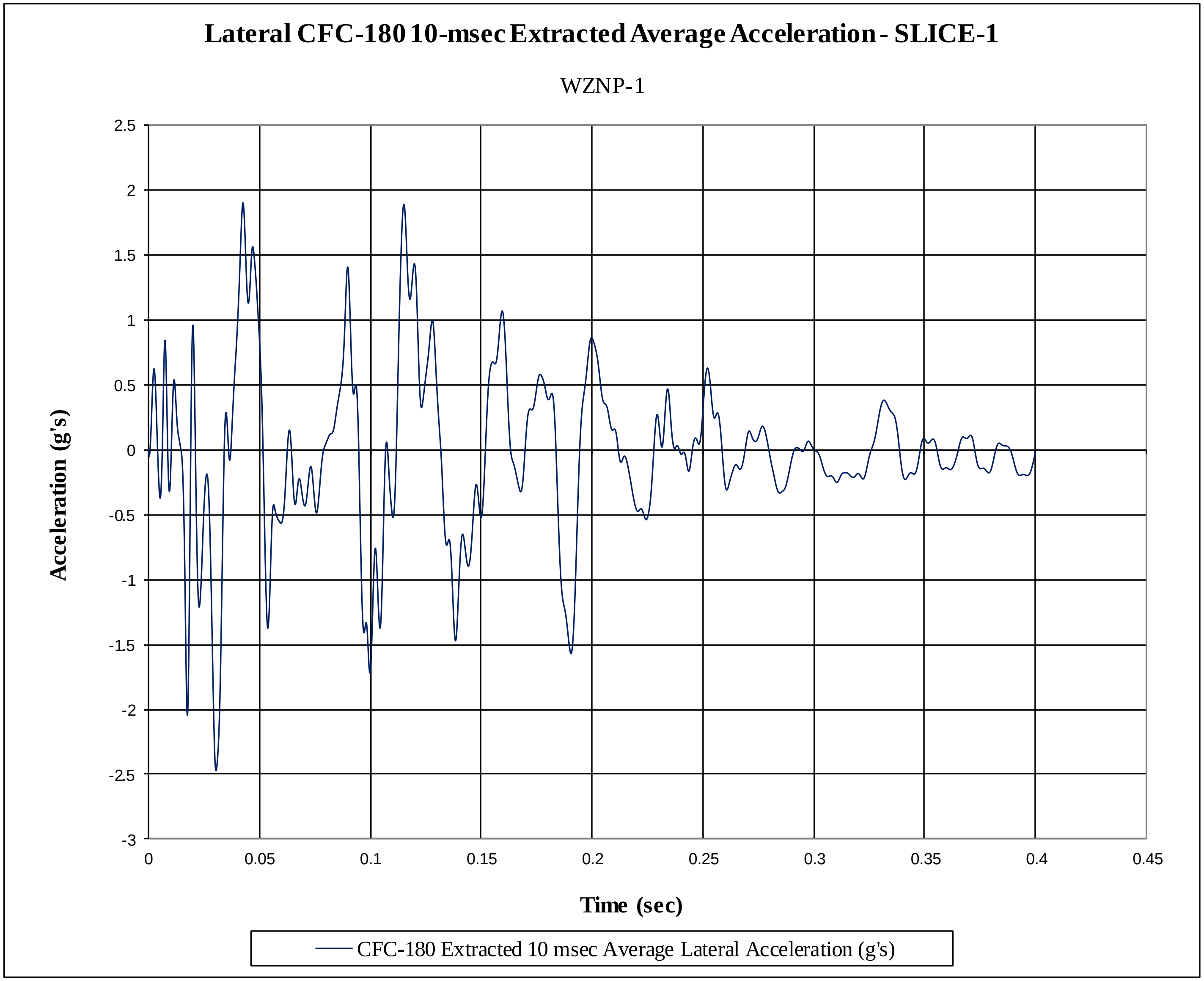


Figure D-4. System A – 10-ms Average Lateral Acceleration (SLICE-1), Test No. WZNP-1

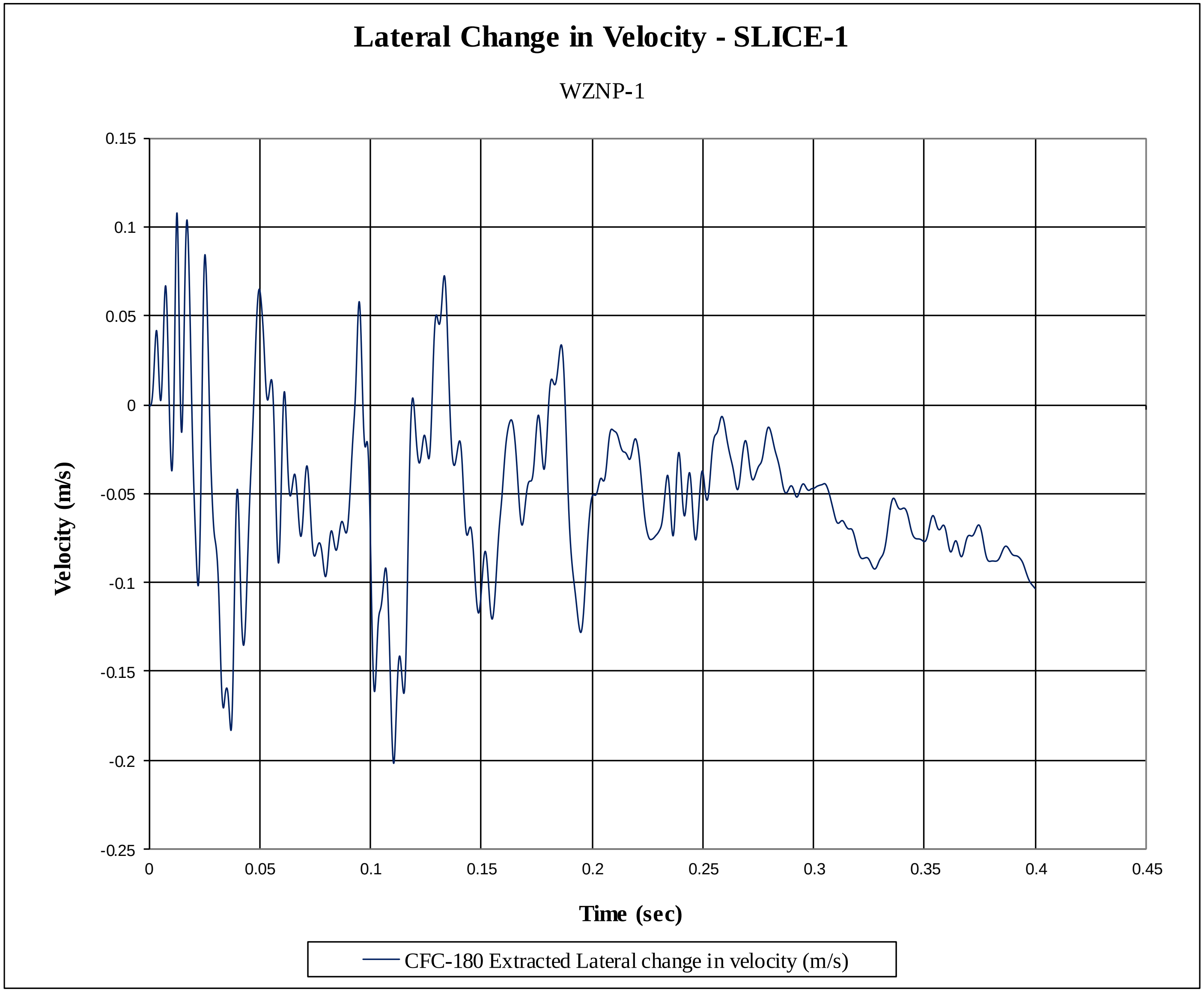


Figure D-5. System A – Lateral Occupant Impact Velocity (SLICE-1), Test No. WZNP-1

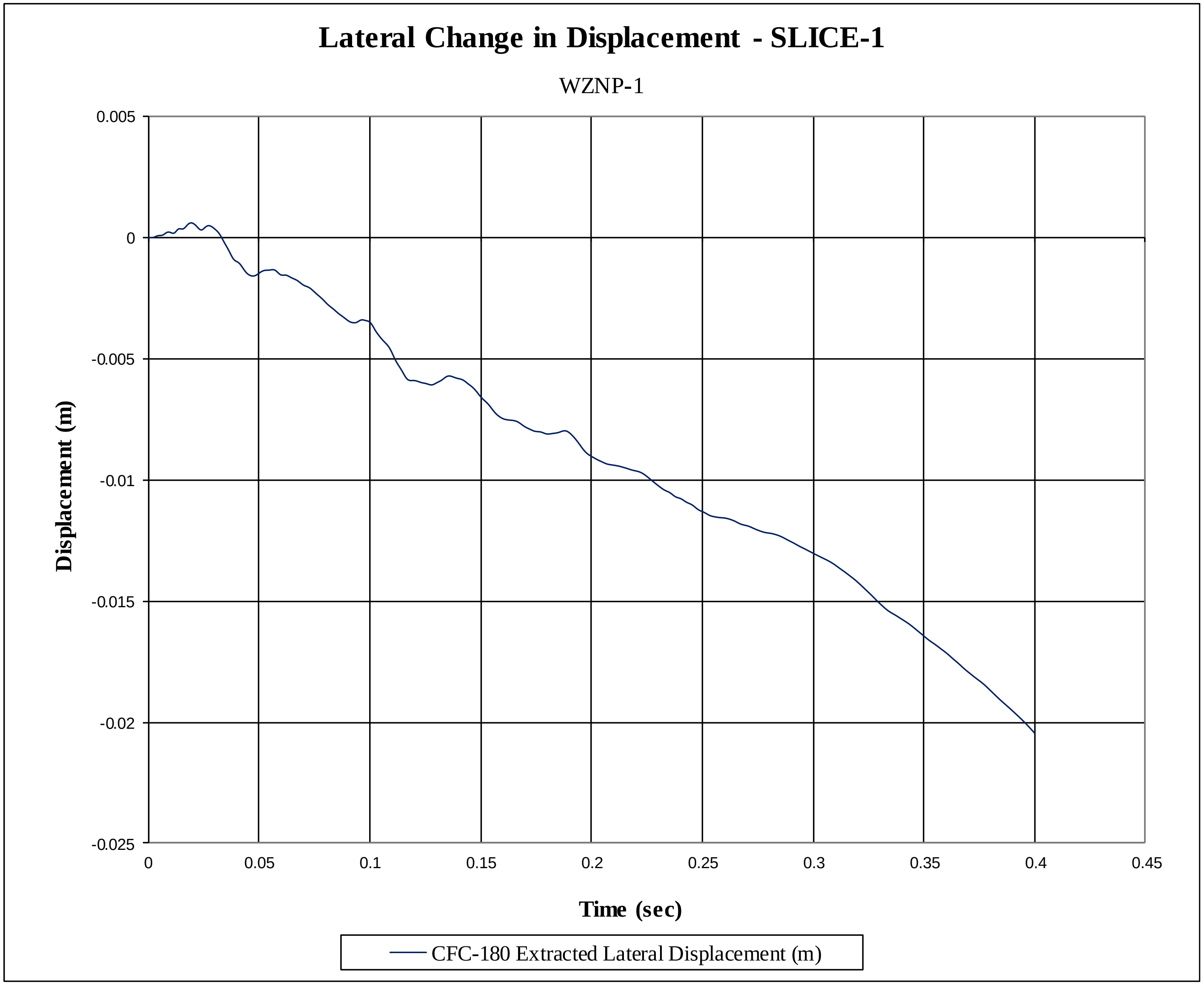


Figure D-6. System A – Lateral Occupant Displacement (SLICE-1), Test No. WZNP-1

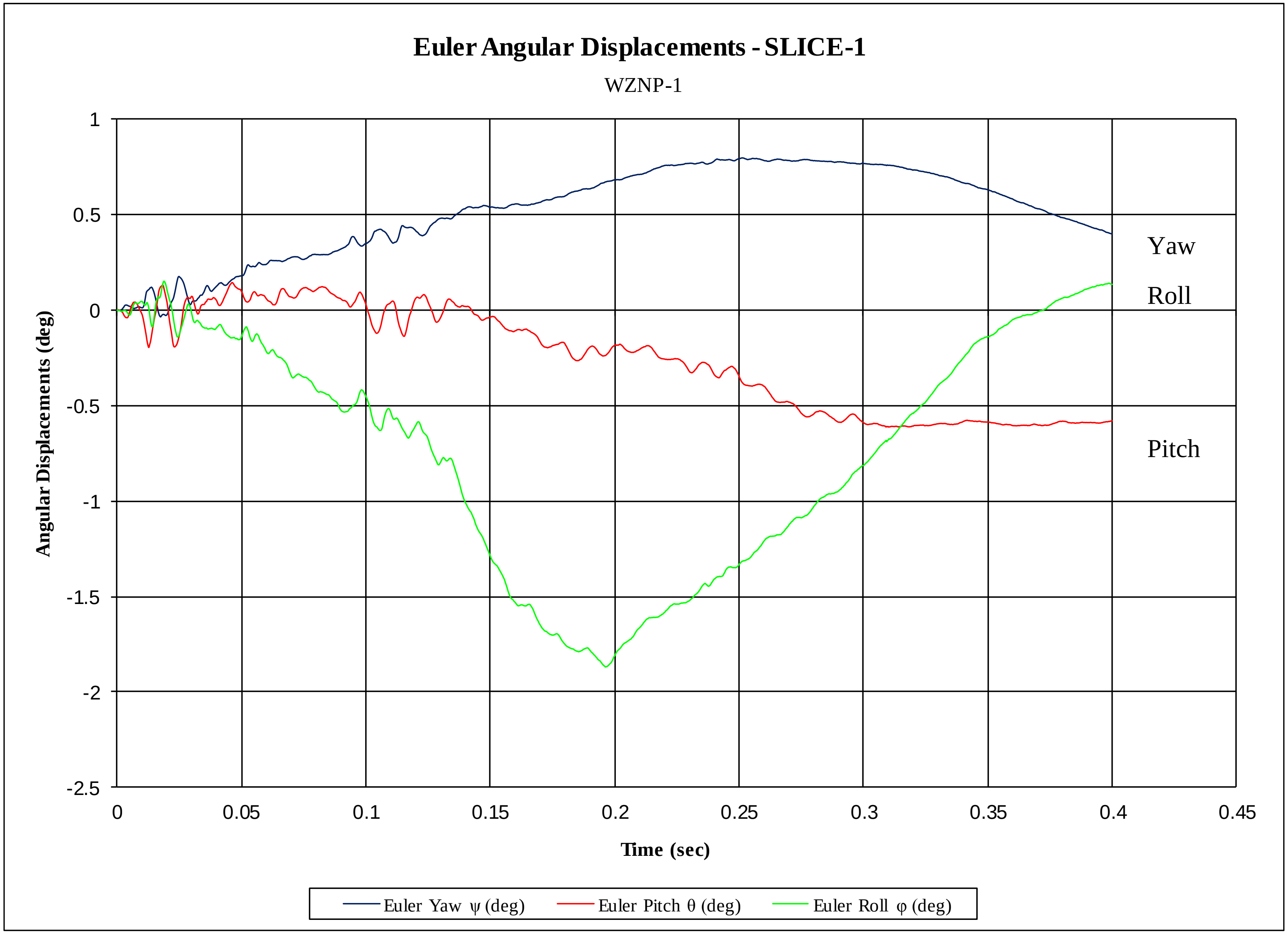


Figure D-7. System A – Vehicle Angular Displacements (SLICE-1), Test No. WZNP-1

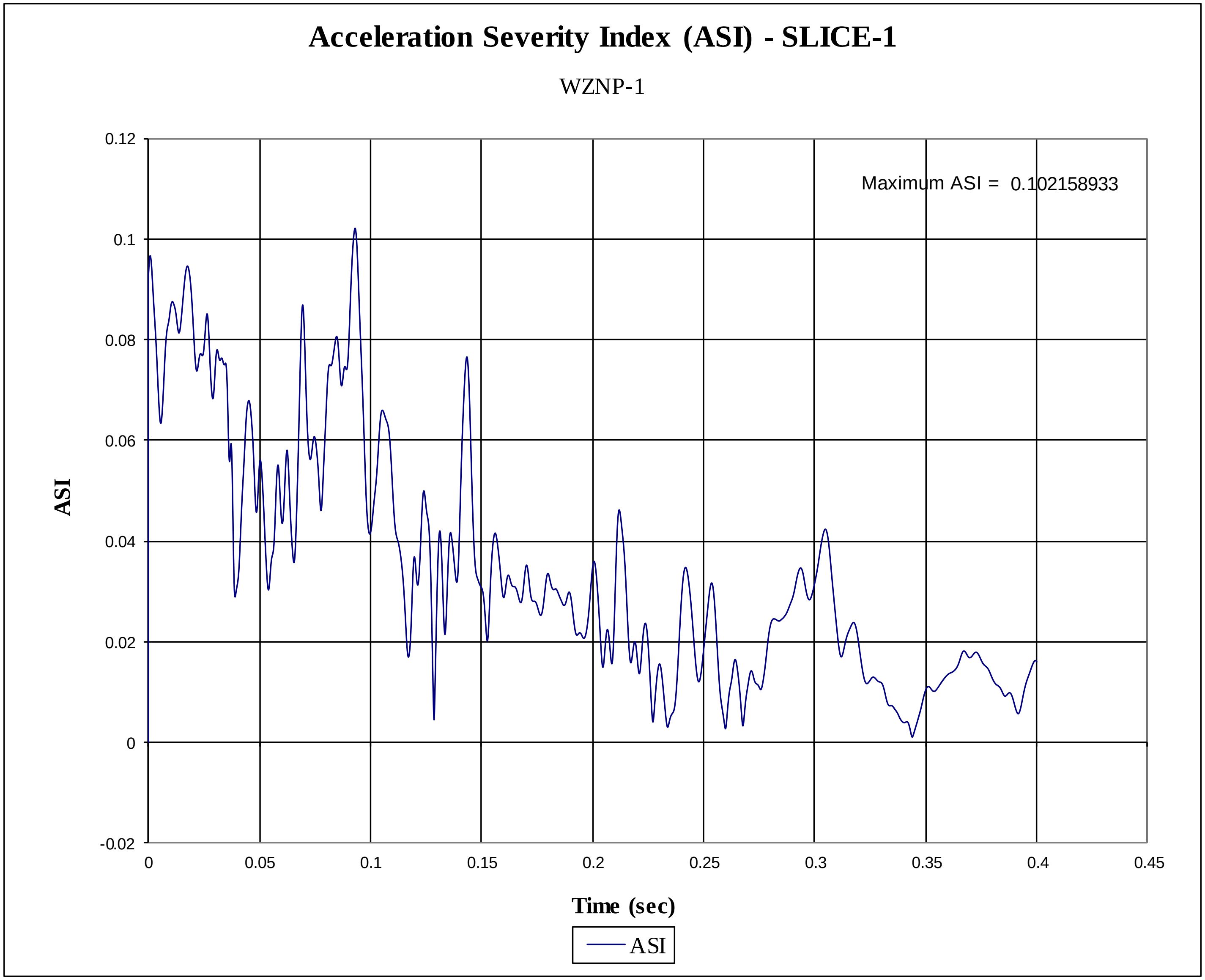


Figure D-8. System A – Acceleration Severity Index (SLICE-1), Test No. WZNP-1

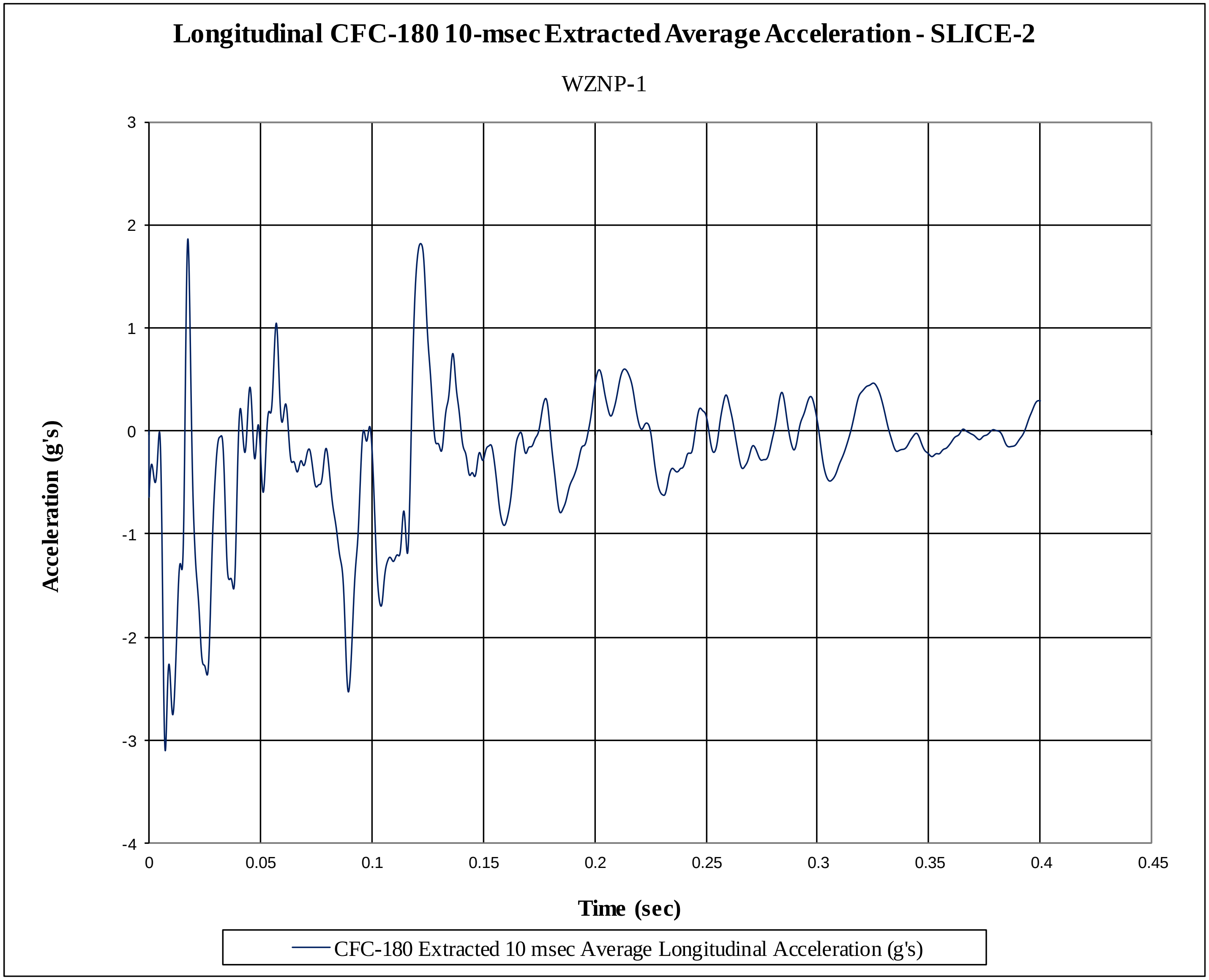


Figure D-9. System A – 10-ms Average Longitudinal Acceleration (SLICE-2), Test No. WZNP-1

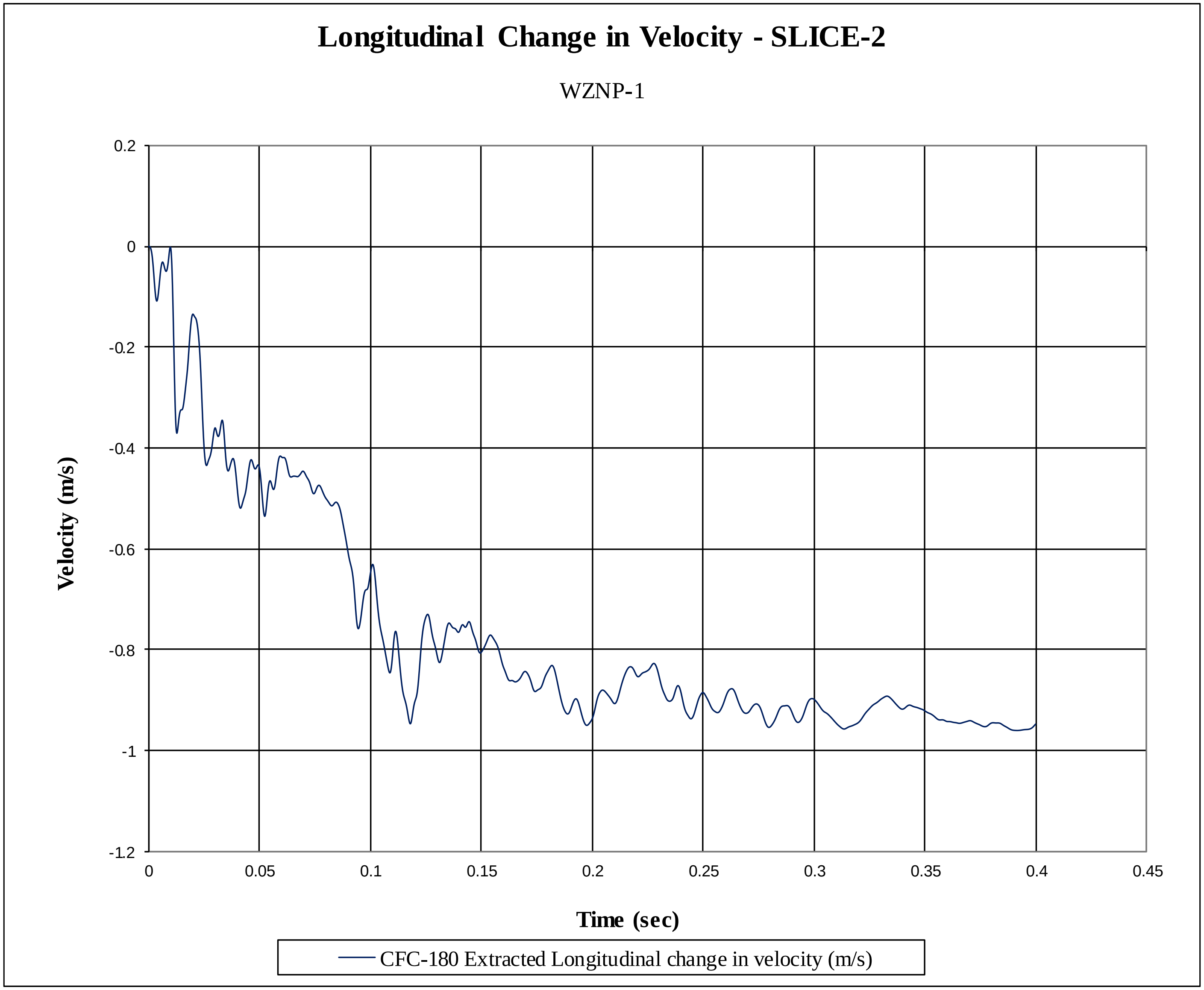


Figure D-10. System A – Longitudinal Occupant Impact Velocity (SLICE-2), Test No. WZNP-1

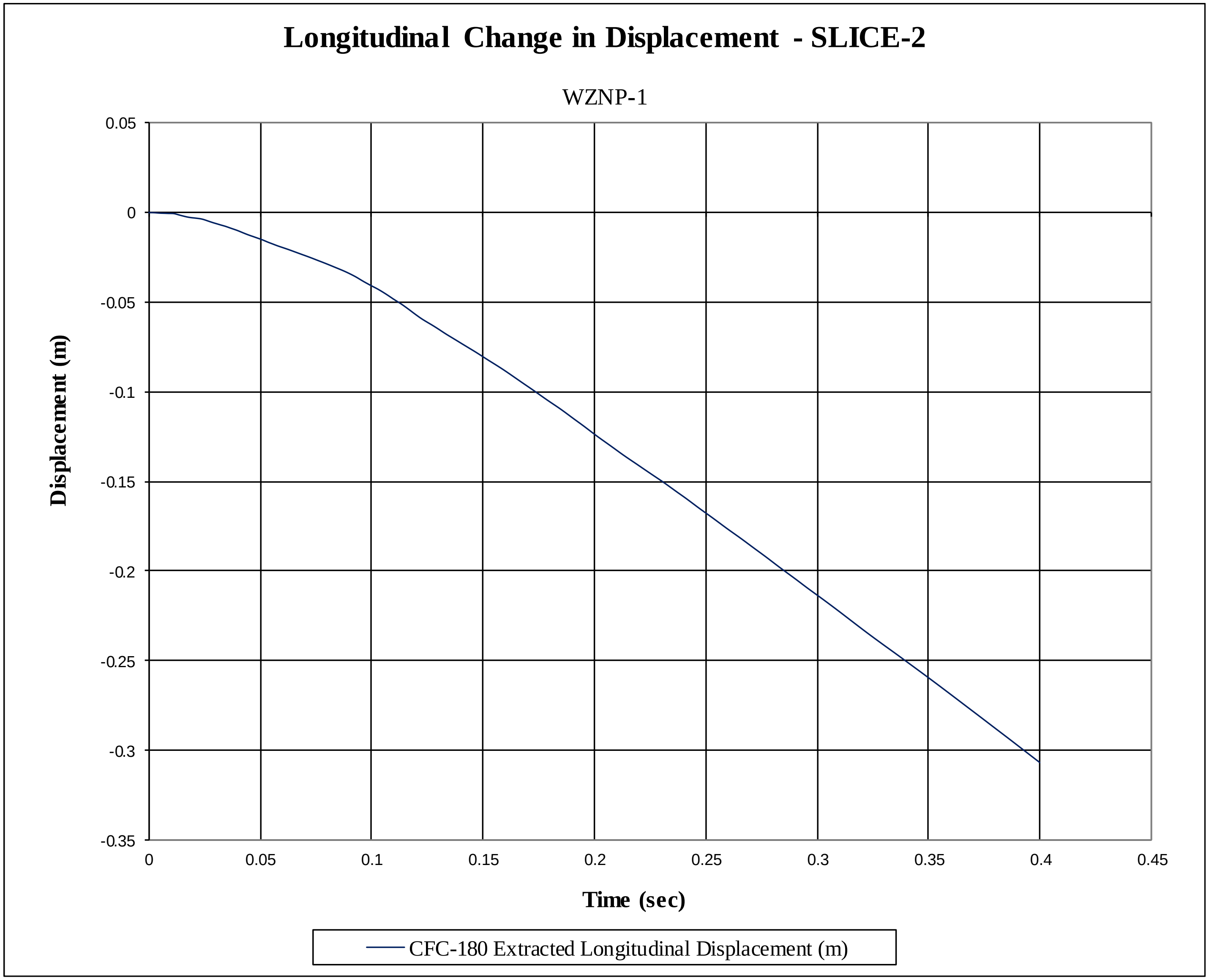


Figure D-11. System A – Longitudinal Occupant Displacement (SLICE-2), Test No. WZNP-1

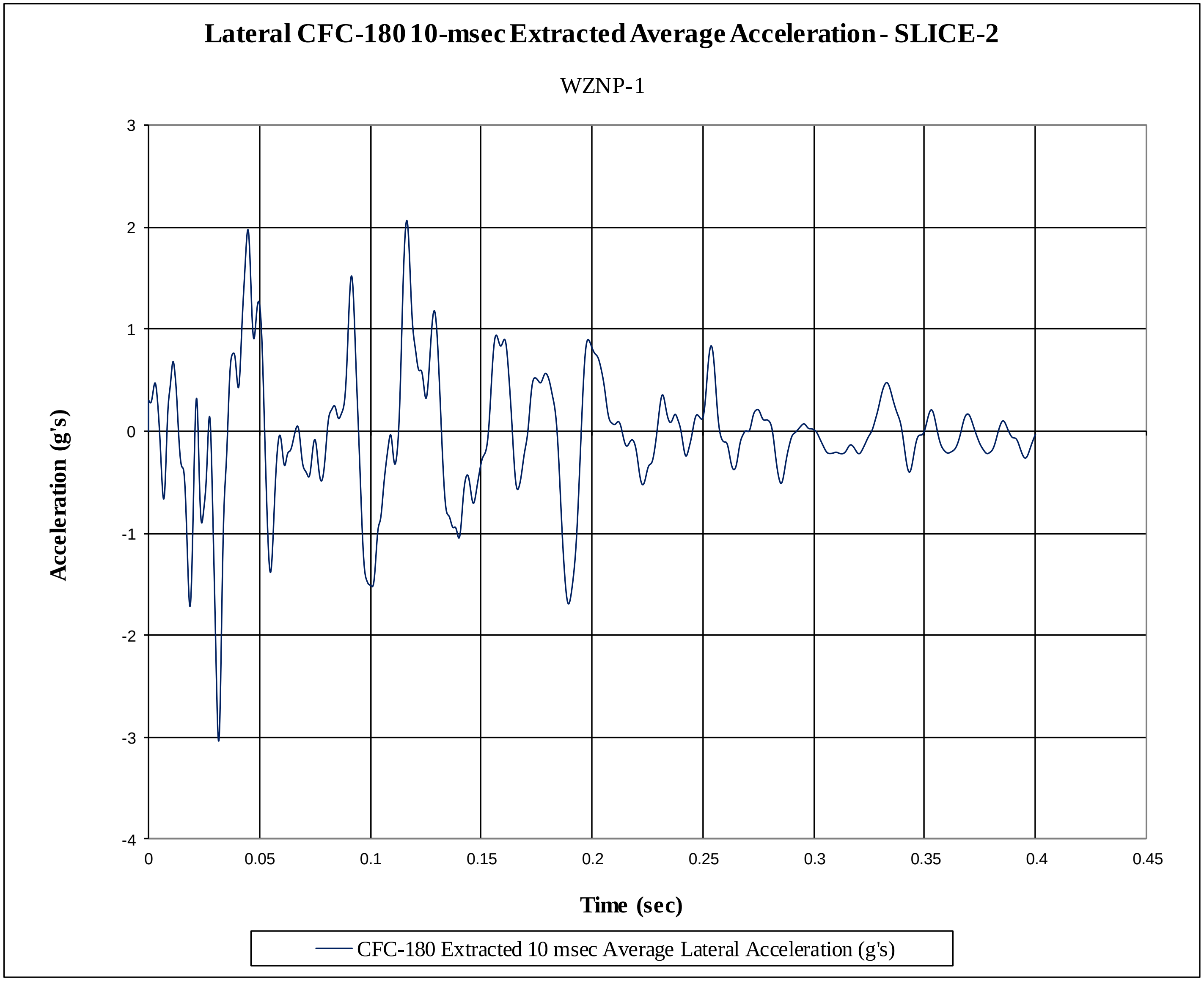


Figure D-12. System A – 10-ms Average Lateral Acceleration (SLICE-2), Test No. WZNP-1

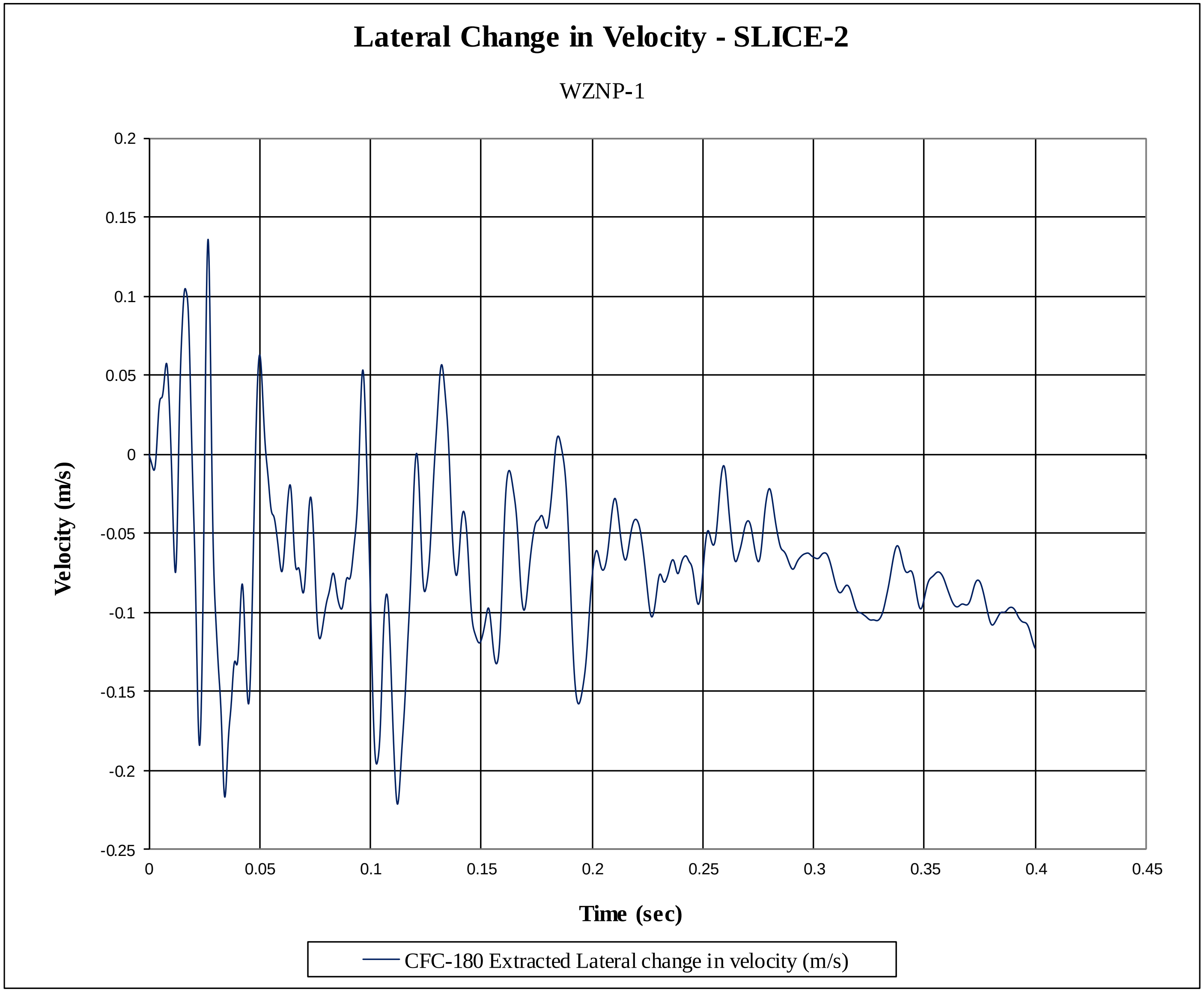


Figure D-13. System A – Lateral Occupant Impact Velocity (SLICE-2), Test No. WZNP-1

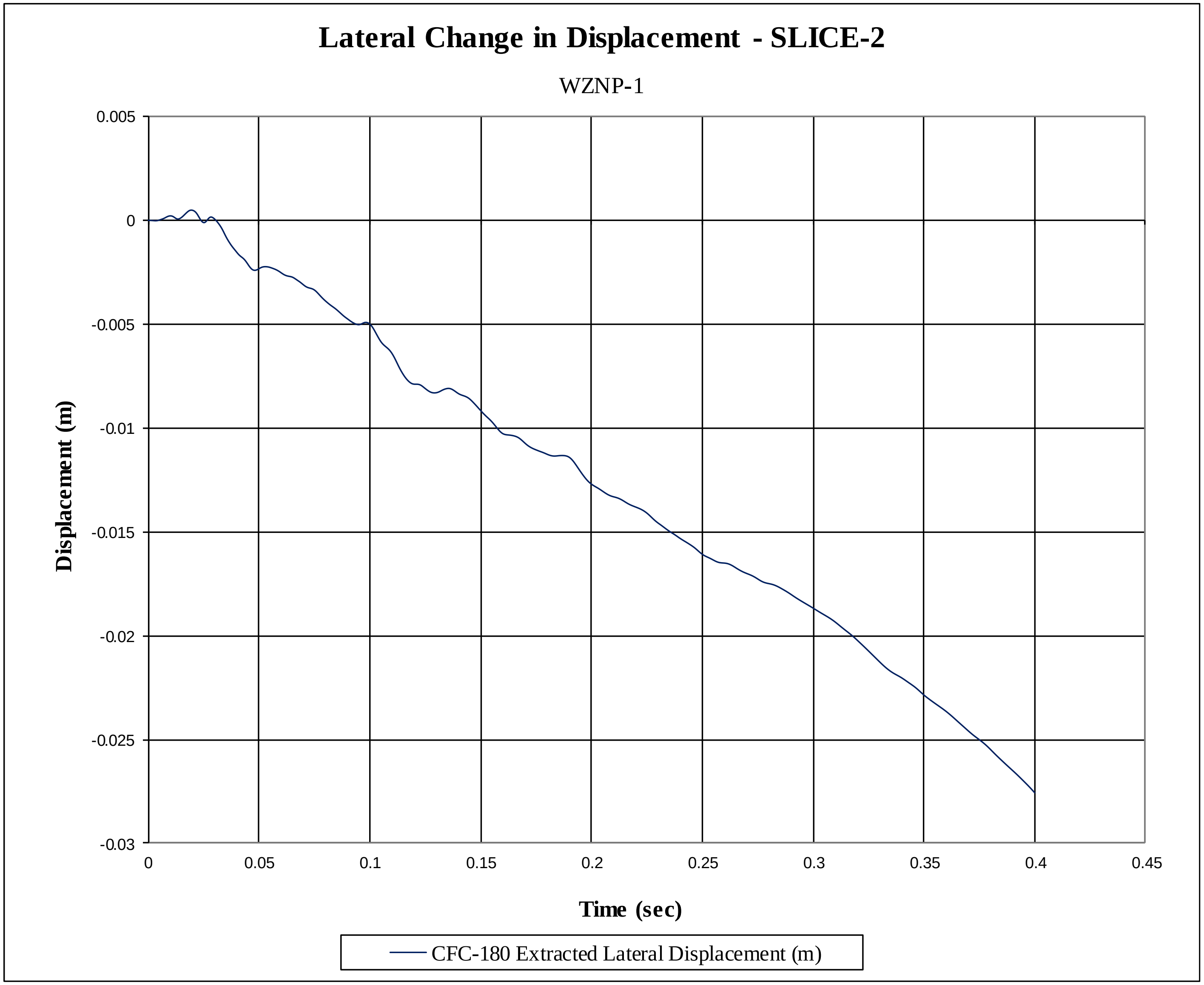


Figure D-14. System A – Lateral Occupant Displacement (SLICE-2), Test No. WZNP-1

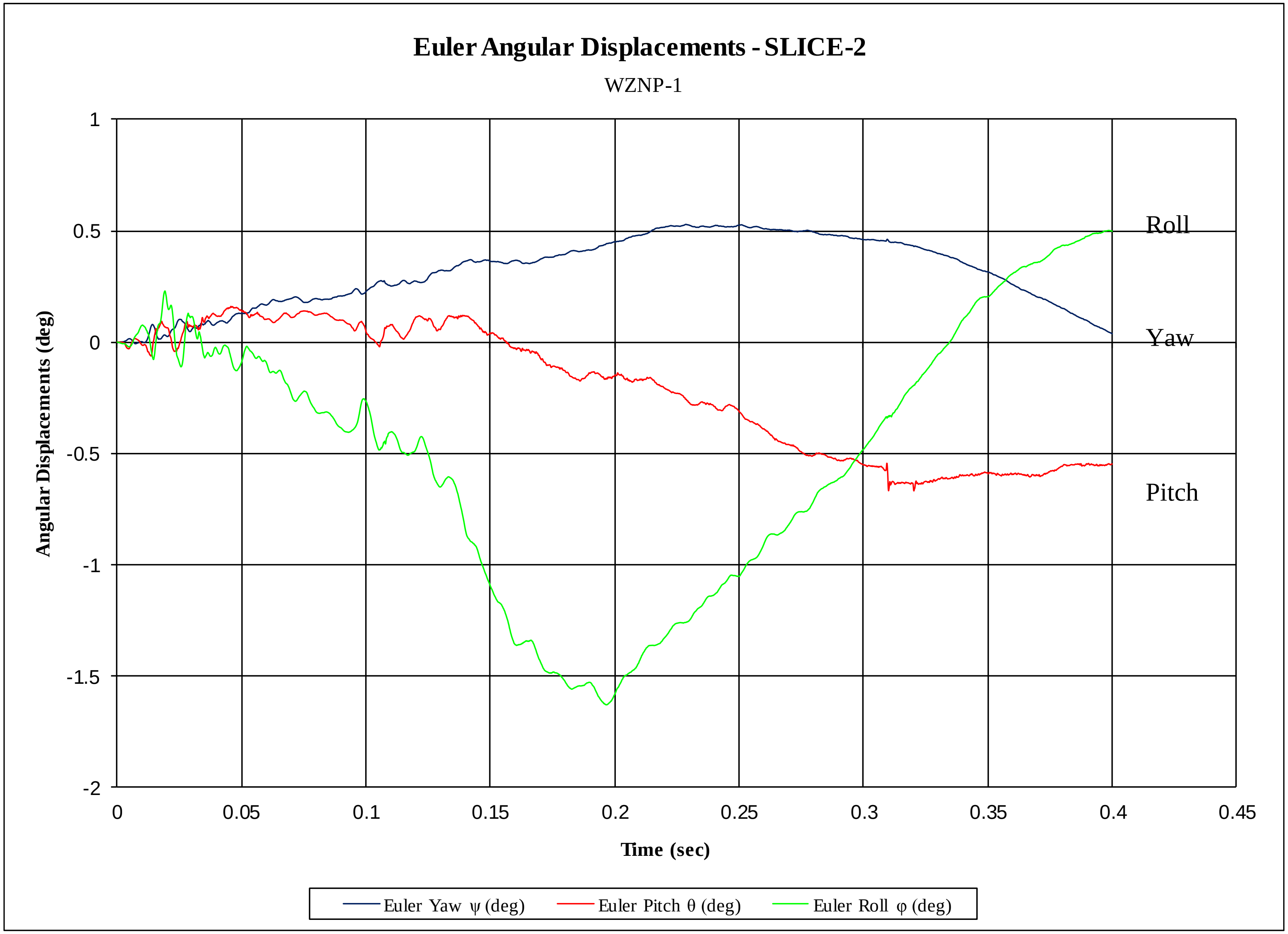


Figure D-15. System A – Vehicle Angular Displacements (SLICE-2), Test No. WZNP-1

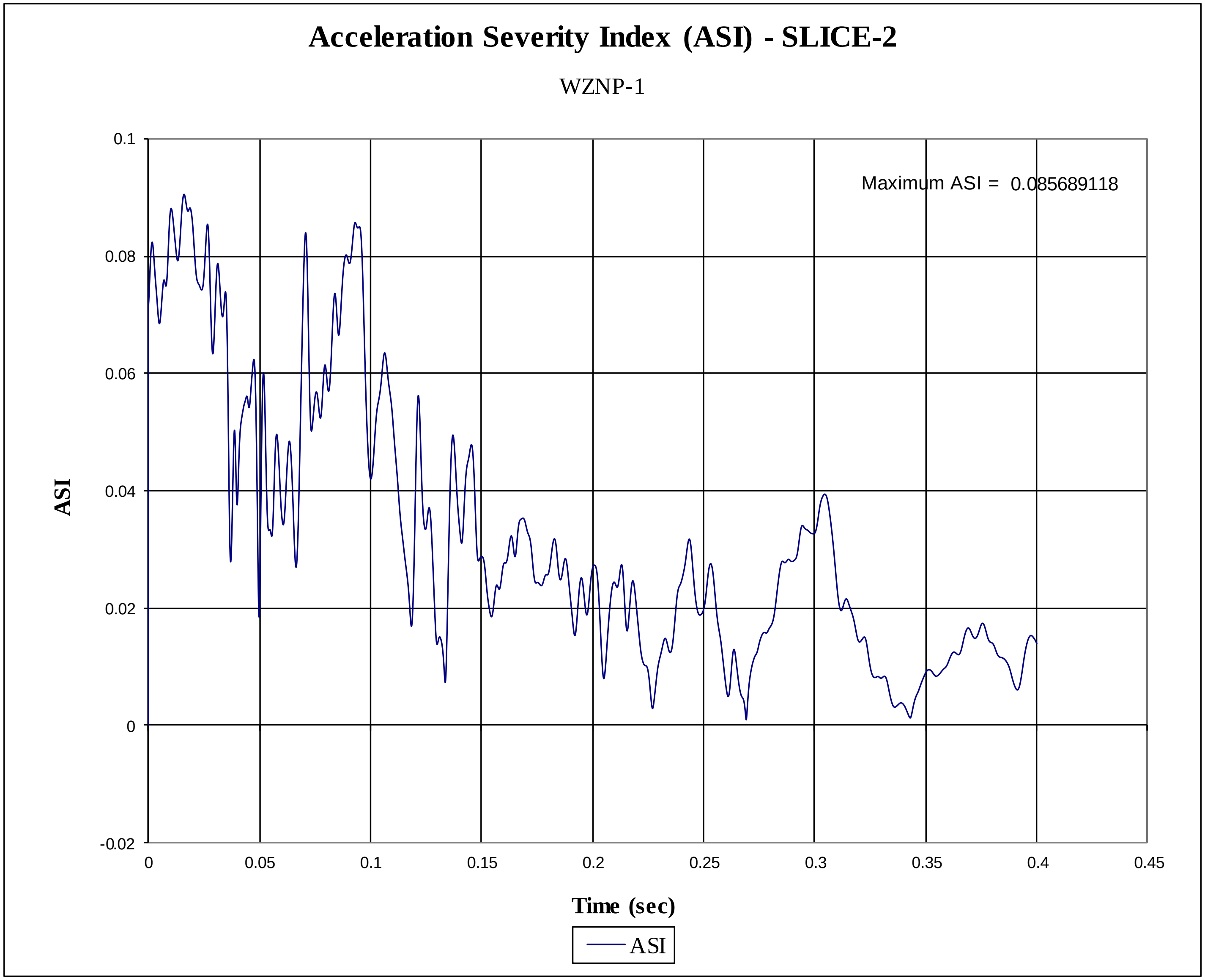


Figure D-16. System A – Acceleration Severity Index (SLICE-2), Test No. WZNP-1

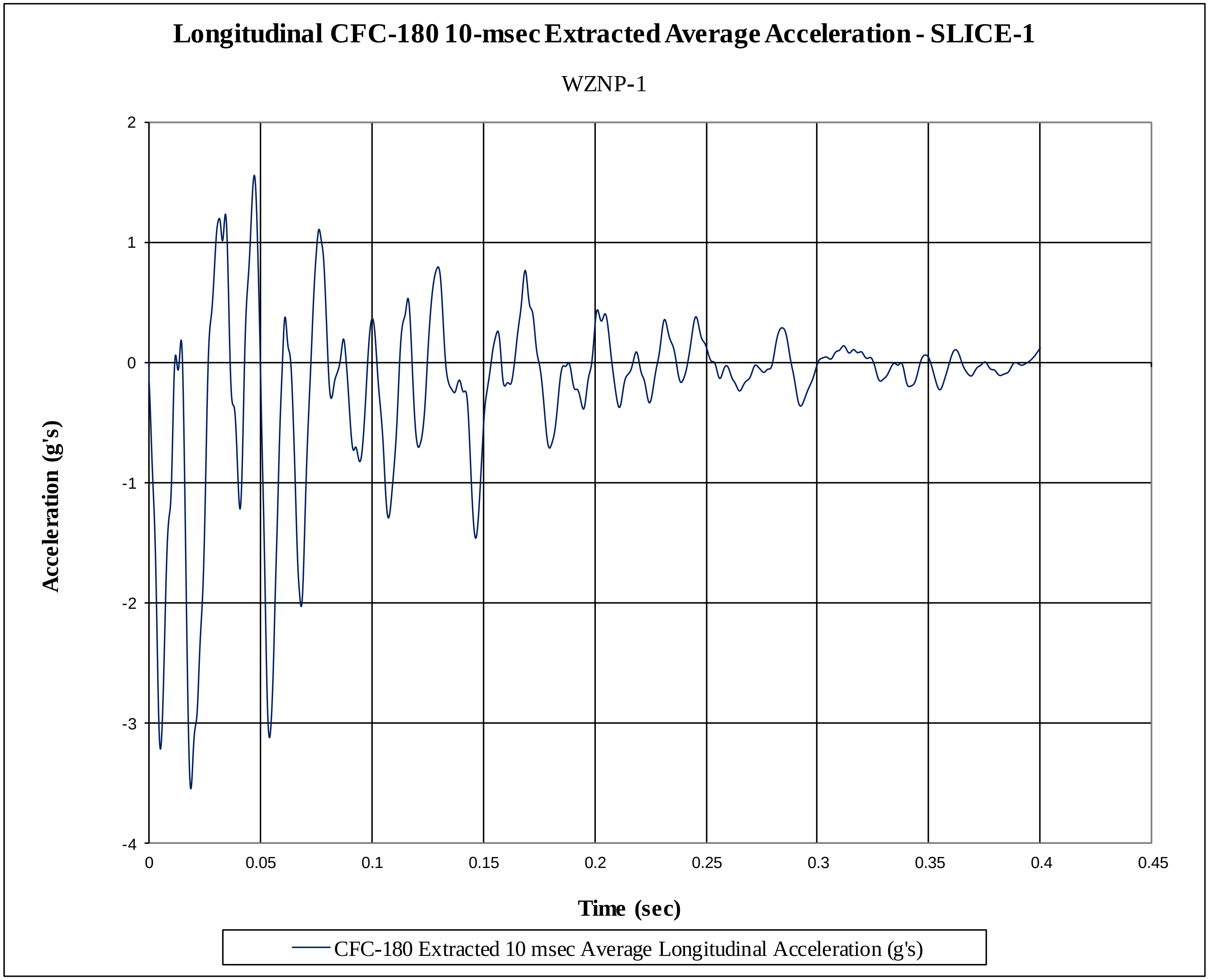


Figure D-17. System B – 10-ms Average Longitudinal Acceleration (SLICE-1), Test No. WZNP-1

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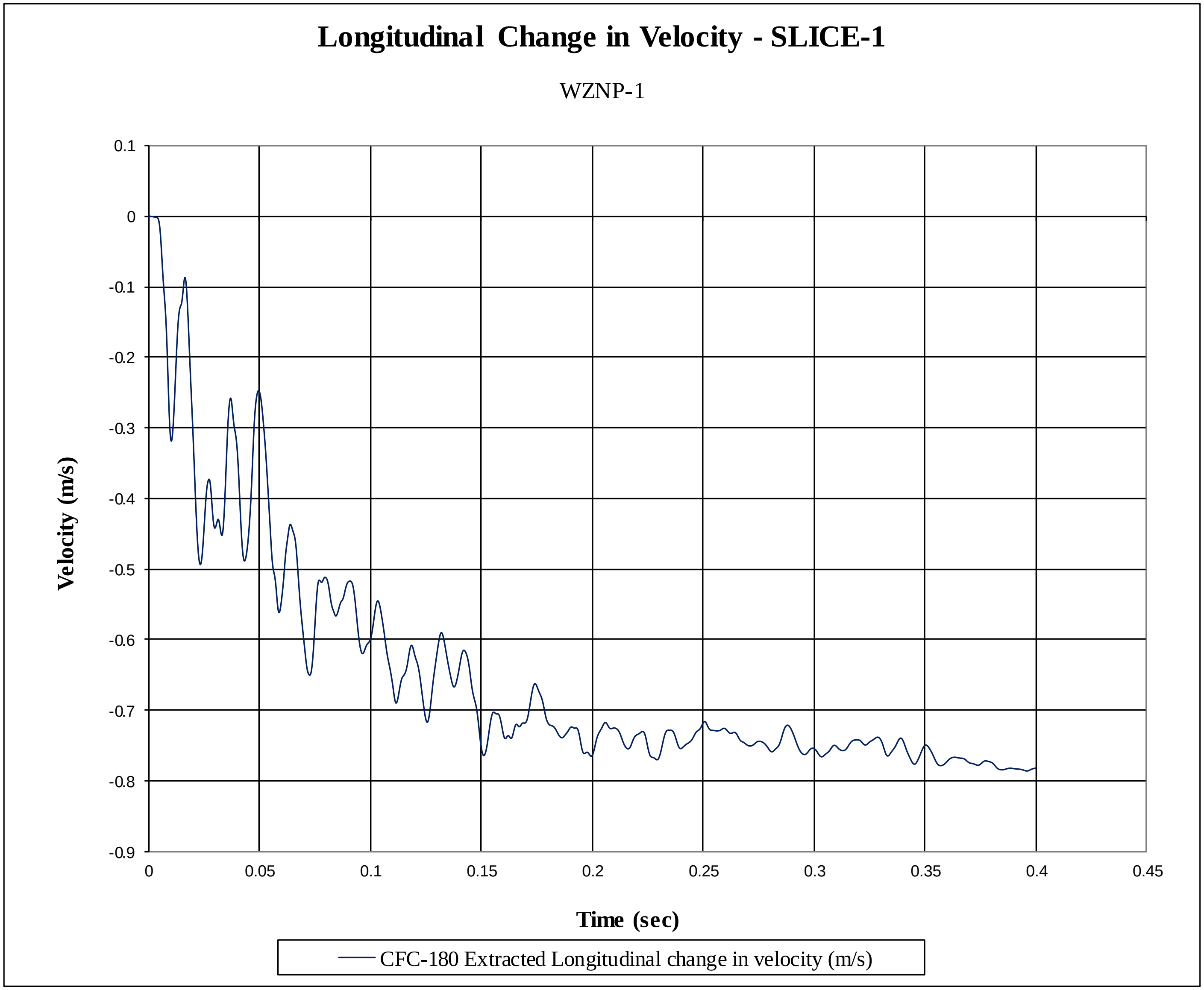

Figure D-18. System B – Longitudinal Occupant Impact Velocity (SLICE-1), Test No. WZNP-1

September 19, 2018
MwRSF Report No. TRP-03-394-18 Revision-1

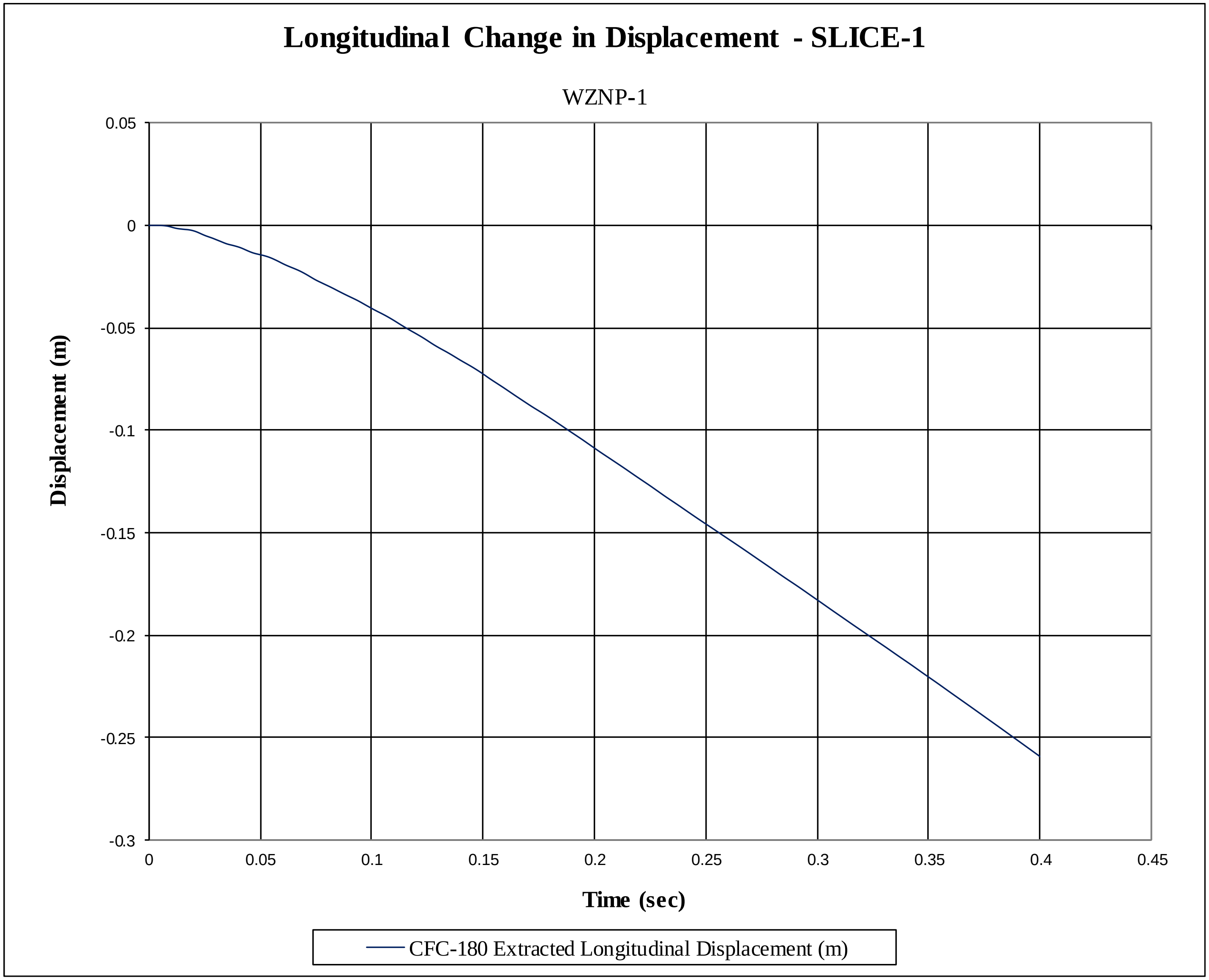

Figure D-19. System B – Longitudinal Occupant Displacement (SLICE-1), Test No. WZNP-1

September 19, 2018
MwRSF Report No. TRP-03-394-18 Revision-1

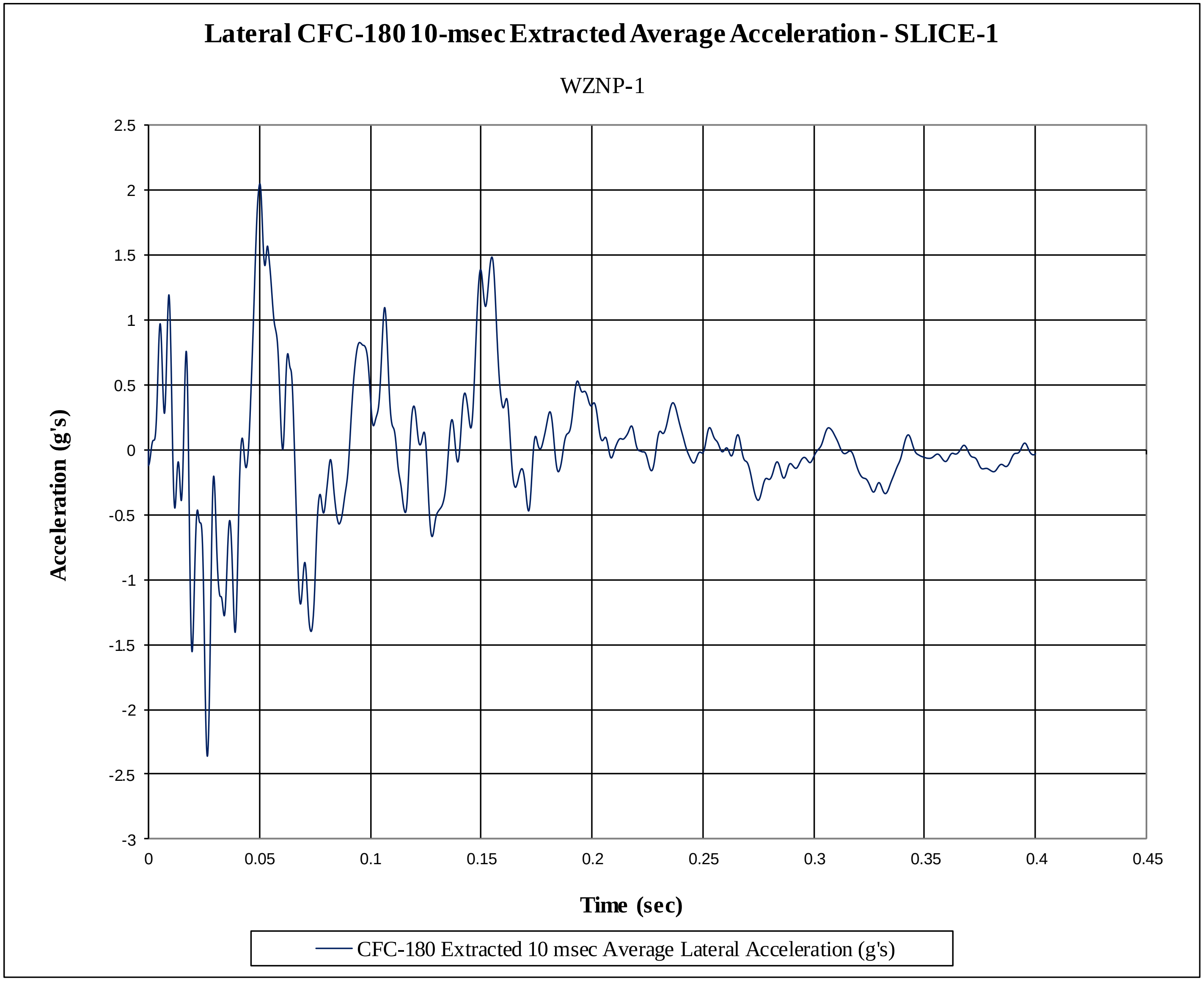

Figure D-20. System B – 10-ms Average Lateral Acceleration (SLICE-1), Test No. WZNP-1

September 19, 2018
MwRSF Report No. TRP-03-394-18 Revision-1

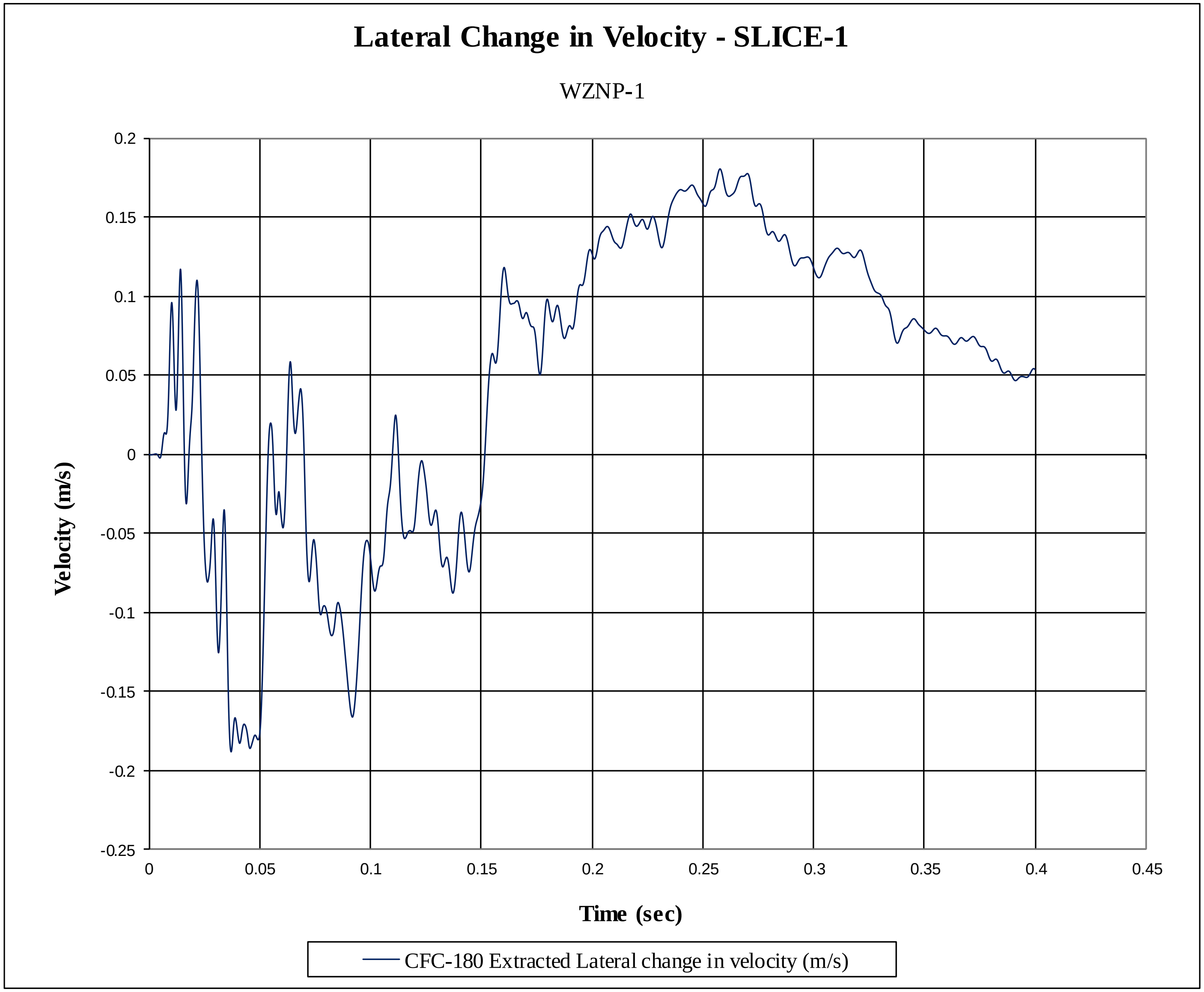

Figure D-21. System B – Lateral Occupant Impact Velocity (SLICE-1), Test No. WZNP-1

September 19, 2018
MwRSF Report No. TRP-03-394-18 Revision-1

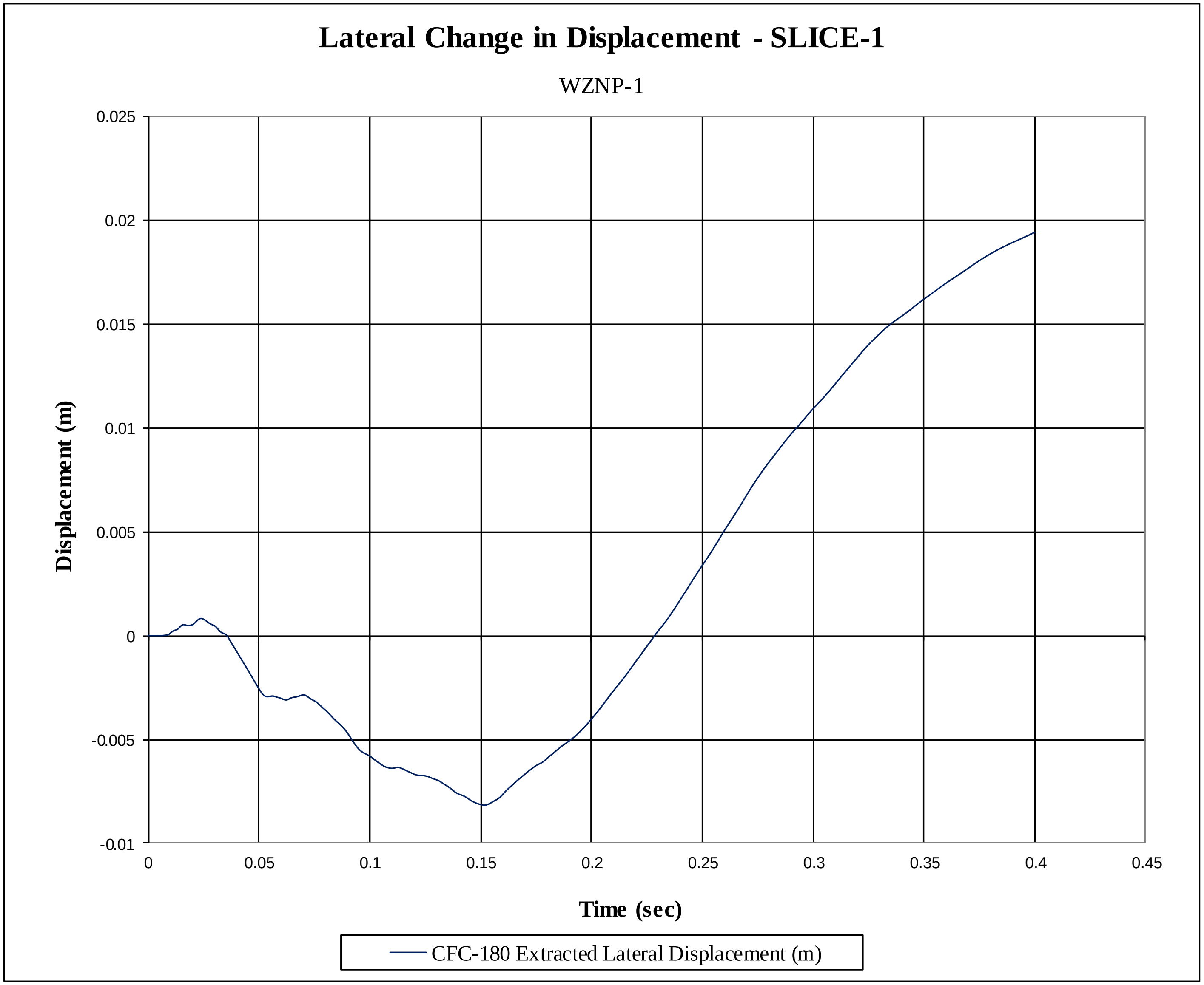

Figure D-22. System B – Lateral Occupant Displacement (SLICE-1), Test No. WZNP-1

September 19, 2018
MwRSF Report No. TRP-03-394-18 Revision-1

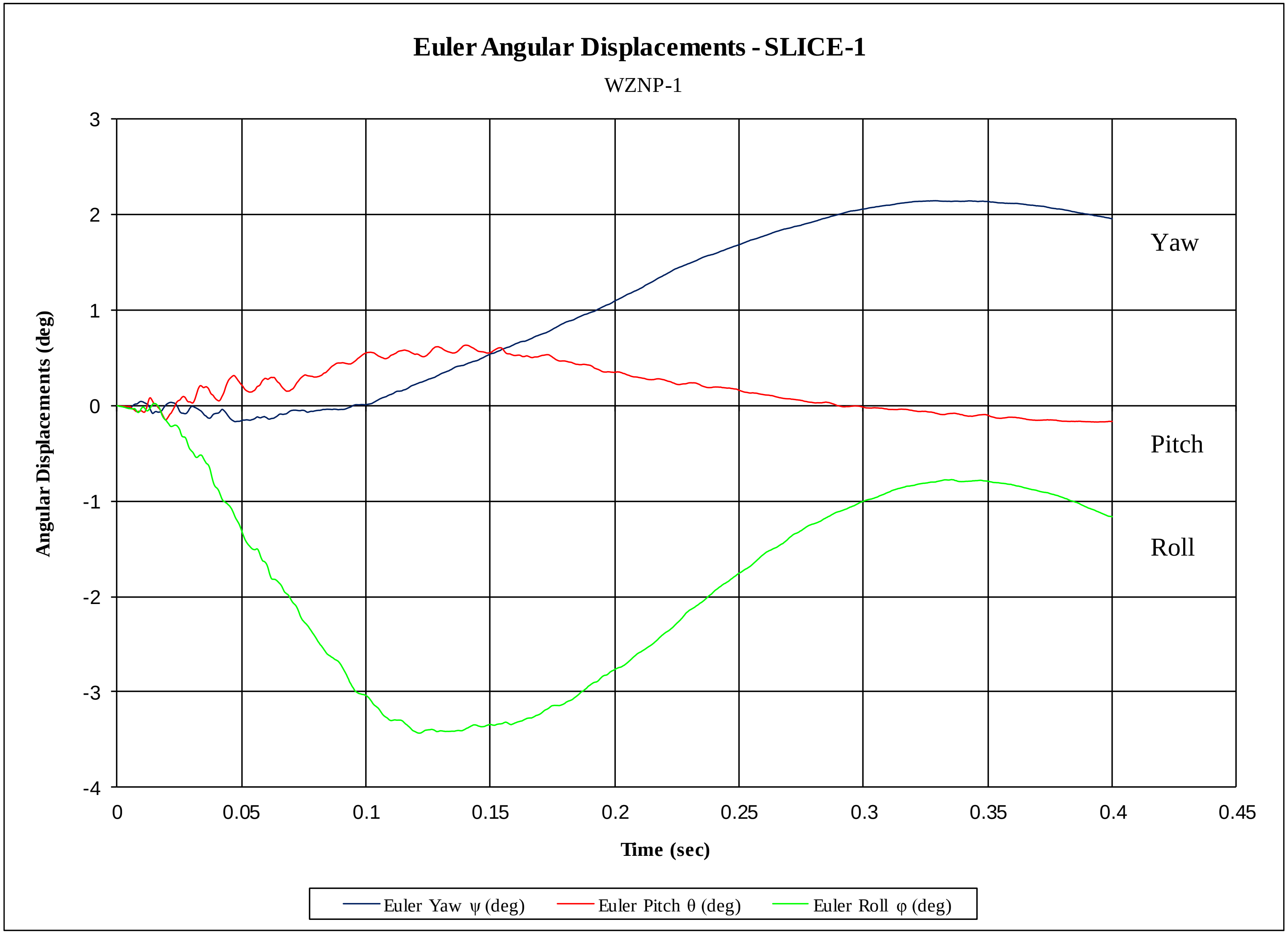

Figure D-23. System B – Vehicle Angular Displacements (SLICE-1), Test No. WZNP-1

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September 19, 2018

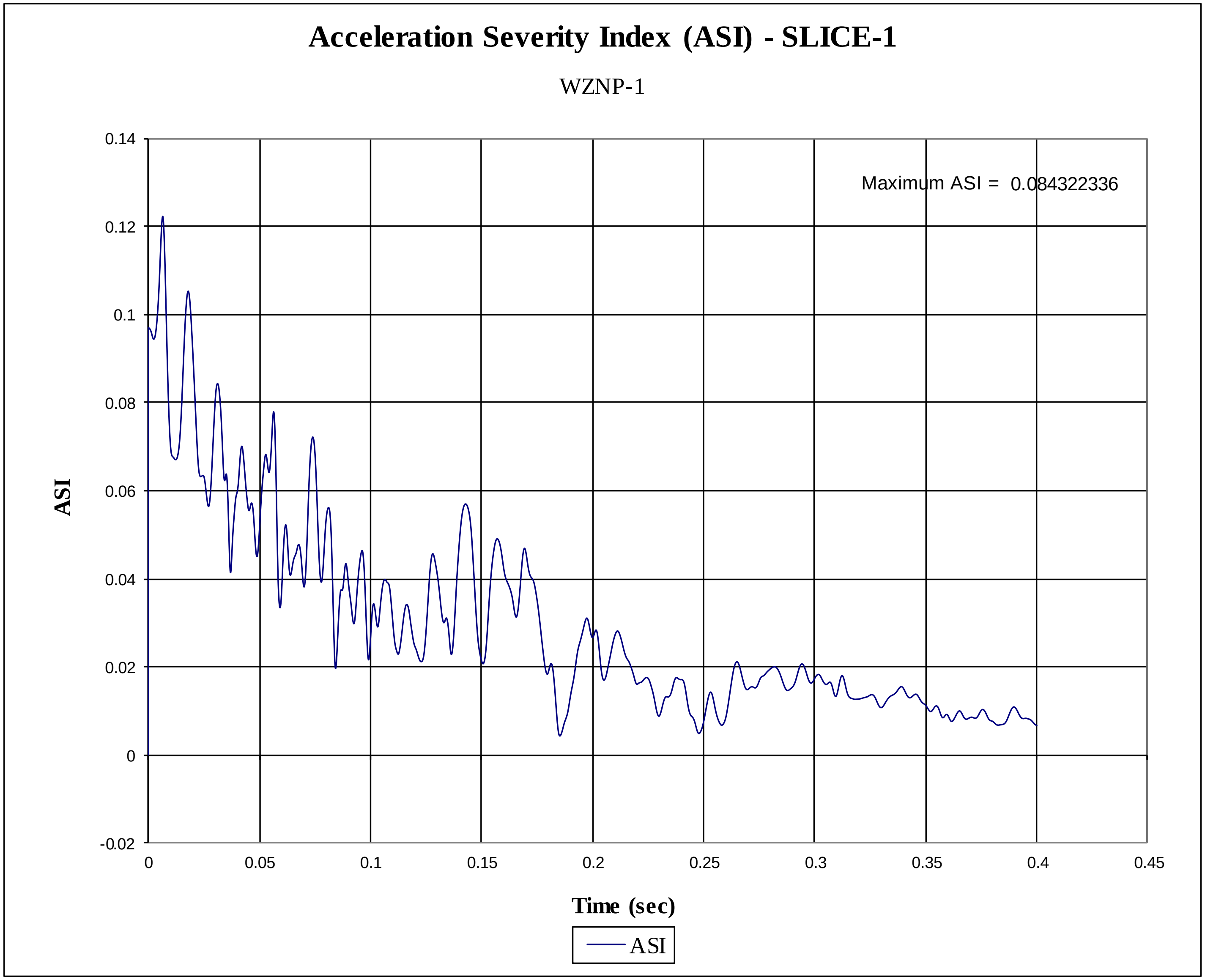

Figure D-24. System B – Acceleration Severity Index (SLICE-1), Test No. WZNP-1

September 19, 2018
MwRSF Report No. TRP-03-394-18 Revision-1

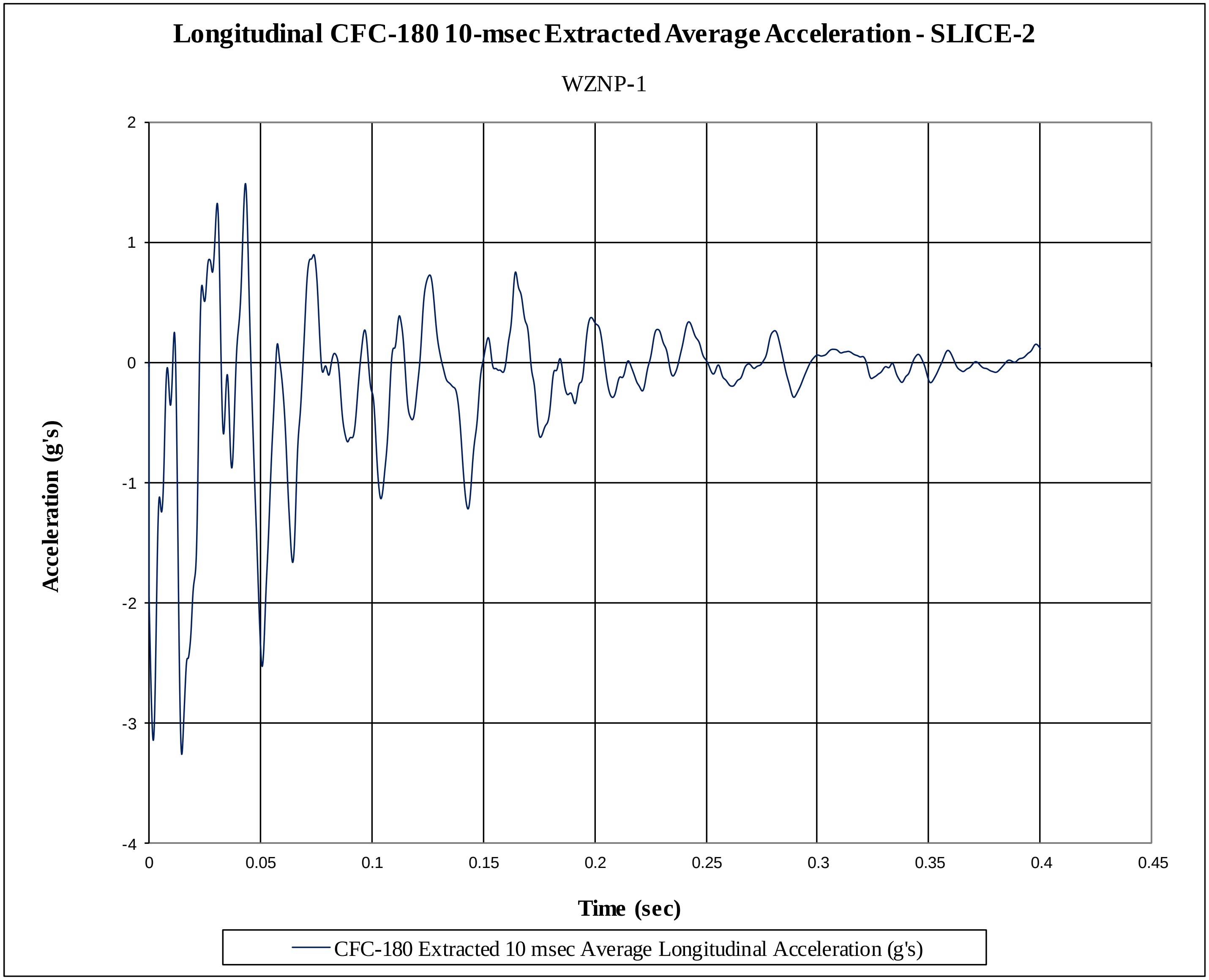

Figure D-25. System B – 10-ms Average Longitudinal Acceleration (SLICE-2), Test No. WZNP-1

September 19, 2018
MwRSF Report No. TRP-03-394-18 Revision-1

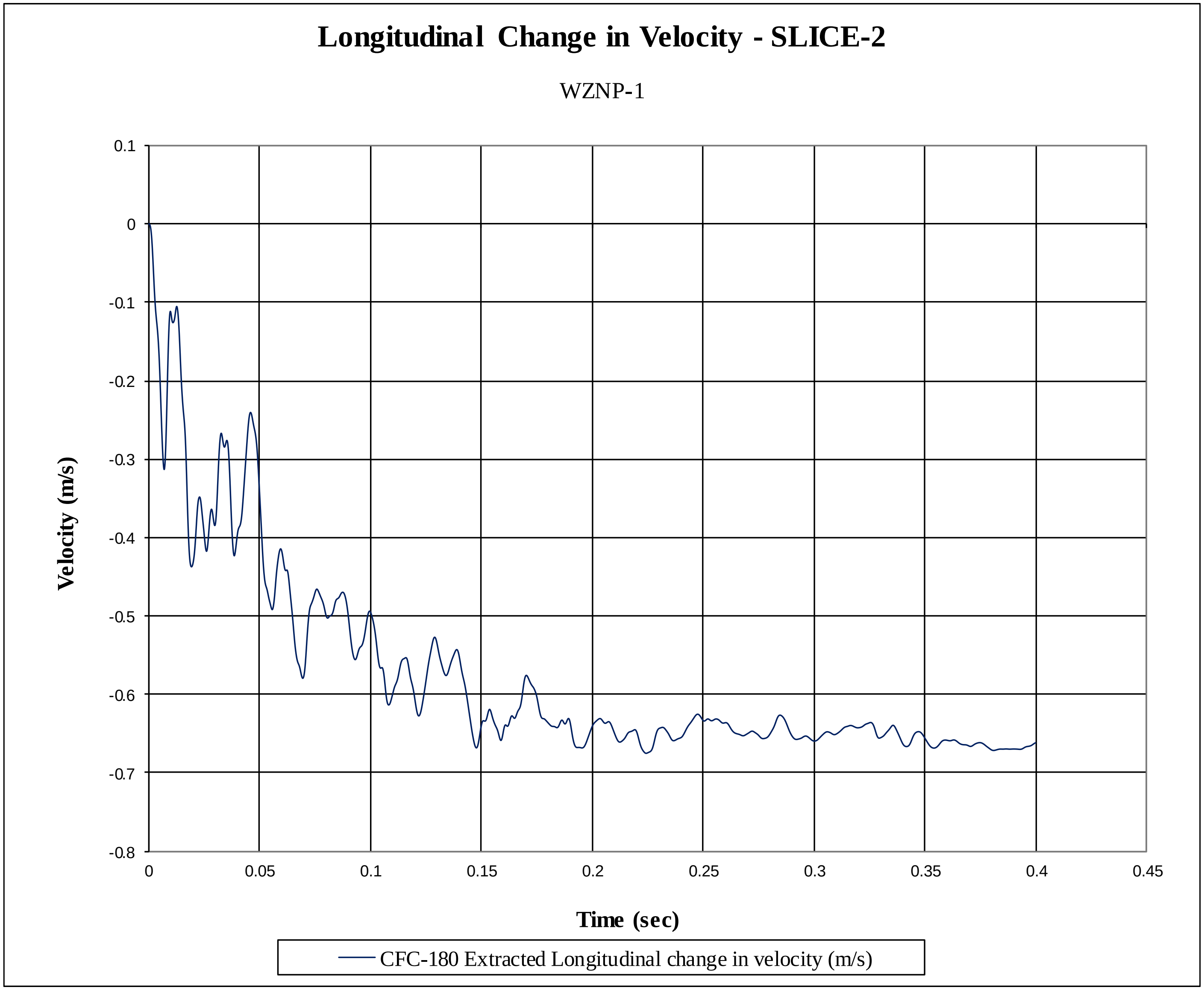

Figure D-26. System B – Longitudinal Occupant Impact Velocity (SLICE-2), Test No. WZNP-1

September 19, 2018
MwRSF Report No. TRP-03-394-18 Revision-1

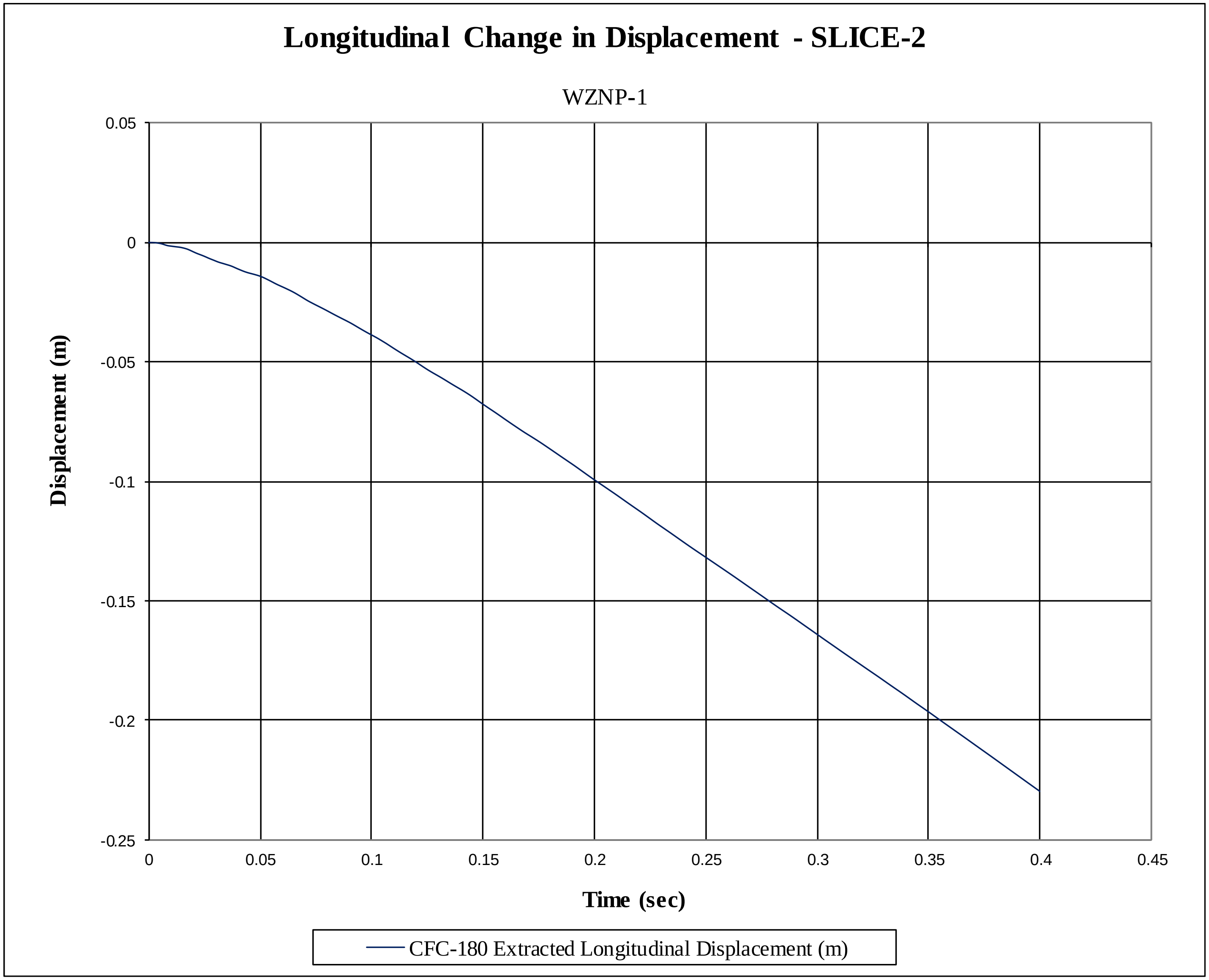

Figure D-27. System B – Longitudinal Occupant Displacement (SLICE-2), Test No. WZNP-1

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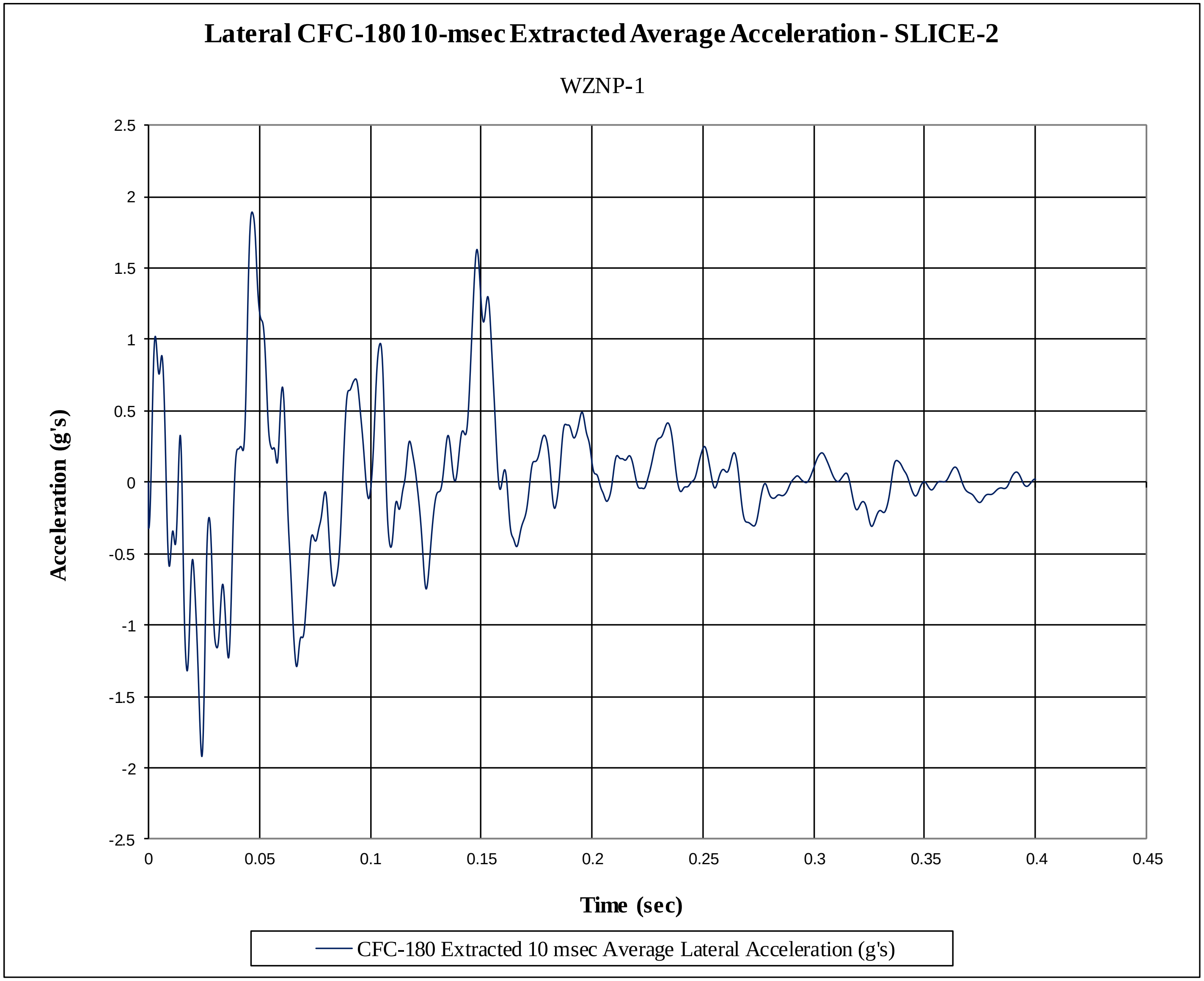

Figure D-28. System B – 10-ms Average Lateral Acceleration (SLICE-2), Test No. WZNP-1

September 19, 2018
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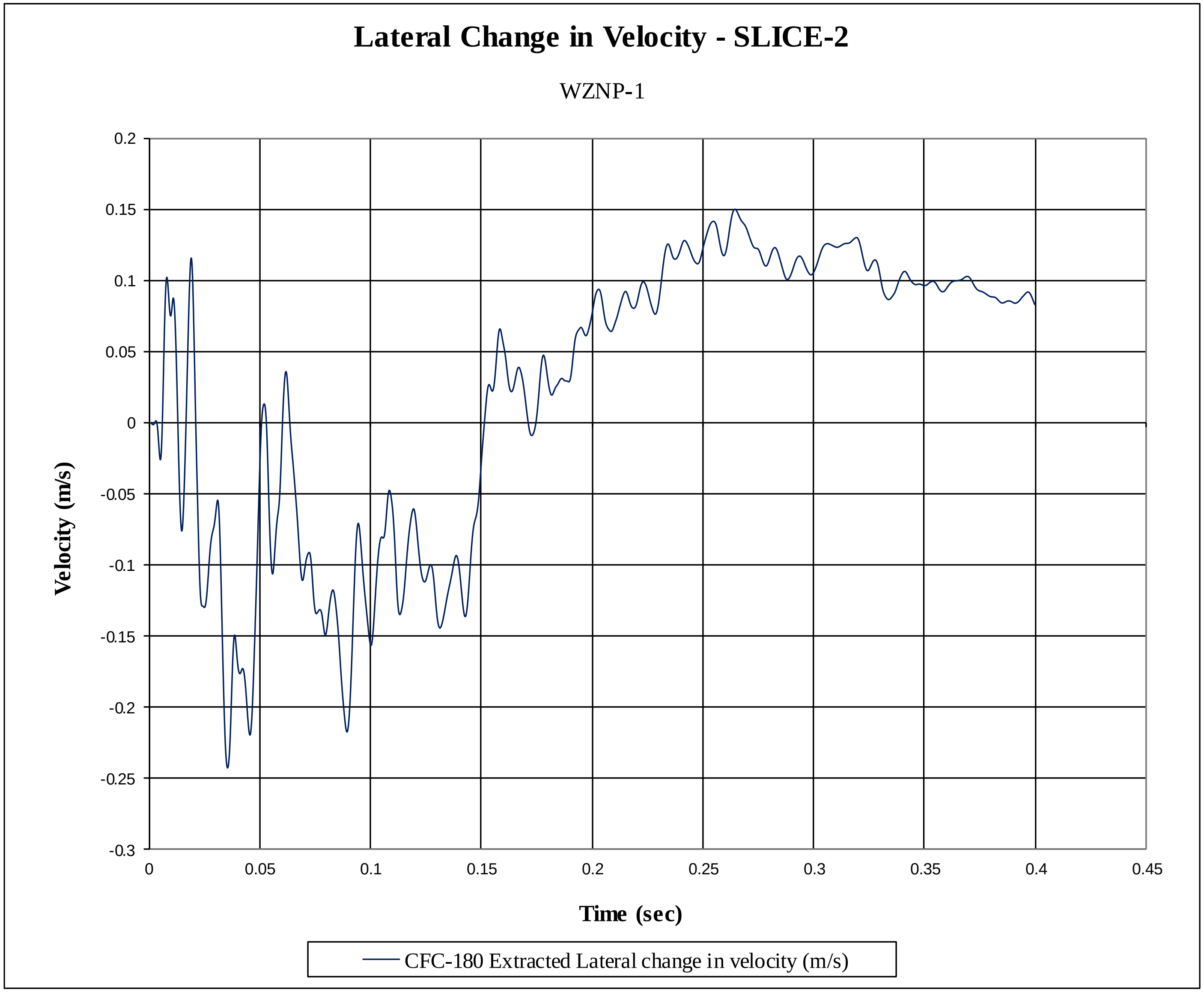

Figure D-29. System B – Lateral Occupant Impact Velocity (SLICE-2), Test No. WZNP-1

September 19, 2018
MwRSF Report No. TRP-03-394-18 Revision-1

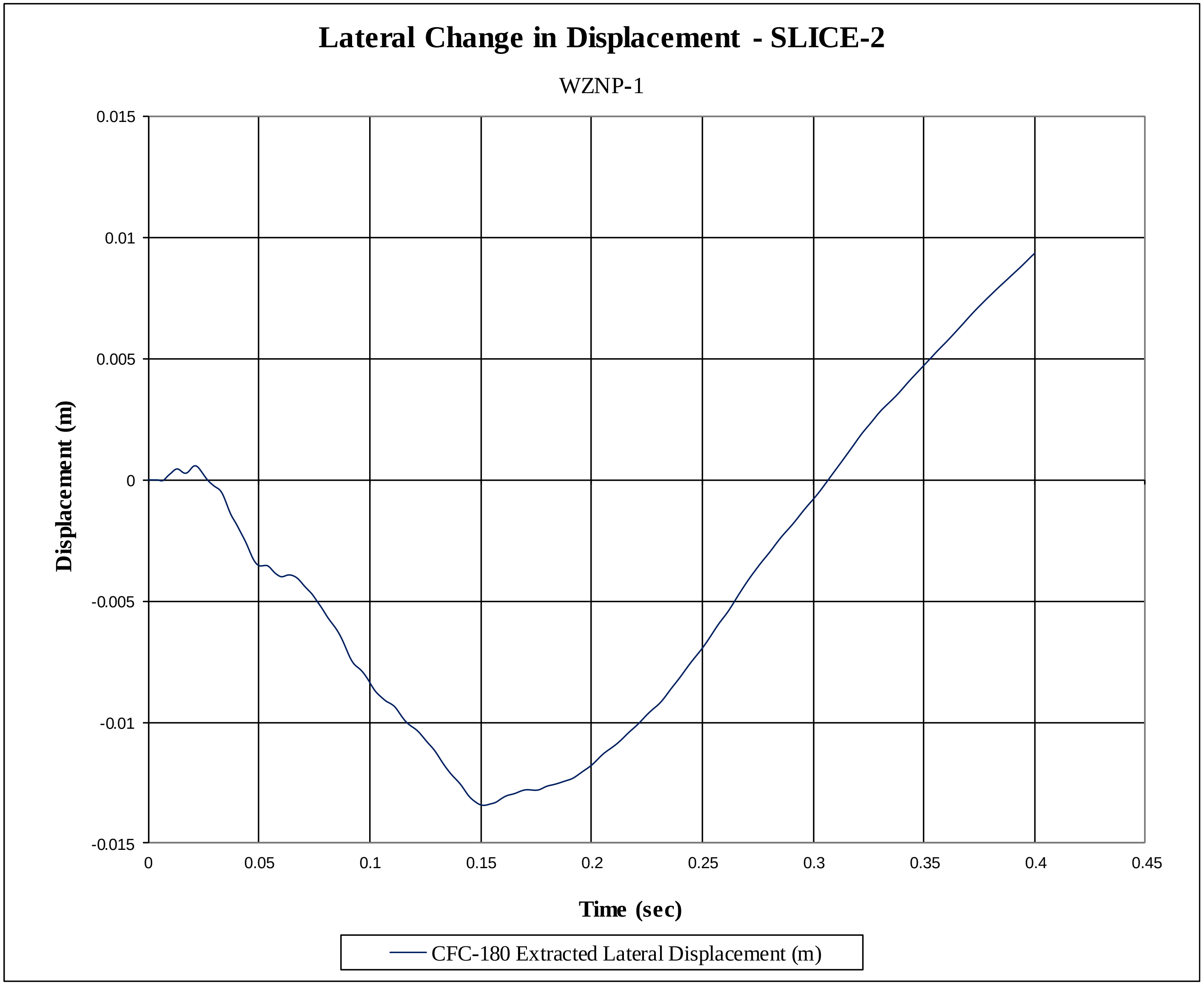

Figure D-30. System B – Lateral Occupant Displacement (SLICE-2), Test No. WZNP-1

September 19, 2018
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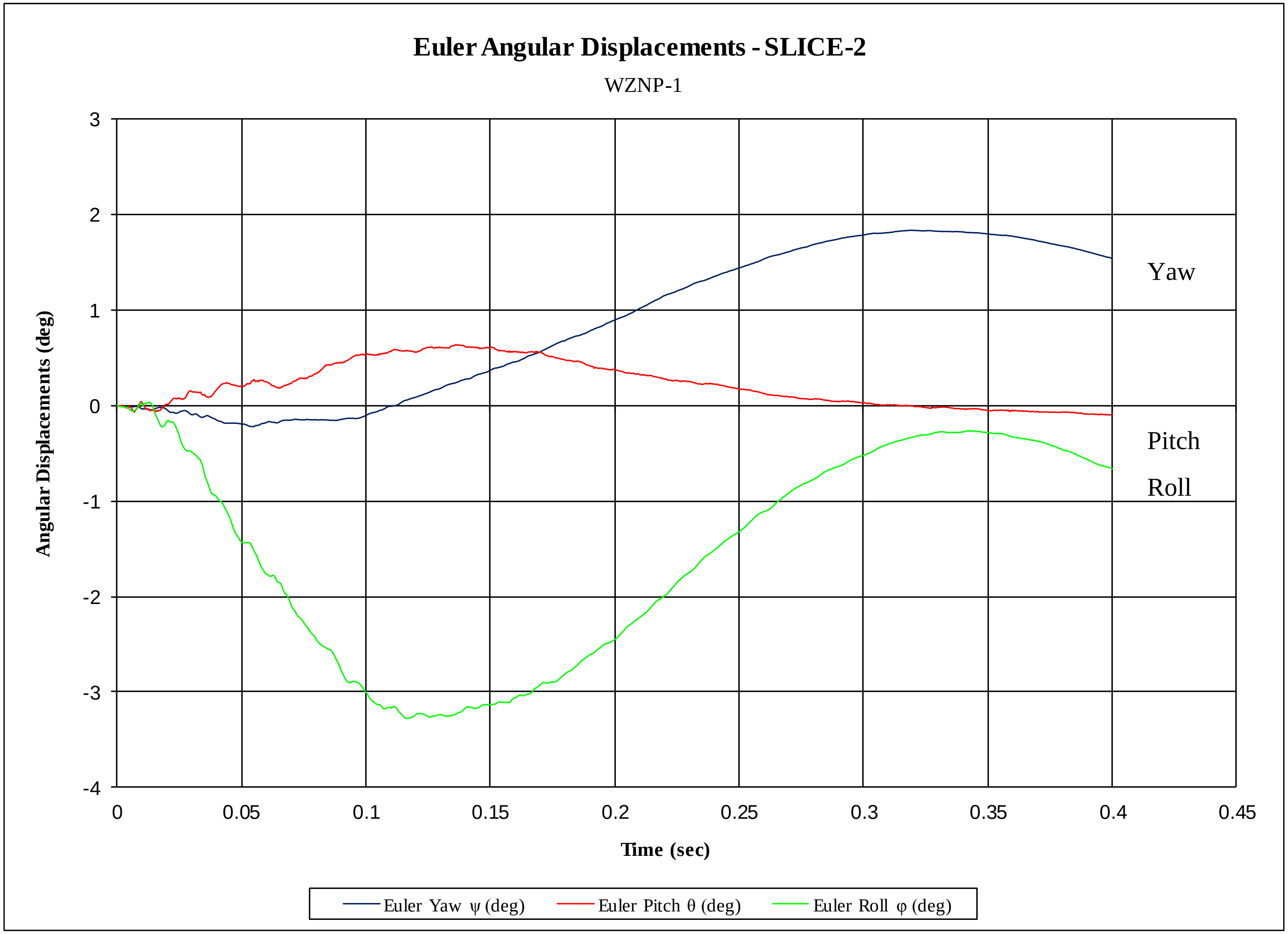

Figure D-31. System B – Vehicle Angular Displacements (SLICE-2), Test No. WZNP-1

September 19, 2018
MwRSF Report No. TRP-03-394-18 Revision-1

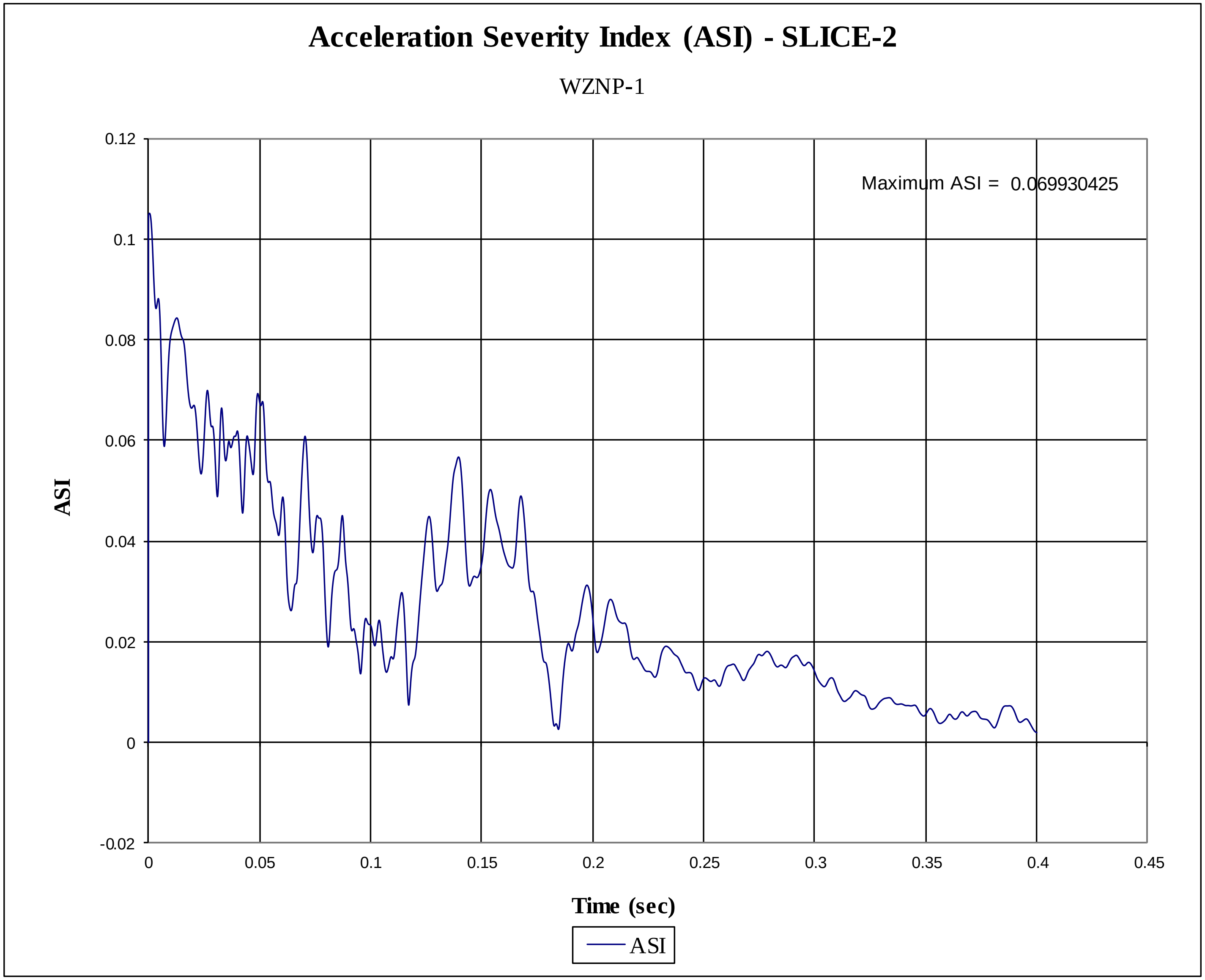

Figure D-32. System B – Acceleration Severity Index (SLICE-2), Test No. WZNP-1

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