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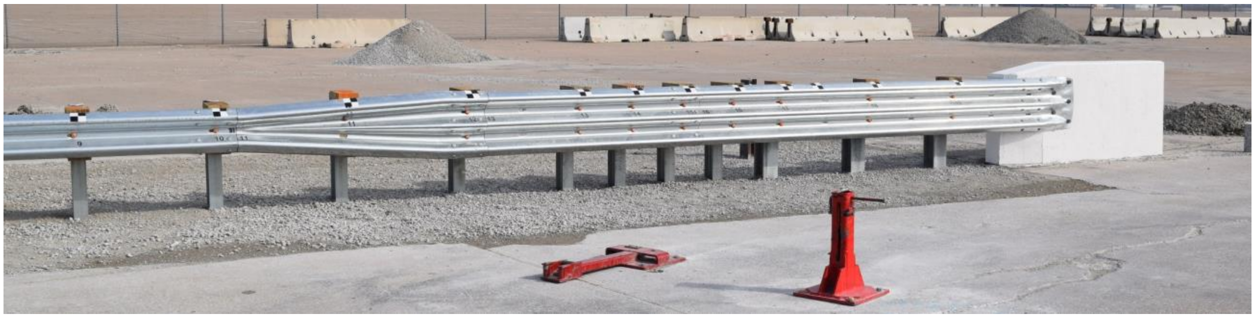
34-IN. TALL THRIE BEAM TRANSITION TO CONCRETE BUTTRESS



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16. Abstract

Roadway resurfacing and overlay projects effectively reduce the height of roadside barriers placed adjacent to the roadway, which can negatively affect their crashworthiness. More recently, bridge rails and concrete barriers have been installed with slightly increased heights to account for future overlays. However, adjacent guardrails and approach transitions have not yet been modified to account for overlays. The objective of this project was to develop an increased-height, approach guardrail transition (AGT) to be crashworthy both before and after roadway overlays of up to 3 in. (76 mm).

A 34-in. (864-mm) tall, thrie beam transition was designed such that the system would be at its nominal 31-in. (787-mm) height following a 3-in. (76-mm) roadway overlay. Additionally, the upstream end of the AGT incorporated a symmetric W-to-thrie transition segment, which would be replaced by an asymmetric transition segment after an overlay in order to keep the W-beam guardrail upstream from the transition at its nominal 31-in. (787-mm) height. The 34-in. (864-mm) tall AGT was connected to a modified version of the standardized buttress to mitigate the risk of vehicle snag below the rail.

The barrier system was evaluated through two full-scale crash tests in accordance with Test Level 3 (TL-3) of the American Association of State Highway Transportation Officials' (AASHTO) *Manual for Assessing Safety Hardware (MASH)*. Both MASH test nos. 3-21 and 3-20 were conducted near the upstream end of the rigid buttress and satisfied all safety performance criteria. Thus, the 34-in. (864-mm) tall AGT with modified transition buttress was determined to be crashworthy to MASH TL-3 standards. Finally, implementation guidance was provided for the increased height AGT and its crashworthy variations.

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UNCERTAINTY OF MEASUREMENT STATEMENT

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

INDEPENDENT APPROVING AUTHORITY

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

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1 INTRODUCTION

1.1 Introduction

Approach guardrail transitions (AGTs) are commonly used to shield the ends of bridge rails and/or concrete barriers as well as provide a safe transition in lateral stiffness between deformable guardrail and the rigid parapet. AGTs are sensitive systems that are designed to gradually increase the lateral stiffness along the transition length. Improper designs or abrupt changes in lateral stiffness can result in guardrail pocketing, vehicle instability, and vehicle snag.

The sensitivity of these roadside safety barriers has been observed through the development and evaluation of AGTs to the safety criteria provided in either the American Association of State Highway and Transportation Officials' (AASHTO) *Manual for Assessing Safety Hardware* (MASH) [1] or National Cooperative Highway Research Program (NCHRP) Report 350 [2]. Modifying a single component or feature of an AGT can significantly alter its safety performance. For example, alterations to the shape of the rigid parapet, the presence of a curb, the embedment depth of the transition posts, or the guardrail height within the AGT can be the difference between a successfully crash-tested AGT and a non-crashworthy system [3-14]. Therefore, AGTs must be installed in their proper configurations to ensure crashworthiness.

Typically, AGTs have been installed with a 31-in. (787-mm) top mounting height based on successful crash testing. However, roadway overlays reduce the effective height of the guardrail relative to the new roadway surface unless milling or grinding of the roadway occurs in conjunction with the resurfacing. Although limited research exists on AGTs with lower heights, full-scale testing on the upstream end of an AGT, which had stiffened W-beam rail mounted at a 27.75 in. (705 mm) height, resulted in the rollover of a 2000P pickup truck [14]. The reduced guardrail height coupled with the increase in barrier stiffness caused the high center-of-mass vehicle to roll toward the system. Thus, reducing the effective height of an AGT below its nominal 31-in. (787-mm) height is not currently recommended, as it has not yet met current crashworthiness requirements, and is not recommended until further research and testing is conducted.

Transportation agencies who regularly resurface roadways without milling or grinding the original surface are often forced to remove AGTs adjacent to roadway overlays and replace or reset them to maintain a crashworthy height, typically 31 in. (787 mm) above the new roadway surface. Not only is guardrail replacement a costly addition to the resurfacing project, but it can be difficult to shift connection plates and anchorage hardware upward on the existing concrete parapets. The rigid buttress may not be tall enough to accommodate the vertical shift, or steel reinforcement may reside at the locations where the new anchorage hardware is needed.

To account for future roadway overlays, many transportation agencies have begun installing concrete bridge rails and median barriers at increased heights. For example, MASH Test Level 4 (TL-4) bridge rails with nominal heights of 36 in. (914 mm) are being installed at 39 in. (991 mm) in anticipation of a future 3-in. (76 mm) overlay, which would bring the effective height of the bridge rail back to its nominal 36-in. (914-mm) height. With the safety performance concerns associated with low-height AGTs and the costs associated with replacing or resetting them after an overlay, there could be great benefits to installing AGTs at increased heights in anticipation of future overlays. However, the effects of increasing the installation height of an

AGT have never been evaluated. Thus, a need existed to develop and evaluate an increased height AGT for use with future roadway overlays.

1.2 Objective

The objective of this project was to adapt the thrie beam AGT used by the Nebraska Department of Transportation (NDOT) for a top mounting height of 34 in. (864 mm) to account for future roadway overlays of up to 3 in. (76 mm). The new 34-in. (864-mm) tall AGT was to incorporate the newly developed standardized transition buttress to minimize the risk of vehicle snag below the raised guardrail. Finally, the new AGT system was required to satisfy the Test Level 3 (TL-3) safety performance criteria of MASH 2016.

1.3 Scope

The project began with the modification of NDOT's standard thrie beam transition to create the new 34-in. (864-mm) tall AGT system. Modifications were made carefully and strategically to maintain the strength of the barrier system, and the upstream end of the system was designed to attach directly to the MGS both before and after roadway overlays. The 34-in. (864-mm) tall AGT was then subjected to two full-scale crash tests in accordance with the MASH 2016 TL-3 testing evaluation matrix. Finally, results and conclusions were formulated and summarized in a summary report.

2 BARRIER DESIGN

2.1 Guardrail Transition Design

The existing NDOT standard guardrail transition provided the basis for the new AGT design. The downstream end of the NDOT transition consisted of 31-in. (787-mm) tall, nested thrie beam rails supported by W6x15 posts spaced 37.5 in. (953 mm) on center. This AGT configuration had been adapted from a number of AGTs successfully evaluated to NCHRP Report 350 TL-3 criteria [15-17]. The upstream end of the NDOT transition utilized the MASH-crashworthy Midwest Guardrail System (MGS) stiffness transition, which transitions from standard MGS guardrail to stiffened thrie beam AGTs with the use of an asymmetrical W-to-thrie transition segment and 6-ft (1.8-m) long W6x8.5 posts [18-19]. The existing NDOT standard transition is shown in Figure 1 [20].

In order to account for future overlays, the thrie beam rail segments of the AGT were raised 3 in. (76 mm) to achieve a top mounting height of 34 in. (864 mm). Raising the posts with the rail segments would have reduced their embedment depth, thereby reducing the post-soil interacting forces and the stiffness of the AGT. Thus, all transition posts remained at their original embedment depths (i.e., 52-in. (1,321-mm) and 40-in. (1,016-mm) embedment depths for the W6x15 and W6x8.5 posts, respectively), and only the rail segments and blockouts were raised 3 in. (76 mm). Previous research has shown that blockouts and guardrail can be raised by up to 4 in. (102 mm) on a post without negatively affecting the performance of the barrier [21-23]. Thus, there was no concern that this raised rail-to-post attachment configuration within the AGT would create performance issues.

The MGS stiffness transition was desired for continued use on the upstream end of the AGT. However, the increased height of the AGT would cause the adjacent W-beam to be installed with a rail height of 34 in. (864 mm) as well. Previous small car impacts on the upstream MGS stiffness transition mounted at the nominal 31-in. (787-mm) height resulted in some vehicle snag on the posts below the rail [18]. Although the snag was not enough to fail MASH safety criteria, increasing the height of the rail would further expose the posts, which may result in excessive vehicle snag. Thus, the MGS upstream from the AGT was to remain with a 31-in. (787-mm) rail height.

To connect the 34-in. (864-mm) thrie beam to 31-in. (787-mm) MGS, the asymmetric W-to-thrie transition segment within the MGS stiffness transition was replaced with the symmetric transition rail segment. This symmetric W-to-thrie segment allowed for an easy connection between the separate rail types using standard rail hardware. Additionally, the bottom edge of the symmetric transition rail segment has a shallower vertical angle as compared to the asymmetric segment (5.7 degrees vs. 11.3 degrees, respectively). Thus, the risk of a small car wedging under the rail during impacts, which could result in more vehicle snag, higher decelerations, and greater vertical forces to the bottom of the rail, was reduced.

After a 3-in. (76-mm) overlay is applied to the roadway, the thrie beam AGT would be at its nominal mounting height of 31 in. (787 mm) relative to the roadway while maintaining the original post embedment depth. However, the MGS guardrail located upstream from the W-to-thrie transition segment would have an effective mounting height of only 28 in. (711 mm), which has previously shown to cause vehicle rollovers [14]. Therefore, it was recommended to raise the

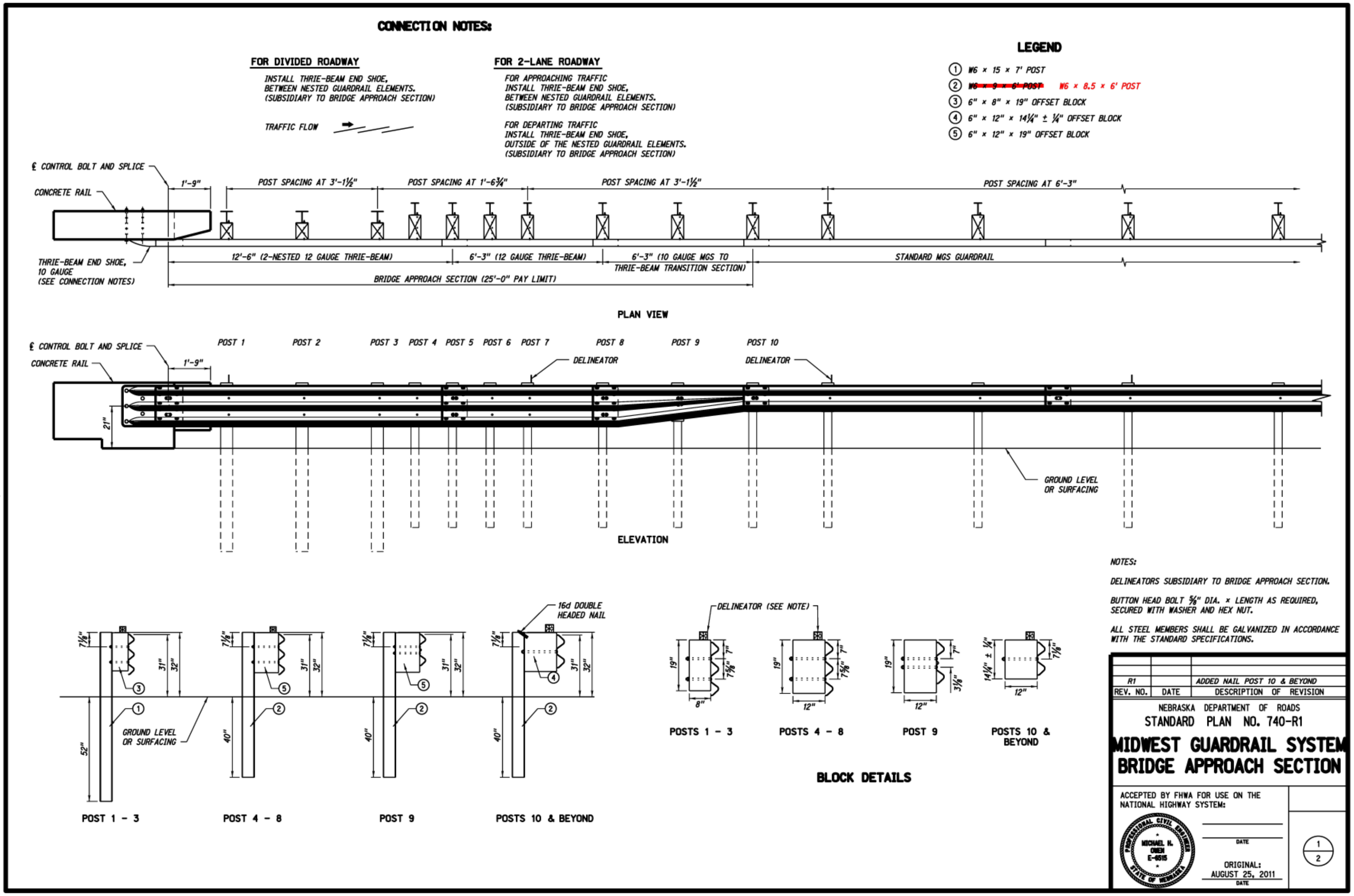


Figure 1. NDOT Approach Guardrail Transition Standard Plan [20]

rail after an overlay placement using a two-step process. First, the W-beam rail and blockouts should be raised 3 in. (76 mm) and reattached to the original posts. Recall that previous research determined that raising guardrail in such a manner was acceptable for vertical shifts up to 4 in. (102 mm) [21-23], which is greater than the 3 in. (76 mm) utilized herein. This process allows the MGS rails to be raised to their nominal height without having to replace or reset the posts while maintaining the nominal post embedment depth as well.

Second, the symmetric W-to-thrie transition segment would be replaced with an asymmetric rail segment, matching the original MGS stiffness transition design. Thus, by replacing only a single rail element and shifting the existing W-beam up 3 in. (76 mm), the entire transition system would be at its nominal 31-in. (787-mm) mounting height and would maintain its crashworthiness after a 3-in. (76-mm) roadway overlay. Drawings of the 34-in. (864-mm) AGT both before and after an overlay are shown in Figures 2 through 4.

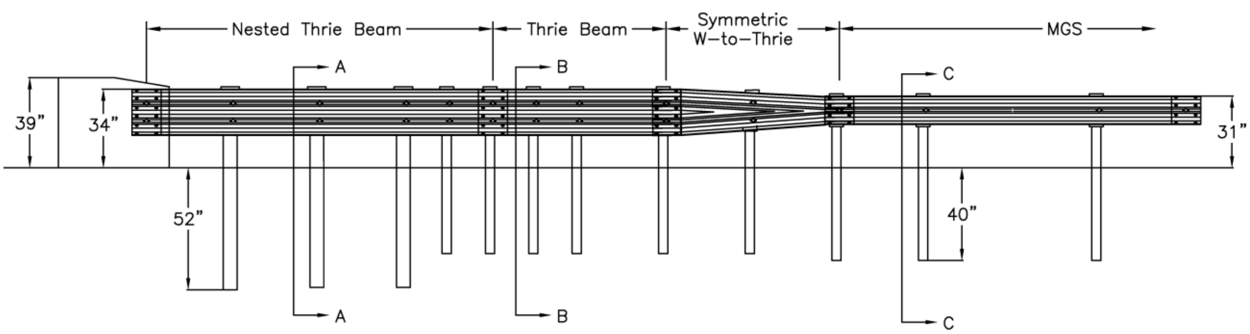


Figure 2. 34-in. (864-mm) Tall AGT Initial Installation, No Overlay

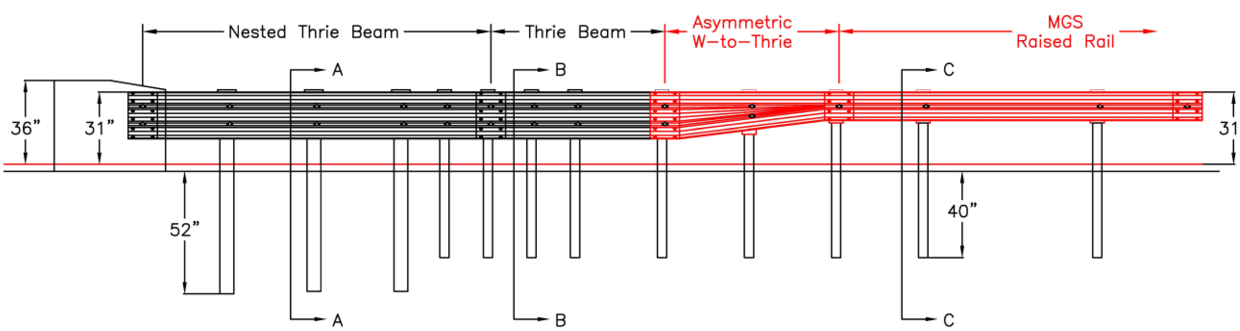


Figure 3. 34-in. (864-mm) Tall AGT After a 3-in. (76-mm) Roadway Overlay

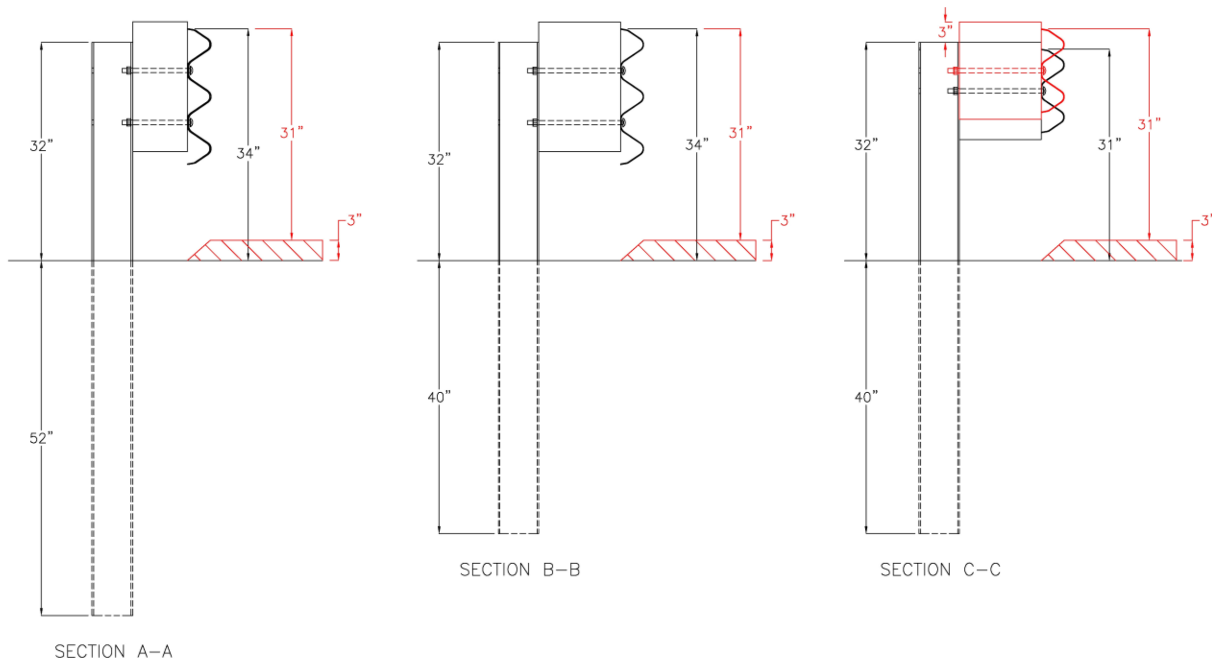


Figure 4. System Cross-Sections both Before and After a 3-in. (76-mm) Roadway Overlay

2.2 Concrete Transition Buttress

The Midwest Roadside Safety Facility (MwRSF) recently developed a standardized concrete transition buttress to be compatible with various crashworthy, thrie-beam AGTs while maintaining a MASH TL-3 safety performance [12-13]. The standardized transition buttress incorporated a dual chamfered front edge to mitigate vehicle snag on the rigid buttress, as shown in Figure 5. The lower chamfer measured 4.5 in. (114 mm) laterally by 18 in. (457 mm) longitudinally and was designed to limit wheel snag. The upper chamfer measured 3 in. (76 mm) laterally by 4 in. (102 mm) longitudinally and was designed to mitigate vehicle bumper and frame snag on the buttress while limiting the unsupported span length of the rail between the buttress and adjacent guardrail post. The transition point between the two chamfers was located 14 in. (356 mm) above the roadway surface. The upstream end of the buttress was 32 in. (813 mm) tall and included a 6H:1V vertical slope to bring the height of the buttress up to match the adjacent bridge rail while minimizing vehicle snag above the rail. Note, for 32-in. (813-mm) tall bridge rail, there would not be a vertical slope and the buttress would have a constant 32-in. (813-mm) height.

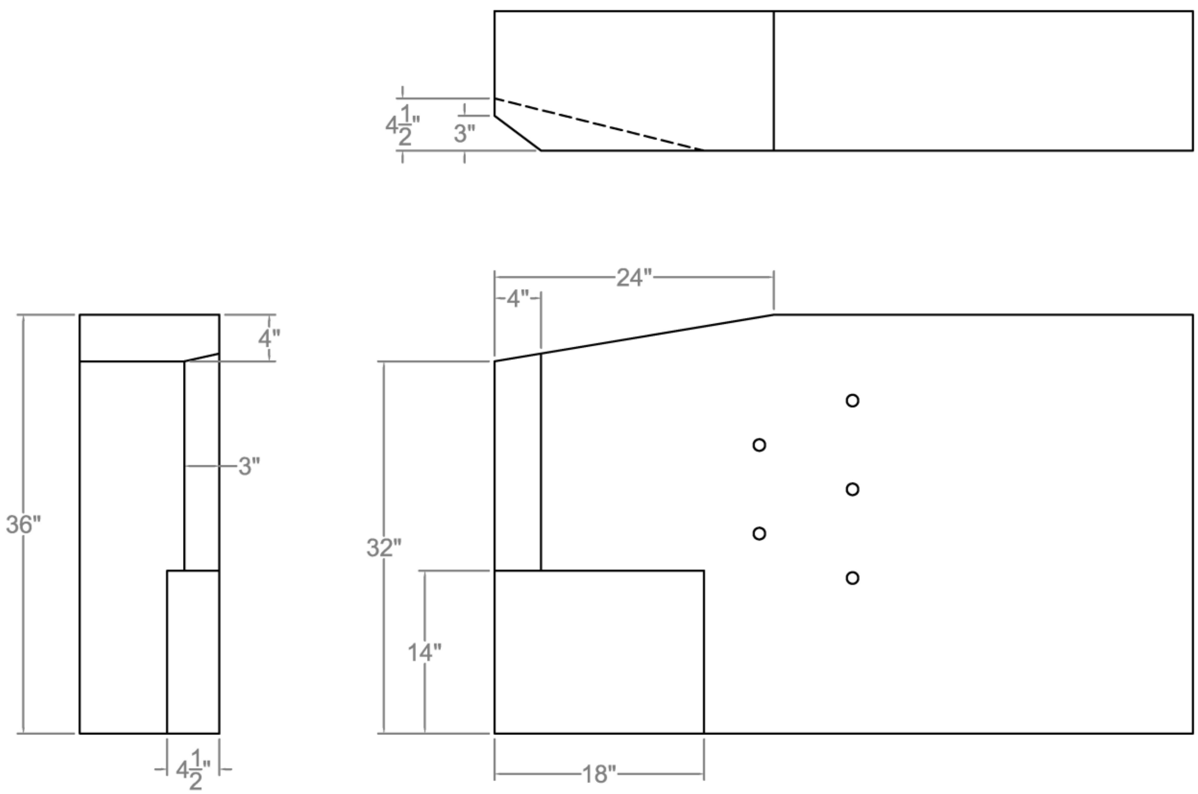


Figure 5. Standardized Transition Buttress Geometry

One concern with developing a 34-in. (864-mm) tall thrie beam AGT was that increasing the height of the rail would expose more of the rigid buttress below the rail and increase the severity of vehicle snag on the buttress. Since the standardized buttress was specifically designed to mitigate snag for a wide array of AGTs, especially below the thrie beam rail, it seemed likely that utilizing the standardized transition buttress would help mitigate snag in the new 34-in. (864-mm) tall AGT. Additionally, the buttress was designed with a vertical front face that could be transitioned into a wide variety of concrete barrier shapes. Thus, the standardized buttress was selected for use as part of the new 34-in. (864-mm) tall AGT.

Since the 34-in. (864-mm) AGT was being developed for future 3-in. (76-mm) overlays, the height of the standardized transition buttress had to be increased by 3-in. (76-mm), similar to the increased height of the thrie beam. Additionally, during the development of the standardized buttress, the height of the lower chamfer was shown be critical in mitigating the amount of wheel snag on the rigid buttress [12-13]. To ensure the crashworthiness of the system after roadway overlays, the height of the lower chamfer on the buttress was also increased by 3 in. (76 mm) from 14 in. (356 mm) to 17 in. (432 mm), as shown in Figure 6. All other dimensions remained the same for this modified version of the standardized transition buttress.

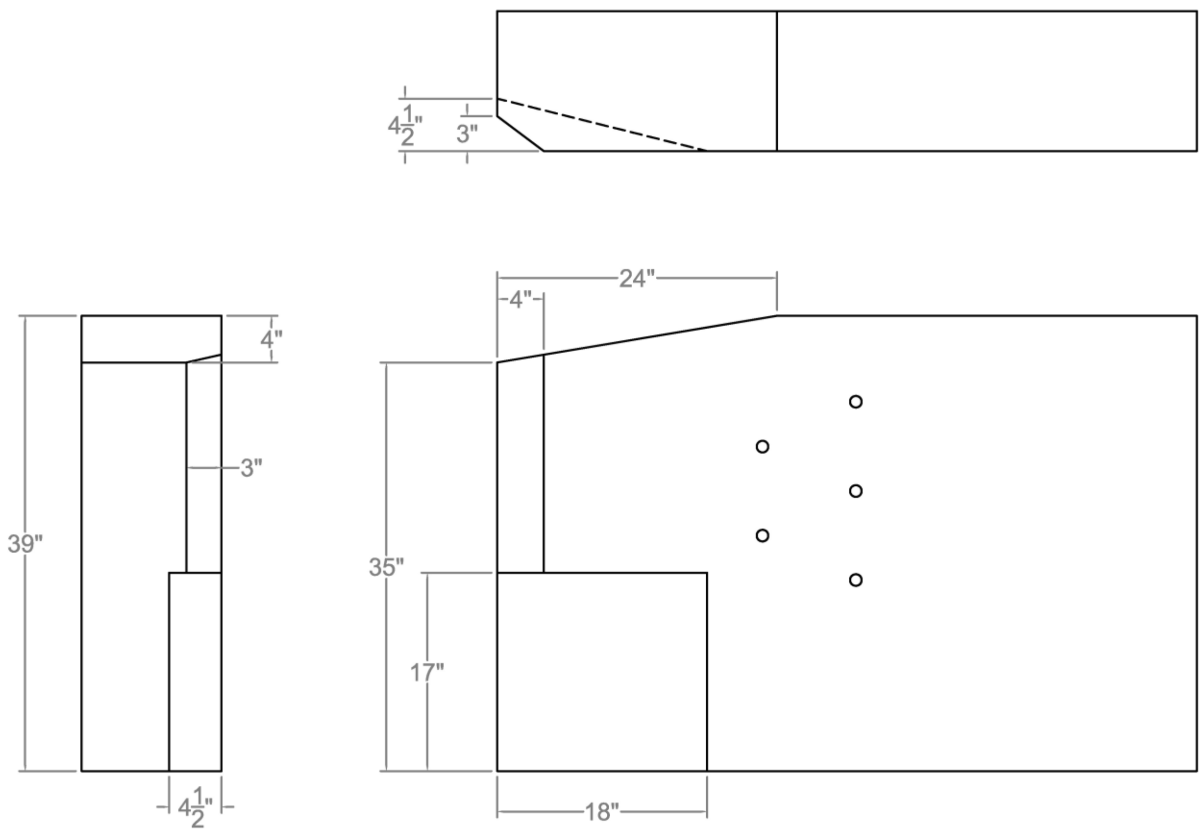


Figure 6. Geometry of the Modified Standardized Transition Buttress

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Longitudinal barriers, such as approach guardrail transitions, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH 2016 [1]. According to TL-3 of MASH 2016, longitudinal barrier transition systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 1. Note that there is no difference between MASH 2009 [24] and MASH 2016 for longitudinal barriers such as the system tested in this project, except that additional occupant compartment deformation measurements are required by MASH 2016.

Table 1. MASH 2016 TL-3 Crash Test Conditions for Longitudinal Barrier Transitions

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

[1] Evaluation criteria explained in Table 2.

Recent testing of AGTs has illustrated the importance in evaluating two different transition regions along the length of the AGT: 1) the downstream transition where the thrie beam connects to the rigid parapet and 2) the upstream stiffness transition where the W-beam guardrail transitions to a stiffer thrie beam barrier. Additionally, the 34-in. (864-mm) tall AGT described herein was designed for use both before and after roadway overlays, which effectively changes the barrier height relative to the roadway surface. The combination of these MASH tests, different transition regions, and pre- and post-overlay barrier configurations resulted in a total of eight recommended tests, but not all of them were considered critical or necessary to evaluate the performance of the new AGT.

The upstream stiffness transition of the 34-in. (864-mm) tall AGT was specifically designed to replicate the MASH-crashworthy MGS stiffness transition [18-19]. Upon initial installation, the only difference between the two systems was that the 34-in. (864-mm) tall AGT utilized a symmetric W-to-thrie transition rail instead of an asymmetric transition rail. Since the W-beam upstream of the transition rail was mounted at its nominal 31-in. (787-mm) height, vehicles impacting this region of the barrier should not extend over the rail and roll excessively. Additionally, the bottom of the symmetric transition rail has a shallower slope, which would produce less snag as a small vehicle tries to wedge underneath the rail. Thus, there were no concerns about vehicle stability and/or snag on the upstream stiffness transition of the 34-in. (864-mm) tall AGT prior to a roadway overlay.

After the roadway overlay, the symmetric rail segment is replaced by an asymmetric rail and the W-beam is raised 3 in. (76 mm) on the post to maintain its nominal 31-in. (787-mm) mounting height. Thus, after an overlay, the upstream stiffness transition is essentially identical to the MGS stiffness transition. Since the MGS stiffness transition was previously subjected to and successfully passed MASH TL-3 criteria, the upstream stiffness transition within the 34-in. (864-mm) tall AGT would be MASH TL-3 crashworthy as well. Therefore, all crash testing of the upstream stiffness transition, both before and after an overlay, was deemed non-critical.

At the downstream end of the AGT, the increased height of the thrie beam exposed more of the rigid buttress below the rail and increased the propensity for vehicle snag. The front ends and tires of both small cars and pickup trucks were susceptible to excessive snag by extending below the rail and impacting the rigid buttress. As such, both MASH crash tests were determined to be critical in evaluating the crashworthiness of the downstream end of the 34-in. (864-mm) tall AGT.

After an overlay, the thrie beam would be at its nominal 31-in. (787-mm) height relative to the roadway, and the buttress geometry would be the same as the original standardized transition buttress. As such, the potential for vehicle snag on the buttress decreased as the exposed area of the buttress is smaller. Further, the standardized transition buttress was developed and MASH crash tested to be compatible with all crashworthy 31-in. (787-mm) tall thrie beam AGTs [12-13]. Subsequently, testing of the downstream end of the 34-in. (864-mm) tall AGT after the application of a 3-in. (76-mm) roadway overlay was deemed non-critical. Thus, only two full-scale tests were recommended for evaluating the crashworthiness of the 34-in. (864-mm) tall AGT, and MASH test nos. 3-20 and 3-21 were conducted on the downstream end of the transition with the rail mounted 34 in. (864 mm) above the roadway surface (pre-overlay configuration).

It should be noted that the test matrix detailed herein represents the researchers' best engineering judgement with respect to the MASH 2016 safety requirements and their internal evaluation of critical tests necessary to evaluate the crashworthiness of the guardrail transition. However, these opinions may change in the future due to the development of new knowledge (crash testing, real-world performance, etc.) or changes to the evaluation criteria. Thus, any tests within the evaluation matrix deemed non-critical may eventually need to be evaluated based on additional knowledge gained over time or revisions to the MASH 2016 criteria.

3.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the guardrail to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 2 and defined in greater detail in MASH 2016. The full-scale vehicle crash tests were 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.

Table 2. MASH 2016 Evaluation Criteria for Longitudinal Barriers

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="10">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>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 and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 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>
</table>

3.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH 2016, foundation soil strength must be verified before any full-scale crash testing can occur. During the installation of a soil dependent system, W6x16 posts are installed near the impact region utilizing the same installation procedures are the system itself. Prior to full-scale testing, a dynamic impact test must be conducted to verify a minimum dynamic soil resistance of 7.5 kips (33.4 kN) at post deflections between 5 in. (127 mm) and 20 in. (508 mm) measured at a height of 25 in. (635 mm). If dynamic testing near the system is not desired, MASH 2016 permits a static test to be conducted instead and compared against the results of a previously established baseline test. In this situation, the soil must provide a resistance of at least 90% of the static baseline test at deflections of 5 in. (127 mm), 10 in. (254 mm), and 15 in. (381 mm). Further details can be found in Appendix B of MASH 2016.

4 TEST INSTALLATION DESIGN DETAILS

The test installation was approximately 87 ft (26.5 m) long and consisted of four major components: 1) a modified version of the standardized transition buttress, 2) the new 34-in. (864-mm) tall AGT, 3) standard MGS, and 4) a guardrail anchorage system. Design details for test nos. 34AGT-1 and 34AGT-2 are shown in Figures 7 through 30. The impact points for both tests are shown in Figures 7 and 8, respectively. Photographs of the test installations are shown in Figures 31 and 32. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The modified version of the standardized transition buttress measured 7 ft (2.1 m) long and 39 in. (991 mm) tall. The buttress utilized a dual chamfer design along its front edge, as detailed in Figure 21, which was developed to mitigate vehicle snag on the upstream end of the buttress. The geometry of the buttress was identical to the original standardized buttress except the height of the barrier and the height of the lower chamfer were increased by 3 in. (76 mm). The buttress was reinforced with transverse stirrups and longitudinal rebar, as shown in Figure 22, and anchored into the test site tarmac using an epoxy with a minimum bond strength of 1,450 psi (10.0 MPa).

The 34-in. (864-mm) tall AGT and adjacent MGS consisted of 12.5 ft (3.8 m) of nested 12-ga. (2.7-mm thick) thrie beam, 6.25 ft (1.9 m) of single ply 12-gauge (2.7-mm thick) thrie beam, a 6.25-ft (1.9 m) long 10-gauge (3.4-mm thick) symmetric W-to-thrie transition rail segment, and 56.25 ft (17.1 m) of 12-gauge (2.7-mm thick) W-beam. All thrie beam rails were mounted at a height of 34 in. (864 mm) while all W-beam rails were mounted at 31 in. (787 mm). The first three posts adjacent to the buttress were 7-ft (2.1-m) long W6x15 posts embedded 52 in. (1,321 mm) into the soil and spaced at 37.5 in. (953 mm) on center. The remaining posts were 6-ft (1.8-m) long W6x8.5 posts embedded 40 in. (1,016 mm) into the soil and spaced at various intervals, as shown in Figures 7 and 8. The tops of the thrie beam rails and the associated blockouts, including the downstream end of the W-to-thrie transition segment, extended above the tops of the posts due to being raised 3 in. (76 mm) while the posts remained at their nominal embedment depths.

Finally, a guardrail anchorage system typically utilized as a trailing end terminal was utilized to anchor the upstream end of the test installation. The guardrail anchorage system was originally designed to simulate the strength of other crashworthy end terminals. The anchorage system consisted of timber posts, foundation tubes, anchor cables, bearing plates, rail brackets, and channel struts, which closely resembled the hardware used in the Modified BCT system. The guardrail anchorage system has been MASH TL-3 crash tested as a downstream trailing end terminal [25-28].

As requested by NDOT, test nos. 34AGT-1 and 34AGT-2 featured two different configurations of the splice between the nested thrie beam and the thrie beam terminal connector. In test no. 34AGT-1, the terminal connector was placed behind both plies of the nested thrie beam, as shown in Figure 31, while in test no. 34AGT-2 the terminal connector was sandwiched between the two plies of the nested thrie beam, as shown in Figure 32. NDOT typically installs terminal connectors in the sandwiched configuration.

Both test nos. 34AGT-1 and 34AGT-2 were conducted with the center of the first post offset 25½ in. (648 mm) from the upstream face of the concrete buttress. However, the nominal offset distance from the buttress to this post is 26¼ in. (667 mm), as discussed in Chapter 8.

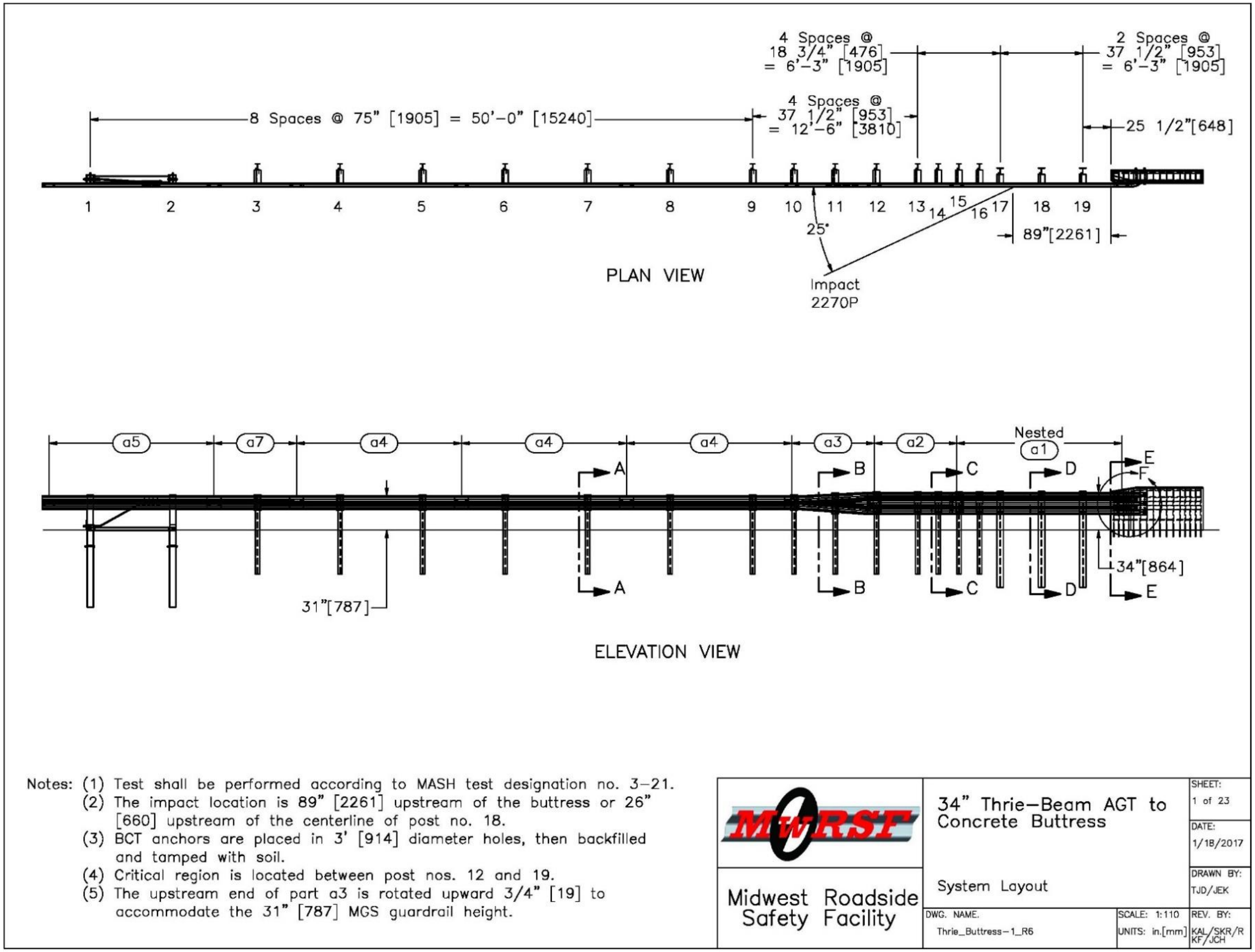


Figure 7. System Layout, Test No. 34AGT-1

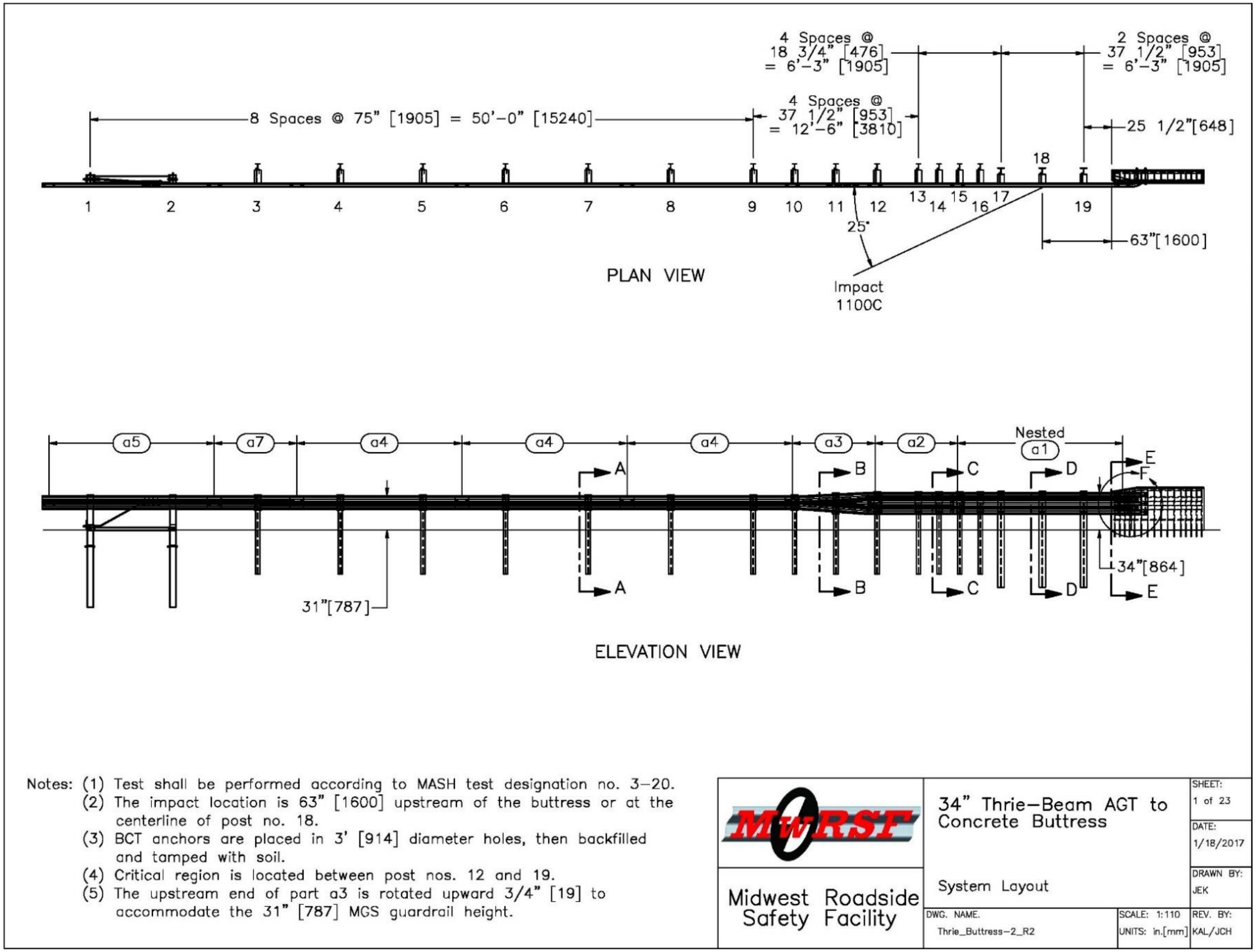


Figure 8. System Layout, Test No. 34AGT-2

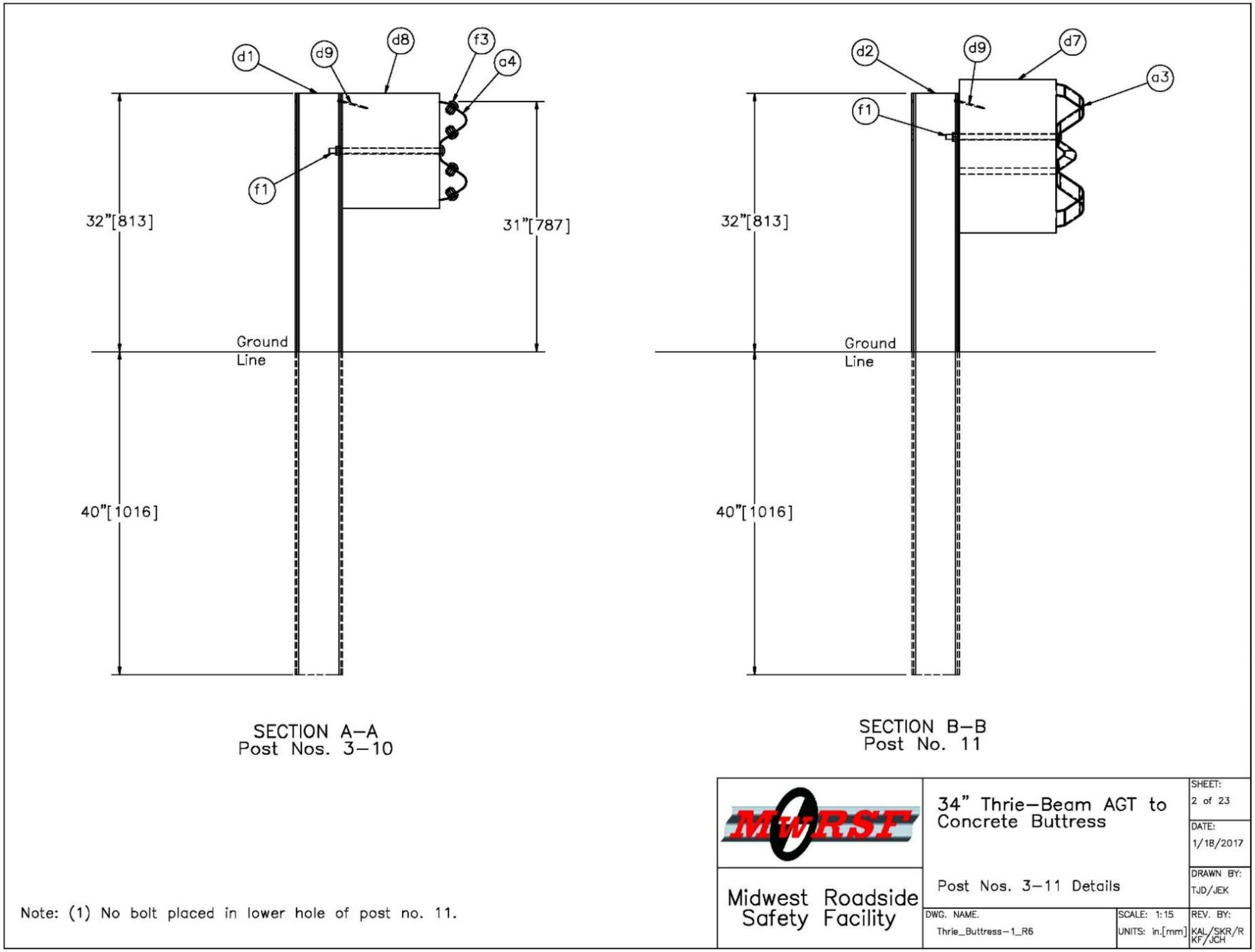


Figure 9. Post Nos. 3-11 Details, Test Nos. 34AGT-1 and 34AGT-2

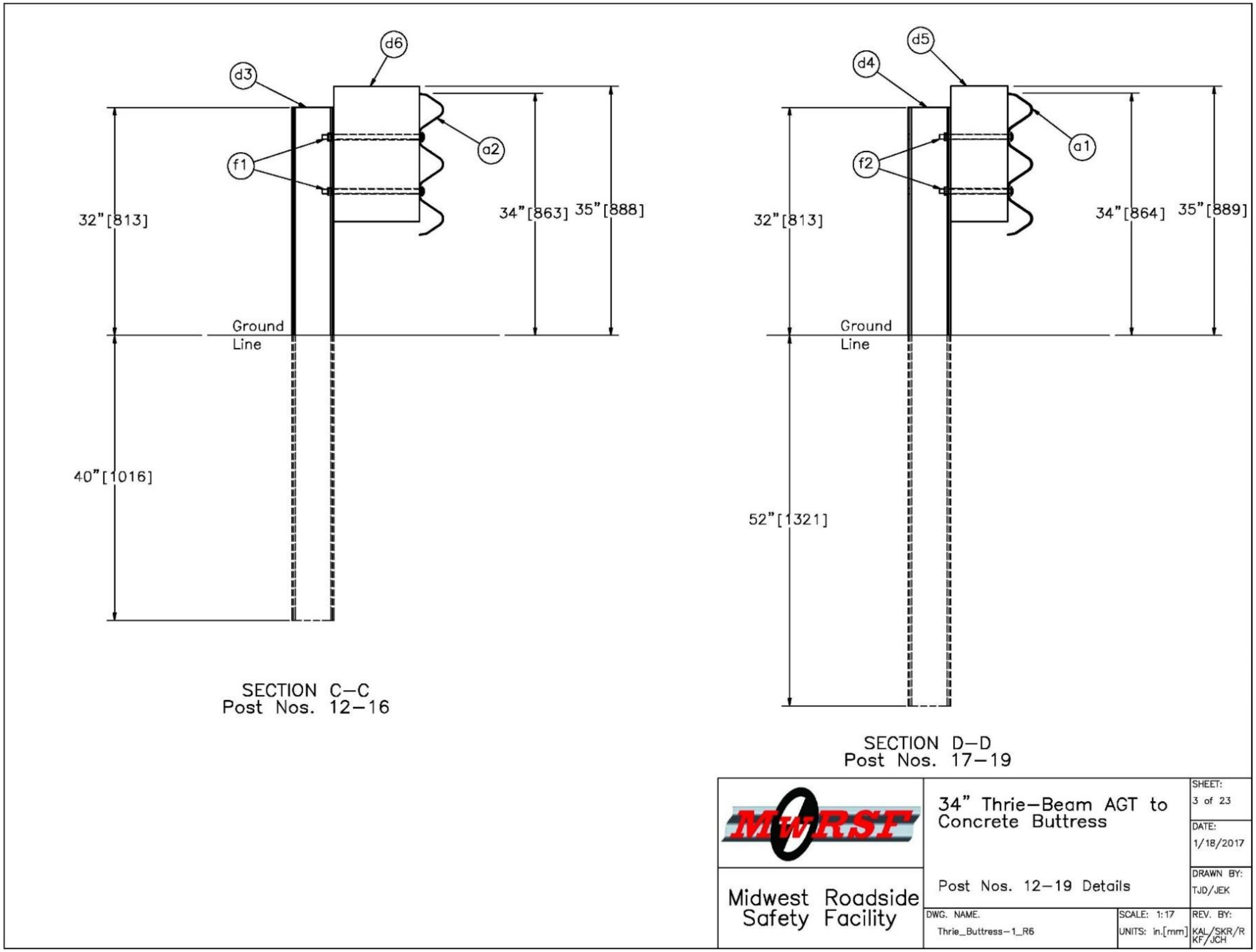


Figure 10. Post Nos. 12-19 Details, Test Nos. 34AGT-1 and 34AGT-2

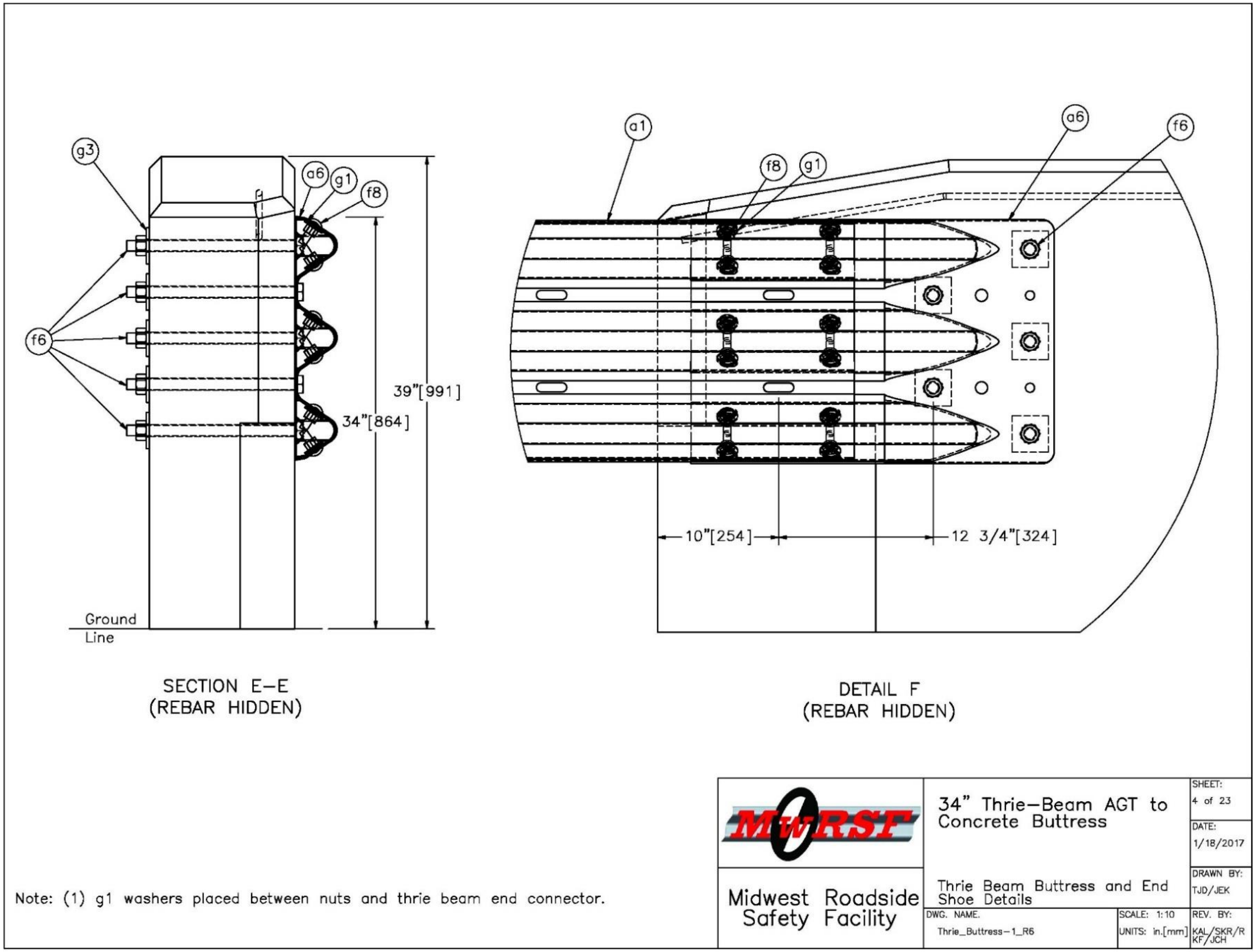


Figure 11. Thrie Beam Terminal Connector and Buttress Details, Test Nos. 34AGT-1 and 34AGT-2

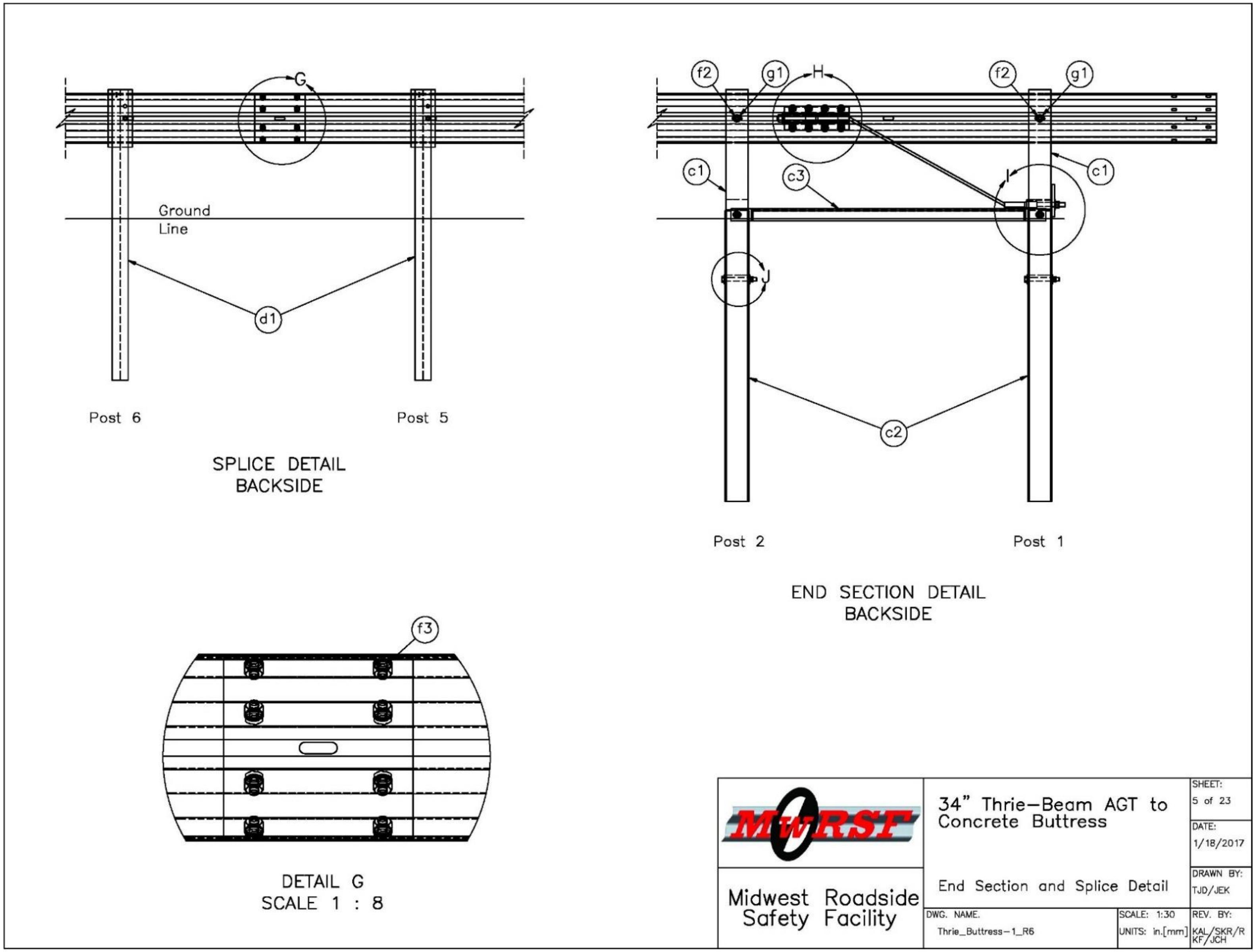


Figure 12. End Section and Splice Detail, Test Nos. 34AGT-1 and 34AGT-2

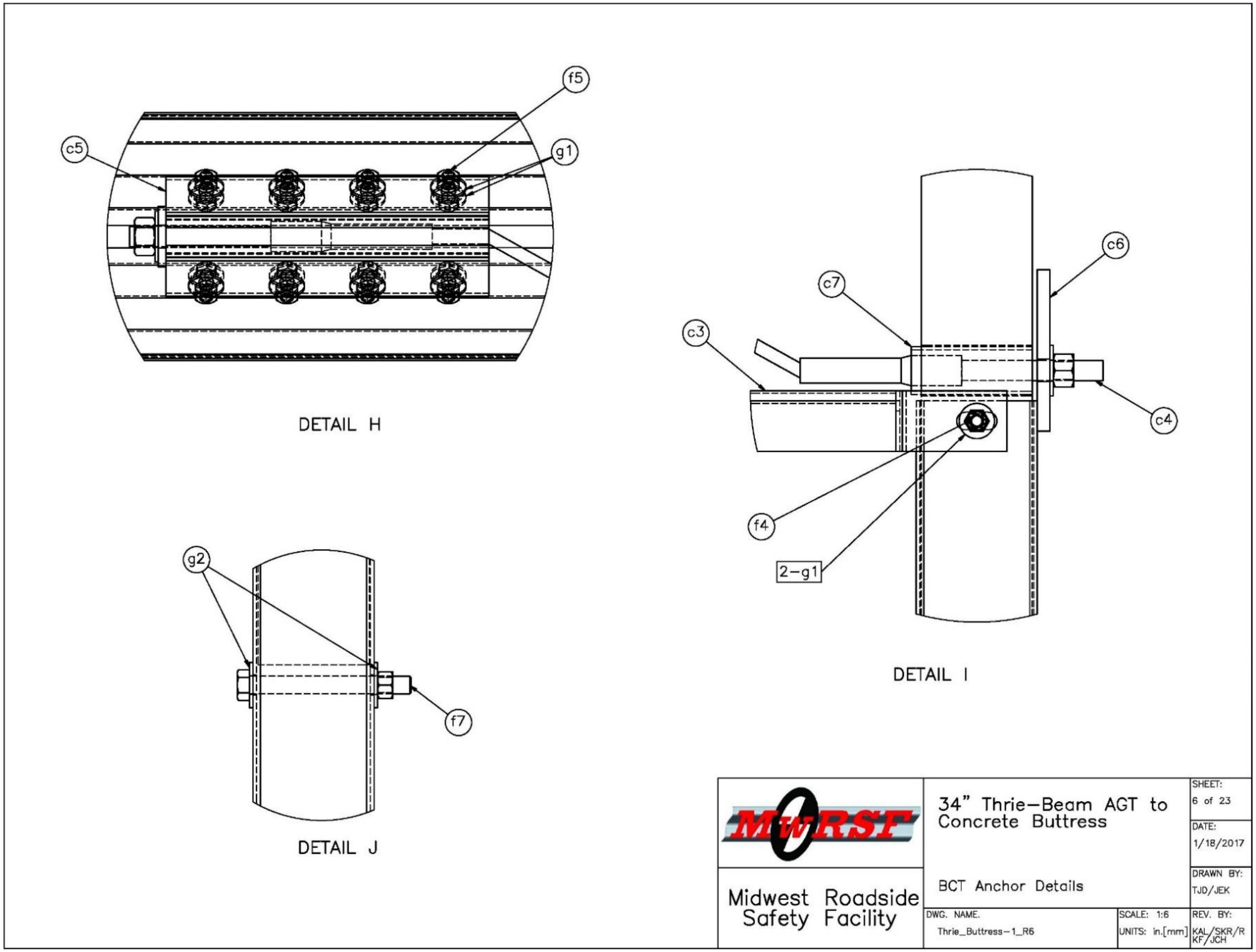


Figure 13. BCT Anchor Details, Test Nos. 34AGT-1 and 34AGT-2

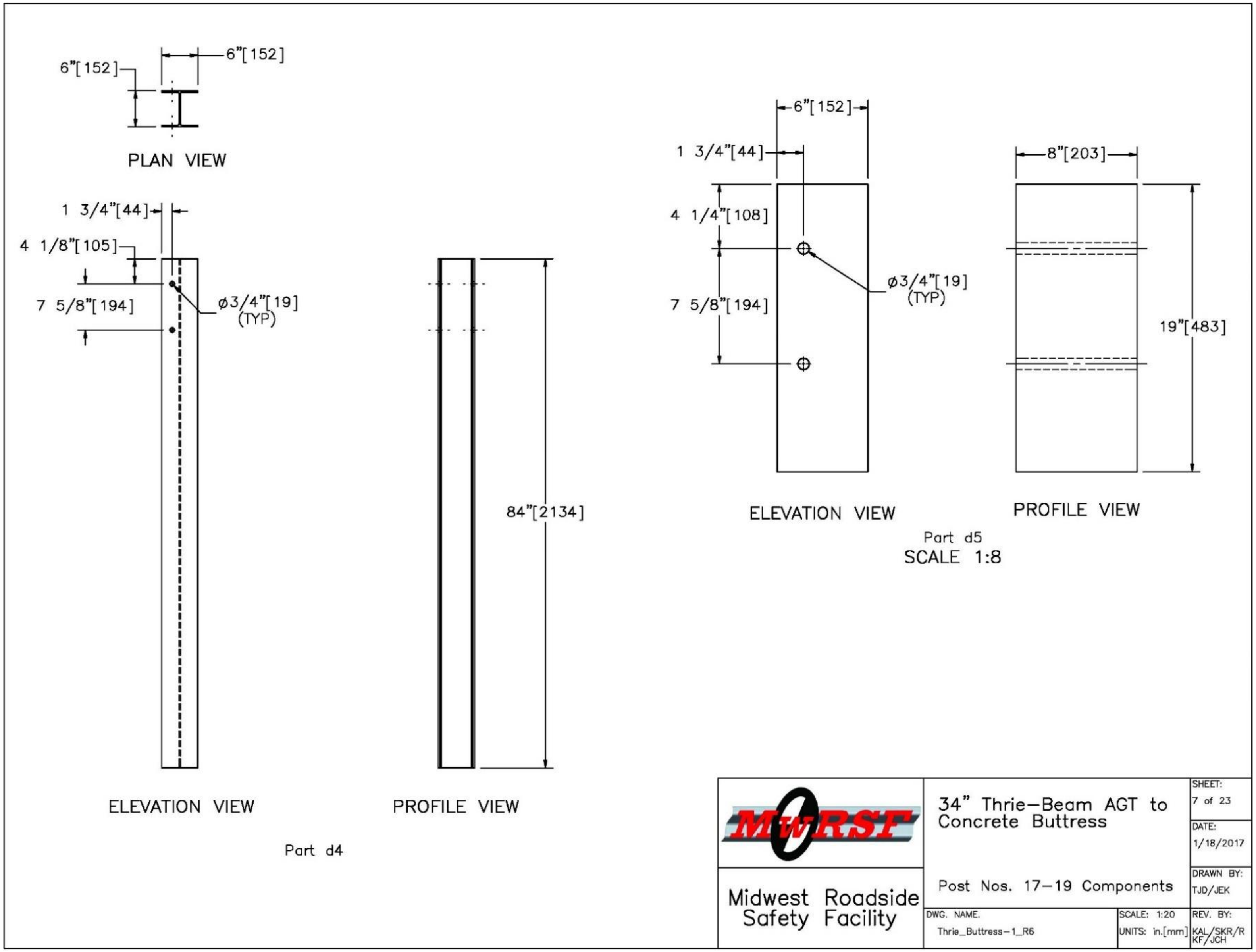


Figure 14. Post Nos. 17-19 Components, Test Nos. 34AGT-1 and 34AGT-2

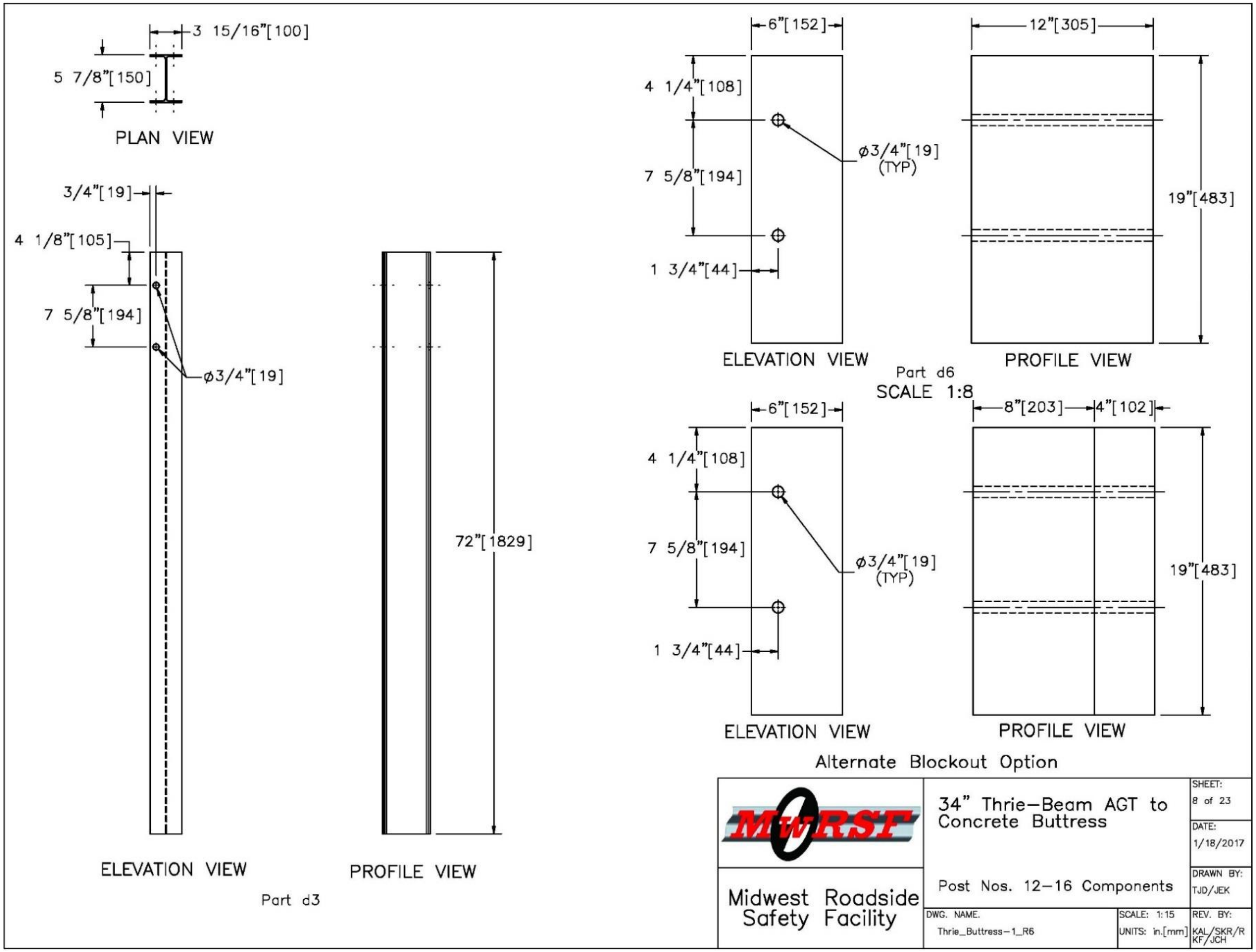


Figure 15. Post Nos. 12-16 Components, Test Nos. 34AGT-1 and 34AGT-2

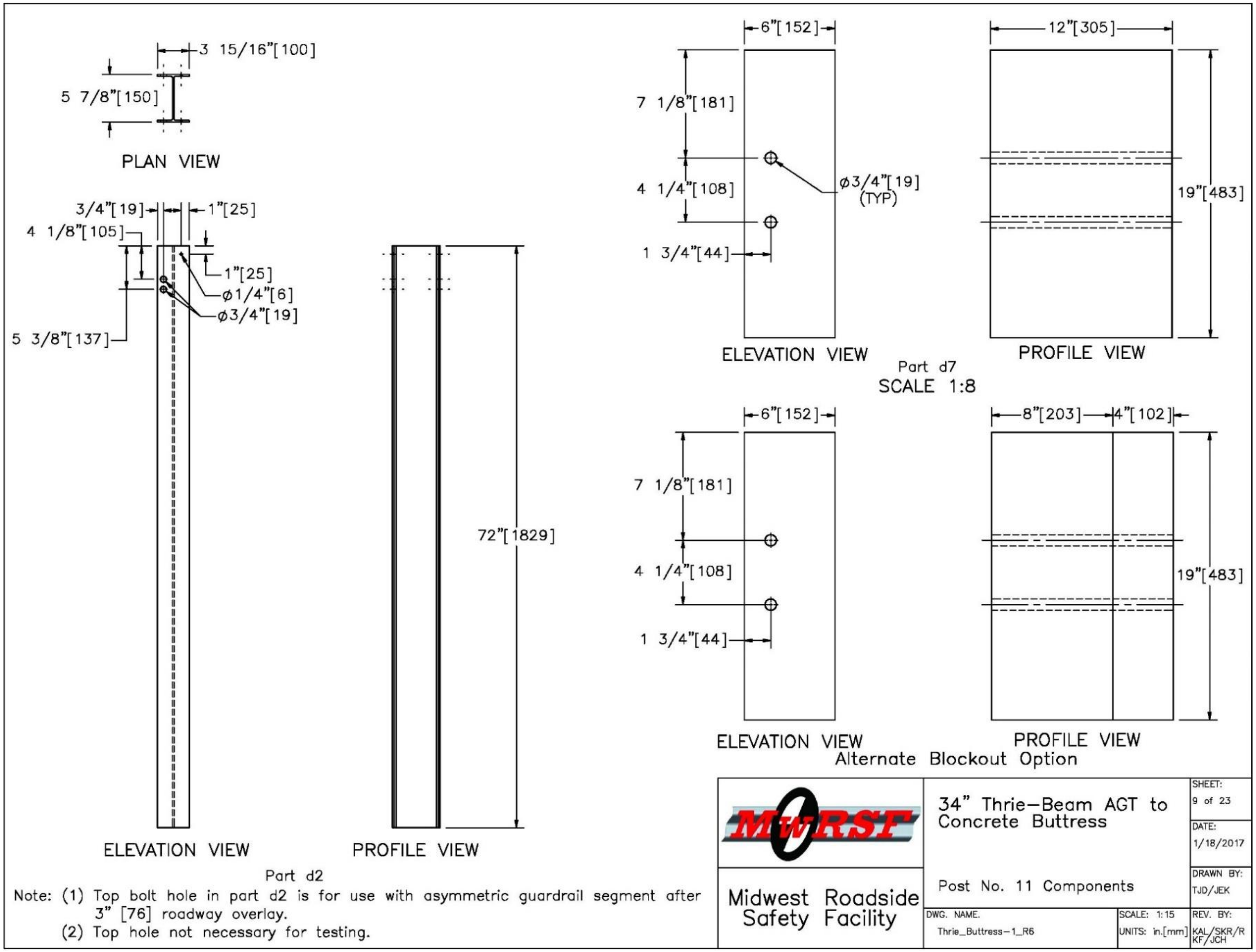


Figure 16. Post No. 11 Components, Test Nos. 34AGT-1 and 34AGT-2

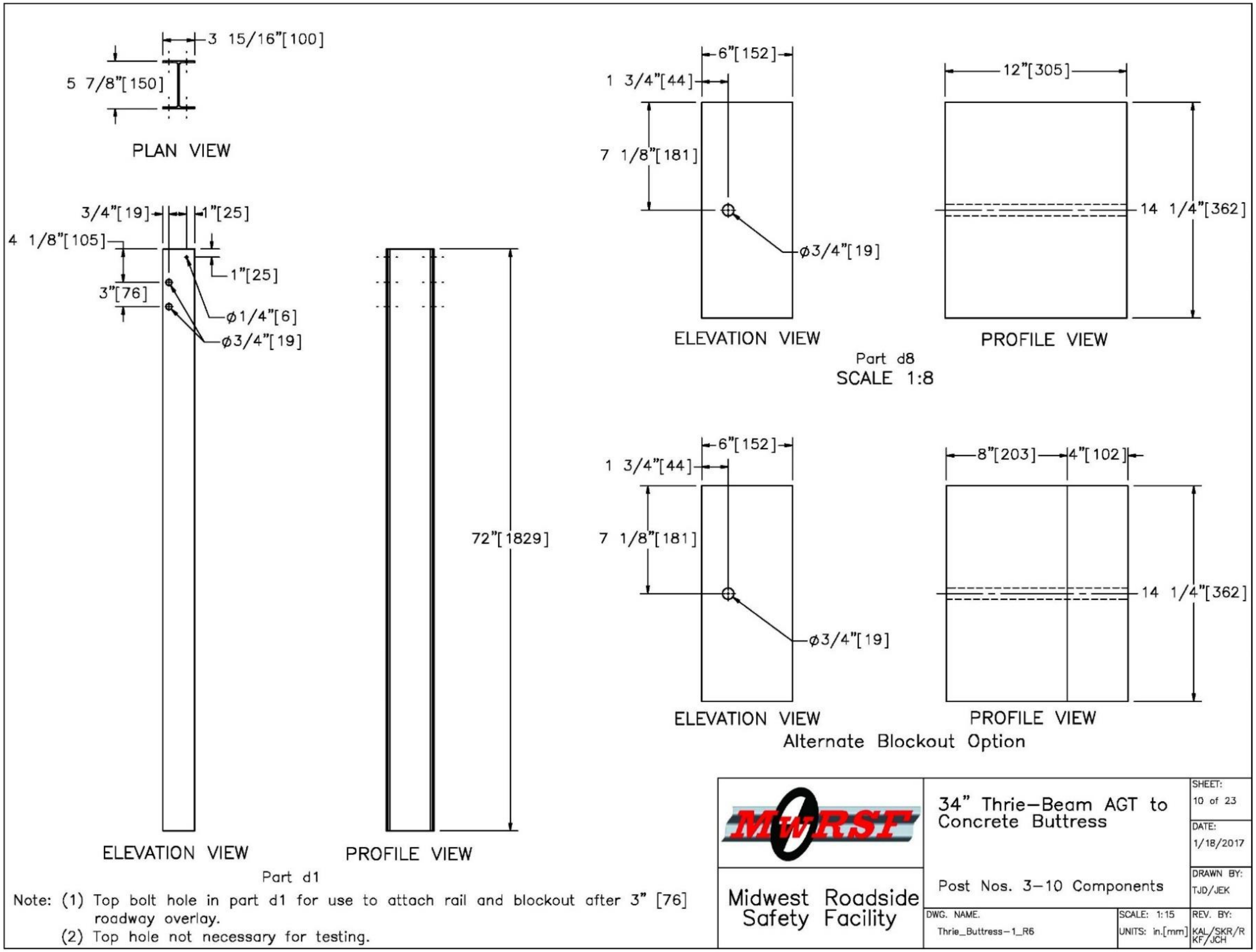


Figure 17. Post Nos. 3-10 Components, Test Nos. 34AGT-1 and 34AGT-2

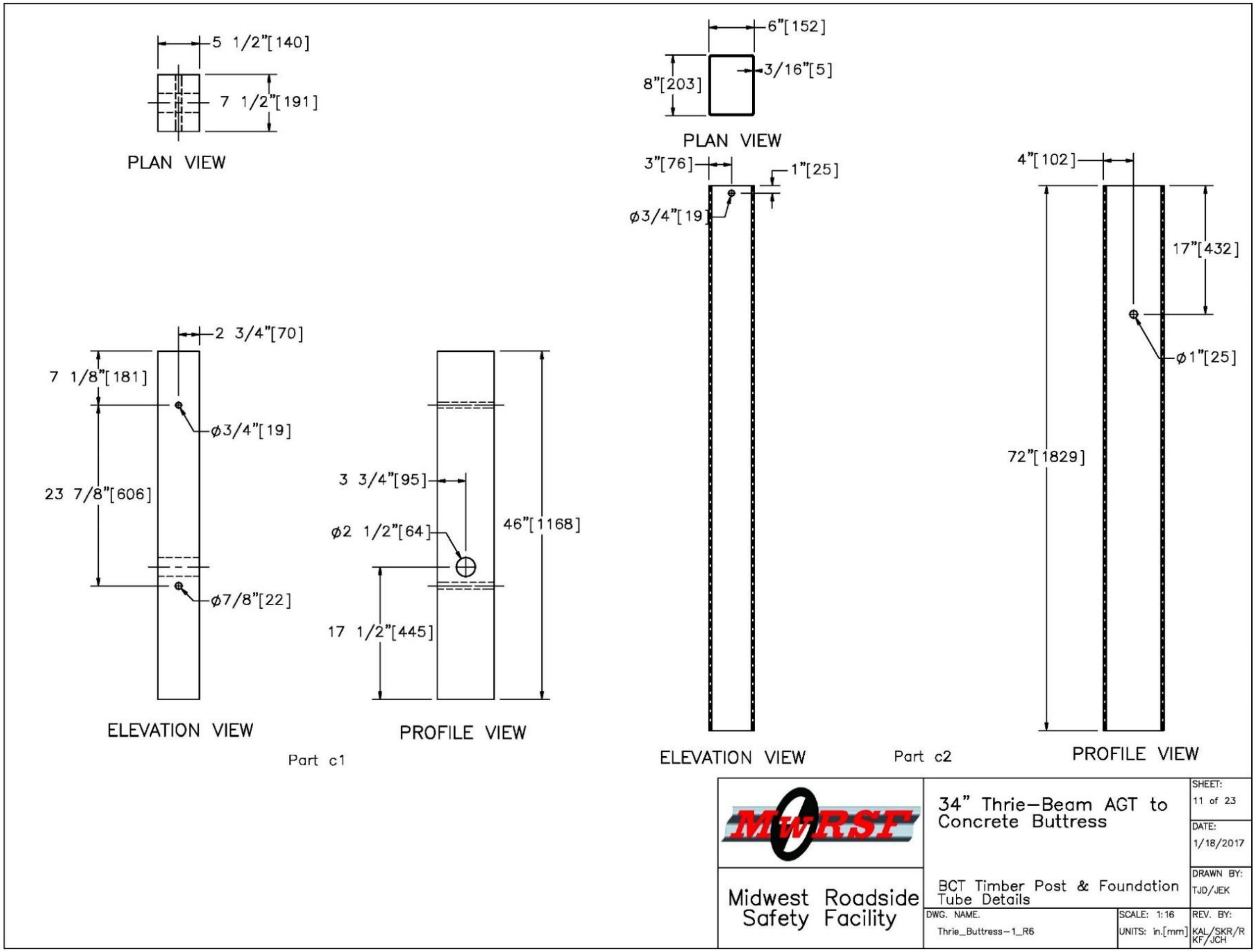


Figure 18. BCT Timber Post & Foundation Tube Details, Test Nos. 34AGT-1 and 34AGT-2

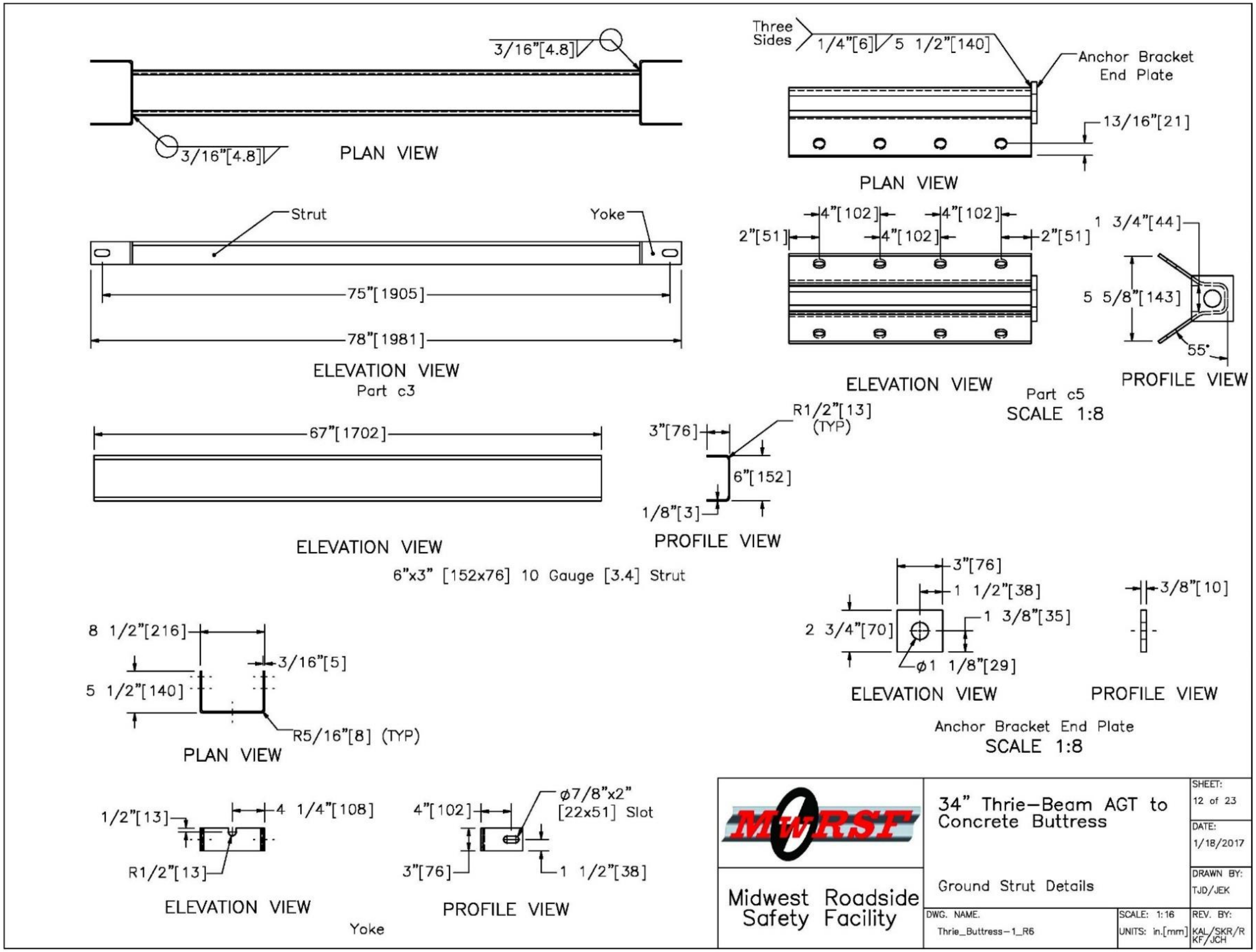


Figure 19. Ground Strut Details, Test Nos. 34AGT-1 and 34AGT-2

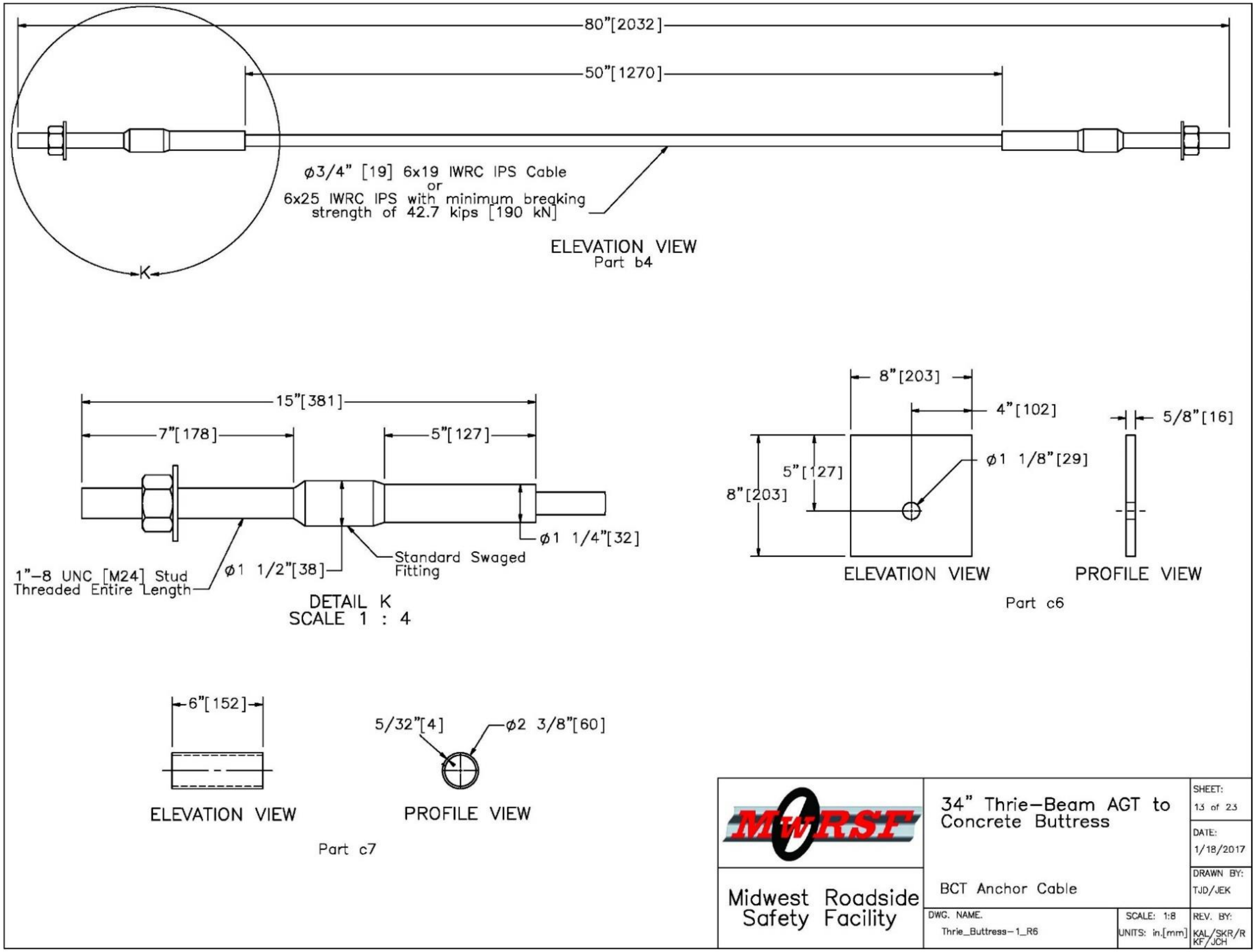


Figure 20. BCT Anchor Cable, Test Nos. 34AGT-1 and 34AGT-2

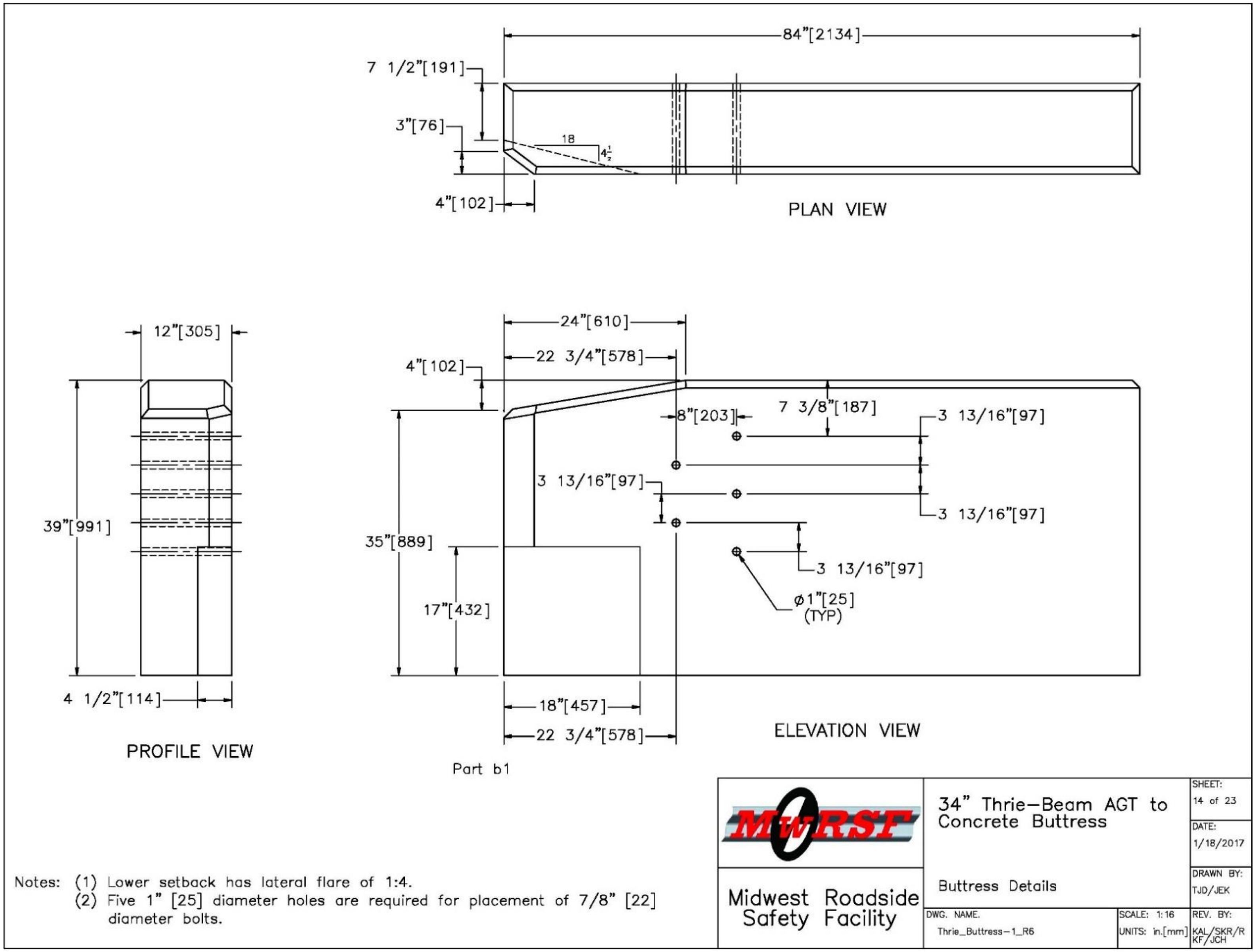


Figure 21. Buttress Details, Test Nos. 34AGT-1 and 34AGT-2

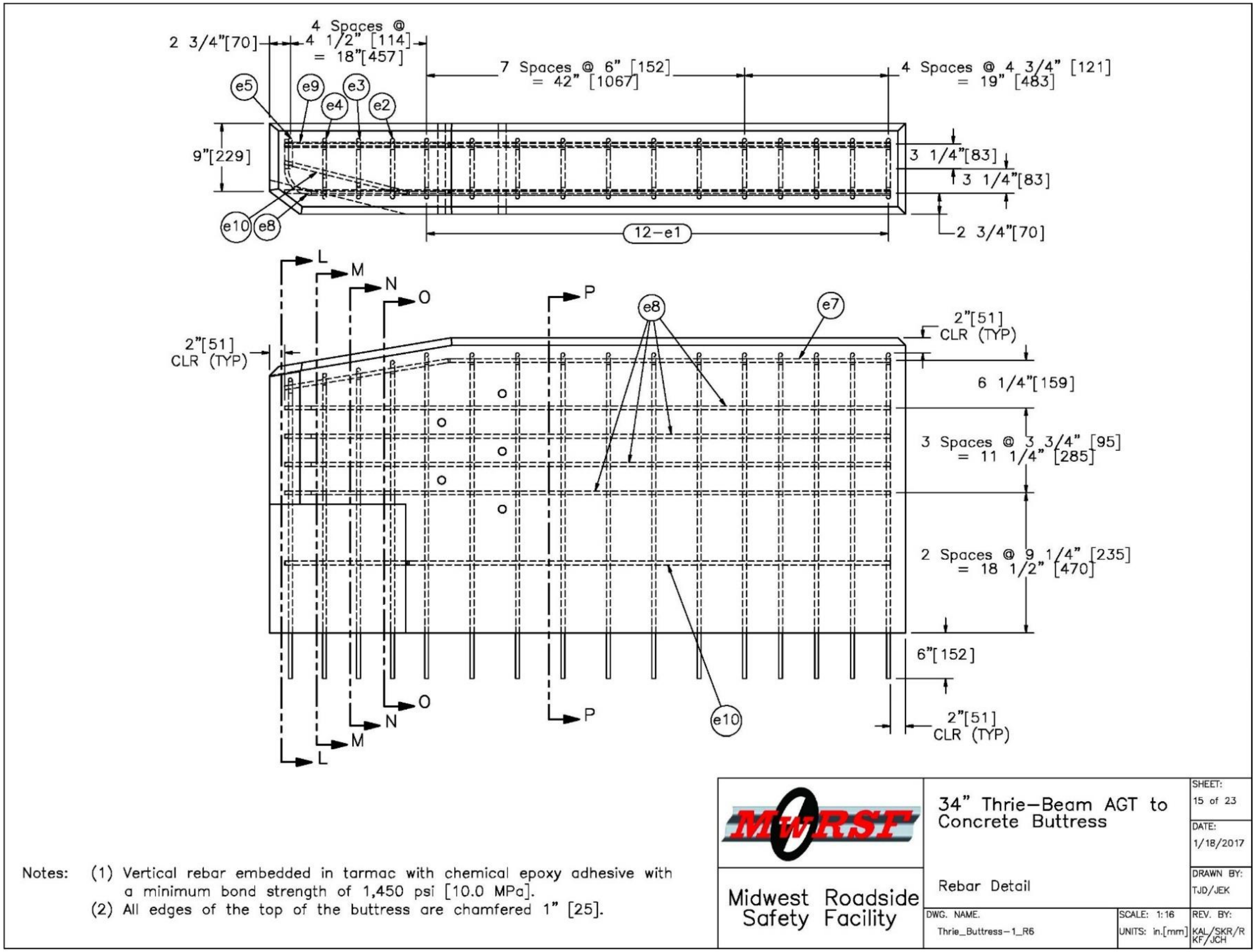
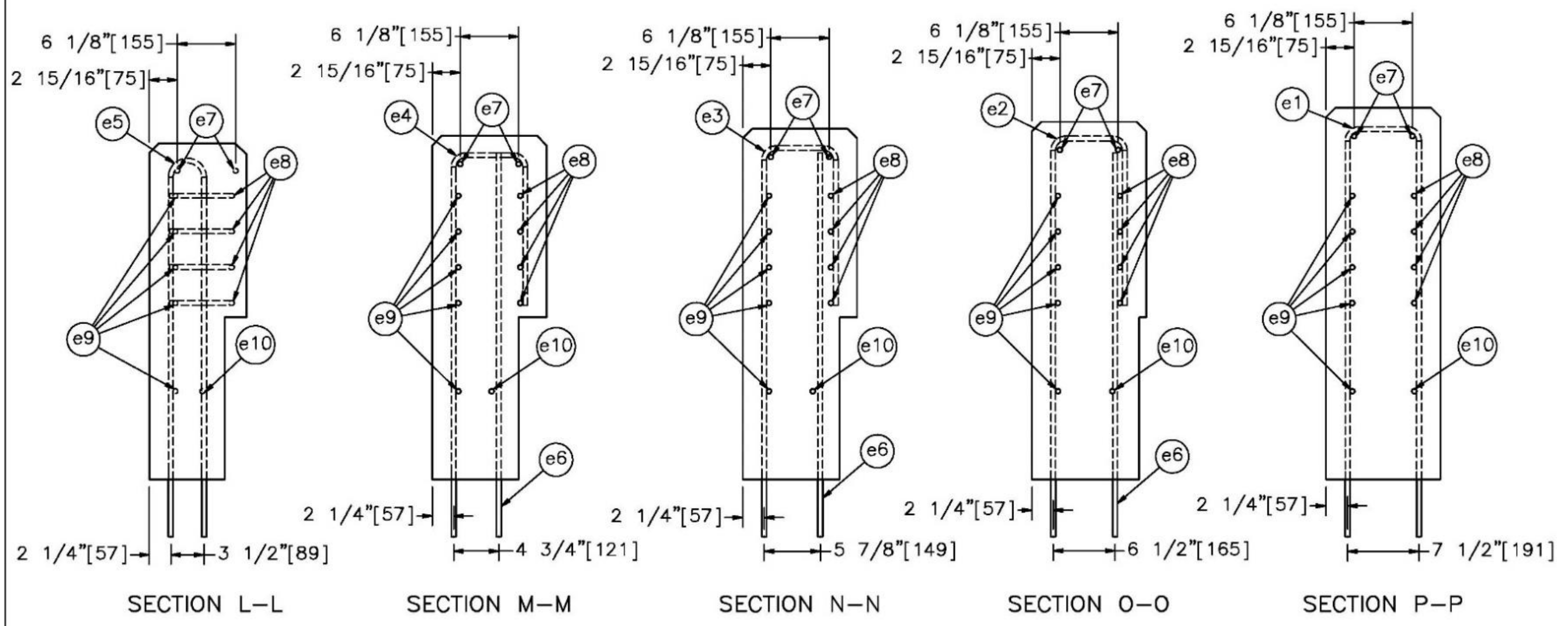


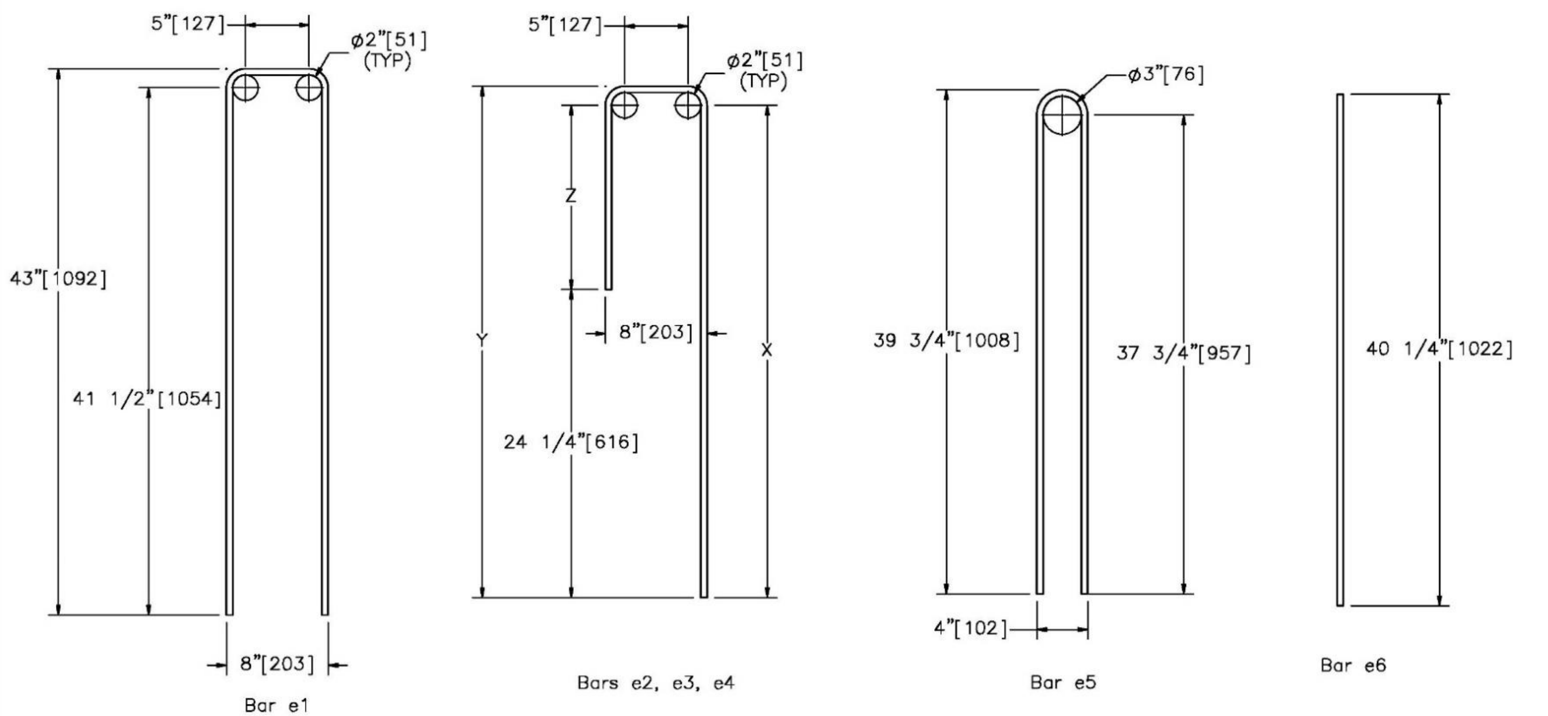
Figure 22. Rebar Detail, Test Nos. 34AGT-1 and 34AGT-2



Note: (1) All stirrups have minimum 2" [51] concrete clear cover.

MwRSF — Midwest Roadside Safety Facility	34" Thrie–Beam AGT to Concrete Buttress		SHEET: 16 of 23
			DATE: 1/18/2017
	Buttress Sections		DRAWN BY: TJD/JEK
	DWG. NAME. Thrie_Buttress–1_R6	SCALE: 1:16 UNITS: in.[mm]	REV. BY: KAL/SKR/RKF/JCH

Figure 23. Buttress Sections, Test Nos. 34AGT-1 and 34AGT-2



Bill of Bars

Part No.	QTY	Size	X	Y	Z	Unbent Length
e1	12	#4	41 1/2" [1,054]	43" [1,092]	–	92" [2,337]
e2	1	#4	40 1/2" [1,029]	42" [1,067]	16 1/4" [413]	65 3/4" [1,670]
e3	1	#4	39 1/2" [1,003]	41" [1,042]	15 1/4" [387]	63 1/2" [1,612]
e4	1	#4	38 3/4" [984]	40 1/4" [1,022]	14 1/2" [368]	62 1/4" [1,581]
e5	1	#4	37 3/4" [959]	39 3/4" [1,010]	–	80 3/4" [2,051]
e6	1	#4	–	–	–	40 1/4" [1,022]

Midwest Roadside Safety Facility

34" Thrie–Beam AGT to Concrete Buttress

Vertical Rebar Details

SHEET: 17 of 23

DATE: 1/18/2017

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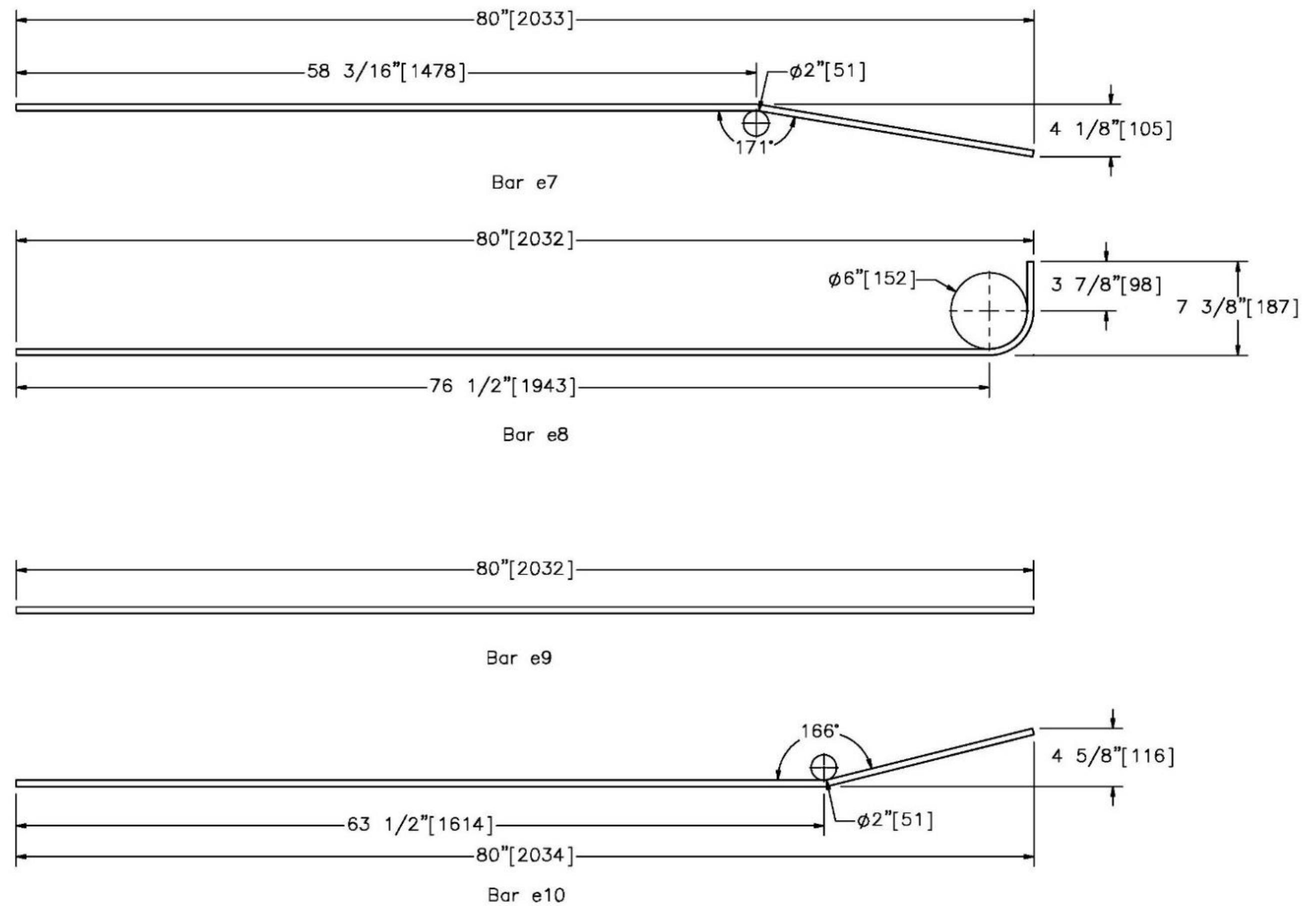
DWG. NAME. Thrie_Buttress–1_R6

SCALE: 1:12 UNITS: in.[mm]

REV. BY: KAL/SKR/R KF/JCH

Figure 24. Vertical Rebar Details, Test Nos. 34AGT-1 and 34AGT-2



Bill of Bars

Part No.	QTY	Size	Unbent Length
e7	2	#4	80 1/4" [2,038]
e8	4	#4	85 1/2" [2,171]
e9	5	#4	80" [2,032]
e10	1	#4	80 1/2" [2,045]

Midwest Roadside Safety Facility

34" Thrie–Beam AGT to Concrete Buttress

Horizontal Rebar Details

SHEET: 18 of 23
DATE: 1/18/2017
DRAWN BY: TJD/JEK
DWG. NAME. Thrie_Buttress–1_R6
SCALE: 1:12
UNITS: in.[mm]
REV. BY: KAL/SKR/R KF/JCH

Figure 25. Horizontal Rebar Details, Test Nos. 34AGT-1 and 34AGT-2

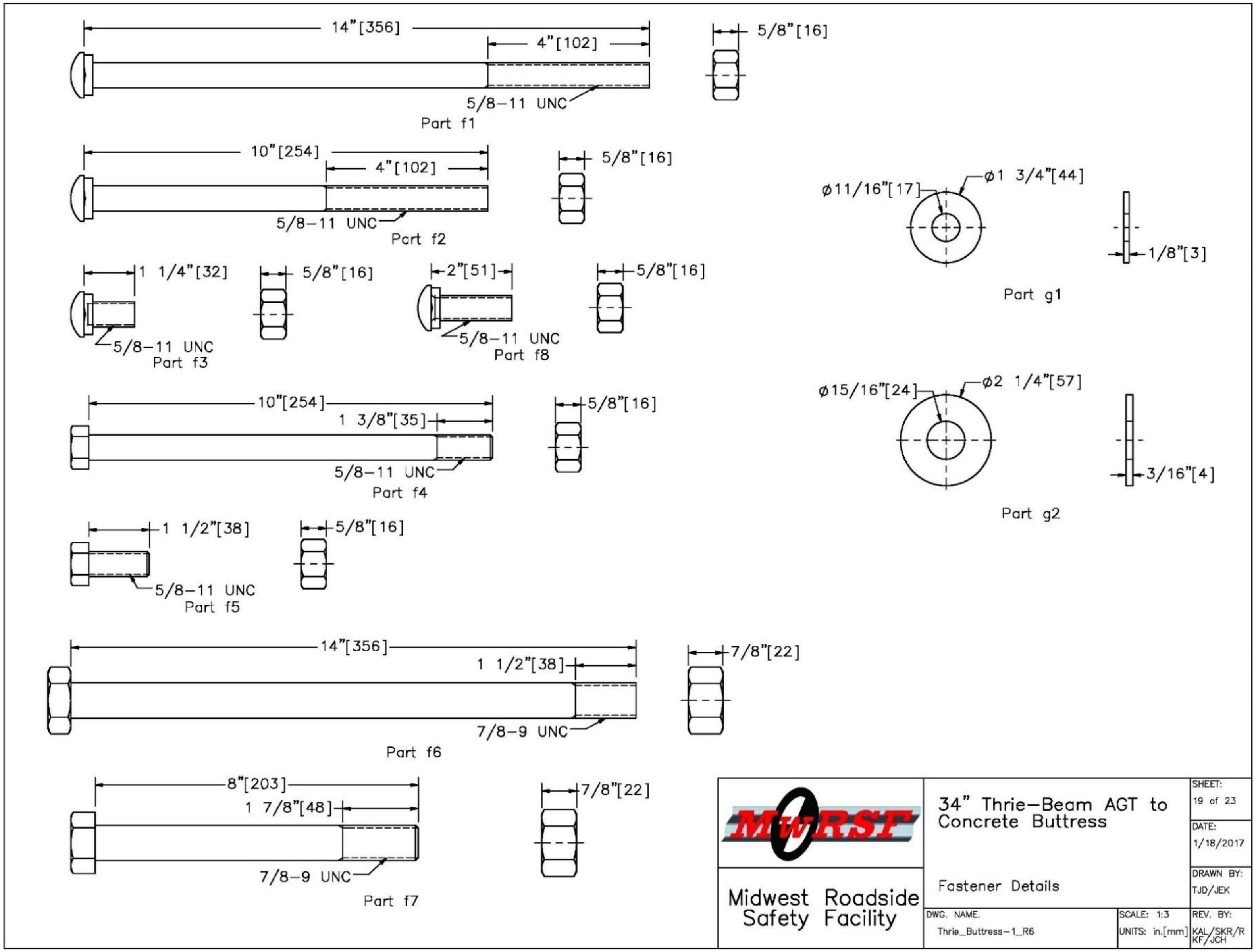


Figure 26. Fastener Details, Test Nos. 34AGT-1 and 34AGT-2

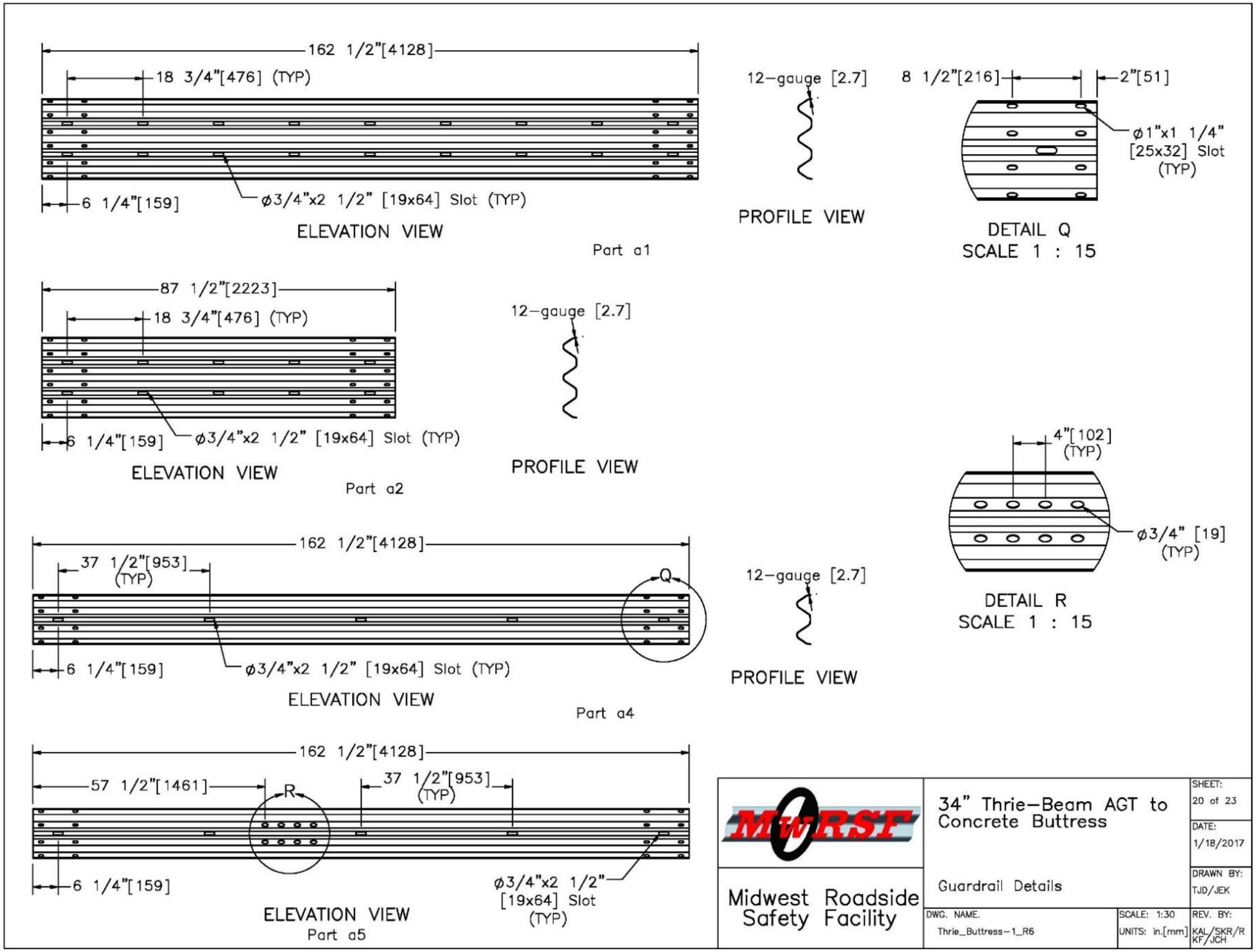


Figure 27. Guardrail Details, Test Nos. 34AGT-1 and 34AGT-2

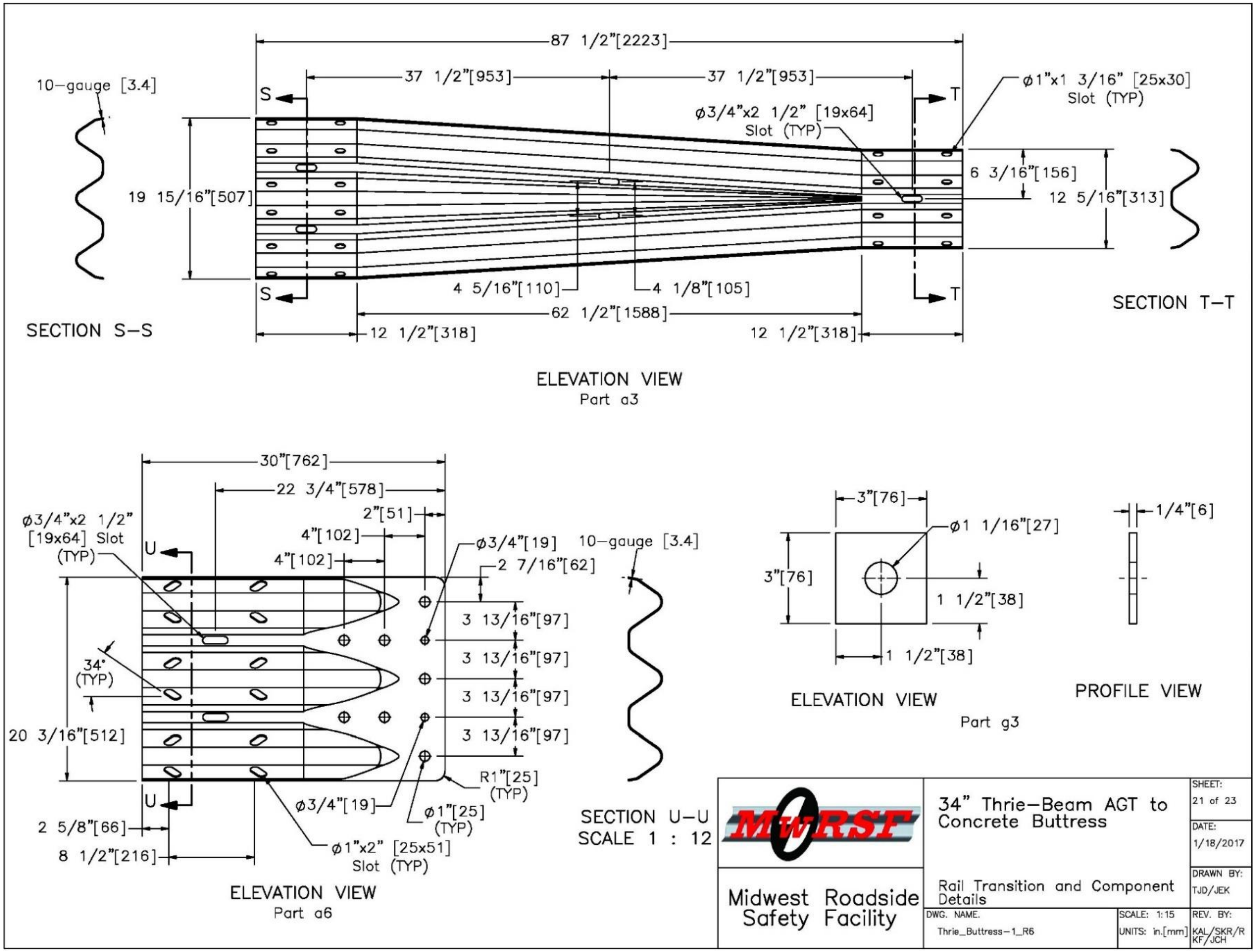


Figure 28. Rail Transition and Component Details, Test Nos. 34AGT-1 and 34AGT-2

Item No.	QTY.	Description	Material Specification	Galvanization Specification	Hardware Guide
a1	2	12'–6" [3,810] 12–gauge [2.7] Thrie Beam Section	AASHTO M180	ASTM A653	RTM08a
a2	1	6'–3" [1,905] 12–gauge [2.7] Thrie Beam Section	AASHTO M180	ASTM A653	RTM19a
a3	1	10–gauge [3.4] Symmetrical W–beam to Thrie Beam Transition	AASHTO M180	ASTM A653	RWT01b
a4	3	12'–6" [3,810] 12–gauge [2.7] W–Beam Section	AASHTO M180	ASTM A653	RWM04a
a5	1	12'–6" [3,810] 12–gauge [2.7] W–Beam MGS End Section	AASHTO M180	ASTM A653	RWM14a
a6	1	10–gauge [3.4] Thrie Beam End Shoe Section	AASHTO M180	ASTM A653	RTE01b
a7	1	6'–3" [1,905] 12–gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A653	RWM04a
b1	1	Concrete – 21.9 cubic ft [0.62 cubic m]	Min. f'c = 4,000 psi [27.6 MPa]	–	–
c1	2	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots +/– 18" [457] from ground on tension face)	–	PDF01
c2	2	72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	*AASHTO M111 (ASTM A123)	PTE06
c3	1	Ground Strut Assembly	ASTM A36	*AASHTO M111 (ASTM A123)	PFP02
c4	1	BCT Cable Anchor Assembly	–	–	FCA01
c5	1	Anchor Bracket Assembly	ASTM A36	*AASHTO M111 (ASTM A123)	FPA01
c6	1	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	*AASHTO M111 (ASTM A123)	FPB01
c7	1	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	*AAHSTO M111 (ASTM A123)	FMM02
d1	8	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1,829] Long Steel Post	ASTM A992	*AASHTO M111 (ASTM A123)	–
d2	1	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1,829] Long Steel Post	ASTM A992	*AASHTO M111 (ASTM A123)	–
d3	5	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1,829] Long Steel Post	ASTM A992	*AASHTO M111 (ASTM A123)	–
d4	3	W6x15 [W152x22.3], 84" [2,134] Long Steel Post	ASTM A992	*AASHTO M111 (ASTM A123)	PWE12
d5	3	6"x8"x19" [152x203x483] Timber Blockout	SYP Grade No.1 or better	–	PDB17
d6	5	6"x12"x19" [152x305x483] Timber Blockout	SYP Grade No.1 or better	–	–
d7	1	6"x12"x19" [152x305x483] Timber Blockout	SYP Grade No.1 or better	–	PDB18
d8	8	6"x12"x14 1/4" [152x305x368] Timber Blockout	SYP Grade No.1 or better	–	PDB10a

* Component does not need to be galvanized for testing purposes.

Midwest Roadside Safety Facility

34" Thrie–Beam AGT to Concrete Buttress

Bill of Materials

SHEET: 22 of 23
DATE: 1/18/2017
DRAWN BY: TJD/JEK
REV. BY: KAL/SKR/RKF/JCH
DWG. NAME. Thrie_Buttress–1_R6
SCALE: None
UNITS: in.[mm]

Figure 29. Bill of Materials, Test Nos. 34AGT-1 and 34AGT-2

Item No.	QTY.	Description	Material Specification	Galvanization Specification	Hardware Guide
d9	9	16D Double Head Nail	–	–	–
e1	12	1/2" [13] Dia., 92" [2,337] Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e2	1	1/2" [13] Dia., 65 3/4" [1,670] Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e3	1	1/2" [13] Dia., 63 1/2" [1,612] Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e4	1	1/2" [13] Dia., 62 1/4" [1,581] Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e5	1	1/2" [13] Dia., 80 3/4" [2,051] Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e6	3	1/2" [13] Dia., 40 1/4" [1,022] Long Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e7	2	1/2" [13] Dia., 80 5/16" [2,039] Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e8	4	1/2" [13] Dia., 85 1/2" [2,171] Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e9	5	1/2" [13] Dia., 80" [2,032] Long Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e10	1	1/2" [13] Dia., 80 1/2" [2,045] Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
f1	19	5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBB06
f2	8	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBB03
f3	52	5/8" [16] Dia. UNC, 1 1/4" [32] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBB01
f4	2	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBX16a
f5	8	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBX16a
f6	5	7/8" [22] Dia. UNC, 14" [356] Long Heavy Hex Bolt and Nut	Bolt – ASTM A325 Type 1 or ASTM A449 or SAI J429 Gr. 5 Nut – ASTM A563DH or ASTM A194 Gr. 2H	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBX22b
f7	2	7/8" Dia. [22] UNC, 8" [203] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBX22a
f8	24	5/8" [16] Dia. UNC, 2" [51] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBB02
g1	34	5/8" [16] Dia. Plain Round Washer	ASTM F844	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FWC16a
g2	4	7/8" [22] Dia. Plain Round Washer	ASTM F844	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	–
g3	5	3"x3"x1/4" [76x76x6] or 3 1/2"x3 1/2"x1/4" [89x89x6] Square Plate Washer	ASTM A572 Gr. 50	*AASHTO M111 (ASTM A123)	FWR10

* Component does not need to be galvanized for testing purposes.

** Rebar does not need to be epoxy–coated for testing purposes.

Midwest Roadside Safety Facility

34" Thrie–Beam AGT to Concrete Buttress

Bill of Materials

SHEET: 23 of 23

DATE: 1/18/2017

DRAWN BY: TJD/JEK

DWG. NAME. Thrie_Buttress–1_R6

SCALE: None UNITS: in.[mm]

REV. BY: KAL/SKR/RKF/JCH

Figure 30. Bill of Materials Continued, Test Nos. 34AGT-1 and 34AGT-2

Figure 31. Test Installation Photographs, Test No. 34AGT-1

Figure 32. Test Installation Photographs, Test No. 34AGT-2

5 TEST CONDITIONS

5.1 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.

5.2 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 barrier system. A digital speedometer on the tow vehicle increased the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch [29] was used to steer the test vehicle. A guide flag, attached to the right-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

5.3 Test Vehicles

For test no. 34AGT-1, a 2010 Dodge Ram 1500 crew cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,085 lb (2,307 kg), 5,024 lb (2,279 kg), and 5,189 lb (2,354 kg), respectively. The test vehicle is shown in Figure 33, and vehicle dimensions are shown in Figure 34. Note, pre-test photographs of the vehicle’s interior floorboards and undercarriage for test no. 34AGT-1were not available.

For test no. 34AGT-2, a 2011 Kia Rio subcompact sedan was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,331 lb (1,057 kg), 2,420 lb (1,098 kg), and 2,580 lb (1,170 kg), respectively. The test vehicle is shown in Figure 35, and vehicle dimensions are shown in Figure 36. Note, pre-test photographs of the vehicle’s interior floorboards and undercarriage for test no. 34AGT-2 were not available.

The longitudinal component of the center of gravity (c.g.) for both vehicles was determined using the measured axle weights. The Suspension Method [30] was used to determine the vertical component of the c.g. for the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The vertical component of the c.g. for the 1100C vehicle was determined utilizing a procedure published by SAE [31]. The location of the final c.g. for test no. 34AGT-1 is shown in Figures 34 and 37. The location of the final c.g. for test no. 34AGT-2 is shown in Figures 36 and 38. Data used to calculate the location of the c.g. and ballast information are in Appendix B.

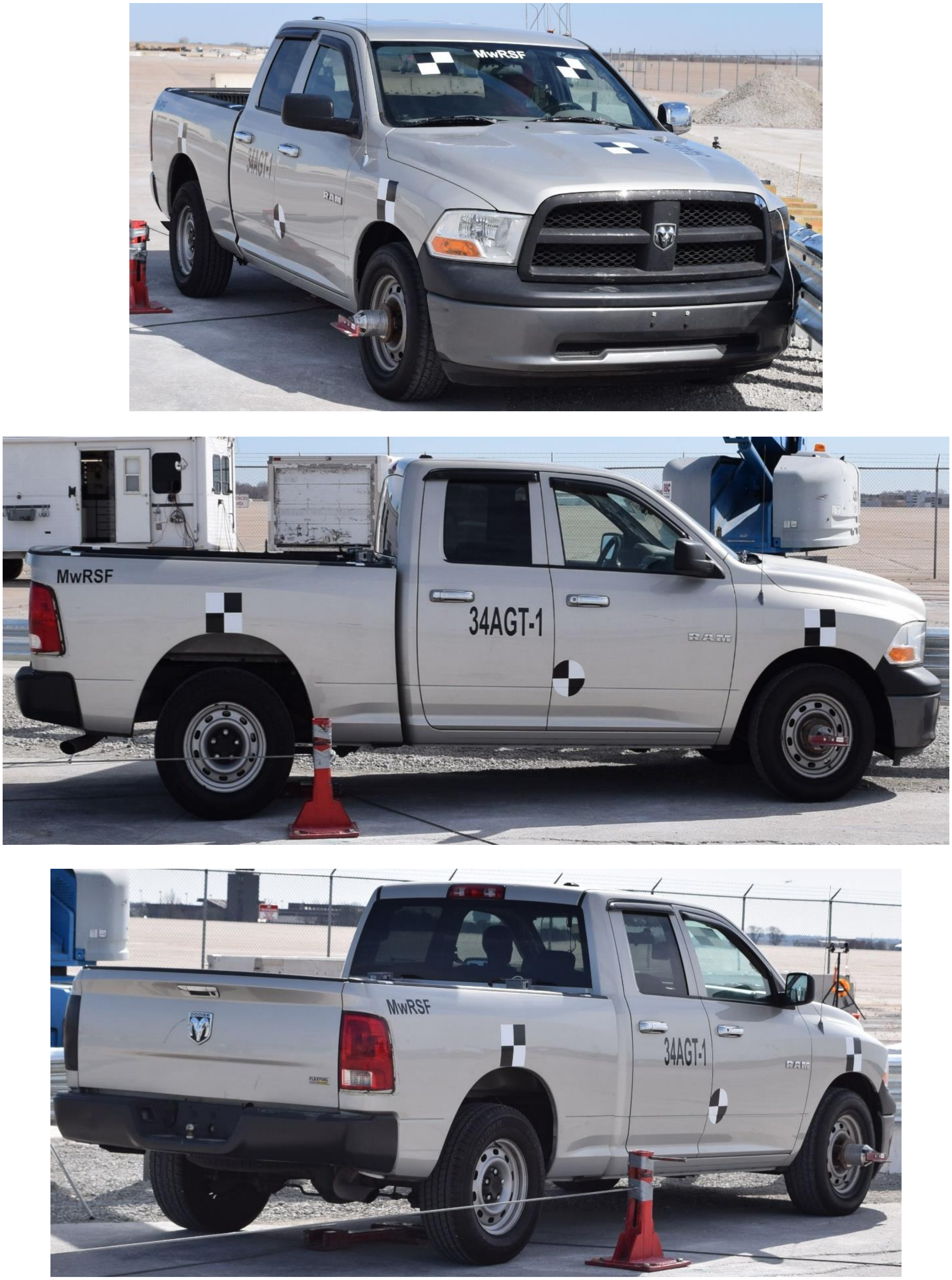
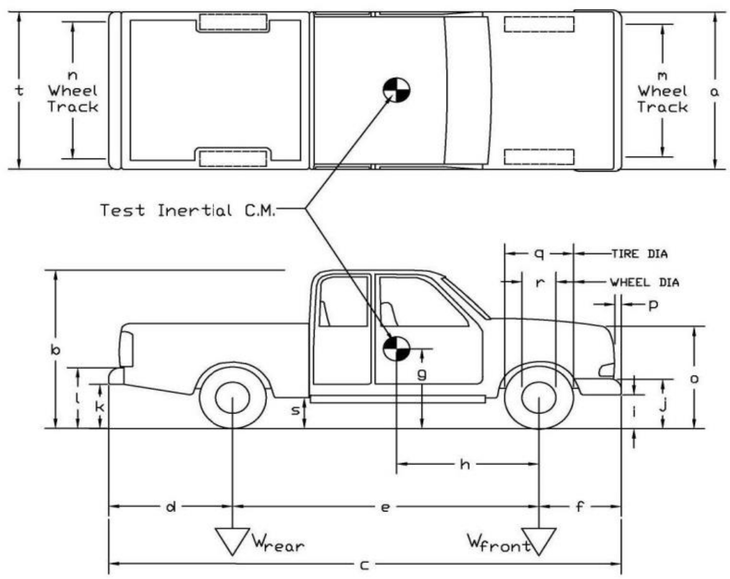


Figure 33. Test Vehicle, Test No. 34AGT-1

Date:	3/17/2017	Test Name:	34AGT-1	VIN No:	1D7RB1GP5AS218232
Year:	2010	Make:	Dodge	Model:	Ram 1500
Tire Size:	265/70R17 115T	Tire Inflation Pressure:	40 Psi	Odometer:	158020



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

a:	77 5/8	(1972)	b:	73 1/4	(1861)
	78±2 (1950±50)				
c:	229 1/4	(5823)	d:	48 3/4	(1238)
	237±13 (6020±325)				
e:	140 1/4	(3562)	f:	40 1/8	(1019)
	148±12 (3760±300)			39±3 (1000±75)	
g:	28	(711)	h:	61 15/16	(1573)
	min: 28 (710)			63±4 (1575±100)	
i:	6 3/8	(162)	j:	29 1/4	(743)
k:	20 3/8	(518)	l:	30	(762)
m:	68 1/4	(1734)	n:	67 3/4	(1721)
	67±1.5 (1700±38)			67±1.5 (1700±38)	
o:	44 1/2	(1130)	p:	4 1/2	(114)
	43±4 (1100±75)				
q:	31 1/4	(794)	r:	18 1/2	(470)
s:	13 1/2	(343)	t:	77	(1956)

Wheel Center Height (Front):	14 3/4	(375)
Wheel Center Height (Rear):	15	(381)
Wheel Well Clearance (Front):	34	(864)
Wheel Well Clearance (Rear):	37 3/4	(959)
Bottom Frame Height (Front):	12 3/8	(314)
Bottom Frame Height (Rear):	21 1/4	(540)
Engine Type:	Gasoline	
Engine Size:	4.7L V8	
Transmission Type:	Automatic	
Drive Type:	RWD	
Cab Style:	Quad Cab	
Bed Length:	76"	

Mass Distribution lb (kg)

Gross Static	LF	1490	(676)	RF	1417	(643)
	LR	1142	(518)	RR	1140	(517)

Weights lb (kg)	Curb		Test Inertial		Gross Static	
W-front	2865	(1300)	2805	(1272)	2907	(1319)
W-rear	2220	(1007)	2219	(1007)	2282	(1035)
W-total	5085	(2307)	5024	(2279)	5189	(2354)
			5000±110 (2270±50)		5165±110 (2343±50)	

GVWR Ratings lb

Front	3700
Rear	3900
Total	6700

Dummy Data

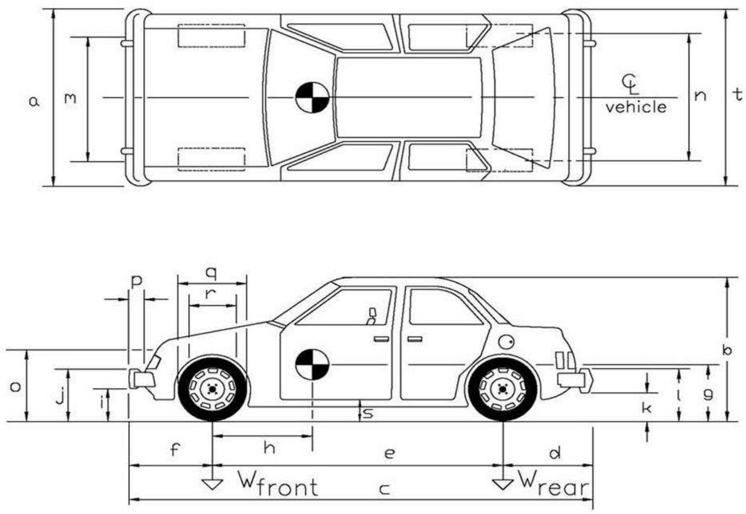
Type:	Hybrid II
Mass:	165 lb
Seat Position:	Driver

Note any damage prior to test: none

Figure 34. Vehicle Dimensions, Test No. 34AGT-1

Figure 35. Test Vehicle, Test No. 34AGT-2

Date:		Test Number:	34AGT-2	VIN:	KNADH4A33B6960761
Year:	2011	Make:	Kia	Model:	Rio
Tire Size:	P175-70R14	Tire Inflation Pressure:	32 Psi	Odometer:	106660



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

a: 65 1/4 (1657) 65±3 (1650±75)		b: 58 1/4 (1480)	
c: 167 (4242) 169±8 (4300±200)		d: 34 3/4 (883)	
e: 98 1/2 (2502) 98±5 (2500±125)		f: 33 5/8 (854) 35±4 (900±100)	
g: 22 3/8 (568)		h: 40 5/16 (1024) 39±4 (990±100)	
i: 9 (229)		j: 22 1/2 (572)	
k: 11 1/8 (283)		l: 24 1/8 (613)	
m: 57 5/8 (1464) 56±2 (1425±50)		n: 58 (1473) 56±2 (1425±50)	
o: 28 (711) 24±4 (600±100)		p: 2 1/4 (57)	
q: 23 3/8 (594)		r: 15 1/4 (387)	
s: 7 1/2 (191)		t: 65 1/8 (1654)	

Mass Distribution lb (kg)

Gross Static	LF	774 (351)	RF	732 (332)
	LR	543 (246)	RR	531 (241)

Weights lb. (kg)	Curb	Test Inertial	Gross Static
W-front	1435 (651)	1430 (649)	1506 (683)
W-rear	896 (406)	990 (449)	1074 (487)
W-total	2331 (1057)	2420 (1098) 2420±55 (1100±25)	2580 (1170) 2585±55 (1175±50)

Top of radiator core support:	9 3/4 (248)
Wheel Center Height (Front):	11 (279)
Wheel Center Height (Rear):	11 1/2 (292)
Wheel Well Clearance (Front):	25 5/8 (651)
Wheel Well Clearance (Rear):	24 3/4 (629)
Bottom Frame Height (Front):	6 1/4 (159)
Bottom Frame Height (Rear):	15 7/8 (403)
Engine Type:	Gasoline
Engine Size:	1.6L 4 cyl
Transmission Type:	Manual
Drive Type:	FWD

GVWR Ratings lb

Front:	1918
Rear:	1874
Total:	3638

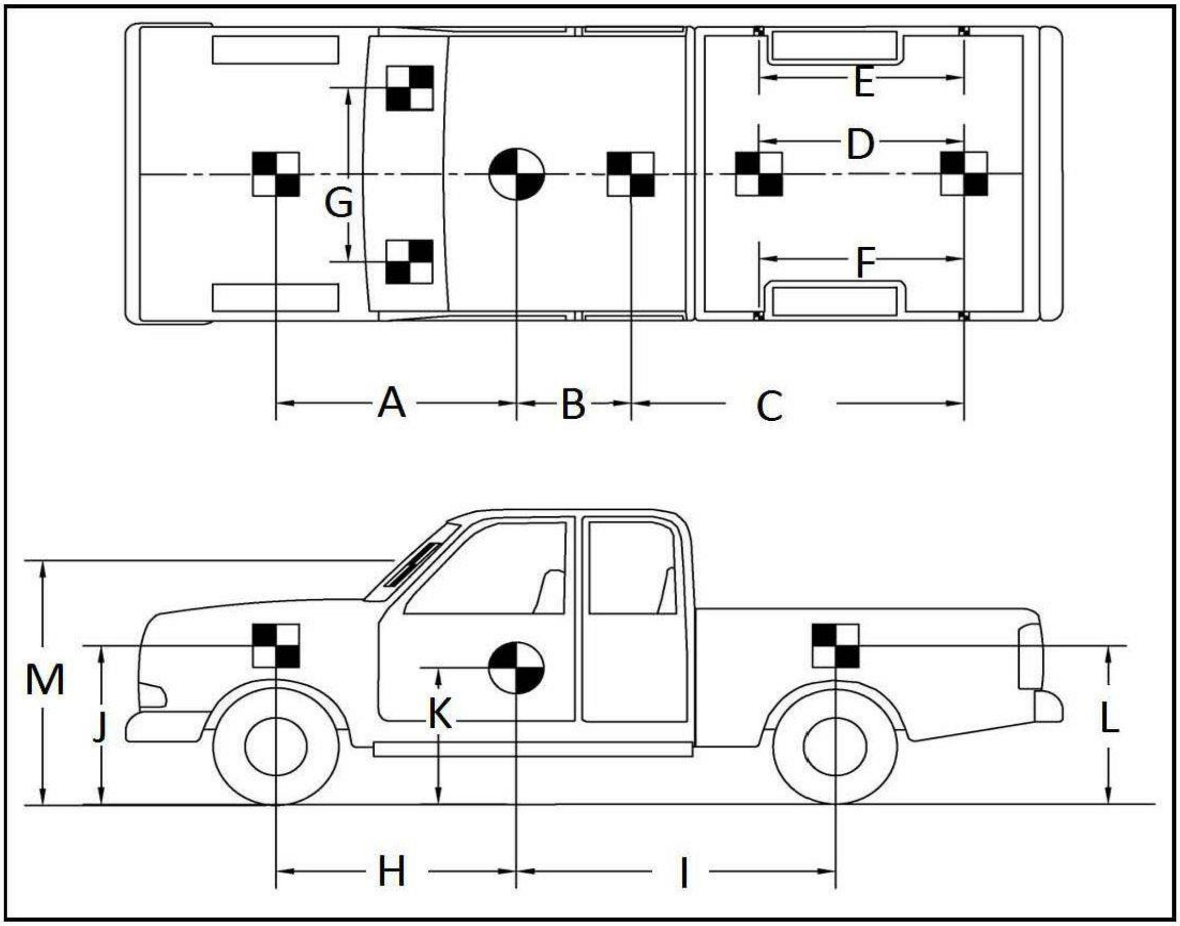
Dummy Data

Type:	Hybrid II
Mass:	160 lb
Seat Position:	Driver

Note any damage prior to test: Small dent on rear bumper driver side

Figure 36. Vehicle Dimensions, Test No. 34AGT-2

Date:	3/17/2017	Test Name:	34AGT-1	VIN:	1D7RB1GP5AS218232
Year:	2010	Make:	Dodge	Model:	Ram 1500

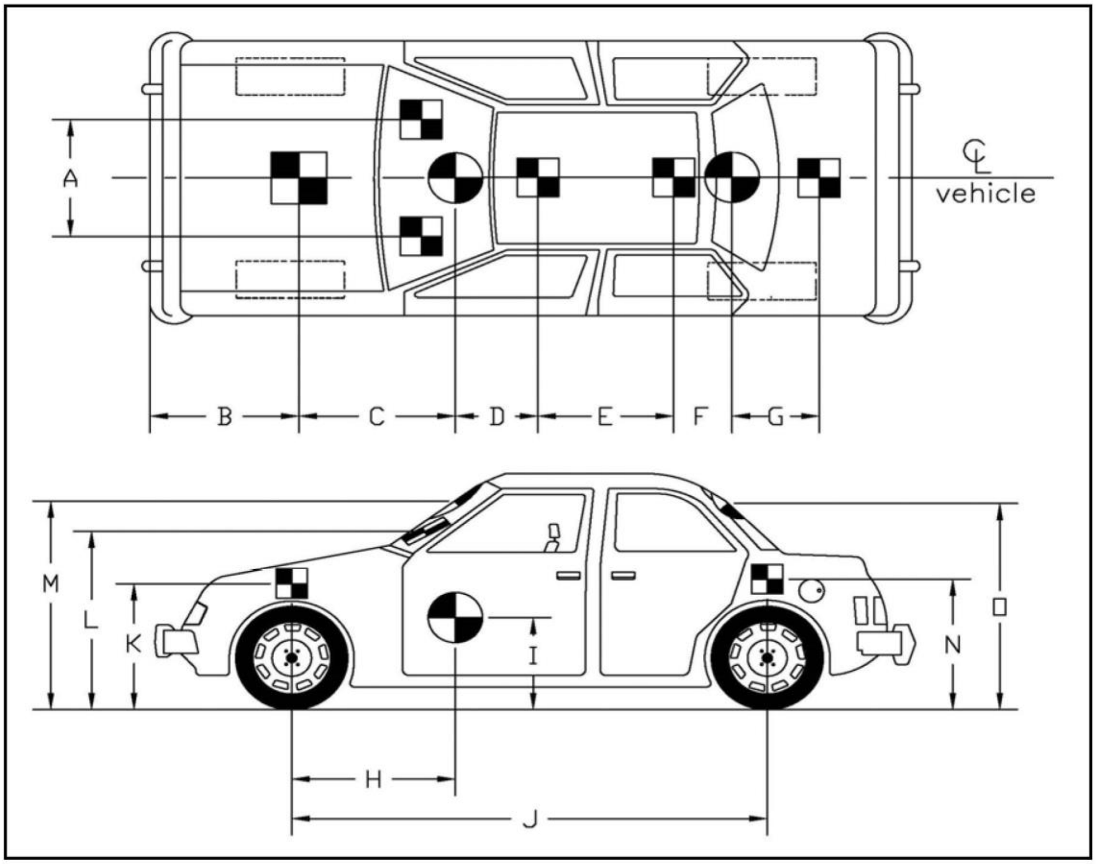


TARGET GEOMETRY– in. (mm)

A:	81 7/8	(2080)	E:	63 3/8	(1610)	J:	38 1/8	(968)
B:	28 3/4	(730)	F:	63 3/8	(1610)	K:	27 7/8	(708)
C:	70 7/8	(1800)	G:	32 1/2	(826)	L:	42	(1067)
D:	41	(1041)	H:	61 7/8	(1572)	M:	64 1/8	(1629)
			I:	78 1/2	(1994)			

Figure 37. Target Geometry, Test No. 34AGT-1

Date:	**4/25/2017**	**Test Name:**	**34AGT-2**	**VIN:**	**KNADH4A33B6960761**
Year:	**2011**	**Make:**	**Kia**	**Model:**	**Rio**



TARGET GEOMETRY - in. (mm)

A	**26 7/8**	**(683)**	**F**	**11 1/8**	**(283)**	**K**	**29 5/8**	**(752)**
B	**20 3/8**	**(518)**	**G**	**27 3/8**	**(695)**	**L**	**48 5/8**	**(1235)**
C	**52 1/4**	**(1327)**	**H**	**40 1/4**	**(1022)**	**M**	**54 5/8**	**(1387)**
D	**13**	**(330)**	**I**	**22 3/8**	**(568)**	**N**	**28 3/4**	**(730)**
E	**30 7/8**	**(784)**	**J**	**98 1/2**	**(2502)**	**O**	**54 3/8**	**(1381)**

Figure 38. Target Geometry, Test No. 34AGT-2

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 Figures 37 and 38. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicle.

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

5.4 Simulated Occupant

For test nos. 34AGT-1 and 34AGT-2, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the left-front seat of the test vehicles with the seat belt fastened. The dummy, which had a weight of 165 lb (75 kg) and 160 lb (72 kg) for test nos. 34AGT-1 and 34AGT-2, respectively, was manufactured by Android Systems of Carson, California. As recommended by MASH 2016, the dummy was not included in calculating the c.g. location.

5.5 Data Acquisition Systems

5.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both accelerometers systems were mounted near the c.g. of the test vehicles. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [32].

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 for both tests as it was mounted closer to the vehicle c.g. 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 program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

5.5.2 Rate Transducers

Two identical angular 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.

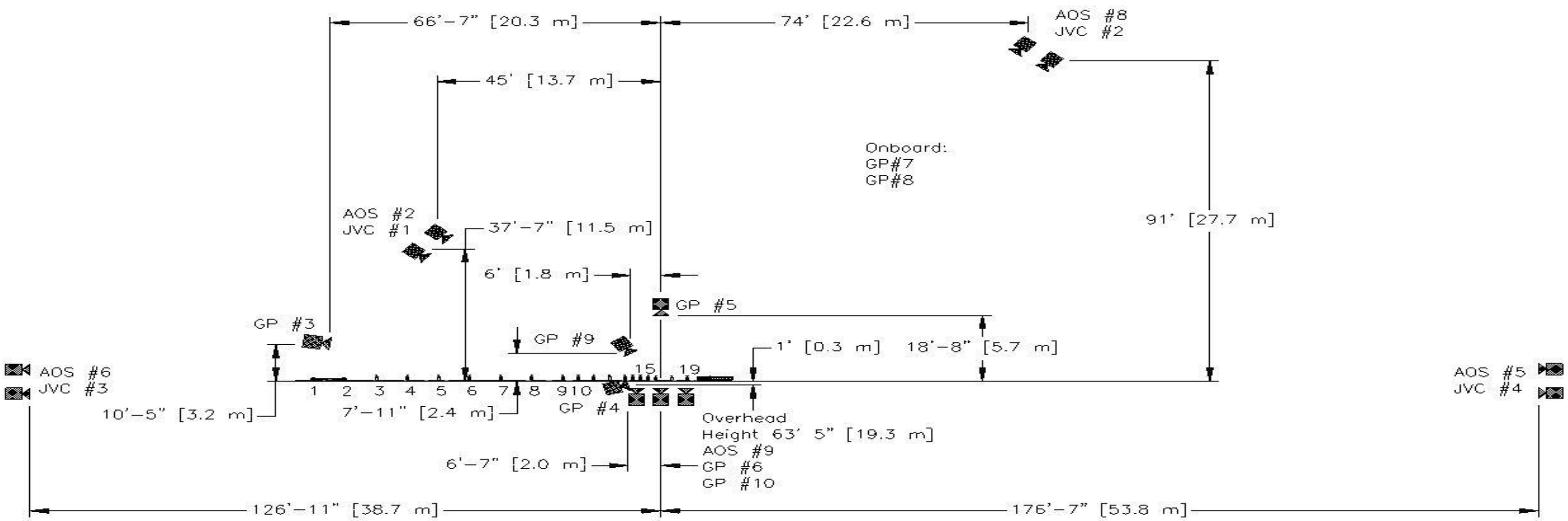
5.5.3 Retroreflective Optic Speed Trap

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.

5.5.4 Digital Photography

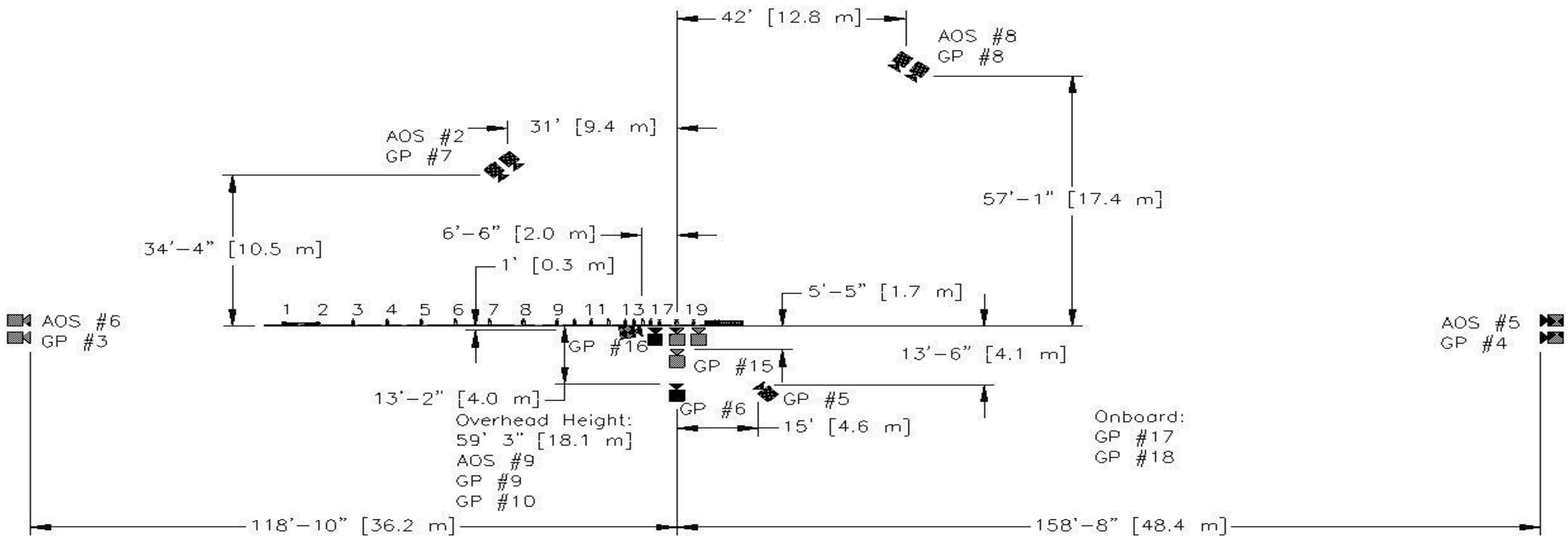
Five AOS high-speed digital video cameras, eight GoPro digital video cameras, and four JVC digital video cameras were utilized to film test no. 34AGT-1. Five AOS high-speed digital video cameras and twelve GoPro digital video cameras were utilized to film test no. 34AGT-2. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figures 39 and 40.

The high-speed videos were analyzed using TEMA Motion 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 two tests.



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-2	AOS Vitcam CTM	500	Fujinon 35 mm Fixed	-
AOS-5	AOS X-PRI Gigabit	500	Vivitar 135 mm Fixed	-
AOS-6	AOS X-PRI Gigabit	500	Fujinon 50 mm Fixed	-
AOS-8	AOS S-VIT 1531	500	Sigma 28-70 DG	70
AOS-9	AOS TRI-VIT 2236	500	Kowa 12 mm Fixed	-
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	240		
GP-10	GoPro Hero 4	240		
JVC-1	JVC – GZ-MC500 (Everio)	29.97		
JVC-2	JVC – GZ-MG27u (Everio)	29.97		
JVC-3	JVC – GZ-MG27u (Everio)	29.97		
JVC-4	JVC – GZ-MG27u (Everio)	29.97		

Figure 39. Camera Locations, Speeds, and Lens Settings, Test No. 34AGT-1



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-2	AOS Vitcam CTM	500	Fujinon 35 mm Fixed	-
AOS-5	AOS X-PRI Gigabit	500	Vivitar 135 mm Fixed	-
AOS-6	AOS X-PRI Gigabit	500	Fujinon 50 mm Fixed	-
AOS-8	AOS S-VIT 1531	500	Sigma 28-70	70
AOS-9	AOS TRI-VIT 2236	500	Kowa 12 mm Fixed	-
GP-3	GoPro Hero 3+ with Cosmicar 12.5 mm	120		
GP-4	GoPro Hero 3+ with Computar 12.5 mm	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	240		
GP-8	GoPro Hero 4	240		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	240		
GP-15	GoPro Hero 4	240		
GP-16	GoPro Hero 4	240		
GP-17	GoPro Hero 4	120		
GP-18	GoPro Hero 4	120		

Figure 40. Camera Locations, Speeds, and Lens Settings, Test No. 34AGT-2

6 FULL-SCALE CRASH TEST NO. 34AGT-1

6.1 Static Soil Test

Before full-scale crash test no. 34AGT-1 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH 2016. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

6.2 Weather Conditions

Test no. 34AGT-1 was conducted on March 17, 2017 at approximately 1:15 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 3.

Table 3. Weather Conditions, Test No. 34AGT-1

Temperature	67°F
Humidity	32%
Wind Speed	10 mph
Wind Direction	350° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.05 in.
Previous 7-Day Precipitation	0.05 in.

6.3 Test Description

The main concern with vehicles impacting the 34-in. (864-mm) tall AGT was related to vehicle snag on the rigid parapet. Accordingly, the critical impact point for test no. 34AGT-1 was selected using the tables provided in section 2.3.2.1 of MASH 2016 to maximize the potential for snag on the upstream face of the concrete buttress. The critical impact point was determined to be 89 in. (2,261 mm) upstream from the concrete buttress, as shown in Figure 41.

During test no. 34AGT-1, the 5,024-lb (2,279-kg) pickup truck impacted the AGT 90½ in. (2,299 mm) upstream from the concrete buttress at a speed of 62.2 mph (100.1 km/h) and an angle of 24.8 degrees. The vehicle was contained and smoothly redirected with an exit speed and angle of 42.1 mph (67.8 km/h) and -10.8 degrees, respectively. The vehicle remained stable throughout the impact event with maximum roll and pitch angular displacements of only 12 degrees and 4 degrees, respectively. After exiting the system, the vehicle impacted a row of temporary concrete barriers 162 ft (49.4 m) downstream from impact and quickly came to a stop.

A detailed description of the sequential impact events is contained in Table 4. Sequential photographs are shown in Figures 42 and 43. Documentary photographs of the crash test are shown in Figure 44. Vehicle trajectory and final position photographs are shown in Figure 45.

Figure 41. Impact Location, Test No. 34AGT-1

Table 4. Sequential Description of Impact Events, Test No. 34AGT-1

TIME (s)	EVENT
0.000	Vehicle’s left-front bumper impacted the rail between posts nos. 17 and 18.
0.002	Vehicle’s front bumper began to deform.
0.010	Vehicle’s left fender began to deform.
0.016	Vehicle’s hood began to deform, and vehicle grill impacted the rail.
0.018	Vehicle’s grill began to deform.
0.020	Post no. 18 began to deflect backward.
0.024	Post nos. 17 and 19 began to deflect backward.
0.026	Vehicle began to yaw away from the system.
0.028	Post no. 16 began to deflect backward.
0.034	Post no. 15 began to deflect backward.
0.048	Vehicle’s left-front door impacted the rail, vehicle began to roll toward the barrier, and vehicle’s airbags were deployed.
0.052	Vehicle’s left-front door began to deform.
0.074	Vehicle’s left fender impacted concrete buttress above the rail, and vehicle began to pitch downward.
0.088	Vehicle’s left-front tire contacted post no. 19.
0.106	Vehicle’s left-front tire contacted the lower chamfer of the concrete buttress
0.128	Vehicle’s left-front window shattered, and vehicle’s left-front door contacted the top of the concrete buttress.
0.138	Vehicle’s right-rear tire became airborne.
0.168	Vehicle’s grill disengaged.
0.188	Vehicle became parallel with the system with a velocity of 47.6 mph (76.6 km/h).
0.194	Vehicle’s rear bumper impacted the rail.
0.196	Vehicle’s left-front tire became detached.
0.198	Vehicle’s left-rear quarter panel impacted rail.
0.204	Vehicle’s left-rear door contacted top of concrete buttress and began to deform.
0.220	Vehicle’s left quarter panel impacted concrete buttress and began to deform.
0.316	Vehicle exited the system at a speed of 42.1 mph (67.8 km/h) and an angle of -10.8 degrees.


0.000 sec

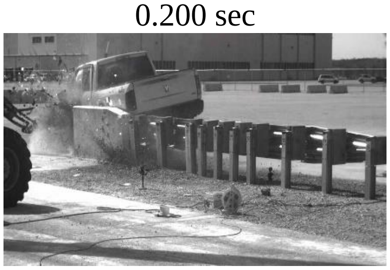

0.000 sec


0.100 sec


0.100 sec


0.200 sec


0.200 sec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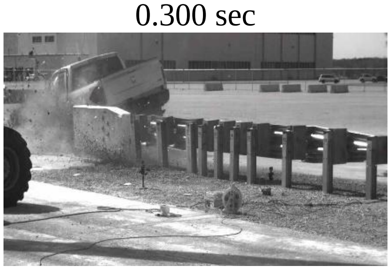
0.300 sec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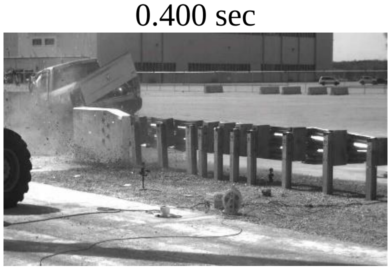
0.400 sec


0.500 sec


0.500 sec

Figure 42. Additional Sequential Photographs, Test No. 34AGT-1


0.000 sec


0.100 sec


0.200 sec


0.300 sec

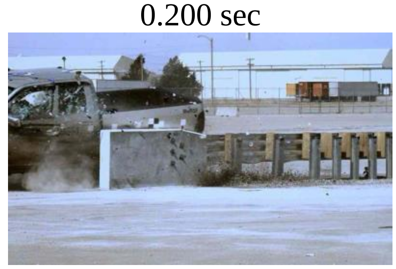

0.400 sec


0.500 sec


0.000 sec


0.100 sec


0.200 sec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0.400 sec

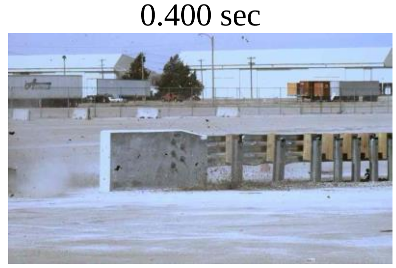

0.500 sec

Figure 43. Additional Sequential Photographs, Test No. 34AGT-1

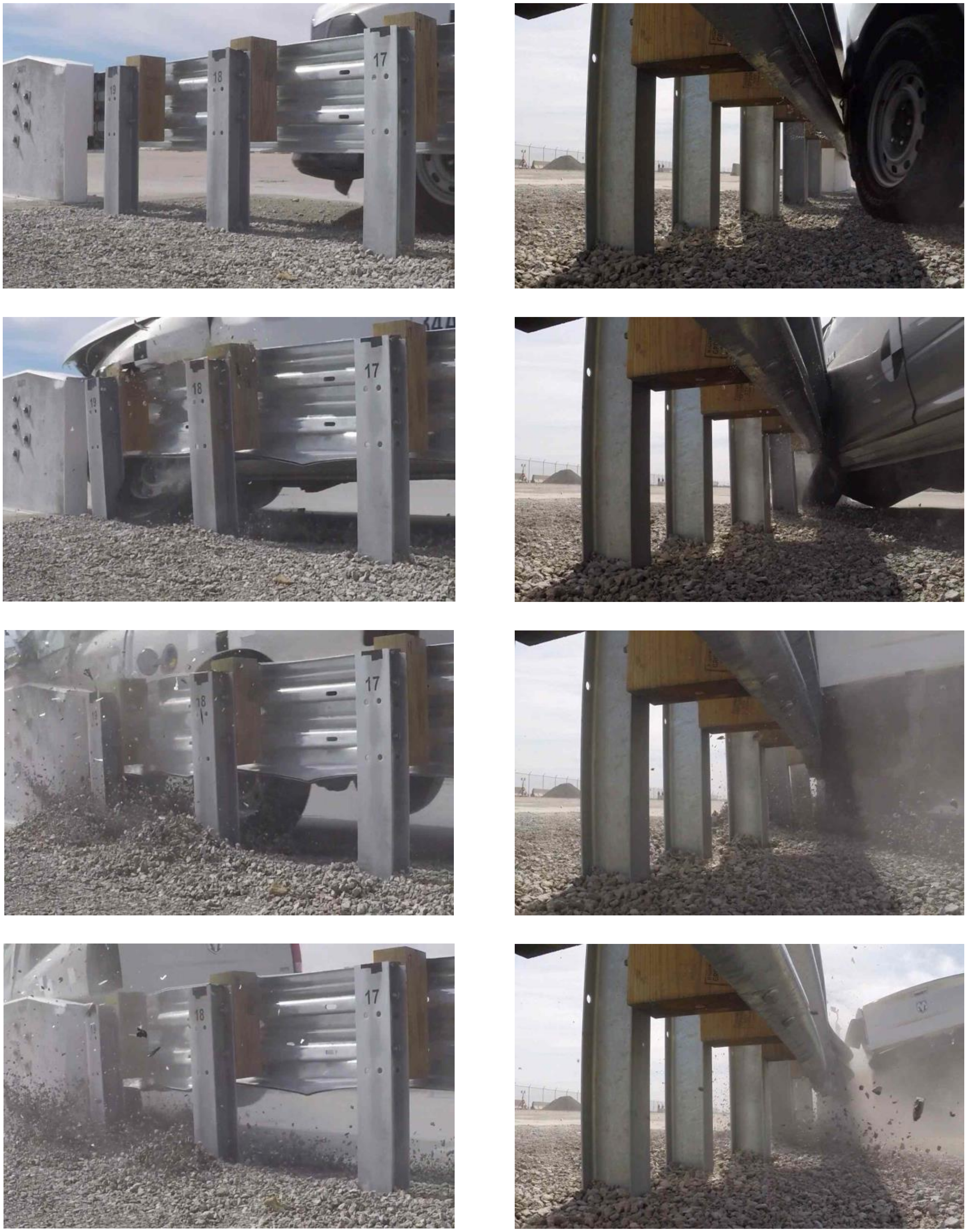


Figure 44. Documentary Photographs, Test No. 34AGT-1

Figure 45. Vehicle Final Position and Trajectory Marks, Test No. 34AGT-1

6.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 46 through 49. Barrier damage consisted of rail and post deformation, contact marks on the top and front face of the concrete buttress, concrete gouging, and concrete cracking. The length of vehicle contact along the barrier was approximately 12 ft – 2½ in. (3.7 m) which spanned from 10 in. (254 mm) downstream from post no. 17 to 28 in. (711 mm) from the downstream end of the concrete buttress.

A kink occurred in the top thrie beam corrugation 7¼ in. (184 mm) upstream from post no. 15, with numerous other kinks, dents, and buckles occurring throughout the impact region. Post nos. 15 through 19 deflected backward, while post nos. 14 through 19 twisted to face downstream. Post no. 19 also rotated downstream and had contact marks on its front flange below the thrie beam.

Tire marks were visible on the front face of the concrete buttress and on the lower chamfer of the buttress. Concrete gouging was observed along the entire length of the lower chamfer of the buttress and extended an additional 3 in. (76 mm) onto the front face of the buttress. The gouging was 3 in. (76 mm) from the bottom, and gradually sloped down to the bottom edge over its duration. Contact marks were found on the top and front face of the buttress beginning at the upstream end and extended to 28 in. (711 mm) from the downstream end. A hairline crack was found on the front face of the concrete buttress, extending upward and downstream at approximately a 45-degree angle from the top bolt hole of the thrie beam terminal connector to the top surface of the buttress.

The maximum lateral permanent set deflections of the rail and posts for the transition barrier system was 5¾ in. (146 mm) at the mid-span between post nos. 18 and 19, and 4¾ in. (121 mm) at post no. 18, respectively, as measured in the field. The maximum lateral dynamic barrier deflection of the rail and posts for the transition barrier system was 7.8 in. (198 mm) at post no. 18 and 7.4 in. (188 mm) at post no. 18, respectively, as determined from high-speed digital video analysis. The working width of the system was established by the deflection of post no. 18 and was found to be 24.7 in. (627 mm), also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 50.

Figure 46. System Damage, Test No. 34AGT-1

Figure 47. System Damage, Post nos. 16 through 18, Test No. 34AGT-1

Figure 48. System Damage, Post No. 19 and Rail Connection Terminal, Test No. 34AGT-1

Figure 49. Buttress Damage, Test No. 34AGT-1

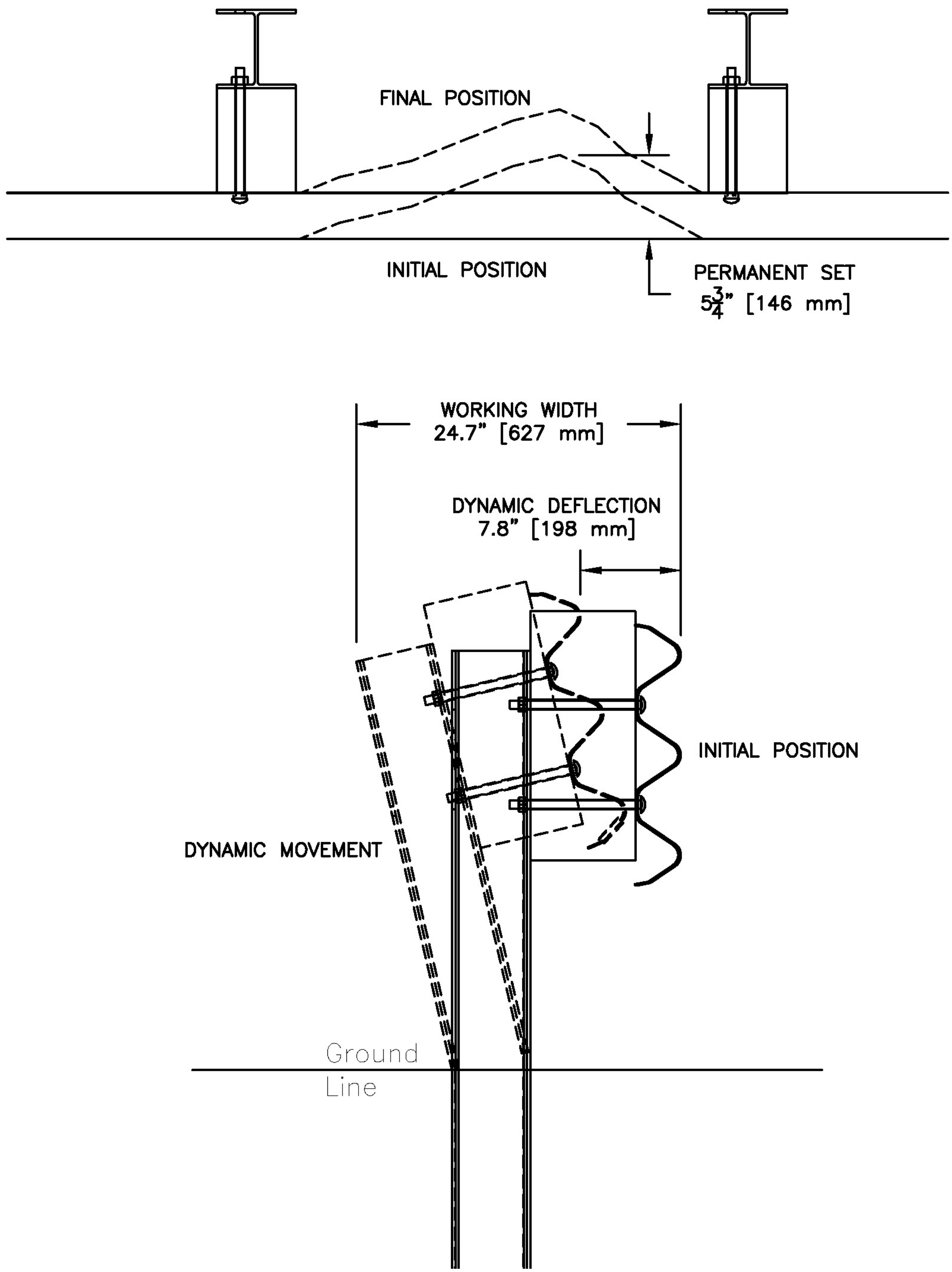


Figure 50. Permanent Set, Dynamic Deflection, and Working Width, Test No. 34AGT-1

6.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 51 through 53. The majority of damage was concentrated on the left-front corner and left side of the vehicle where the impact occurred. The left side of the front bumper was crushed inward and back. The left-front fender was pushed upward near the door panel and was dented and torn behind the left-front wheel. Both headlights and the grille were disengaged from the vehicle. The left side of the radiator was pushed backward. Denting and scraping was observed on the entire left side of the pickup truck. The bottom of the left-front door was crushed inward, and the top of the door was ajar. The left-rear door was dented. The left taillight was out of socket, but remained attached. The left side of the rear bumper was dented, scuffed, and partially disengaged.

The left-front wheel was disengaged from the vehicle, and the steel rim was deformed with tears and significant crushing. The left-front tire was torn and deflated. The left upper control arm was fractured. The left-front steering knuckle and ball joints were disengaged, and the upper control arm was bent toward the engine. The left-rear wheel assembly was deformed inward, the steel rim was dented, and scuff marks were found on the tire.

The right side of the front bumper was deformed inward and downward. The hood had a 2-in. (51-mm) gap on the right side. The right-front fender was dented in at the top and back, and the right-front tire was deformed inward. The right side of the windshield was deformed and had spiderweb cracking from the airbag deployment. The left-front window was shattered. The roof had a minor dent, and the remaining window glass remained undamaged. Note, a portion of the vehicle damage, especially to the front and right side of the truck, was due to the secondary impact with the portable concrete barriers downstream of the system that was set up to contain the vehicle after exiting the system.

The maximum occupant compartment intrusions are listed in Table 5 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size. Significant crushing was observed to the left-side front panel and the toe pan where the tire, which had impacted the buttress, was pushed backward and toward the occupant compartment. However, none of the MASH 2016 deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Figure 51. Vehicle Damage, Test No. 34AGT-1

Figure 52. Windshield Damage and Occupant Compartment Deformation, Test No. 34AGT-1

Figure 53. Undercarriage Damage, Test No. 34AGT-1

Table 5. Maximum Occupant Compartment Intrusions by Location, Test No. 34AGT-1

LOCATION	MAXIMUM INTRUSION in. (mm)	MASH 2016 ALLOWABLE INTRUSION in. (mm)
Wheel Well & Toe Pan	3.0 (76)	≤ 9 (229)
Floor Pan & Transmission Tunnel	2.3 (58)	≤ 12 (305)
A-Pillar	0.9 (23)	≤ 5 (127)
A-Pillar (Lateral)	0.8 (20)	≤ 3 (76)
B-Pillar	1.1 (28)	≤ 5 (127)
B-Pillar (Lateral)	1.0 (25)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	6.6 (168)	≤ 12 (305)
Side Door (Above Seat)	4.1 (104)	≤ 9 (229)
Side Door (Below Seat)	4.1 (104)	≤ 12 (305)
Roof	1.0 (25)	≤ 4 (102)
Windshield	0 (0)	≤ 3 (76)
Side Window	Shattered from contact with dummy head	No shattering resulting from contact with structural member of test article
Dash	3.0 (76)	N/A

N/A – Not Applicable

6.6 Occupant Risk

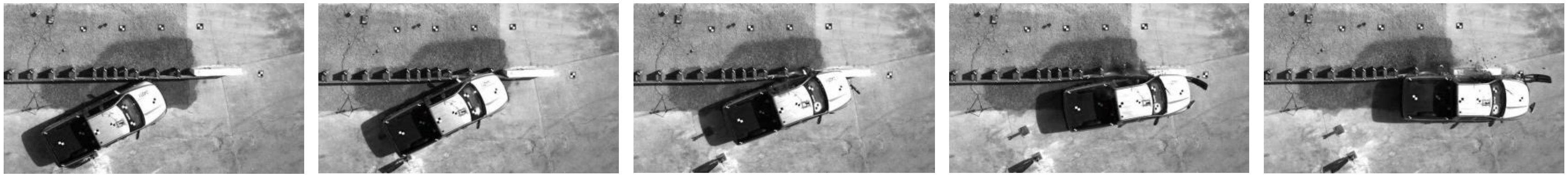
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 6. Note that the OIVs and ORAs obtained from both accelerometer units were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 6. The recorded data from each accelerometer and rate transducer are shown graphically in Appendix E.

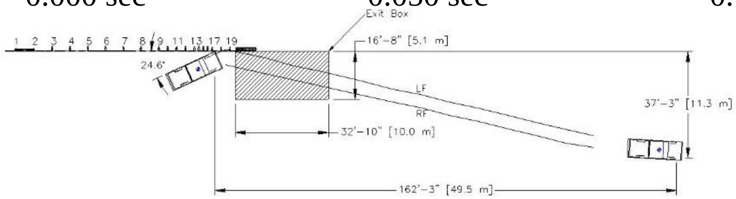
Table 6. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. 34AGT-1

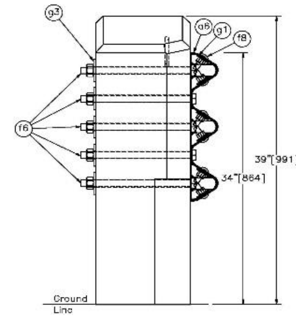
Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-21.06 (-6.42)	-20.18 (-6.15)	±40 (12.2)
	Lateral	24.62 (7.50)	25.92 (7.90)	±40 (12.2)
ORA g's	Longitudinal	-10.05	-10.77	±20.49
	Lateral	10.44	8.85	±20.49
MAX. ANGULAR DISPL. deg.	Roll	-15.1	-12.0	±75
	Pitch	-3.3	-4.4	±75
	Yaw	39.6	38.9	not required
THIV ft/s (m/s)		30.78 (9.38)	31.50 (9.60)	not required
PHD g's		10.71	11.15	not required
ASI		1.49	1.59	not required

6.7 Discussion

The analysis of the test results for test no. 34AGT-1 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 54. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor overrride the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix E, were deemed acceptable because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of -10.8 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. 34AGT-1 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-21.







- Test Agency .... MwRSF
- Test Number 34AGT-1
- Date 3/17/17
- MASH 2016 Test Designation No. 3-21
- Test Article .... 34-in. (864-mm) Tall Thrie Beam AGT
- Total Length .... 87 ft – 11¼ in. (26.8 m)
- Key Component – Thrie beam Guardrail
  - Thickness .... 12 ga. (2.7 mm)
  - Mounting Height .... 34 in. (864 mm)
- Key Component –W6x15 Steel Post
  - Length .... 84 in. (2,134 mm)
  - Embedment Depth .... 52 in. (1,321 mm)
  - Spacing .... 37½ in. (953 mm)
- Key Component – Concrete Transition Buttress
  - Length .... 84 in. (2,134 mm)
  - Width .... 12 in. (305 mm)
  - Height .... 39 in. (991 mm)
- Soil Type .... Coarse Crushed Limestone
- Vehicle Make /Model .... Dodge Ram 1500
  - Curb .... 5,085 lb (2,307 kg)
  - Test Inertial .... 5,024 lb (2,279 kg)
  - Gross Static .... 5,189 lb (2,354 kg)
- Impact Conditions
  - Speed .... 62.2 mph (100.1 km/h)
  - Angle .... 24.8 deg.
  - Impact Location .... 90½ in. (2,299 mm) upstream from buttress
- Impact Severity (IS) .... 114 kip-ft (155 kJ) > 106 kip-ft (144 kJ) MASH 2016 limit
- Exit Conditions
  - Speed .... 42.1 mph (67.8 km/h)
  - Angle .... -10.8 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 162.3 ft (49.5 m) downstream and 37.3 ft (11.4 m) in front

- Vehicle Damage .... Moderate
  - VDS [33] 11-LFQ-6
  - CDC [34] 11-FLEW-4
  - Maximum Interior Deformation .... 6⅝ in. (168 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 5¾ in. (146 mm)
  - Dynamic .... 7.8 in. (198 mm)
  - Working Width .... 24.7 in. (627 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-21.06 (-6.42)	-20.18 (-6.15)	±40 (12.2)
	Lateral	24.62 (7.50)	25.92 (7.90)	±40 (12.2)
ORA g's	Longitudinal	-10.05	-10.77	±20.49
	Lateral	10.44	8.85	±20.49
MAX ANGULAR DISP. deg.	Roll	-15.1	-12.0	±75
	Pitch	-3.3	-4.4	±75
	Yaw	39.6	38.9	not required
THIV – ft/s (m/s)		30.78 (9.38)	31.50 (9.60)	not required
PHD – g's		10.71	11.15	not required
ASI		1.49	1.59	not required

Figure 54. Summary of Test Results and Sequential Photographs, Test No. 34AGT-1

7 FULL-SCALE CRASH TEST NO. 34AGT-2

7.1 Static Soil Test

Before full-scale crash test no. 34AGT-2 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH 2016. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

7.2 Weather Conditions

Test no. 34AGT-2 was conducted on May 9, 2017 at approximately 1:15 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 7.

Table 7. Weather Conditions, Test No. 34AGT-2

Temperature	77°F
Humidity	45%
Wind Speed	8 mph
Wind Direction	50° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0 in.
Previous 7-Day Precipitation	0.17 in.

7.3 Test Description

The main concern with vehicles impacting the 34-in. (864-mm) tall AGT was related to vehicle snag on the rigid parapet. Accordingly, the critical impact point for test no. 34AGT-2 was selected using the tables provided in section 2.3.2.1 of MASH to maximize the potential for snag on the upstream face of the concrete buttress. The critical impact point was determined to be 63 in. (1,600 mm) upstream from the concrete buttress, as shown in Figure 55.

During test no. 34AGT-2, the 2,420-lb (1,098-kg) small car impacted the AGT 65 in. (1,651 mm) upstream from the concrete buttress at a speed of 62.1 mph (99.9 km/h) and an angle of 25.5 degrees. The vehicle was contained and smoothly redirected with an exit speed and angle of 40.7 mph (65.5 km/h) and -6.4 degrees, respectively. The vehicle remained stable throughout the impact event with maximum roll and pitch angles of 10 degrees and 6 degrees, respectively. After exiting the system, the left-front door opened as the small car rolled away and impacted a row of temporary concrete barriers 145 ft (44.2 m) downstream from impact and rapidly came to a stop.

A detailed description of the sequential impact events is contained in Table 8. Sequential photographs are shown in Figures 56 and 57, and documentary photographs of the crash test are shown in Figure 58. The vehicle trajectory and final position are shown in Figure 59.

Figure 55. Impact Location, Test No. 34AGT-2

Table 8. Sequential Description of Impact Events, Test No. 34AGT-2

TIME (sec)	EVENT
0.000	Vehicle’s impacted the AGT 2 in. (51 mm) upstream from post no. 18.
0.010	Vehicle’s left fender contacted rail.
0.014	Post no. 18 began to deflect backward, vehicle hood contacted rail.
0.016	Post no. 19 began to deflect backward.
0.022	Vehicle’s hood deformed.
0.024	Vehicle’s left-front tire contacted rail.
0.026	Vehicle’s grille deformed, vehicle rolled toward the barrier.
0.030	Post no. 17 deflected backward.
0.034	Vehicle’s left-front door contacted rail, vehicle pitched downward and yawed away from the barrier.
0.044	Vehicle’s left-front door deformed, and vehicle airbag deployed.
0.050	Vehicle rolled away from the barrier.
0.052	Vehicle’s left A-pillar deformed, vehicle hood contacted buttress above the rail, and vehicle windshield shattered
0.058	Vehicle’s left-front door opened. Vehicle roof deformed.
0.066	Vehicle’s left-front tire impacted the upstream face of buttress.
0.102	Vehicle’s left-front window shattered from contact with dummy head
0.116	Occupant head passed through left-front window.
0.136	Occupant head re-entered vehicle.
0.154	Vehicle’s left-rear door contacted rail.
0.164	Vehicle’s rear bumper contacted rail, vehicle was parallel to the system with a velocity of 45.2 mph (72.7 km/h).
0.220	Vehicle exited system with a velocity of 40.7 mph (65.5 km/h) and an angle of -6.4 degrees.

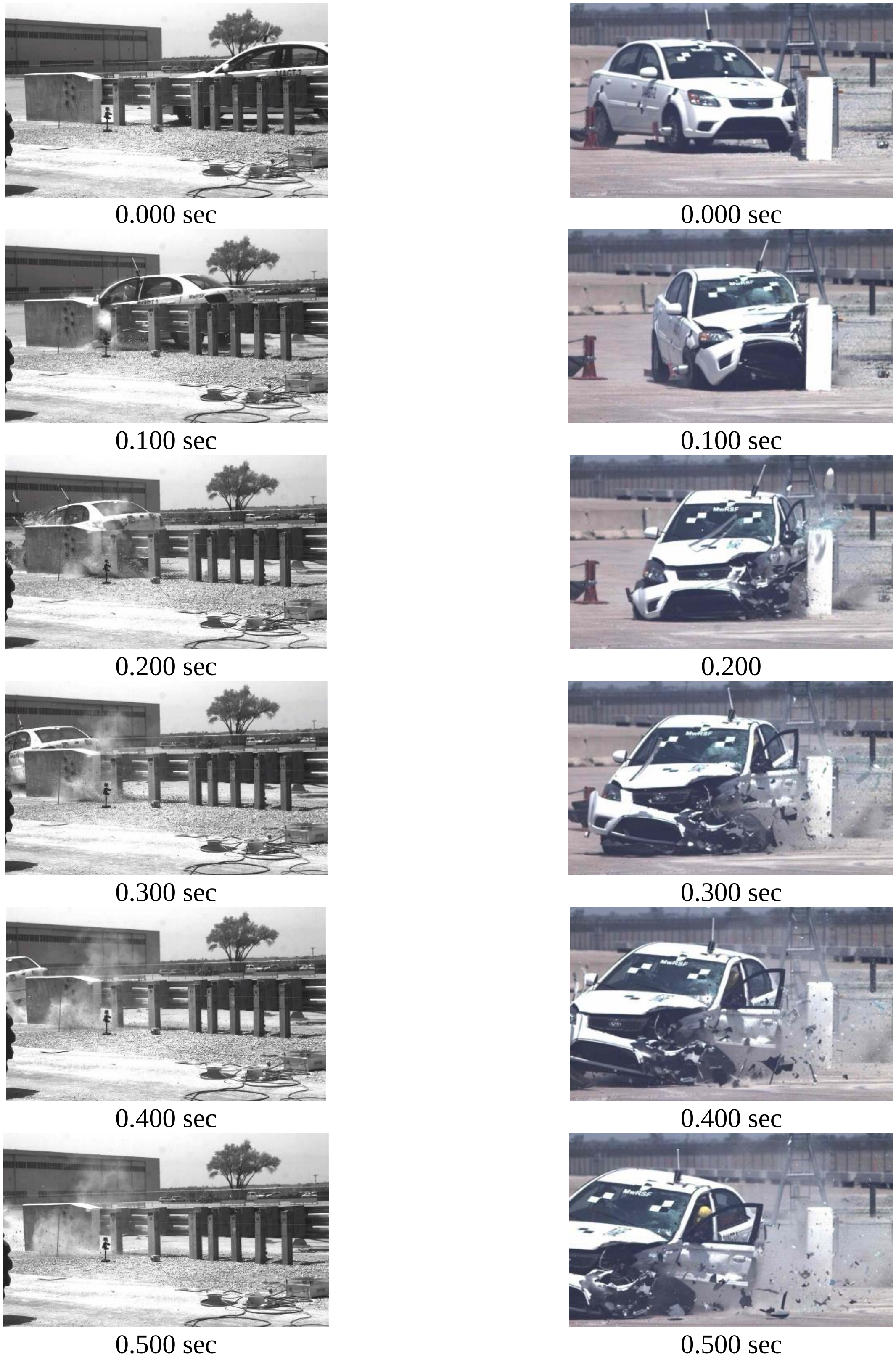
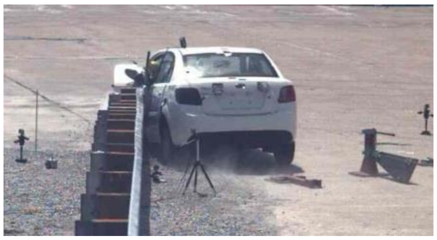


Figure 56. Additional Sequential Photographs, Test No. 34AGT-2

0.000 sec

0.000 sec



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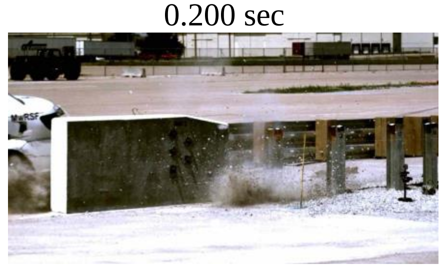

0.300 sec

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Figure 57. Additional Sequential Photographs, Test No. 34AGT-2

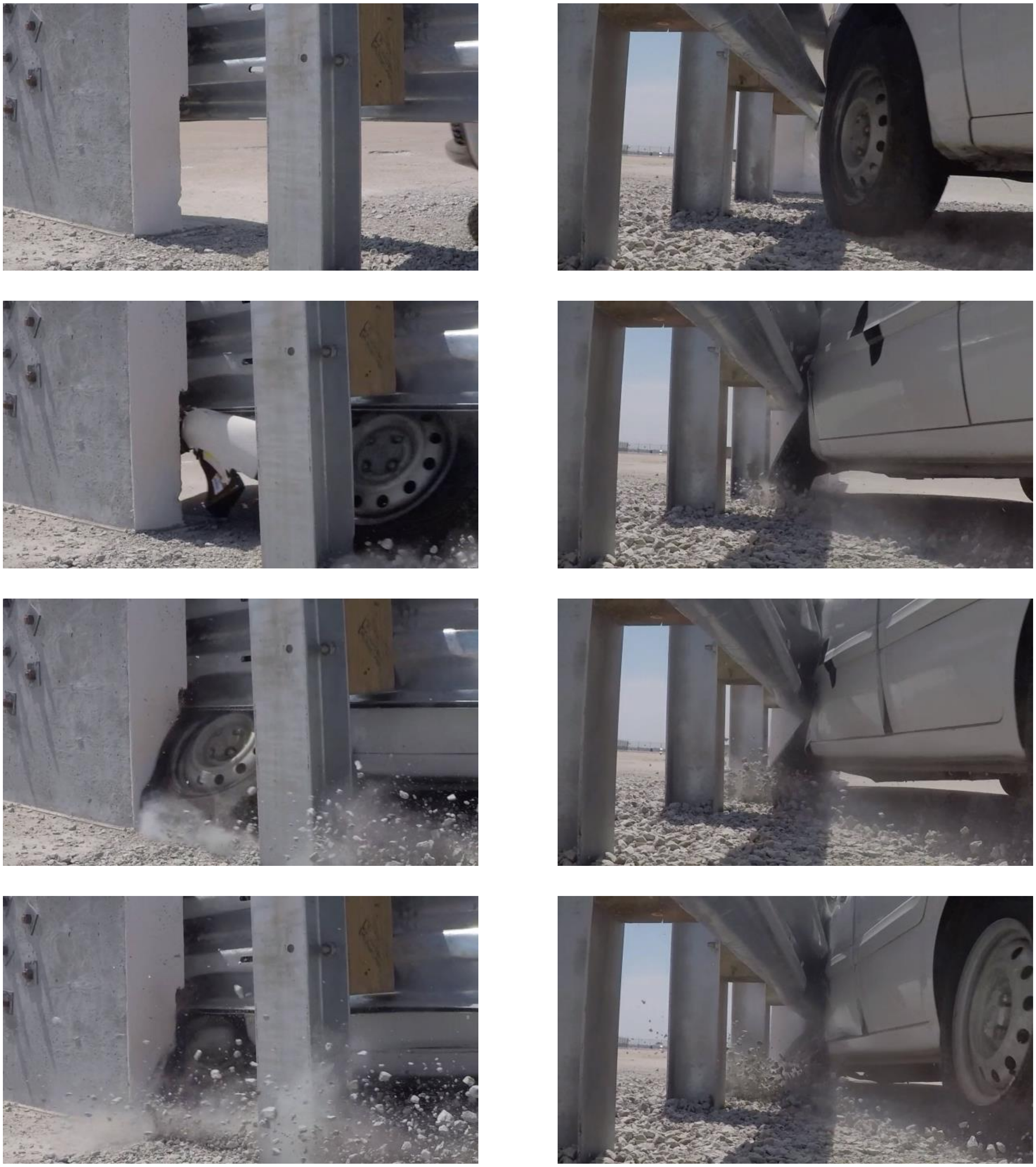


Figure 58. Documentary Photographs, Test No. 34AGT-2

Figure 59. Vehicle Final Position and Trajectory Marks, Test No. 34AGT-2

7.4 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 60 through 62. Barrier damage consisted of rail and post deformation, contact marks on the upstream and traffic faces of the concrete buttress, and concrete gouging. The length of vehicle contact along the barrier was approximately 12 ft – 1 in. (3.7 m) which spanned from 2 in. (51 mm) upstream from the centerline of post no. 18 to 4 in. (102 mm) from the downstream end of the concrete buttress.

Tire marks were visible on the bottom corrugation of the thrie beam starting at the centerline of post no. 18 and extending 8½ in. (216 mm) onto the terminal connector. General contact marks and minor deformations were found on the upper half of the thrie beam between post no. 18 and the concrete buttress. A kink occurred in the bottom of the thrie beam, 13 in. (330 mm) downstream from the centerline of post no. 18. Approximately 4 ft (1.2 m) of the thrie beam's bottom corrugation was flattened at the downstream end. Tire marks were also found on the front flange of post no. 19 just above the ground line. Post nos. 18 and 19 were each deflected backward less than 1 in. (25 mm).

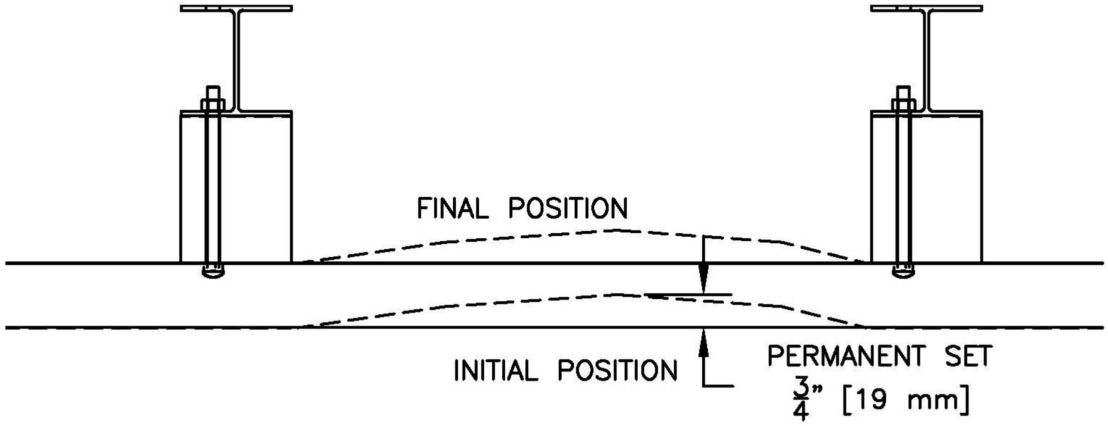
The concrete buttress had tire marks visible on its upstream end starting 1 in. (25 mm) from the back surface of the buttress and extended across the upstream face, the lower chamfer, and onto the front face of the buttress. Tire marks continued on the front face of the buttress for a distance of 80 in. (2032 mm) downstream from the upstream face. Concrete gouging was found on the lower chamfer and front face of the buttress below the thrie beam rail. Minor contact marks were also present on the top, sloped face of the buttress.

The maximum permanent set of the rail and posts for the AGT was ¾ in. (19 mm) at the mid-span between post nos. 18 and 19, and ⅜ in. (10 mm) at post nos. 18 and 19, respectively, as measured in the field. The maximum lateral dynamic barrier deflections of the rail and posts were 2.7 in. (69 mm) at post no. 19 and 2.7 in. (69 mm) at post no. 19, respectively, as determined from high-speed digital video analysis. The working width of the system was found to be 19.9 in. (505 mm), also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 63.

Figure 60. System Damage, Test No. 34AGT-2

Figure 61. System Damage, Post Nos. 18 and 19, Test No. 34AGT-2

Figure 62. System Damage, Concrete Buttress, Test No. 34AGT-2



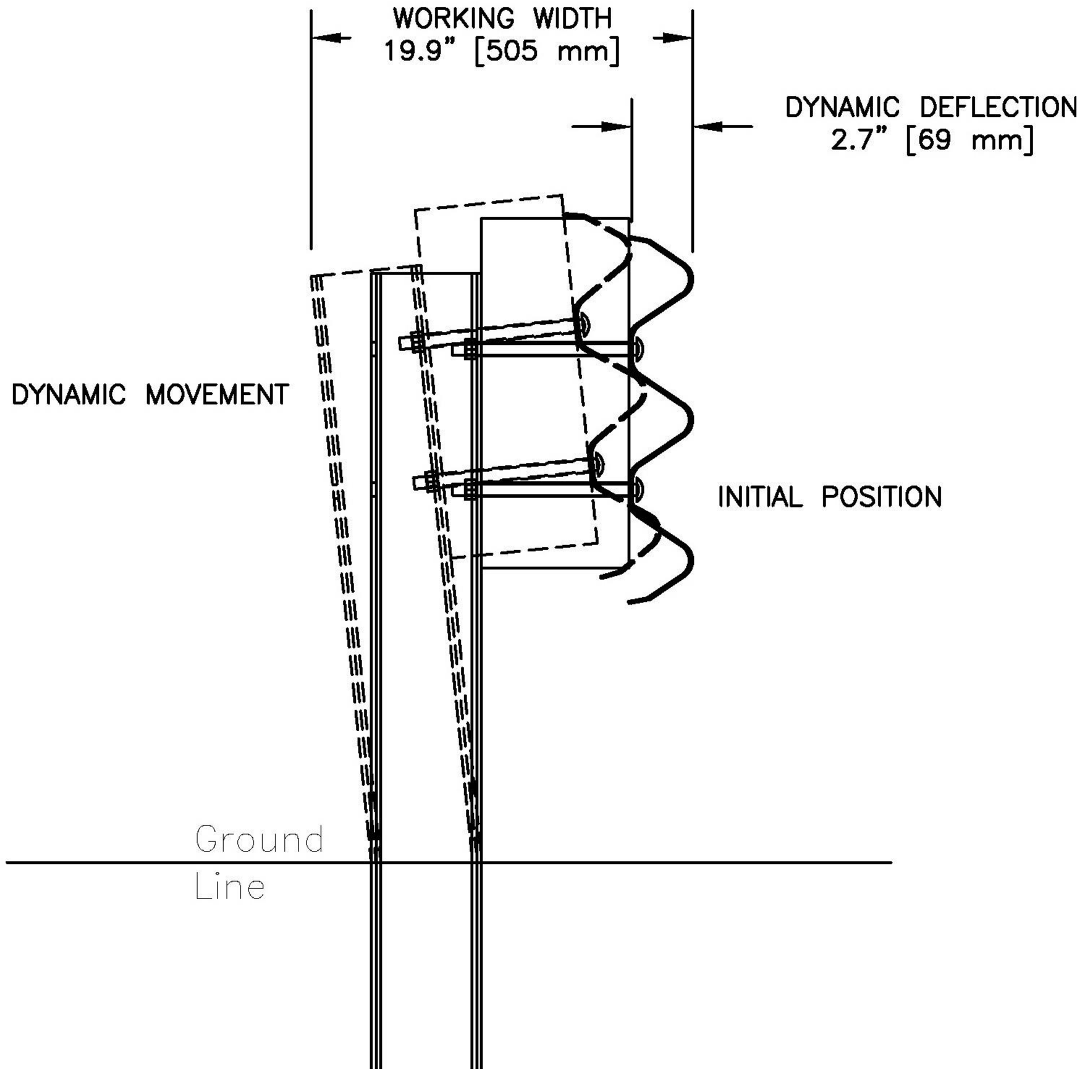


Figure 63. Permanent Set, Dynamic Deflection, and Working Width, Test No. 34AGT-2

7.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 64 through 68. The majority of damage was concentrated on the left-front corner and left side of the vehicle where the impact occurred. The left side of the bumper and the left-front fender were crushed, and the fender was dented and torn behind the left-front wheel. The left side of the radiator was pushed backward. The left-front steel rim was deformed with tears and significant crushing. The left lower control arm and ball joint were disengaged, and the left-front tire was torn. The left side frame horn and chassis mount were bent back and up. Denting and scraping was observed on the entire left side of the vehicle. The left-front door was ajar, and the left-rear door was dented. The left-rear steel rim was dented, and scuff marks were found on the tire.

The right side of the front bumper was detached. There was a 1-in. (25-mm) gap along the B-pillar and the right-front door. The hood was crushed and buckled, but remained attached. The right-front fender was dented in at the top and back. The windshield experienced significant cracking over its entirety and had a 20 in. (508 mm) long tear from the right-top corner down toward the left-bottom corner. A small hole was found near the left-bottom of the windshield, which occurred due to airbag deployment and contact with the hood. The left-front window was shattered. The roof buckled, leaving a 2¼-in. (57-mm) dent. The remaining window glass remained undamaged. Note, part of the vehicle damage was due to the secondary impact with the temporary concrete barrier system that was set up to contain the vehicle after exiting the AGT.

The maximum occupant compartment intrusions are listed in Table 9 along with the deformation limits established in MASH 2016 for various areas of the occupant compartment. MASH 206 defines intrusion as vehicle deformations that result in a reduction in size of the occupant compartment. Note, damage to the lower front corner of the vehicle door frame prevented the left-front door from being shut after it had opened during the test. Consequently, intrusion deformations could not be measured along the door. The door itself was not severely damaged, so intrusion of the door into the occupant compartment would have been minimal and was not a safety concern. During test no. 34AGT-2, the left-front tire extended below the thrie beam rail, impacted the buttress, and was pushed toward the occupant compartment creating significant displacements to the toe pan and side front panel of the vehicle. Although, none of the established MASH 2016 deformation limits were violated, these deformations shifted the reference points established within the vehicle that would have been utilized to measure deformations. Thus, maximum occupant crush intrusions had to be made by comparisons to an exemplar vehicle of the same make, model, and year.

Figure 64. Vehicle Damage, Test No. 34AGT-2

Figure 65. Vehicle Damage, Test No. 34AGT-2

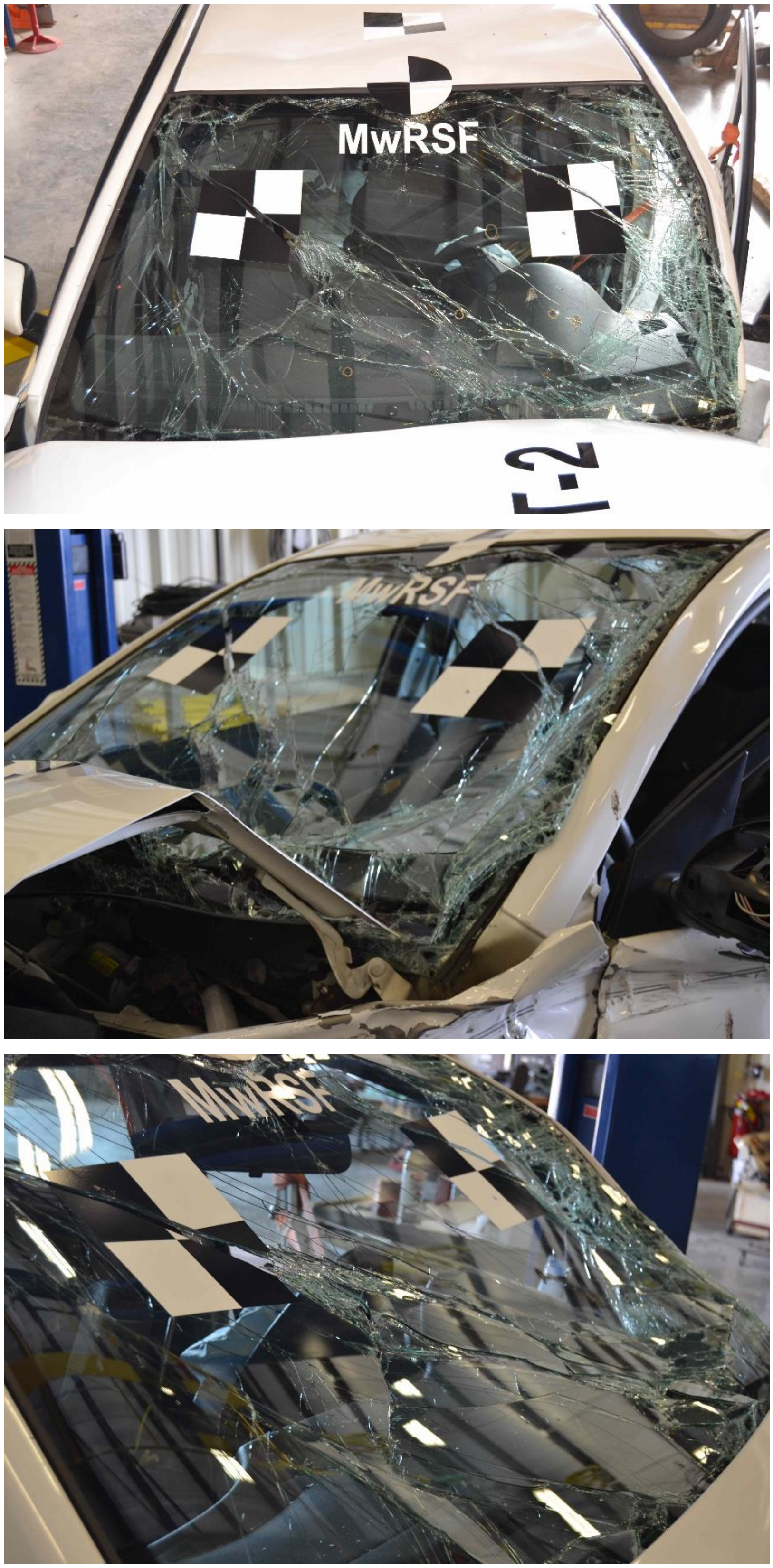


Figure 66. Windshield Damage, Test No. 34AGT-2

Figure 67. Occupant Compartment Deformation, Test No. 34AGT-2

Figure 68. Undercarriage Damage, Test No. 34AGT-2

Table 9. Maximum Occupant Compartment Intrusions by Location

LOCATION	MAXIMUM INTRUSION in. (mm)	MASH 2016 ALLOWABLE INTRUSION in. (mm)
Wheel Well & Toe Pan	4 (102)	≤ 9 (229)
Floor Pan & Transmission Tunnel	2¾ (70)	≤ 12 (305)
A-Pillar	½ (13)	≤ 5 (127)
A-Pillar (Lateral)	¾ (19)	≤ 3 (76)
B-Pillar	0 (0)	≤ 5 (127)
B-Pillar (Lateral)	0 (0)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	7 (178)	≤ 12 (305)
Side Door (Above Seat)	N/A	≤ 9 (229)
Side Door (Below Seat)	N/A	≤ 12 (305)
Roof	2¼ (57)	≤ 4 (102)
Windshield	2¼ (57)	≤ 3 (76)
Side Window	Shattered due to contact with dummy head	No shattering resulting from contact with structural member of test article

N/A – Not Applicable

7.6 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 10. Note that the OIVs and ORAs were within suggested limits for the primary transducer, as provided in MASH 2016. The backup transducer unit recorded longitudinal accelerations in excess of the ORA limits. However, the backup unit was not mounted at the vehicle c.g., which introduced significant error to the readings. Additionally, the time of assumed occupant impact, referred to in MASH 2016 as t*, occurs on the tail end of a longitudinal force spike. Thus, the variations in the accelerations observed by the two accelerometers, which resulted in slightly different t* times, resulted in greatly different longitudinal ORA values. Previous discussions among ISO 17025 accredited crash labs and the FHWA during Task Force 13 Subcommittee 7 meetings concluded with an agreement that accelerations at the c.g. (primary unit) should be trusted over accelerometers mounted elsewhere. Note, MASH 2016 procedures for the calculation of OIV and ORA are to be taken within 2 in. (51 mm) of the vehicle c.g. As such, the values calculated from the primary unit placed at the vehicle c.g., the SLICE-2, were considered to be more precise and in compliance with MASH 2016 evaluation standards. The calculated THIV, PHD, and ASI values are also shown in Table 10. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Table 10. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

Table 10. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. 34AGT-2

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-20.54 (-6.26)	-22.65 (-6.90)	±40 (12.2)
	Lateral	35.29 (10.76)	32.71 (9.97)	±40 (12.2)
ORA g's	Longitudinal	-25.55	-10.84	±20.49
	Lateral	-12.69	14.70	±20.49
MAX. ANGULAR DISPL. deg.	Roll	-15.3	-10.0	±75
	Pitch	-6.0	-5.5	±75
	Yaw	96.4	94.9	not required
THIV ft/s, (m/s)		38.39 (11.70)	36.65 (11.17)	not required
PHD g's		13.44	15.07	not required
ASI		2.43	2.30	not required

7.7 Discussion

The analysis of the test results for test no. 34AGT-2 showed that the system adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 69. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix E, were deemed acceptable as they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of -6.4 degrees, and its trajectory did not violate the bounds of the exit box.

The windshield of the small car was cracked and torn during the impact event. However, the windshield damage was initiated by the impact of the airbags deploying during the impact event. Damage to the windshield was intensified by deformations of the vehicle's A-frame and contact from the vehicle's hood. The test article never contacted the windshield directly, and there was no potential for the test article to penetrate into the vehicle. As such, the windshield damage was not considered to be a result of the system performance, and there was no perceived risk to the occupant.

The left-front door opened during the test as a result of contact with the barrier. The test article did not spear into the door nor extend through the opening and into the occupant compartment. Also, the door was not pushed inward thereby risking contact with the occupant. MASH 2016 does not contain language addressing door opening as a violation of the occupant compartment integrity. In May 2018, AASHTO issued a MASH clarifications document [35] stating that "a door opening during a crash test is not considered cause for test failure in and of itself; however, penetration of the test article and/or intrusion limits must be verified." Since there was no observed penetration or intrusion into the occupant compartment through the open door, the occupant compartment integrity criteria was not violated. Therefore, test no. 34AGT-2 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-20.

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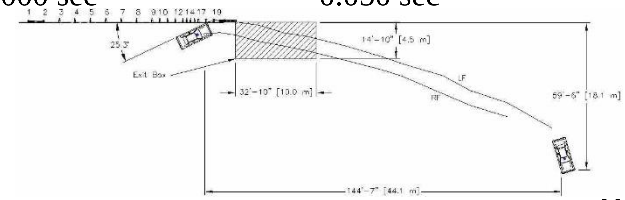

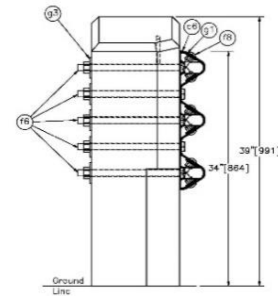

- Test Agency .... MwRSF
- Test Number 34AGT-2
- Date 5/9/17
- MASH 2016 Test Designation No. 3-20
- Test Article .... 34-in. (864-mm) Tall Thrie Beam AGT
- Total Length .... 87 ft – 11¼ in. (26.8 m)
- Key Component – Thrie beam Guardrail
  - Thickness .... 12 ga. (2.7 mm)
  - Mounting Height .... 34 in. (864 mm)
- Key Component – ASTM A992 W6x15 Steel Post
  - Length .... 84 in. (2,134 mm)
  - Embedment Depth .... 52 in. (1,321 mm)
  - Spacing .... 37½ in. (953 mm)
- Key Component – 4,000 psi Concrete Buttress
  - Length .... 84 in. (2134 mm)
  - Width .... 12 in. (305 mm)
  - Height .... 39 in. (991 mm)
- Soil Type .... Coarse Crushed Limestone
- Vehicle Make /Model .... Kia Rio
  - Curb .... 2,331 lb (1,057 kg)
  - Test Inertial .... 2,420 lb (1,098 kg)
  - Gross Static .... 2,580 lb (1,170 kg)
- Impact Conditions
  - Speed .... 62.1 mph (99.9 km/h)
  - Angle .... 25.5 deg
  - Impact Location .... 2 in. (51 mm) upstream from post no. 18
- Impact Severity (IS) ... 57.7 kip-ft (78.3 kJ) > 51 kip-ft (69.7 kJ) limit from MASH 2016
- Exit Conditions
  - Speed .... 40.7 mph (65.5 km/h)
  - Angle .... -6.4 deg
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 144.6 ft (44.1 m) downstream and 69.5 ft (21.2) in front
- Vehicle Damage .... Moderate
  - VDS [33] 11-LFQ-6
  - CDC [34] 11-FLEW-4
  - Maximum Interior Deformation .... 7 in. (178 mm)
- Test Article Damage .... Minimal
- Maximum Test Article Deflections
  - Permanent Set .... ¾ in. (19 mm)
  - Dynamic .... 2.7 in. (69 mm)
  - Working Width .... 19.9 in. (505 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-20.54 (-6.26)	-22.65 (-6.90)	±40 (12.2)
	Lateral	35.29 (10.76)	32.71 (9.97)	±40 (12.2)
ORA g's	Longitudinal	-25.55	-10.84	±20.49
	Lateral	-12.69	14.70	±20.49
MAX ANGULAR DISP. deg.	Roll	-15.3	-10.0	±75
	Pitch	-6.0	-5.5	±75
	Yaw	96.4	94.9	not required
THIV – ft/s (m/s)		38.39 (11.70)	36.65 (11.17)	not required
PHD – g's		13.44	15.07	not required
ASI		2.43	2.30	not required

Figure 69. Summary of Test Results and Sequential Photographs, Test No. 34AGT-2

8 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objective of this project was to modify the thrie beam AGT used by the NDOT by increasing the rail top-mounting height to 34 in. (864 mm) to account for future roadway overlays of up to 3 in. (76 mm). To accomplish this objective, the thrie beam rail segments were shifted upward 3 in. (76 mm) from their nominal 31-in. (787-mm) height, and a symmetric W-to-thrie transition segment was utilized to connect the 34-in. (864-mm) tall thrie beam to the adjacent 31-in. (787-mm) tall MGS. All posts maintained their original length and embedment depths from the existing/nominal NDOT transition detail. Thus, the rails and blockouts were simply shifted upward and attached 3 in. (76 mm) higher on the posts. The downstream end of the AGT was attached to a modified version of the standardized transition buttress to mitigate vehicle snag. The height of the standardized transition buttress was increased to match the 34-in. (864-mm) tall AGT by extending the height of the lower chamfer and the overall buttress height by 3 in. (76 mm). All other buttress dimensions remained the same.

Two full-scale crash tests were conducted on the 34-in. (864-mm) tall AGT according to the TL-3 safety performance criteria found in MASH 2016. A summary of the safety performance evaluation for both tests is provided in Table 11. The first full-scale crash test, test no. 34AGT-1, was performed according to test designation no. 3-21 of MASH 2016 with a 2270P pickup truck impacting the system 90½ in. (2,299 mm) upstream from the concrete buttress. The vehicle was safely contained and redirected with minor damage to the transition components. During the impact event, the left-front tire contacted the buttress and was pushed backward causing significant deformations to the left-side front panel and the toe pan. However, none of the MASH 2016 occupant compartment deformation limits were violated. All ORA and OIV values were within MASH 2016 safety limits. Therefore, test no. 34AGT-1 was determined to be acceptable according to test designation no. 3-21 of MASH 2016.

The second full-scale crash test, test no. 34AGT-2, was performed according to test designation no. 3-20 of MASH 2016 with an 1100C small car impacting the transition 65 in. (1,651 mm) upstream from the buttress. The vehicle was safely contained and redirected with minimal damage to the barrier transition system. During the test, the front tire extended under the thrie beam rail and impacted the upstream face of the buttress. Subsequently, the tire was pushed backward and caused significant deformations to the toe pan and left side front panel. A maximum crush value of 7 in. (178 mm) was recorded on the left-side front panel, but all deformations were within the MASH 2016 limits for occupant compartment deformations. ORA and OIV values from the primary unit were within the MASH 2016 safety limits. Therefore, test no. 34AGT-2 was determined to be acceptable according to test designation no. 3-20 of MASH 2016.

The upstream stiffness transition of the 34-in. (864-mm) AGT was designed to replicate the MASH-tested MGS stiffness transition, but a symmetric W-to-thrie rail transition segment was utilized instead of the asymmetric segment to increase the rail height from 31 in. (787 mm) to 34 in. (864 mm). This change was not a cause for concern as the bottom of the symmetric transition segment has a shallower vertical slope, which would reduce the severity of vehicle snag and wedging under the transition segment. Thus, testing of the upstream stiffness transition was not deemed critical.

Table 11. Summary of Safety Performance Evaluation Results

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. 34AGT-1</th><th>Test No. 34AGT-2</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td><td>S</td></tr>
<tr><td rowspan="5">Occupant Risk</td><td rowspan="2">D.</td><td>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.</td><td>S</td><td>S</td></tr>
<tr><td>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.</td><td>S</td><td>S</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td><td>S</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:<table><tr><th colspan="3">Occupant Impact Velocity Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr></table></td><td>S</td><td>S</td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr></table></td><td>S</td><td>S</td></tr>
<tr><td colspan="3">MASH 2016 Test Designation No.</td><td>3-21</td><td>3-20</td></tr>
<tr><td colspan="3">Final Evaluation (Pass or Fail)</td><td>Pass</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

After a roadway overlay, the symmetric W-to-thrie rail transition segment is to be replaced with an asymmetric transition segment, and the W-beam rail and corresponding blockouts are to be raised 3 in. (76 mm) on the supporting posts. These changes in combination with a 3-in. (76-mm) overlay will effectively result in the system being returned to its original MASH-tested configuration with a rail height of 31 in. (787 mm) throughout the entire guardrail transition and the buttress returning to its nominal configuration relative to the roadway surface. Therefore, testing of the AGT after a 3-in. (76-mm) roadway overlay was deemed non-critical, and the 34-in. (864-mm) tall AGT developed herein was considered MASH 2016 TL-3 crashworthy for roadways with overlays between 0-3 in. (0-76 mm) thick.

The 34-in. (864-mm) tall AGT resulted in stable redirections with minimal vehicle roll and pitch motions compared to historical guardrail transition tests. The increased height of the guardrail is likely the main cause for this decrease in vehicle angular displacements as it prevents larger vehicles (e.g., pickup trucks) from rolling into the barrier. These observations support previous research indicating that lower height transitions can cause vehicle instability and rollovers [14].

A modified version of the standardized buttress was incorporated into the design of the 34-in. (864-mm) AGT detailed herein. This buttress was previously designed to minimize vehicle snag within guardrail transitions and is considered vital to the safety performance of the 34-in. (864-mm) tall AGT. Therefore, it is recommended to utilize the buttress design detailed herein with the 34-in. (864-mm) tall AGT.

Conversely, the unique shape of the standardized buttress does allow other thrie beam transitions to be installed at the increased mounting height of 34 in. (864 mm). The standardized buttress was developed to be compatible with all NCHRP Report 350 and MASH crashworthy, 31-in. (787-mm) tall, thrie beam AGTs. Thus, any other crashworthy, 31-in. (787-mm) tall AGT with a similar lateral stiffness (or stiffer) should also be considered as crashworthy when used at an increased mounting height of 34 in. (864 mm). Note, both the modified buttress design and the upstream stiffness transition detailed herein (before and after an overlay) must be utilized to ensure the safety performance of the system. Details on connecting the MGS stiffness transition to various thrie beam AGTs were provided in a previous research report [18].

Through previous crash testing, curbs located beneath AGTs have been shown to aide in the mitigation of vehicle snag on the rigid parapet. The 34-in. (864-mm) tall AGT was successfully crash tested in a critical configuration without a curb, and the standardized transition buttress was originally designed to be crashworthy with or without a curb. As such, the addition of a curb below the 34-in. (864-mm) tall AGT should also be considered a crashworthy configuration. However, if the curb extends into the region of the upstream stiffness transition, 12.5 ft (3.8 m) of nested W-beam rail must be placed upstream from the W-to-thrie transition segment to prevent rail rupture [36-37], as shown in Figure 70.

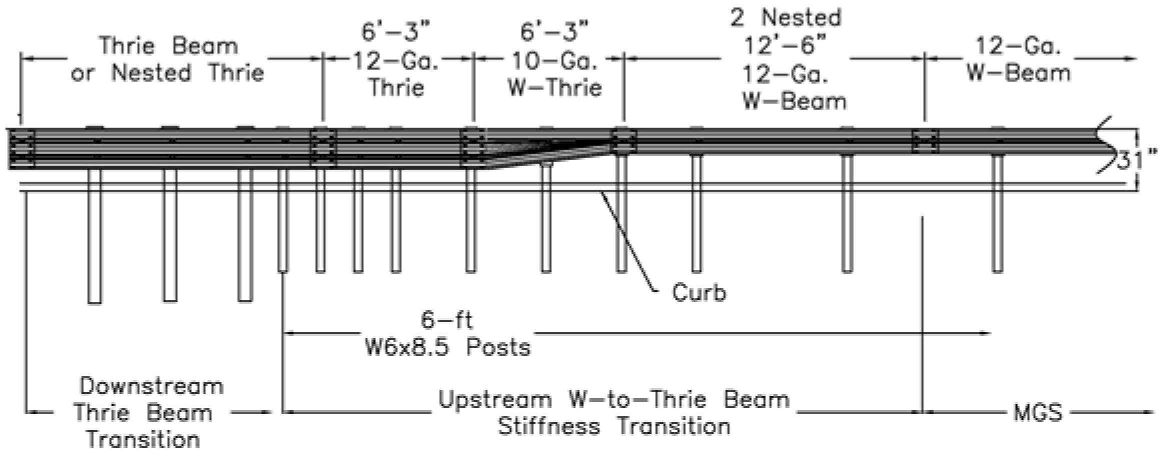

Figure 70. Nested W-beam Upstream from W-to-Thrie Segment for Curbed Installations

The AGT tested herein incorporated 8-in. (203-mm) deep blockouts on the W6x15 posts within the downstream end of the transition and 12-in. (305-mm) deep blockouts on the W6x8.5 posts within the upstream MGS stiffness transition. Utilizing 12-in. (305-mm) deep blockouts throughout the AGT may help reduce vehicle snag on the larger transition posts, since the posts would need to be offset 4 in. (102 mm) farther from the rail. Thus, incorporating 12-in. (305-mm) deep blockouts throughout the AGT should also be considered a crashworthy configuration. However, the upstream stiffness transition was developed and tested exclusively with 12-in. (305-mm) deep blockouts. Full-scale testing of the MGS stiffness transition did result in moderate vehicle snag on the guardrail posts when impacted with the small car [18-19, 36-37]. There are concerns that reducing the blockout depth in the MGS stiffness transition may result in increased vehicle snag. Consequently, blockouts less than 12 in. (305-mm) deep are not recommended for use within the upstream stiffness transition until further analysis is conducted.

The concrete buttress utilized during the testing of the 34-in. (864-mm) tall AGT utilized a vertical front face to optimize vehicle stability during impacts. However, the adjacent bridge rail or concrete parapet may not have the same geometry. Thus, the downstream end of the buttress must contain a shape transition aligned with the adjacent bridge rail or concrete parapet. Shape transitions should be gradual to prevent vehicle instabilities. Based on previous simulation efforts, transitions to the face geometry of a rigid barrier incorporating lateral slopes steeper than 10:1 may cause stability issues [38]. Thus, it is recommended to utilize a 10:1 lateral slope to transition the shape of the standardized buttress, and shape transitions may begin 6 in. (152 mm) downstream from the thrie beam terminal connector, or 8 in. (203 mm) downstream from the attachment bolts. Further guidance on buttress shape transitions can be found in previous reports on the standardized buttress [12-13].

Height transitions may be necessary for attachment to taller bridge rails and concrete parapets. The upstream end of the buttress was successfully tested with a vertical taper of 4 in. (102 mm) over a 24-in. (610-mm) length. This vertical slope on the upstream end may be continued upward with the same 6:1 slope until the desired height is reached. Thus, the 34-in. (864-mm) AGT developed herein can be utilized in conjunction with many different concrete barriers by simply altering the shape of the downstream end of the buttress.

The 34-in. (864-mm) tall AGT design requires the W-beam rail upstream from the AGT to be raised 3 in. (76 mm) after an overlay to maintain a 31-in. (787-mm) rail mounting height. To make this process easier, it is recommended that the guardrail posts supporting the MGS upstream from the AGT be fabricated with a secondary set of bolt holes located 3 in. (76 mm) above the typical holes. This will prevent installers from having to drill new holes in the post when adjusting the rail height, thereby making raising the W-beam rail a quick and easy process and reducing the potential for corrosion due to field drilled holes.

With the successful testing conducted within this project, NDOT’s thrie beam transition in combination with the standardized transition buttress has been shown to be MASH crashworthy with rail mounting heights of 31 in. (787 mm) and 34 in. (864 mm). However, there have not been any studies to evaluate the system with rail heights below 31 in. (787 mm) or above 34 in (864 mm). As such, the performance of the system outside of these bounds remains unknown.

It was assumed herein that any roadways overlays would be extended laterally at least to the face of the rail, but not farther than the face of the posts. Extending an overlay past the posts would increase the embedment depth and stiffen the soil resistance around the posts. Previous crash testing has shown this to alter the behavior of the posts, increase rail pocketing and stresses, and ultimately lead to rail rupture. As such, any applied roadway overlay should not be extended beyond the face of the posts unless leave-outs are placed around the posts.

It is recognized that not all roadway overlays are 3 in. (76 mm) thick, and thinner overlays may be placed in front of the AGT. Although overlays of all thicknesses reduce the effective height of the barrier, which may lead to increased vehicle instabilities and rollovers [14, 39], it is unlikely that the barrier performance would be significantly affected by very thin overlays. In the authors’ opinion, it would seem unreasonable to have to alter long lengths of approach W-beam guardrail that is connected to the 34-in. (864-mm) tall AGT for minimal thickness roadway overlays. Thus, it is suggested that the symmetric W-beam to thrie beam transition rail be replaced with the asymmetric rail and the approach W-beam guardrail be raised only for overlays exceeding 1 in. (25 mm) thick.

Finally, the system was originally detailed, constructed, and tested with the center of the first transition post offset a distance of 25½ in. (648 mm) from the upstream face of the concrete buttress. However, based on the geometry of the buttress, the location of the bolt holes, and the standard dimensions of thrie beam guardrail hardware, the nominal offset distance for this post should be 26¼ in. (667 mm). The bolt slots located within guardrail splices and at post attachment locations allowed for the test article to be installed with the shorter distance. Changing this post offset distance by ¾ in. (19 mm) is not believed to affect the performance of the transition. Thus, it is recommended to utilize the nominal 26¼ in. (667 mm) offset distance for future, real-world installations. The finalized system details, including the 26¼ in. (667 mm) post offset distance, are shown in Appendix G.

9 MASH EVALUATION

The 34-in. (864-mm) tall approach guardrail transition (AGT) developed for the Nebraska Department of Transportation was intended for use on roadways which may receive future overlays. The 34-in. (864-mm) tall AGT was based on the current NDOT thrie beam guardrail transition. However, the thrie beam rails were raised 3 in. (76 mm) from their nominal 31-in. (787-mm) height. Rail at the downstream end of the AGT was supported by W6x15 posts spaced at 37.5 in. (953 mm), while the upstream end rail elements were supported by W6x8.5 posts at various spacings corresponding to the MGS stiffness transition. The posts maintained their nominal embedment depths of 52 in. (1,321 mm) and 40 in. (1,016 mm), respectively, in order to maintain the stiffness of the AGT. Thus, the thrie beam rails and blockouts were attached 3 in. (76 mm) higher on the posts than nominal. Previous studies have concluded that guardrail can be raised up to 4 in. (102 mm) on the support posts and the system will remain crashworthy. A symmetric W-to-thrie transition segment was utilized to attach the 34-in. (864-mm) tall thrie beam to 31-in. (787-mm) tall MGS upstream from the AGT.

The downstream end of the 34-in. (864-mm) transition was attached to a modified version of the standardized transition buttress. The overall height of the buttress was increased by 3 in. (76 mm) to match the increased height of the thrie beam. Additionally, the height of the lower chamfer was increased from 14 in. (356 mm) to 17 in. (432 mm), but all other dimensions from the original standardized transition buttress remained the same.

The upstream stiffness transition of the 34-in. (864-mm) tall AGT was specifically designed to replicate the MASH-crashworthy MGS stiffness transition. Upon initial installation, the only difference between the two systems was that the 34-in. (864-mm) tall AGT utilized a symmetric W-to-thrie transition rail instead of an asymmetric transition rail. Since the W-beam upstream from the transition rail was mounted at its nominal 31-in. (787-mm) height, vehicles impacting this region of the barrier should not extend over the rail and roll excessively. Additionally, the bottom of the symmetric transition rail has a shallower slope than the asymmetric segment and would likely produce less snag as a small vehicle tries to wedge underneath the rail. Thus, there were no concerns about vehicle stability and/or snag on the upstream stiffness transition of the 34-in. (864-mm) tall AGT prior to a roadway overlay.

After the roadway overlay, the symmetric rail segment is replaced by an asymmetric segment and the W-beam of the adjacent MGS is raised 3 in. (76 mm) on the posts to maintain its nominal 31-in. (787-mm) mounting height. Thus, after an overlay, the upstream stiffness transition is essentially identical to the MASH-tested MGS stiffness transition. Since the MGS stiffness transition was previously subjected to and successfully passed MASH TL-3 criteria, the upstream stiffness transition within the 34-in. (864-mm) tall AGT would be MASH TL-3 crashworthy as well. Therefore, all crash testing of the upstream stiffness transition, both before and after an overlay, was deemed non-critical.

At the downstream end of the 34-in. (864-mm) tall AGT, the increased height of the thrie beam exposed more of the rigid buttress below the rail and increased the propensity for vehicle snag. Both the front end of small cars and pickup truck tires were susceptible to excessive snag by extending below the rail and impacting the rigid buttress. As such, MASH TL-3 crash tests with both the small car and pickup truck were determined to be critical in evaluating the crashworthiness of the downstream end of the 34-in. (864-mm) tall AGT.

After a 3-in. (76-mm) overlay, the thrie beam would be at its nominal 31-in. (787-mm) height relative to the roadway, and the buttress geometry would be the same as the original standardized transition buttress. As such, the potential for vehicle snag on the buttress is decreased as the exposed area of the buttress is smaller. Further, the standardized transition buttress was developed and MASH crash tested to be compatible with all crashworthy 31-in. (787-mm) tall thrie beam AGTs. Subsequently, testing of the downstream end of the 34-in. (864-mm) tall AGT after the application of a 3-in. (76-mm) roadway overlay was deemed non-critical. Thus, only two full-scale tests were recommended to evaluate the crashworthiness of the 34-in. (864-mm) tall AGT to MASH 2016 TL-3 criteria.

MASH test nos. 3-21 and 3-20 were both conducted on the downstream end of the transition with the rail mounted 34 in. (864 mm) above the roadway surface (pre-overlay configuration). Test no. 34AGT-1 was performed with a 2270P pickup truck impacting the system 90½ in. (2,299 mm) upstream from the concrete buttress, while test no. 34AGT-2 was performed with an 1100C small car impacting 65 in. (1,651 mm) upstream from the buttress. Both vehicles were contained and smoothly redirected with minimal roll and pitch angular displacements. The system received only minor damage in the form of rail deformations, post deflections, and contact marks. The front tire of both vehicles did contact the buttress below the thrie beam rail causing significant deformations to the side front panels and toe pans of both vehicles. However, none of the MASH 2016 occupant compartment deformation limits were violated, and all ORA and OIV values were within MASH 2016 safety limits. Therefore, test nos. 34AGT-1 and 34AGT-2 were determined to be acceptable according to test designation nos. 3-21 and 3-20, respectively, of MASH 2016.

Due to the two successful full-scale tests, the incorporation of the upstream MGS stiffness transition, and use of a modified version of the standardized transition buttress, as described herein, the 34-in. (864-mm) tall AGT was determined to be crashworthy to MASH 2016 TL-3 standards both before and after a 3-in. (76-mm) roadway overlay.

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11 APPENDICES

Appendix A. Material Specifications

Table A-1. Bill of Materials for Test Nos. 34AGT-1 and 34AGT-2

Item No.	Description	Material Specification	Reference
a1	12’-6” [3,810] 12-gauge [2.7] Thrie Beam Section	AASHTO M180	H#L30117
a2	6’-3” [1,905] 12-gauge [2.7] Thrie Beam Section	AASHTO M180	H#L34816
a3	10-gauge [3.4] Symmetrical W-beam to Thrie Beam Transition	AASHTO M180	H#184354 H#41224740
a4	12’-6” [3,810] 12-gauge [2.7] W-Beam Section	AASHTO M180	H#9411949
a5	12’-6” [3,810] 12-gauge [2.7] W-Beam MGS End Section	AASTHO M180	H#9411949
a6	10-gauge [3.4] Thrie Beam End Shoe Section	AASHTO M180	H#NF4556 H#A78617
a7	6’-3” [1,905] 12-gauge [2.7] W-Beam MGS Section	AASHTO M180	H#515690
b1	Concrete – 21.9 cubic ft [0.62 cubic m]	Min. f’c = 4,000 psi [27.6 MPa]	TICKET#4190653
c1	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots +/- 18” [457] from ground on tension face)	CNWP COC – 11/11/2016
c2	72” [1,829] Long Foundation Tube	ASTM A500 Gr. B	H#0173175
c3	Ground Strut Assembly	ASTM A36	TII COC – 6/30/2008
c4	BCT Cable Anchor Assembly	n/a	H#DL15103032 L#366055B
c5	Anchor Bracket Assembly	ASTM 36	H#V911470
c6	8”x8”x5/8” [203x203x16] Anchor Bearing Plate	ASTM 36	H#DL15103543
c7	2 3/8” [60] O.D. x 6” [152] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	H#E86298
d1	W6x8.5, 72” [1,829] Long Steel Post	ASTM A992	H#55044258
d2	W6x8.5, 72” [1,829] Long Steel Post	ASTM A992	H#55044258
d3	W6x8.5, 72” [1,829] Long Steel Post	ASTM A992	H#55044258
d4	W6x15, 84” [2,134] Long Steel Post	ASTM A992	H#2612103
d5	6”x8”x19” [152x203x483] Timber Blockout	SYP Grade No. 1 or better	CNWP COC – 7/18/2016
d6	6”x12”x19” [152x305x483] Timber Blockout	SYP Grade No. 1 or better	CNWP COC – 7/18/2016
d7	6”x12”x19” [152x305x483] Timber Blockout	SYP Grade No. 1 or better	CNWP COC – 7/18/2016

Table A-2. Bill of Materials for Test Nos. 34AGT-1 and 34AGT-2, Continued

Item No.	Description	Material Specification	Reference
d8	6”x12”x14 1/4” [152x305x368] Timber Blockout	SYP Grade No. 1 or better	CNWP COC – 7/26/2016
d9	16D Double Head Nail	n/a	McMaster-Carr COC
e1	1/2” [13] Dia., 92” [2,337] Long Bent Rebar	ASTM A615 Gr. 60	H#62139047
e2	1/2” [13] Dia., 65 3/4” [1,670] Long Bent Rebar	ASTM A615 Gr. 60	H#62139047
e3	1/2” [13] Dia., 63 1/2” [1,612] Long Bent Rebar	ASTM A615 Gr. 60	H#62139047
e4	1/2” [13] Dia., 62 1/4” [1,581] Long Bent Rebar	ASTM A615 Gr. 60	H#62139047
e5	1/2” [13] Dia., 80 3/4” [2,051] Long Bent Rebar	ASTM A615 Gr. 60	H#62139047
e6	1/2” [13] Dia., 40 1/4” [1,022] Long Rebar	ASTM A615 Gr. 60	H#62139047
e7	1/2” [13] Dia., 80 5/16” [2,039] Long Bent Rebar	ASTM A615 Gr. 60	H#62139047
e8	1/2” [13] Dia., 85 1/2” [2,171] Long Bent Rebar	ASTM A615 Gr. 60	H#62139047
e9	1/2” [13] Dia., 80” [2,032] Long Rebar	ASTM A615 Gr. 60	H#62139047
e10	1/2” [13] Dia., 80 1/2” [2,045] Long Bent Rebar	ASTM A615 Gr. 60	H#62139047
f1	5/8” [16] Dia. UNC, 14” [356] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	H#NF16100453
f2	5/8” [16] Dia. UNC, 10” [254] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	H#20351510
f3	5/8” [16] Dia. UNC, 1 1/4” [32] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	Bolt: H#0053777-115516 Nut: H#0055551-116146
f4	5/8” [16] Dia. UNC, 10” [254] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	Bolt: H#DL15102793 Nut: Stelfast COC – 12/7/2015
f5	5/8” [16] Dia. UNC, 1 1/2” [38] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	Bolt: H#10207560 Nut: Stelfast COC – 12/7/2015
f6	7/8” [22] Dia. UNC, 14” [356] Long Heavy Hex Bolt and Nut	n/a	Bolt: H#3051123 Nut: H#NF14204558
f7	7/8” [16] Dia. UNC, 8” [203] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	Bolt: H#2038622 Nut: H#12101054
f8	5/8” [16] Dia. UNC, 2” [51] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	H#1377346
g1	5/8” [16] Dia. Plain Round Washer	ASTM F844	n/a
g2	7/8” [22] Dia. Plain Round Washer	ASTM F844	n/a
g3	3”x3”x1/4” [76x76x6] Square Plate Washer	ASTM A572 Gr. 50	H#B505037

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1272514 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3376
BOL Number: 98293 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 1/9/17

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
100	901G	12/FLARE/8 HOLE	M-180	A	2	193147	62,430	81,280	26.2	0.190	0.730	0.014	0.003	0.020	0.110	0.000	0.060	0.001	4
4	974G	T12/TRANS RAIL/6'3"/3'1.5	M-180	A	2	184354	64,550	83,590	22.1	0.190	0.730	0.010	0.003	0.020	0.100	0.000	0.050	0.000	4
10,000	3340G	5/8" GR HEX NUT	HW			0057933-117335													
6,000	3360G	5/8"X1.25" GR BOLT	HW			0049412-112338													
1,200	3400G	5/8"X2" GR BOLT	HW			1377346													
200	3480G	5/8"X8" GR BOLT A307	HW			29038-b													
675	3500G	5/8"X10" GR BOLT A307	HW			29366													
2,100	3540G	5/8"X14" GR BOLT A307	HW			29253													
10	12173G	T12/6'3/4@1'6.75"/S			2	L35216													
			M-180	A	2	209331	62,090	81,500	28.1	0.190	0.720	0.013	0.002	0.020	0.110	0.000	0.070	0.002	4
			M-180	A	2	209332	61,400	81,290	25.3	0.190	0.730	0.014	0.003	0.020	0.120	0.000	0.060	0.001	4
			M-180	A	2	209333	61,200	80,050	25.8	0.200	0.740	0.016	0.005	0.010	0.120	0.000	0.070	0.002	4
	12173G				2	L34816													
			M-180	A	2	208674	63,250	82,410	22.7	0.190	0.730	0.011	0.003	0.020	0.100	0.000	0.060	0.002	4
			M-180	A	2	208675	62,100	81,170	22.7	0.190	0.730	0.012	0.004	0.020	0.090	0.000	0.050	0.001	4
			M-180	A	2	208676	62,920	82,040	25.4	0.190	0.720	0.012	0.004	0.010	0.100	0.000	0.060	0.002	4
140	12365G	T12/12'6/8@1'6.75/S			2	L30117													
			M-180	A	2	209331	62,090	81,500	28.1	0.190	0.720	0.013	0.002	0.020	0.110	0.000	0.070	0.002	4
			M-180	A	2	209332	61,400	81,290	25.3	0.190	0.730	0.014	0.003	0.020	0.120	0.000	0.060	0.001	4

2 of 4

Figure A-2. 12-ft 6-in. (3.8-m) Thrie Beam Sections for Test Nos. 34AGT-1 and 34AGT-2

Certified Analysis

Trinity Highway Products, LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1272514 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3376
BOL Number: 98293 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 1/9/17

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
100	901G	12/FLARE/8 HOLE	M-180	A	2	193147	62,430	81,280	26.2	0.190	0.730	0.014	0.003	0.020	0.110	0.000	0.060	0.001	4
4	974G	T12/TRANS RAIL/6'3"/3'1.5	M-180	A	2	184354	64,550	83,590	22.1	0.190	0.730	0.010	0.003	0.020	0.100	0.000	0.050	0.000	4
10,000	3340G	5/8" GR HEX NUT	HW			0057933-117335													
6,000	3360G	5/8"X1.25" GR BOLT	HW			0049412-112338													
1,200	3400G	5/8"X2" GR BOLT	HW			1377346													
200	3480G	5/8"X8" GR BOLT A307	HW			29038-b													
675	3500G	5/8"X10" GR BOLT A307	HW			29366													
2,100	3540G	5/8"X14" GR BOLT A307	HW			29253													
10	12173G	T12/6'3/4@1'6.75"/S			2	L35216													
			M-180	A	2	209331	62,090	81,500	28.1	0.190	0.720	0.013	0.002	0.020	0.110	0.000	0.070	0.002	4
			M-180	A	2	209332	61,400	81,290	25.3	0.190	0.730	0.014	0.003	0.020	0.120	0.000	0.060	0.001	4
			M-180	A	2	209333	61,200	80,050	25.8	0.200	0.740	0.016	0.005	0.010	0.120	0.000	0.070	0.002	4
	12173G				2	L34816													
			M-180	A	2	208674	63,250	82,410	22.7	0.190	0.730	0.011	0.003	0.020	0.100	0.000	0.060	0.002	4
			M-180	A	2	208675	62,100	81,170	22.7	0.190	0.730	0.012	0.004	0.020	0.090	0.000	0.050	0.001	4
			M-180	A	2	208676	62,920	82,040	25.4	0.190	0.720	0.012	0.004	0.010	0.100	0.000	0.060	0.002	4
140	12365G	T12/12'6/8@1'6.75/S			2	L30117													
			M-180	A	2	209331	62,090	81,500	28.1	0.190	0.720	0.013	0.002	0.020	0.110	0.000	0.070	0.002	4
			M-180	A	2	209332	61,400	81,290	25.3	0.190	0.730	0.014	0.003	0.020	0.120	0.000	0.060	0.001	4

Figure A-3. 6-ft 3-in. (1.9-m) Thrie Beam Sections for Test Nos. 34AGT-1 and 34AGT-2

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1266588 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3319
BOL Number: 96589 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 9/16/16

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
			M-180	A	2	204522	62,180	80,590	25.5	0.190	0.720	0.014	0.003	0.020	0.120	0.000	0.060	0.000	4
			M-180	A	2	204664	61,480	79,120	26.8	0.190	0.720	0.013	0.002	0.020	0.090	0.000	0.070	0.001	4
			M-180	A	2	204665	59,050	78,290	25.9	0.200	0.720	0.007	0.002	0.020	0.060	0.000	0.040	0.000	4
20	957G	T12/BUFFER/ROLLED	A-36			4145361	56,100	71,000	32.0	0.210	0.400	0.007	0.003	0.020	0.030	0.000	0.030	0.000	4
8	974G	T12/TRANS RAIL/6'3"/3'1.5	M-180	A	2	184354	64,550	83,590	22.1	0.190	0.730	0.010	0.003	0.020	0.100	0.000	0.050	0.000	4

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy QMS-LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT , 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED

BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

State of Ohio, County of Allen. Sworn and subscribed before me this 16th day of September, 2016 .

Notary Public: Monique Holmes
Commission Expires: 7/5/2020

NOTARIAL SEAL STATE OF OHIO
MONIQUE HOLMES
Notary Public, State of Ohio
My Commission Expires
July 5, 2020

Trinity Highway Products, LLC
Certified By:
Quality Assurance

5 of 5

Figure A-4. Symmetrical W-Beam to Thrie Beam Transitions for Test No. 34AGT-1

Roadway Construction Productions
511 West Main Street
Clarkson, Ky 42726

****
MILL CERTIFICATION REPORT
****

Invoice No.: 80369 Page 1
Date: 03/30/2017
Purchase Order:
County:
Project No.:
Bill of Lading: 80369

Sold to:
MIDWEST ROADSIDE SAFETY FAC.

Tested in accordance with ASTM A36. R#17-554 RCP
All structural steel meets AASHTO-111. Thrie Beam Transition Materials
All steel used in MFG. is of domestic orgin.
Galv. material conforms with ASTM-123 & AASHTO M 232-82
All guardrail & terminal sections meets AASHTO M-180.
Bolts, nuts & washers comply with ASTM-307 and/or A325 specifications.

Hereby certify that the material test results presented here are from the reported heat and are correct. All test were reported accordance to the specifications reported above. All steel is electric furnace melted, manufactured, processed and tested in the U.S.A. with satisfactory results, and is free from mercury contamination in the product.

STATE OF KENTUCKY, COUNTY OF STATE AT LARGE
Sworn and Subscribed Before Me This 30th day of March 2017
Notary Public: Michelle Smith
My Commission expires: 7/25/18

MICHELL ANN SMITH NOTARY PUBLIC ID NO. MY COMMISSION EXPIRES STATE AT LARGE

QTY	HEAT NO	PART NO	DESCRIPTION	YIELD	TENSILE	ELONGATION	LENGTH	TEST
2	A78617	G20055BF-G	10GA.THRI.END G	62.7	85.3	23.8	92"	#1 #2
1	41224740	G20001TS-G	10GA THRIE BEAM	64105	84939	25.0		#1 #2
1	A78617	G20002TS-G	10GA.RIGHTTHRIE	62.7	85.3	23.8	92"	#1 #2
1	A78617	G20003TS-G	LEFT ASYM TRANS	62.7	85.3	23.8	92"	#1 #2

C	MN	P	S	SI	CU	NI	CR	MO	CB	V	AL
.200	.67	.009	.002	.03							.022
.21	.82	.010	.006	.020	.110	.040	.050	.010		.002	.021
.200	.67	.009	.002	.03							.022
.200	.67	.009	.002	.03							.022

Figure A-5. Symmetrical W-Beam to Thrie Beam Transition for Test No. 34AGT-2 and Thrie Beam Terminal Connector for Test No. 34AGT-2

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

Customer:	UNIVERSITY OF NEBRASKA-LINCOLN 401 CANFIELD ADMIN BLDG P O BOX 880439 LINCOLN,NE,68588-0439	Test Report	
		Ship Date:	7/9/2015
		Customer P.O.:	4500274709/ 07/07/2015
		Shipped to:	UNIVERSITY OF NEBRASKA-LINCOLN
		Project:	TESTING COIL
		GHP Order No.:	183306

HT # code	Heat #	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
8534	9411949	0.21	0.75	0.01	0.006	0.01	75774	56527	27.15	10	A	2	12GA 25FT WB T2 MGS ANCHOR PANEL
8534	9411949	0.21	0.75	0.01	0.006	0.01	75774	56527	27.15	100	A	2	12GA 12FT6IN/3FT1 1/2IN WB T2
8534	9411949	0.21	0.75	0.01	0.006	0.01	75774	56527	27.15	20	A	2	12GA 25FT0IN 3FT1 1/2IN WB T2

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

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

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public by Andrew Artar this 17 day of July, 2015
Notary Public, State of Ohio

NOTARIAL SEAL
STATE OF OHIO

DAWN R. BATTON
NOTARY PUBLIC
STATE OF OHIO
Comm. Expires
March 03, 2018
Recorded in
Portage County

Figure A-6. 12-ft 6-in. (3.8-m) W-Beam Sections and MGS End Sections for Test Nos. 34AGT-1 and 34AGT-2

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1270666 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3360
BOL Number: 97906 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 12/6/16

Qty	Part#	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
20	261G	T12/25/3'1.5/S	RHC		2	L31116													4
			M-180	A	2	199734	61,020	79,950	25.0	0.190	0.720	0.012	0.003	0.030	0.110	0.000	0.050	0.001	4
			M-180	A	2	199735	63,000	80,900	25.6	0.190	0.730	0.011	0.004	0.020	0.110	0.000	0.050	0.000	4
			M-180	A	2	199734	61,020	79,950	25.0	0.190	0.720	0.012	0.003	0.030	0.110	0.000	0.050	0.001	4
			M-180	A	2	199735	63,000	80,900	25.6	0.190	0.730	0.011	0.004	0.020	0.110	0.000	0.050	0.000	4
110	901G	12/FLARE/8 HOLE	M-180	A	2	193147	62,430	81,280	26.2	0.190	0.730	0.014	0.003	0.020	0.110	0.000	0.060	0.001	4
10	929G	10/END SHOE/KS/2 EXT	M-180	B	2	193144	59,120	78,090	29.2	0.190	0.720	0.013	0.004	0.010	0.120	0.000	0.040	0.000	4
8	969G	T12/BARRIER/ROLLED/84"	A-36			9412222	54,100	72,900	31.0	0.200	0.400	0.008	0.005	0.010	0.020	0.000	0.040	0.001	4
50	980G	T10/END SHOE/SLANT	M-180	B	2	NF4556	40,000	53,600	36.5	0.040	0.180	0.009	0.003	0.016	0.120	0.002	0.040	0.002	4
600	3320G	3/16"X1.75"X3" WASHER	HW			P37058													
5,000	3340G	5/8" GR HEX NUT	HW			16-54-031													
4,000	3360G	5/8"X1.25" GR BOLT	HW			0049412-112338													
200	3480G	5/8"X8" GR BOLT A307	HW			29038-b													
450	3500G	5/8"X10" GR BOLT A307	HW			29168-B													
700	3540G	5/8"X14" GR BOLT A307	HW			29253													
20	6901B	PLYMR BLK 4X7.5X22	HW			14689													
10	10431G	12/12'6/8@1'6-3/4/S			2	L14416													

R#17-395 Order for Thrie Buttress
Order includes Blockouts, w6x15 posts,
Transitions and End Shoes
January 2017 SMT

1 of 7

Figure A-7. Thrie Beam Terminal Connector Sections for Test No. 34AGT-1

Certified Analysis

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

MILFORD, NE 68405
Project: RESALE

Order Number: 1164746
Customer PO: 2563
BOL Number: 69500
Document #: 1
Shipped To: NE
Use State: KS

As of: 5/16/12

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
50	6G	12/6'3/S	M-180	A	2	515691	64,000	72,300	27.0	0.060	0.740	0.009	0.008	0.010	0.021	0.04	0.032	0.000	4
			M-180	A	2	4111321	63,100	80,200	29.0	0.210	0.710	0.009	0.007	0.010	0.030	0.000	0.030	0.000	4
			M-180	A	2	515659	67,000	75,200	26.0	0.064	0.790	0.012	0.008	0.008	0.022	0.000	0.025	0.000	4
			M-180	A	2	515660	66,800	74,300	27.0	0.064	0.740	0.012	0.006	0.009	0.017	0.000	0.025	0.000	4
			M-180	A	2	515662	63,900	72,900	28.0	0.064	0.770	0.010	0.006	0.009	0.016	0.000	0.025	0.000	4
			M-180	A	2	515663	64,900	76,500	21.0	0.064	0.740	0.009	0.007	0.007	0.023	0.000	0.026	0.000	4
			M-180	A	2	515668	66,700	75,500	27.0	0.063	0.770	0.014	0.007	0.010	0.024	0.000	0.030	0.000	4
			M-180	A	2	515668	70,200	80,800	21.0	0.063	0.770	0.014	0.007	0.010	0.024	0.000	0.030	0.000	4
			M-180	A	2	515669	64,500	74,100	26.0	0.063	0.790	0.014	0.007	0.009	0.017	0.000	0.028	0.000	4
			M-180	A	2	515687	63,400	74,100	30.0	0.068	0.750	0.012	0.010	0.008	0.025	0.000	0.060	0.000	4
			M-180	A	2	515687	65,100	74,400	28.0	0.068	0.750	0.012	0.010	0.008	0.025	0.000	0.060	0.000	4
			M-180	A	2	515690	63,000	71,800	27.0	0.059	0.720	0.010	0.008	0.013	0.024	0.000	0.042	0.000	4
			M-180	A	2	515696	62,900	72,500	28.0	0.058	0.740	0.013	0.008	0.011	0.029	0.000	0.046	0.000	4
			M-180	A	2	515696	63,900	73,400	29.0	0.058	0.740	0.013	0.008	0.011	0.029	0.000	0.046	0.000	4
			M-180	A	2	515700	67,800	77,700	28.0	0.065	0.800	0.013	0.009	0.012	0.036	0.000	0.035	0.000	4
			M-180	A	2	616068	62,900	71,600	27.0	0.061	0.740	0.013	0.010	0.012	0.027	0.000	0.064	0.000	4
			M-180	A	2	616068	66,700	74,200	30.0	0.061	0.740	0.013	0.010	0.012	0.027	0.000	0.064	0.000	4
			M-180	A	2	616071	64,000	74,000	28.0	0.061	0.760	0.016	0.007	0.011	0.021	0.000	0.028	0.000	4
			M-180	A	2	616072	63,800	74,200	29.0	0.066	0.750	0.014	0.009	0.010	0.026	0.000	0.039	0.000	4
			M-180	A	2	616073	63,900	73,300	27.0	0.064	0.760	0.016	0.009	0.012	0.024	0.000	0.041	0.000	4
			M-180	A	2	616073	65,000	74,500	28.0	0.064	0.760	0.016	0.009	0.012	0.024	0.000	0.041	0.000	4
30	60G	12/25/6'3/S	M-180	A	2	4111321	63,100	80,200	29.0	0.210	0.710	0.009	0.007	0.010	0.030	0.00	0.030	0.000	4
			M-180	A	2	515656	63,600	73,600	27.0	0.066	0.720	0.012	0.006	0.011	0.021	0.000	0.026	0.000	4
			M-180	A	2	515658	64,800	74,300	26.0	0.069	0.740	0.010	0.006	0.011	0.022	0.000	0.021	0.000	4
			M-180	A	2	515659	67,000	75,200	26.0	0.064	0.790	0.012	0.008	0.008	0.022	0.000	0.025	0.000	4
			M-180	A	2	515663	64,900	76,500	21.0	0.064	0.740	0.009	0.007	0.007	0.023	0.000	0.026	0.000	4

1 of 4

Figure A-8. 6-ft 3-in. (1.9-m) W-Beam MGS Sections for Test Nos. 34AGT-1 and 34AGT-2

CAUTION
FRESH CONCRETE

Body and or eye contact with fresh (moist) concrete should be avoided because it contains alkali and is caustic.

Ready Mixed Concrete Company
6200 Cornhusker Highway, P.O. Box 29288
Lincoln, Nebraska 68529
Telephone 402-434-1844

PLANT	MIX CODE	YARDS	TRUCK	DRIVER	DESTINATION	CLASS	TIME	DATE	TICKET
4	24043000	1.25	0242	9264			14:33	02/10/17	4190653

CUSTOMER	JOB	CUSTOMER NAME	TAX CODE	PARTIAL	NIGHT R.	LOADS
00003	3	CIA--MIDWEST ROADSIDE SAFETY				77

DELIVERY ADDRESS	SPECIAL INSTRUCTIONS	P.O. NUMBER
4630 NW 36TH ST	NEAR GOODYEAR HANGAR AIRPORT	JAMES 450 6250

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UNIT PRICE	AMOUNT
1.25	1.25	1.25	24043000	L4000.47 50% 3	$117.08	$146.35
				SLUMP: 3.00		
50				MINIMUM HAUL		57.
00				WINTER SERVICE		5.

WATER ADDED ON JOB AT CUSTOMER'S REQUEST 3 GAL. RECEIVED BY [signature]

SUBTOTAL	
TAX	$208.8
TOTAL	
	$208.8

5

Thrie Buttress
Concrete for Thrie Buttress
R#17-407 February 2017 SMT

$208.85

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
0242	9264	user	4190653	4190449	14:33	2/10/17

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
1.25 CYDS	24043000				W	77

Material	Description	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
G47B	47B GRAVEL	2090.0 lb	2656.9 lb	2720.0 lb	) 2.37%	1.70% M	5.4 gl
L47B	47B ROCK	890.0 lb	1112.5 lb	1100.0 lb	-1.12%		
CEM1	TYPE I/II CEMENT	306.0 lb	382.5 lb	525.0 lb	+ 37.25%		
CEM3	CEMENT TYPE III	306.0 lb	382.5 lb	460.0 lb	+ 20.26%		
WATER	WATER	32.9 gl	35.8 gl	35.2 gl	-1.60%		35.2 gl
AIR	MB AE 200 air ent	5.0 oz	6.3 oz	6.0 oz	-4.00%		

Actual Num Batches: 1 Manual
Load Total: 5099 lb Design 0.449 Water/Cement 0.348 T Design 41.1 gl Actual 40.7 gl To Add: 0.4 gl
Slump: 3.00 in Water in Truck: 0.0 gl Adjust Water: 0.0 gl / Load Trim Water: 0.0 gl/ CYD

ORIGINAL

Figure A-9. Concrete for Test Nos. 34AGT-1 and 34AGT-2

CENTRAL
NEBRASKA
WOOD PRESERVERS, INC.

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

R#17-282 BCT Posts 70 Acct AND Wood Blocks for Bullnose
Nov2016 SMT Wood Blockouts are painted Light Blue

Date: 11/11/16

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery + Supply BOL# 10055387

Customer PO# 3339 Preservative: CCA – C 0.60 pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
GR6806.5PST	6x8-6.5" PST	35	22973	.679
GR6806.5CRT	6x8-6.5" CRT	35	22973	.679
GS6846PST	5.5-7.5-46" BCT	42	22927	.638
GR61214BLK	6x12-14" OCD	168	22927	.638

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

VA: Central Nebraska Wood Preservers certifies that the treated wood products listed above have been treated in accordance with AWPA standards, Section 236 of the VDOT Road & Bridge Specifications and meets the applicable minimum penetration and retention requirements.

Nick Sowl, General Counsel

11/11/16
Date

Figure A-10. BCT Timber Posts at MGS Height for Test Nos. 34AGT-1 and 34AGT-2

Certified Analysis

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

MILFORD, NE 68405
Project: STOCK

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

As of: 4/14/14

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

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

1 of 3

Figure A-11. 72-in. (1,829-mm) Long Foundation Tubes for Test Nos. 34AGT-1 and 34AGT-2

425 E. O'Connor
Lima, OH

Customer: MIDWEST MACH.& SUPPLY CO.	Sales Order: 1093497	Print Date: 6/30/08	
P. O. BOX 81097	Customer PO: 2030	Project: RESALE	
	BOL # 43073	Shipped To: NE	
	Document # 1	Use State: KS	
LINCOLN, NE 68501-1097			

Trinity Highway Products. LLC

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

NCHRP Report 350 Compliant

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

MGSBR

Ground Strut

090453-8

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

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB
State of Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

Notary Public: [signature]
Commission Expires [illegible]

Trinity Highway Products, LLC
Certified By: [signature]

2 of 4

05/04/2009 16:36 402-761-3288

Figure A-12. Ground Strut Assembly for Test Nos. 34AGT-1 and 34AGT-2

NUCOR
FASTENER DIVISION

LOT NO.
366055B

Post Office Box 6100
Saint Joe. Indiana 46785
Telephone 260/337-1800

CUSTOMER NO/NAME
8061 STRUCTURAL BOLT CO LLC
TEST REPORT SERIAL# FB482520
TEST REPORT ISSUE DATE 1/08/16
DATE SHIPPED 1/21/16
NAME OF LAB SAMPLER: JOSEPH BYERLY, LAB TECHNICIAN

NUCOR ORDER # 957233
CUST PART #
CUSTOMER P.O. # 18131

****************CERTIFIED MATERIAL TEST REPORT****************

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
175647	3600	366055B	1-8 GR DH HV H.D.G. HEX NUT H.D.G./GREEN LUBE

MANUFACTURE DATE 10/01/15

--CHEMISTRY MATERIAL GRADE -1045L

**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER NUCOR STEEL - SOUTH CAROL

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI
RM030068	DL15103032	.45	.67	.003	.019	.20

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A563-07a

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 90900 LBS	TENSILE STRENGTH (LBS)	DEG-WEDGE STRESS (PSI)
N/A	30.8	PASS	N/A	N/A
N/A	28.6	PASS	N/A	N/A
N/A	26.6	PASS	N/A	N/A
N/A	26.2	PASS	N/A	N/A
N/A	24.5	PASS	N/A	N/A

AVERAGE VALUES FROM TESTS
27.3

PRODUCTION LOT SIZE 42800 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A563-07a 80 PCS. SAMPLED LOT PASSED

--COATING - HOT DIP GALVANIZED TO ASTM F2329-13 - GALVANIZING PERFORMED IN THE U.S.A.

1. 0.00278 2. 0.00892 3. 0.00428 4. 0.00237 5. 0.00321 6. 0.00228 7. 0.00603
8. 0.00676 9. 0.00315 10. 0.00321 11. 0.00371 12. 0.00264 13. 0.00252 14. 0.00348
15. 0.00287

AVERAGE THICKNESS FROM 15 TESTS .00388
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2012

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	1.823	1.833
Thickness	32	0.978	0.996

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION. NO INTENTIONAL ADDITIONS OF BISMUTH, SELENIUM, TELLURIUM, OR LEAD WERE USED IN THE STEEL USED TO PRODUCE THIS PRODUCT.
THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A. PRODUCT COMPLIES WITH DFARS 252.225-7014. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL.

ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 01/31/16

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

John W. Ferguson
JOHN W. FERGUSON
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

Figure A-13. BCT Cable Anchor Assembly for Test Nos. 34AGT-1 and 34AGT-2

Certified Analysis

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

MILFORD, NE 68405

Project: RESALE

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

As of: 4/15/11

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
10	206G	T12/6'3/S	M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.00	0.060	0.000	
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	0.002	
			M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.000	0.050	0.002	
			M-180	A	2	139589	55,670	74,810	27.7	0.190	0.720	0.012	0.003	0.020	0.130	0.000	0.060	0.002	
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	0.001	
55	260G	T12/25/6'3/S	M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.00	0.050	0.000	
			M-180	A	2	139206	61,730	78,580	26.0	0.180	0.710	0.012	0.004	0.020	0.140	0.000	0.050	0.001	
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	0.002	
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	0.001	
			M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.000	0.060	0.002	
	260G		M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.00	0.060	0.000	
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	0.002	
			M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.000	0.050	0.002	
			M-180	A	2	139589	55,670	74,810	27.7	0.190	0.720	0.012	0.003	0.020	0.130	0.000	0.060	0.002	
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	0.001	
26	701A	.25X11.75X16 CAB ANC	A-36			V911470	51,460	71,280	27.5	0.120	0.800	0.015	0.030	0.190	0.300	0.00	0.090	0.025	4
	701A		A-36			N3540A	46,200	65,000	31.0	0.120	0.380	0.010	0.019	0.010	0.180	0.00	0.070	0.001	4
24	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			N4747	63,548	85,106	27.0	0.150	0.610	0.013	0.001	0.040	0.160	0.00	0.160	0.004	
24	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			N4747	63,548	85,106	27.0	0.150	0.610	0.013	0.001	0.040	0.160	0.00	0.160	0.004	
22	782G	5/8"X8"X8" BEAR PL/OF	A-36			18486	49,000	78,000	25.1	0.210	0.860	0.021	0.036	0.250	0.260	0.00	0.170	0.014	
25	974G	T12/TRANS RAIL/6'3"/3'1.5	M-180	A	2	140735	61,390	80,240	27.1	0.200	0.740	0.014	0.005	0.010	0.120	0.00	0.070	0.001	

Figure A-14. Anchor Bracket Assembly for Test Nos. 34AGT-1 and 34AGT-2

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1269489 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3346
BOL Number: 97457 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 11/7/16

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
	701A	Anchor Box	A-36			JK16101488	56,172	75,460	25.0	0.160	0.780	0.017	0.028	0.200	0.280	0.001	0.140	0.028	4
	701A		A-36			535133	43,300	68,500	33.0	0.019	0.460	0.013	0.016	0.013	0.090	0.001	0.090	0.002	4
4	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			A49248	64,818	78,412	32.0	0.200	0.810	0.014	0.002	0.040	0.020	0.000	0.040	0.001	4
20	738A	5'TUBE SL.188X6X8 1/4 /PL	A-36		2	4182184	45,000	67,900	31.0	0.210	0.760	0.012	0.008	0.010	0.050	0.001	0.030	0.002	4
	738A		A-500			A49248	64,818	78,412	32.0	0.200	0.810	0.014	0.002	0.040	0.020	0.000	0.040	0.001	4
6	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			A49248	64,818	78,412	32.0	0.200	0.810	0.014	0.002	0.040	0.020	0.000	0.040	0.001	4
6	782G	5/8"X8"X8" BEAR PL/OF	A-36			DL15103543	58,000	74,000	25.0	0.150	0.750	0.013	0.025	0.200	0.360	0.003	0.090	0.000	4
20	783A	5/8X8X8 BEAR PL 3/16 STP	A-36			PL14107973	48,167	69,811	25.0	0.160	0.740	0.012	0.041	0.190	0.370	0.000	0.220	0.002	4
	783A		A-36			DL15103543	58,000	74,000	25.0	0.150	0.750	0.013	0.025	0.200	0.360	0.003	0.090	0.000	4
45	3000G	CBL 3/4X6'6/DBL	HW			119048													
7,000	3340G	5/8" GR HEX NUT	HW			0055551-116146													
4,000	3360G	5/8"X1.25" GR BOLT	HW			0053777-115516													
450	3500G	5/8"X10" GR BOLT A307	HW			28971-B													
1,225	3540G	5/8"X14" GR BOLT A307	HW			29053-B													

3 of 5

Figure A-15. 8-in. x 8-in. x ⅝-in. (203-mm x 203-mm x 16-mm) Anchor Bearing Plates and ⅝-in. (16-mm) Dia. UNC, 1¼-in. (32-mm) Long Guardrail Bolts and Nuts for Test Nos. 34AGT-1 and 34AGT-2

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

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

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

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

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

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

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

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

		Pcs	Wgt
		111	8,508

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

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

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

WE PROUDLY MANUFACTURE ALL OF OUR HSS IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED,
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.

CURRENT STANDARDS:
..................................A500/A500M-13
..................................A513-12
..................................A252-10
..................................A847/A847M-12

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

Page: 1 .... Last

Figure A-16. 2⅜-in. (60-mm) O.D. x 6-in. (152-mm) Long BCT Post Sleeves for Test Nos. 34AGT-1 and 34AGT-2

R#16-635 w6x8.5 Steel Posts
Orange Paint H#55044258
May2016 SMT

HIGHWAY SAFETY CORP

P.O. BOX 358
GLASTONBURY, CT 06033

CERTIFICATE OF COMPLIANCE/ANALYSIS REPORT

SOLD TO:	SHIP TO:
MIDWEST MACHINERY & SUPPLY 974-238th Road Milford, NE, USA	MIDWEST MACHINERY & SUPPLY 974 238TH ROAD MILFORD,

INVOICE / S.O.: 0190361 / 0135868
CUSTOMER P.O.: 3244

REFERENCE: STOCK
DATE SHIPPED: 4/15/2016

QTY:	ITEM NUMBER: HEAT/LOT NO:	YIELD:	CC: TENSILE:	%ELONG:	DESCRIPTION: C:	Mn:	P:	S:	Si:	Cl:	Type	ACW
850	T-POG060080600		IB-B0600800		THRIE POST W06 x 008.5# x 06'00 GALV							
(150)	55044257											
(700)	55044258											

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

HIGHWAY SAFETY CORPORATION
[signature]
QUALITY ASSURANCE MANAGER

NOTARIZED UPON REQUEST:
STATE OF CONNECTICUT COUNTY OF HARTFORD
SWORN AND SUBSCRIBED BEFORE ME THIS 26th DAY OF April, 2016
Debra M. Thompson
Notary Public

DEBRA M. THOMPSON
NOTARY PUBLIC
MY COMMISSION EXPIRES NOV. 30, 2018

Page 1 - 0135868

Figure A-17. W6x8.5, 72-in. (1,829-mm) Long Steel Posts for Test Nos. 34AGT-1 and 34AGT-2

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1266229 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3307
BOL Number: 96376 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 9/6/16

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
300	3580G	5/8"X18" GR BOLT A307	HW			29040B													
15	4063B	WD 6'0 POST 6X8 CRT	HW			22421													
20	4147B	WD 3'9 POST 5.5"X7.5"	HW			45902													
8	6696G	CBL 5/8"X14'4.75/DBL BTN	HW			248853													
40	12173G	T12/6'3/4@1'6.75"/S			2	L33416													
			M-180	A	2	204521	54,830	73,610	29.2	0.190	0.720	0.012	0.003	0.020	0.120	0.000	0.080	0.000	4
			M-180	A	2	204664	61,480	79,120	26.8	0.190	0.720	0.013	0.002	0.020	0.090	0.000	0.070	0.001	4
			M-180	A	2	204665	59,050	78,290	25.9	0.200	0.720	0.007	0.002	0.020	0.060	0.000	0.040	0.000	4
80	12365G	T12/12'6/8@1'6.75/S			2	L32916													
			M-180	A	2	203660	58,830	76,800	26.7	0.190	0.720	0.013	0.005	0.010	0.120	0.000	0.070	0.000	4
			M-180	A	2	204522	62,180	80,590	25.5	0.190	0.720	0.014	0.003	0.020	0.120	0.000	0.060	0.000	4
100	54043G	7'0 PST/6X15/DB:3HI	A-572			2612103	57,000	68,400	25.2	0.070	0.880	0.008	0.025	0.200	0.150	0.029	0.070	0.003	4

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy QMS-LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT , 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED

2 of 3

Figure A-18. W6x15, 84-in. (2,133-mm) Long Steel Posts for Test Nos. 34AGT-1 and 34AGT-2

CENTRAL NEBRASKA WOOD PRESERVERS, INC.

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

Date: 7/18/16

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery + Supply BOL# 100 54525

Customer PO#: 3289 Preservative: CCA – C 0.60 pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
GR6814BLK	6x8-14" BLK	126	22416	.623
GR6819BLK	6x8-19" BLK	84	22402	.676
GR61219BLK	6x12-19" BLK	168	22402	.676
GR61219BLK	6x12-19" BLK	168	22416	.623
GR61219BLK	6x12-19" BLK	56	22397	.607
GR61219BLK	6x12-19" BLK Trag	56	22402	.676

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

VA: Central Nebraska Wood Preservers certifies that the treated wood products listed above have been treated in accordance with AWPA standards, Section 236 of the VDOT Road & Bridge Specifications and meets the applicable minimum penetration and retention requirements.

Nick Sowl, General Counsel

7/18/16
Date

Figure A-19. 6-in. x 8-in. x 19-in. (152-mm x 203-mm x 483-mm) Timber Blockouts for Test Nos. 34AGT-1 and 34AGT-2

CENTRAL NEBRASKA WOOD PRESERVERS, INC.

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

Date: 7/18/16

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery + Supply BOL# 100 54525

Customer PO#: 3289 Preservative: CCA – C 0.60 pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
GR6814BLK	6x8-14" BLK	126	22416	.623
GR6819BLK	6x8-19" BLK	84	22402	.676
GR61219BLK	6x12-19" BLK	168	22402	.676
GR61219BLK	6x12-19" BLK	168	22416	.623
GR61219BLK	6x12-19" BLK	56	22397	.607
GR61219BLK	6x12-19" BLK Trag	56	22402	.676

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

VA: Central Nebraska Wood Preservers certifies that the treated wood products listed above have been treated in accordance with AWPA standards, Section 236 of the VDOT Road & Bridge Specifications and meets the applicable minimum penetration and retention requirements.

Nick Sowl, General Counsel

7/18/16
Date

Figure A-20. 6-in. x 12-in. x 19-in. (152-mm x 305-mm x 483-mm) Timber Blockouts for Test Nos. 34AGT-1 and 34AGT-2

CENTRAL NEBRASKA WOOD PRESERVERS, INC.

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

Date: 7/26/16

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery + Supply BOL# 10054605

Customer PO# 3292 Preservative: CCA – C 0.60 pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
40756	6x8-14" BLK	126	22416	.676
GR61214BLK	6x12-14" OCD BLK	84	21292	.623
		84	22397	.607
		168	22421	.733

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

VA: Central Nebraska Wood Preservers certifies that the treated wood products listed above have been treated in accordance with AWPA standards, Section 236 of the VDOT Road & Bridge Specifications and meets the applicable minimum penetration and retention requirements.

Nick Sowl, General Counsel

7/26/16
Date

Figure A-21. 6-in. x 12-in. x 14¼-in. (152-mm x 305-mm x 362-mm) Timber Blockouts for Test Nos. 34AGT-1 and 34AGT-2

McMASTER-CARR.

Certificate of Compliance

600 N County Line Rd
Elmhurst IL 60126-2081
630-600-3600
chi.sales@mcmaster.com

University of Nebraska
Midwest Roadside Safety Facility
M W R S F
4630 Nw 36TH St
Lincoln NE 68524-1802
Attention: Shaun M Tighe
Midwest Roadside Safety Facility

Purchase Order
E000357170

Order Placed By
Shaun M Tighe

McMaster-Carr Number
2098331-01

Page 1 of 1

Line		Product	Ordered	Shipped
1	**97812A109**	Steel Double-Headed Nail Size 16D, 3" Length, .16" Shank Diameter, 200 Pieces/Pack, Packs of 5	**5 Packs**	**5**

Certificate of compliance

This is to certify that the above items were supplied in accordance with the description and as illustrated in the catalog. Your order is subject only to our terms and conditions, available at www.mcmaster.com or from our Sales Department.

Sarah Weinberg
Compliance Manager

Figure A-22. 16D Double Head Nails for Test Nos. 34AGT-1 and 34AGT-2

SIMCOTE, INC.

Date: November 4, 2016

Nebraska Department of Transportation
Material and Tests Division
Lincoln, NE 68509

Attention: Stan Karel
Physical Tests

Re: PO# 122461

Project No: Stock #4, #7 & #8 Epoxy Bar

County: NE

Contractor:

We certify that the reinforcing steel is represented by the attached mill certification analysis of laboratory numbers listed.

SIZE	POUNDS	HEAT OR LAB
11		
10		
9		
8	5,372	62140969
7	8,201	KN16103753
6		
5		
4	34,504	62139047
3		
TOTAL	48,077	

Sincerely,

Robert P. Simmet
Vice President

1645 Red Rock Road, St. Paul, MN 55119
Phone: (651) 735-9660 Fax: (651) 735-9664

250 N. Greenwood St., Marion, OH 43302
Phone: (740) 382-5000 Fax: (740) 383-1167

Figure A-23. ½-in. (13-mm) Dia. Bent Rebar for Test Nos. 34AGT-1 and 34AGT-2

R#16-692 5/8"x14"GR Bolt
Orange Paint H#16100453 L#28667-B
June2016 SMT

33406

CERTIFICATE OF COMPLIANCE

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

CUSTOMER NAME: TRINITY INDUSTRIES

CUSTOMER PO: 176703

SHIPPER #: 057716
DATE SHIPPED: 05/17/2016

LOT#: 28667-B

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

TENSILE: SPEC: 60,000 psi*min RESULTS: 78,080 76,544

HARDNESS: 100 max 82.10 83.50

*Pounds Per Square Inch.

COATING: ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE
ROGERS GALVANIZE: 28667-B

CHEMICAL COMPOSITION

MILL	GRADE	HEAT#	C	Mn	P	S	Si
NUCOR	1010	NF16100453	.12	.56	.006	.030	.19

QUANTITY AND DESCRIPTION:

5,950 PCS 5/8" X 14" GUARD RAIL BOLT
P/N 3540G

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

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS

17th DAY OF May 2016 Linda Melomas 5/17/16
Merry F Shane APPROVED SIGNATORY DATE

OFFICIAL SEAL
MERRY F. SHANE
NOTARY PUBLIC – STATE OF ILLINOIS
MY COMMISSION EXPIRES OCTOBER 3, 2018

Figure A-24. ⅝-in. (16-mm) Dia. UNC, 14-in. (356-mm) Long Guardrail Bolts and Nuts for Test Nos. 34AGT-1 and 34AGT-2

R#16-692 5/8"x10" GR Bolt
Orange Paint H#20351510 L#150424L

3500G

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

MATERIAL CERTIFICATION

Customer: Stock

Date: December 16, 2015

Invoice Number:

Lot Number: 150424L

Part Number: 3500G

Quantity: 16,702 Pcs.

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

Heat Numbers: 20351510 16,702

Specification: ASTM A307-A / A153 / F2329

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
20351510	.09	.33	.007	.002	.06	.04	.05	.01	.06	.004	.001	.028	.007	.0001	.001	.001

PLATING OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.52 (2.0 Mils Minimum)

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

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

TRINITY HIGHWAY PRODUCTS LLC

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 12-17-15

NOTARY PUBLIC

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

NOTARIAL SEAL STATE OF OHIO

MONIQUE HOLMES
Notary Public, State of Ohio
My Commission Expires
July 5, 2020

Figure A-25. ⅝-in. (16-mm) Dia. UNC, 10-in. (254-mm) Long Guardrail Bolts and Nuts for Test Nos. 34AGT-1 and 34AGT-2

25ct BCT 10" Hex Bolts
R#16-0226 L#206239
H#DL15102793 WHITE
December 2015

Certificate of Compliance

Birmingham Fastener Manufacturing
PO Box 10323
Birmingham, AL 35202
(205) 595-3512

Customer: Midwest Machinery & Supply
Date Shipped:
Customer Order Number: 3180
BFM Order Number: 1294219

Item Description

Description: 5/8"-11 x 10" HEX BOLT
Qty: 153
Lot #: 206239
Specification: ASTM A307-14 Gr A
Finish: HDG

Raw Material Analysis

Heat#: DL15102793

Chemical Composition (wt% Heat Analysis) By Material Supplier

C	Mn	P	S	Si	Cu	Ni	Cr	Mo
0.21	.82	0.015	0.019	.24	0.41	0.08	0.13	0.010

Mechanical Properties

Sample #	Hardness	Tensile Strength (lbs)	Tensile Strength (psi)
1	89 HRBW	19,980	88,000
2			
3			
4			
5			

This information represents the most recent analysis of the product supplied on the stated customer order. The samples tested conform to the ASTM standard listed above.
All steel melted and manufactured in the U.S.A.

Authorized Signature: [signature]
Cody Calvert
Quality Assurance

Date: 12/4/2015

Figure A-26. ⅝-in. (16-mm) Dia. UNC, 10-in. (254-mm) Long Hex Head Bolts for Test Nos. 34AGT-1 and 34AGT-2

R#16-0217
BCT Hex Nuts
December 2015 SMT
Fastenal part#36713
Control# 210101523

STELFAST® INC.

22979 Stelfast Parkway
Strongsville, Ohio 44149

CERTIFICATE OF CONFORMANCE

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

- Sales Order #: 129980
- Part No: AFH2G0625C
- Cust Part No: 36713
- Quantity (PCS): 1200
- Description: 5/8-11 Fin Hx Nut Gr2 HDG/TOS 0.020
- Specification: SAE J995(99) - GRADE 2 / ANSI B18.2.2
- Stelfast I.D. NO: 595689-O201087
- Customer PO: 210101523
- Warehouse: DAL

The data in this report is a true representation of the information provided by the material supplier certifying that the product meets the mechanical and material requirements of the listed specification. This certificate applies to the product shown on this document, as supplied by STELFAST INC. Alterations to the product by our customer or a third party shall render this certificate void.

This document may only be reproduced unaltered and only for certifying the same or lesser quantity of the product specified herein. Reproduction or alteration of this document for any other purpose is prohibited.

Stelfast certifies parts to the above description. The customer part number is only for reference purposes.

David Biss
Quality Manager

December 07, 2015

Page 1 of 1

Figure A-27. ⅝-in. (16-mm) Dia. Hex Head Nuts for Test Nos. 34AGT-1 and 34AGT-2

33806

Mid West Fabricating
3115 W. Fair Ave.
Lancaster, Oh 43130

CERTIFICATE OF COMPLIANCE

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

TO: **Trinity Industries, Inc.**
Plant #55
550 East Robb Ave.
Lima, Ohio 45801

5/8"x1-1/2" Hex Bolt
Lot#25203 H#10207560 R#16-0009
July 2015 SMT

SHIP DATE: 12/12/12
MANUFACTURER: MID WEST FABRICATING CO.
ASTM: A307A
PROCESSOR
GALVANIZERS: AZZ-Pilot

TO A-153 CLASS C

QTY	PART NO.	HEAT NO.	LOT NO.	P.O. NO.
38,000	5/8 X 1 1/2"	10207560	25203	150897

PASSED & CERTIFIED
DEC 19 2012
Trinity Highway Products, LLC
Dallas, Texas Plant 99

SIGNATURE:__ Amy Bailes
TITLE: QUALITY CONTROL
Date: 12/12/12

Figure A-28. ⅝-in. (16-mm) Dia. UNC, 1½-in. (38-mm) Long Hex Head Bolts for Test Nos. 34AGT-1 and 34AGT-2

Portland Bolt
& MANUFACTURING COMPANY

Phone: 800-547-6758 | Fax: 503-227-4634
3441 NW Guam Street, Portland, OR 97210
Web: www.portlandbolt.com | Email: sales@portlandbolt.com

CERTIFICATE OF CONFORMANCE

For: CASH SALE
PB Invoice#: 95717
Cust PO#: MIDWEST ROADSIDE
Date: 1/10/2017
Shipped: 1/11/2017

We certify that the following items were manufactured and tested in accordance with the chemical, mechanical, dimensional and thread fit requirements of the specifications referenced.

Description: 7/8 X 14 BLK ASTM A449 HEAVY HEX BOLT

Heat#: 3051123 **Base Steel:** 4140 **Diam:** 7/8
Source: COMMERCIAL METALS CO **Proof Load:** 39,250 LBF

C :	.400	**Mn:**	.800	**P :**	.009	**Hardness:**	269 HBN				
S :	.038	**Si:**	.220	**Ni:**	.080	**Tensile:**	55,920 LBF	**RA:**	.00%		
Cr:	.860	**Mo:**	.230	**Cu:**	.240	**Yield:**	0	**Elon:**	.00%		
Pb:	.000	**V :**	.026	**Cb:**	.000	**Sample Length:**	0				
N :	.000			**CE:**	.6221	**Charpy:**		**CVN Temp:**			

LOT#18271 R#17-389 Buttress Hardware

Nuts:
ASTM A194-2H HVY HEX

Other:
ALL ITEMS MELTED & MANUFACTURED IN THE USA

By: Certification Department Quality Assurance
Dane McKinnon

Figure A-29. ⅞-in. (22-mm) Dia. UNC, 14-in. (356-mm) Long Heavy Hex Bolts for Test Nos. 34AGT-1 and 34AGT-2

UNYTITE INC. INNOVATIVE FASTENING SYSTEMS

Unytite, Inc.
One Unytite Drive
Peru, IL 61354
Tel 815-224-2221
Fax 815-224-3434

INSPECTION CERTIFICATE

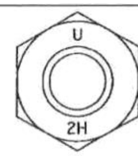
Job No: 20188 **Job Information** **Certified Date:** 2/19/15

Customer:
Customer PO No:
Lot Number: 20188-NF14204558
Ship To:
Shipped Qty:

Part Information

Part No: A194 7/8-9 2H HHN
Name: ASTM A194 Heavy Hex Nut, Grade 2H, Plain

Manufactured Quantity: 81,005



Applicable Specifications

Specification	Amend	Specification	Amend
ASME B1.1	2008	ASME B18.2.2	2010
ASTM A194/A194M	2012	ASTM A962/A962M	2010

Test Results
Test No: 7088 **Test:** A194 Mechanical Properties

Description	Hardness (HRC)	Tempering (Min 850 Degrees)	24 Hr 1000 degrees (HRB Min)	Proof Load (Pass/Fail) (ASTM Min)	Shape & Dimension ASME B18.2.2	Thread Precision ASME B1.1	Visual	ASTM F2328 (HV)	ASTM F2328 (HV)	ASTM F2328 (HV)	ASTM E381
Sample Inspection	28.98	1,058	100.3	80,850	Pass	Pass	Pass	323	314	332	Pass

Certified Chemical Analysis

Heat No	Grade	Manufacturer	Origin	C	Mn	P	S	Si	Cr	Ni	Cu
NF14204558	1045	Shinsho American Corporation	USA	0.4500	0.8300	0.006	0.023	0.2300	0.0600	0.0500	0.1100

Notes

All tests are in accordance with the latest revisions of the methods prescribed in the applicable SAE and ASTM Specifications.

The samples tested conform the specifications as described/listed above and were manufactured free of mercury contamination and there is no welding performed in the production of the products. No heats to which Bismuth, Selenium, Tellurium, or Lead was intentionally added have been used to produce products.
The steel was melted and manufactured in the U.S.A. and the product was manufactured and tested in the U.S.A.

We certify that this data is true representation of information provided by the material supplier and our testing laboratory. This certified material test report relates only to the items listed on this document and may not be reproduced except in full.

OFFICIAL SEAL
JEAN MARGHERIO
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES:10/18/17

Savage, Dan - Supervisor, Quality 2/19/15
Date

Plex 2/19/15 5:56 AM dsavage Page 1

Figure A-30. ⅞-in. (22-mm) Dia. Heavy Hex Nuts for Test Nos. 34AGT-1 and 34AGT-2

GAFFNEY BOLT COMPANY
6100 MATERIAL AVENUE
ROCKFORD, IL 61111

FASTENER TEST REPORT

DATE SHIPPED: 28-May-15

LOT NO: 39685

CUSTOMER: THE STRUCTURAL BOLT COMPANY

P.O. NO: 17009

QUANTITY: 6

DESCRIPTION: 7/8-9 X 7 1/2 A307 HEX PLN

HEAT NO: 2038622

CHEMICAL ANALYSIS ATTACHED

MATERIAL: A36

PASSED VISUAL INSPECTION

ALL TEST ARE IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. PRODUCT MEETS ASME B18.2.1 DIMENSIONAL SPECIFICATION AND THREADS MEET ANSI B1.1 CLASS 2A. WE CERTIFY THAT THIS DATA IS TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

THESE PARTS WERE MANUFACTURED BY GAFFNEY BOLT COMPANY FROM STEEL MELTED AND MANUFACTURED IN THE USA.

GAFFNEY BOLT COMPANY
Mary P. Gaffney
MARY P. GAFFNEY
SECRETARY

BCT Foundation Tube Keeper Bolt R#15-0600
June 2015 SMT

Figure A-31. ⅞-in. (22-mm) Dia. UNC, 8-in. (203-mm) Long Hex Head Bolts for Test Nos. 34AGT-1 and 34AGT-2

INSPECTION CERTIFICATE

UNYTITE, INC.
One Unytite Drive
Peru, Illinois 61354
815-224-2221 — FAX# 815-224-3434

Customer	Specification	Size	Lot No.	Date
	ASTM A-563 GRADE DH HEAVY HEX NUT	7/8- 9 UNC	WA651	Jun. 29,'12

Mechanical properties tested in accordance to ASTM F606/F606M, ASTM A370, ASTM E18

Chemical Composition (%)

Mill Maker	Material Size	Heat No.	Spec.	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	
				0.20 0.55	-	MIN. 0.60	MAX. 0.040	MAX. 0.050	-	-	-	-	-
NUCOR STEEL	CARBON STEEL	12101054		0.43	0.24	0.87	0.015	0.020	0.09	0.04	0.08	-	-

Mechanical Property Inspection

Item	Proof Load	Cone stripping	Hardness	After Heat Treatment Hardness	Absorbed Energy	Heat Treatment
Spec.	80,850 lbf	- kN·kgf·lbf	24-38 HrC	HrB·HB	J·kgfm·ftlbf	T:MIN.800 F
Results	n: 5 Results: GOOD	n: - Results: -	29.4 28.9 29.7 29.7 29.5 29.4	5 Piece Average After Heat Treament Hardness Treatment After 24 Hr.X °F(°C)	at °F(°C)	Q:FORGING Q (W.Q.) T:1058 F/45M. (W.C.) Q: Quenching T: Tempering ST: Solution Treatment

OFFICIAL SEAL
JEAN MARGHERIO
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES:10/18/13

07-10-12

Shape & Dimension	
Inspection	ANSI B18.2.2 GOOD
Thread Precision Inspection	ANSI B1.1 CLASS 2B GOOD
Appearance Inspection	GOOD

Remarks:

"DH U"

Production Quantity
22,391 pcs.

BCT Foundation Tube
Keeper Bolt Nuts
R#15-0600 June 2015 SMT

Material used for the nut was melted and manufactured in the USA. The nut was manufactured in the USA to the above specification.

We hereby certify that the material described has been manufactured and inspected satisfactorily with the requirement of the above specification.

Chief of Quality Assurance Section

Figure A-32. ⅞-in. (22-mm) Dia. Hex Head Nuts for Test Nos. 34AGT-1 and 34AGT-2

Certified Analysis

Trinity Highway Products, LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1272514 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3376
BOL Number: 98293 Ship Date: 1/9/2017
Document #: 1
Shipped To: NE
Use State: NE

As of: 1/16/17

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
100	901G	12/FLARE/8 HOLE	M-180	A	2	193147	62,430	81,280	26.2	0.190	0.730	0.014	0.003	0.020	0.110	0.000	0.060	0.001	4
4	974G	T12/TRANS RAIL/6'3"/3'1.5	M-180	A	2	184354	64,550	83,590	22.1	0.190	0.730	0.010	0.003	0.020	0.100	0.000	0.050	0.000	4
10,000	3340G	5/8" GR HEX NUT	HW			0057933-117335													
6,000	3360G	5/8"X1.25" GR BOLT	HW			27761-B													
1,200	3400G	5/8"X2" GR BOLT	HW			1377346	<<This is LOT # 62C200BMBU1G/grd (see page 23 circled in red.)												
200	3480G	5/8"X8" GR BOLT A307	HW			29038-b													
675	3500G	5/8"X10" GR BOLT A307	HW			29366													
2,100	3540G	5/8"X14" GR BOLT A307	HW			28667-B													
	3540G		HW			28707													
10	12173G	T12/6'3/4@1'6.75"/S			2	L34816													
			M-180	A	2	208674	63,250	82,410	22.7	0.190	0.730	0.011	0.003	0.020	0.100	0.000	0.060	0.002	4
			M-180	A	2	208675	62,100	81,170	22.7	0.190	0.730	0.012	0.004	0.020	0.090	0.000	0.050	0.001	4
			M-180	A	2	208676	62,920	82,040	25.4	0.190	0.720	0.012	0.004	0.010	0.100	0.000	0.060	0.002	4
	12173G				2	L35216													
			M-180	A	2	209331	62,090	81,500	28.1	0.190	0.720	0.013	0.002	0.020	0.110	0.000	0.070	0.002	4
			M-180	A	2	209332	61,400	81,290	25.3	0.190	0.730	0.014	0.003	0.020	0.120	0.000	0.060	0.001	4
			M-180	A	2	209333	61,200	80,050	25.8	0.200	0.740	0.016	0.005	0.010	0.120	0.000	0.070	0.002	4
140	12365G	T12/12'6/8@1'6.75/S			2	L34816													

2 of 4

Figure A-33. ⅝-in. (16-mm) Dia. UNC, 2-in. (51-mm) Long Guardrail Bolts and Nuts for Test Nos. 34AGT-1 and 34AGT-2

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

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 07/20/2015
TIME 17:59:11
USER MEHEULAL

SOLD TO
12355
Midwest Steel Works, Inc.
81096
Lincoln NE 68501

SHIP TO
12355
Midwest Steel Works, Inc.
737 N Street
Lincoln NE 68508

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
1864149-0010	70872120TM	1/4 72 X 120 A36 TEMPERPASS STPMLPL				47816	07/20/2015

Chemical Analysis

Heat No. B505037 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS Melted and Manufactured in the USA
Batch 0003988521 15 EA 9,189 LB Produced from Coil

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.2000	0.8200	0.0160	0.0030	0.0200	0.0500	0.0700	0.0100	0.0001	0.1100	0.0250	0.0010	0.0050	0.0010	0.0067	0.0060

Mechanical/ Physical Properties

Mill Coil No. B505037-02

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
79000.000	54500.000	25.40			0	NA			
77300.000	53900.000	27.80			0	NA			
76000.000	52800.000	30.50			0	NA			
73600.000	51600.000	27.80			0	NA			

AGT Buttress Square Washers
R#16-0015 H#B505037
July 2015 SMT

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

Figure A-34. 3-in. x 3-in. x ¼-in. (76-mm x 76-mm x 6-mm) Square Plate Washers for Test Nos. 34AGT-1 and 34AGT-2

Appendix B. Vehicle Center of Gravity Determination

Date:	3/17/2017	Test Name:	34AGT-1	VIN:	1D7RB1GP5AS218232
Year:	2010	Make:	Dodge	Model:	Ram 1500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Truck (Curb)	5085	28	142380
+	Hub	19	14 3/4	280.25
+	Brake activation cylinder & frame	7	25 1/2	178.5
+	Pneumatic tank (Nitrogen)	27	26	702
+	Strobe/Brake Battery	5	25	125
+	Brake Receiver/Wires	5	51 1/2	257.5
+	CG Plate including DAS	42	29 3/4	1249.5
-	Battery	-42	40 1/4	-1690.5
-	Oil	-9	26	-234
-	Interior	-81	27 1/2	-2227.5
-	Fuel	-193	16 1/2	-3184.5
-	Coolant	-14	31	-434
-	Washer fluid	-5	33 1/2	-167.5
+	Water Ballast (In Fuel Tank)	123	14 1/2	1783.5
+	Onboard Supplemental Battery	14	24 1/2	343
	Steel Plate Ballast	43	35 1/4	1515.75
				140877

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

Estimated Total Weight (lb) 5026
Vertical CG Location (in.) 28.0296

Vehicle Dimensions for C.G. Calculations

Wheel Base: 140 1/4 in.
Front Track Width: 68 1/4 in.
Rear Track Width: 67 3/4 in.

Center of Gravity	**2270P MASH Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb)	5000 ± 110	5024	24.0
Longitudinal CG (in.)	63 ± 4	61.945611	-1.05439
Lateral CG (in.)	NA	0.1759554	NA
Vertical CG (in.)	28 or greater	28.03	0.02965

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	1483	1382
Rear	1110	1110

FRONT	2865	lb
REAR	2220	lb
TOTAL	5085	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	1400	1405
Rear	1099	1120

FRONT	2805	lb
REAR	2219	lb
TOTAL	5024	lb

Figure B-1. Vehicle Mass Distribution, Test No. 34AGT-1

Date:	3/17/2017	Test Name:	34AGT-1	VIN:	1D7RB1GP5AS218232
Year:	2010	Make:	Dodge	Model:	Ram 1500

Vehicle CG Determination

VEHICLE	Equipment	Long CG (in.)	Lat CG (in.)	Long M (lb-in.)	Lat M (lb-in.)
+	Unballasted Truck (Curb)	61 1/2	- 2/3	312886.4	-3434
+	Hub	0	44 1/8	0	838.375
+	Brake activation cylinder & frame	35	-18	245	-126
+	Pneumatic tank (Nitrogen)	74 1/2	17	2011.5	459
+	Strobe/Brake Battery	84	17 1/2	420	87.5
+	Brake Receiver/Wires	105 1/2	0	527.5	0
+	CG Plate including DAS	69 1/2	0	2919	0
-	Battery	-8	-25	336	1050
-	Oil	3	1 1/2	-27	-13.5
-	Interior	65	0	-5265	0
-	Fuel	103	-13	-19879	2509
-	Coolant	-24	1	336	-14
-	Washer fluid	-30	-18	150	90
+	Water Ballast (In Fuel Tank)	103	-13	12669	-1599
+	Onboard Supplemental Battery	68 1/2	19	959	266
	Steel Plate Ballast	110	- 1/4	4730	-10.75
				313018.4	102.625

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

	Long	Lat
Estimated CG Location (in.)	62.27983	0.020419

Calibrated Scales Used

Equipment Type	Manufacturer	Serial #	Capacity
Pad Scale	Pennsylvania Scale	95-228908	5000 lbs.
Pad Scale	Pennsylvania Scale	95-228909	5000 lbs.
Race Wheel Scales	Intercomp	22033056	1500/pad

Figure B-2. Vehicle Mass Distribution Continued, Test No. 34AGT-1

Date:	1/0/1900	Test Name:	34AGT-2	VIN:	KNADH4A33B6960761
Year:	2011	Make:	Kia	Model:	Rio

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)
+	Unbalasted Car (Curb)	2331
+	Hub	19
+	Brake activation cylinder & frame	7
+	Pneumatic tank (Nitrogen)	22
+	Strobe/Brake Battery	5
+	Brake Reciever/Wires	6
+	CG Plate including DAS	13
-	Battery	-28
-	Oil	-6
-	Interior	-53
-	Fuel	-18
-	Coolant	-6
-	Washer fluid	-2
+	Water Ballast (In Fuel Tank)	114
+	Onboard Battery	14

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

Estimated Total Weight (lb) 2418

Vehicle Dimensions for C.G. Calculations

Roof Height:	58 1/4	in.	Front Track Width:	57 5/8	in.
Wheel Base:	98 1/2	in.	Rear Track Width:	58	in.

Center of Gravity	1100C MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	2420 ± 55	2420	0
Longitudinal CG (in.)	39 ± 4	40.29545	1.2954545
Lateral CG (in.)	NA	0.262784	NA
Vertical CG (in.)	NA	22.37423	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	731	704
Rear	454	442

FRONT	1435	lb
REAR	896	lb
TOTAL	2331	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	712	718
Rear	487	503

FRONT	1430	lb
REAR	990	lb
TOTAL	2420	lb

Figure B-3. Vehicle Mass Distribution, Test No. 34AGT-2

Date:	5/9/2017	Test Name:	34AGT-2	VIN:	KNADH4A33B6960761
Year:	2011	Make:	Kia	Model:	Rio

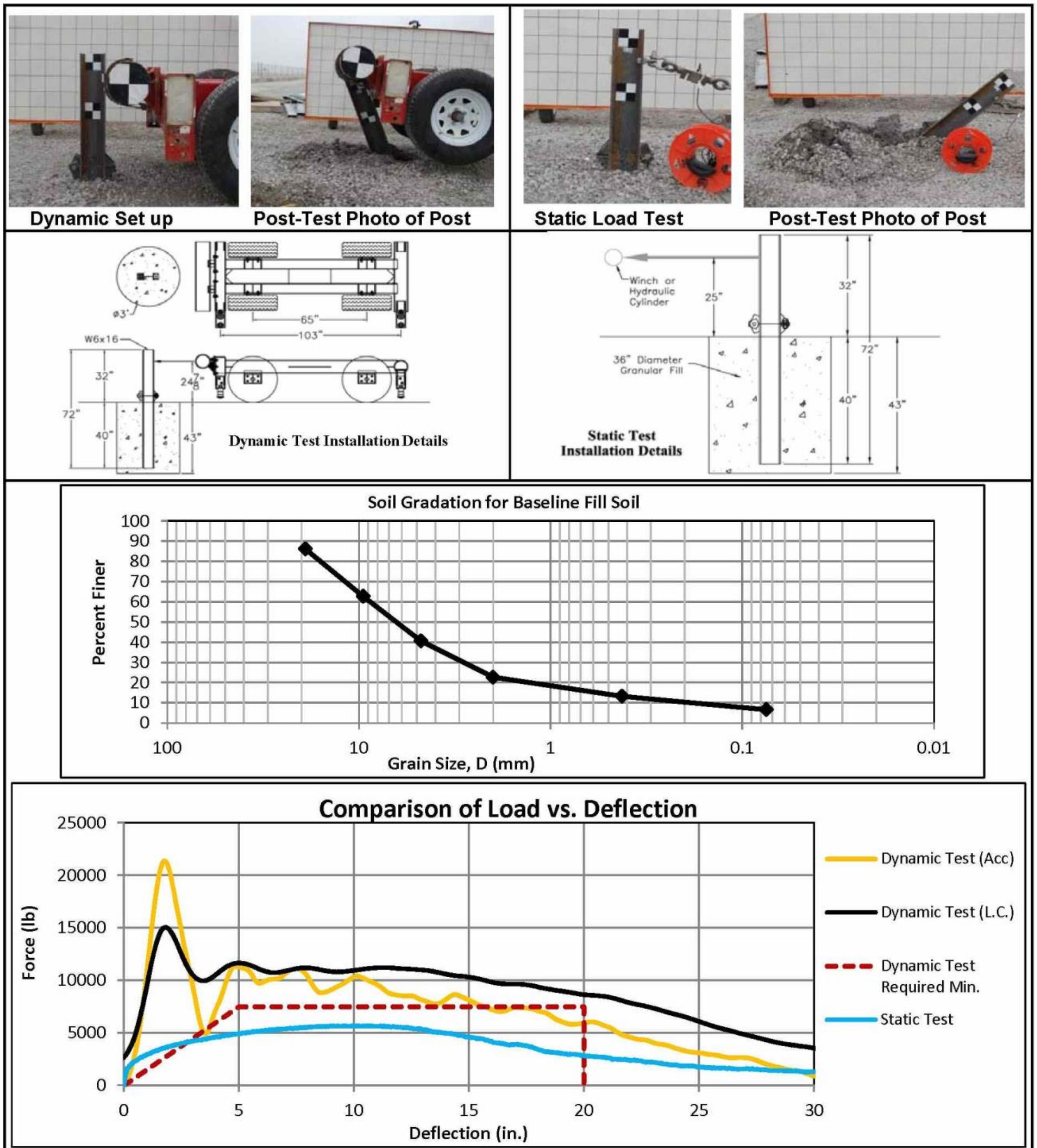
Vehicle CG Determination

VEHICLE	Equipment	Long CG (in.)	Lat CG (in.)	Vertical CG (in.)	Long M (lb-in.)	Lat M (lb-in.)	Vertical M (lb-in.)
+	Unbalasted Car (Curb)	37 6/7	-0.48363	23	88256	-1127.34	53633.396
+	Hub	0	38 4/5	11	0	737.4375	209
+	Brake activation cylinder & frame	30	-11 1/2	16 1/4	210	-80.5	113.75
+	Pneumatic tank (Nitrogen)	64 1/2	16	14	1419	352	308
+	Strobe/Brake Battery	83	12	18 3/4	415	60	93.75
+	Brake Reciever/Wires	127	0	35	762	0	210
+	CG Plate including DAS	41	0	16 3/4	533	0	217.75
-	Battery	-14	-15 1/2	28	392	434	-784
-	Oil	-4	4 1/2	20	24	-27	-120
-	Interior	57	0	15 1/4	-3021	0	-808.25
-	Fuel	77	-10 1/2	7	-1386	189	-126
-	Coolant	-21 1/2	1	21	129	-6	-126
-	Washer fluid	-15	23 1/2	18 1/2	30	-47	-37
+	Water Ballast (In Fuel Tank)	77	-10 1/2	9	8778	-1197	1026
+	Onboard Battery	72 1/2	9	20 3/4	1015	126	290.5
					0	0	0
Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle					97556	-586.406	54100.896
				Estimated CG Location (in.)	40.34574	-0.24252	22.374233

Calibrated Scales Used			
Equipment Type	Manufacturer	Serial #	Capacity
Pad Scale	Pennsylvania Scale	95-228908	5000 lbs
Pad Scale	Pennsylvania Scale	95-228909	5000 lbs
Race Wheel Scales	Intercomp	22033056	1500/pad

Figure B-4. Vehicle Mass Distribution Continued, Test No. 34AGT-2

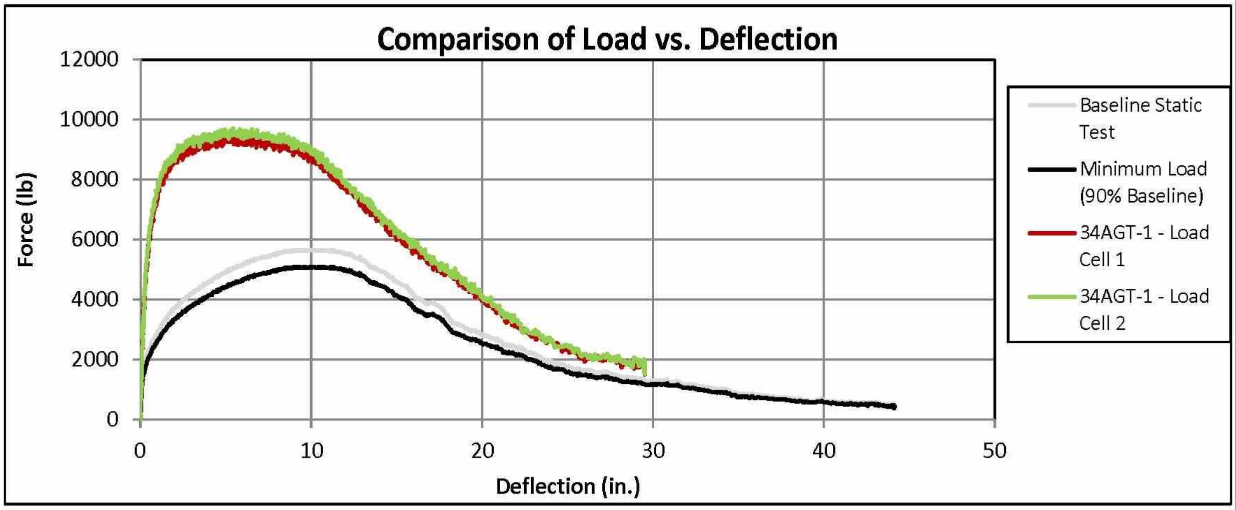
Appendix C. Static Soil Tests

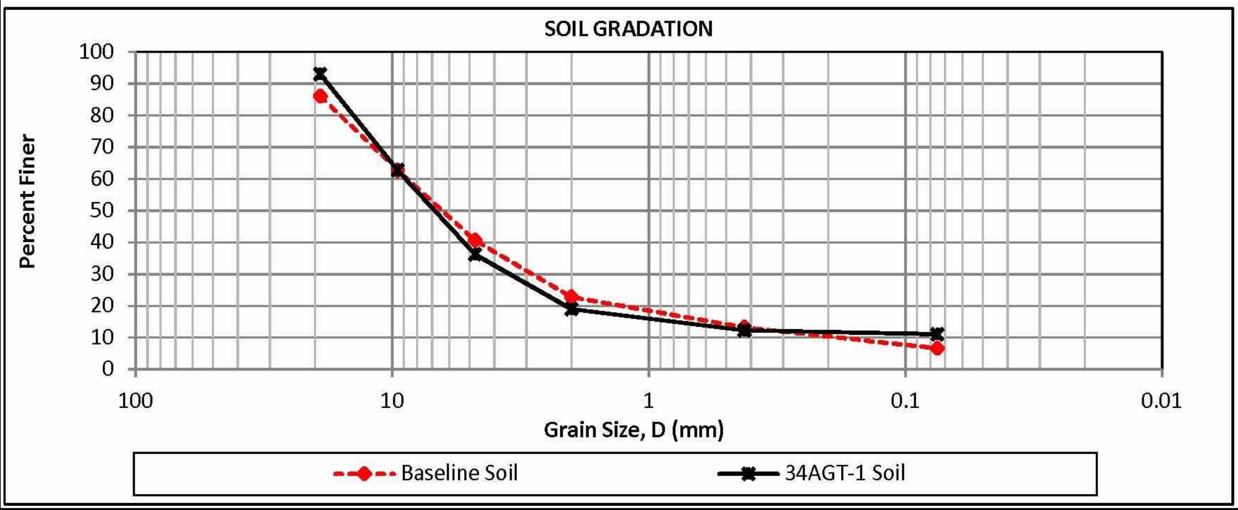


Date	5/17/2013			
Test Facility & Site Location	Midwest Roadside Safety Facility			
In situ soil description (ASTM D2487)	Well-Graded Gravel (GW)			
Fill material description (ASTM D2487)	Well-Graded Gravel (GW) (see sieve analyses above)			
Description of fill placement procedure	H.E.-8			
Bogie Weight	1857	lb	842	kg
Impact Velocity	20.6	mph	33.2	km/h

Figure C-1. Soil Strength, Initial Calibration Tests, Test No. 34AGT-1

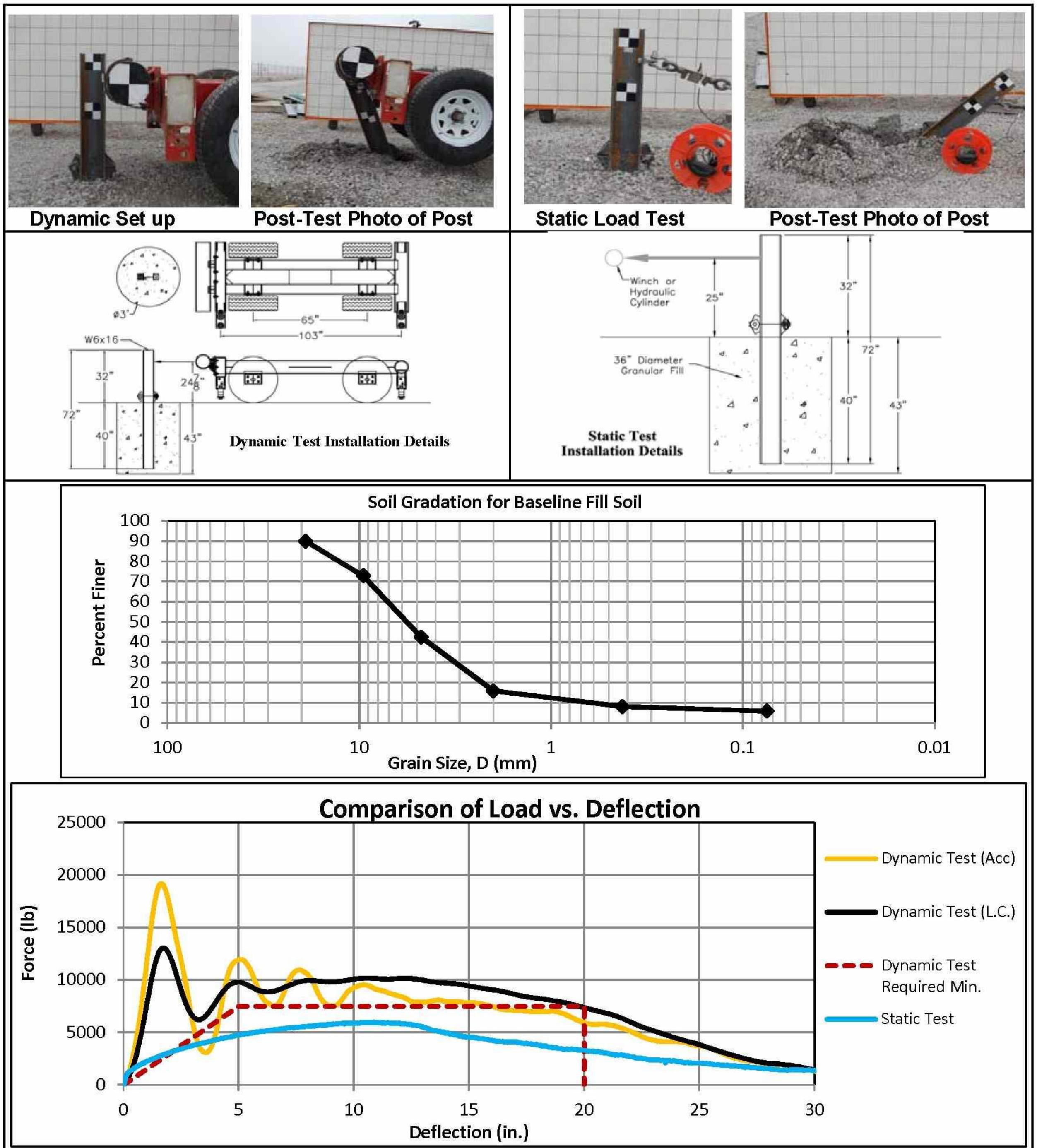
Static Load Test Setup	Post-Test Photo of Post
	





Date………………………………………………	3/16/2017
Test Facility & Site Location…………………	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)……….	Well-Graded Gravel (GW)
Fill material description (ASTM D2487)………	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure……..	8-inch lifts tamped with a pneumatic compactor

Figure C-2. Static Soil Test, Test No. 34AGT-1

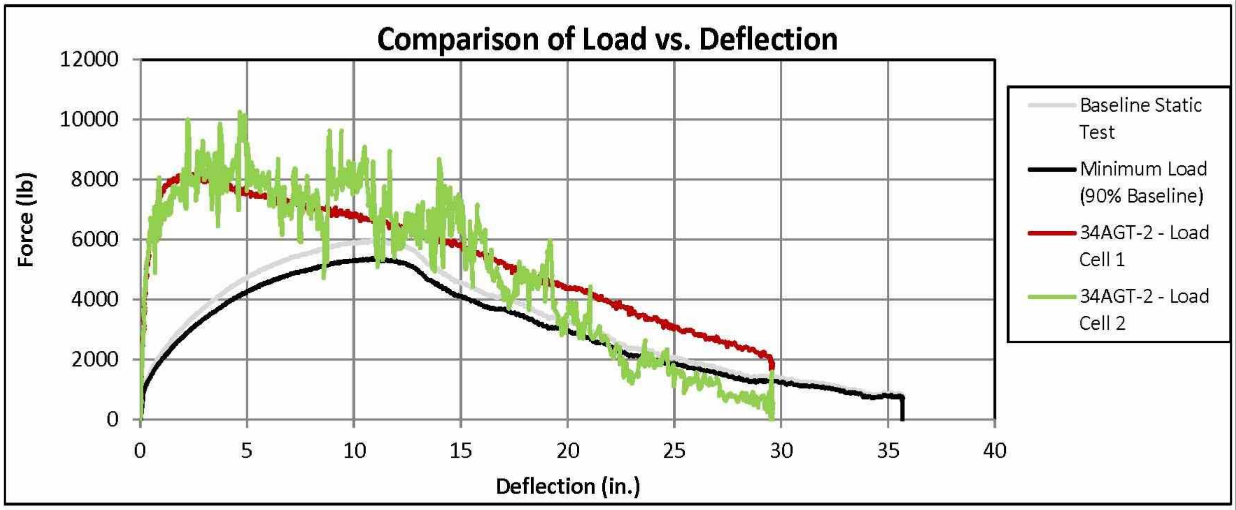


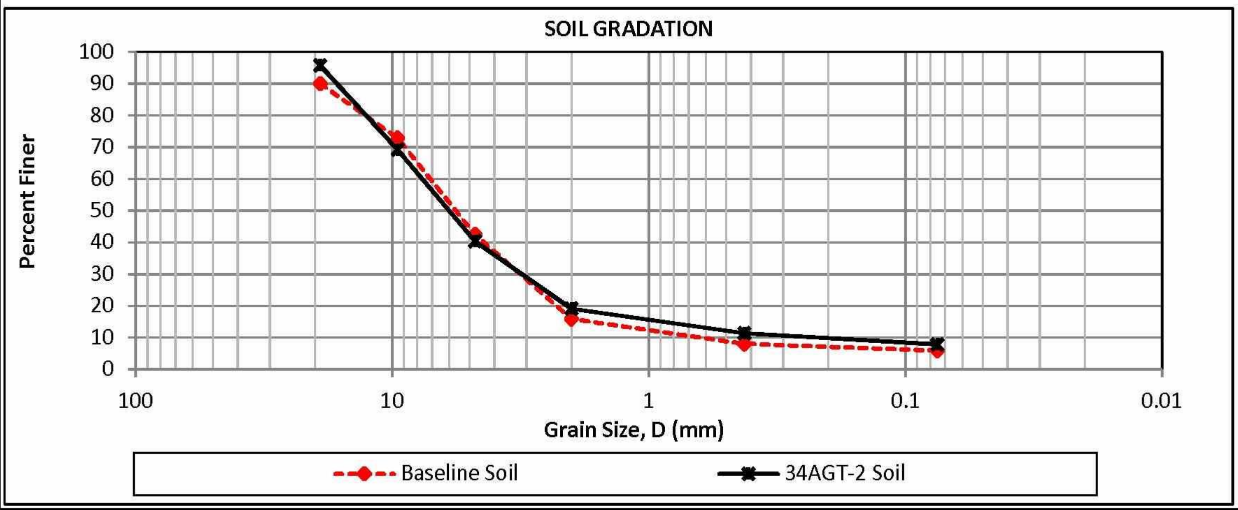
Date	3/20/2012
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Well-Graded Gravel (GW)
Fill material description (ASTM D2487)	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	8" lift 3-4 passes
Bogie Weight	1843 lb — 836 kg
Impact Velocity	20.0 mph — 32.2 km/h

Figure C-3. Soil Strength, Initial Calibration Tests, Test No. 34AGT-2

Static Load Test Setup

Post-Test Photo of Post





Date………………………………………………	5/25/2017
Test Facility & Site Location……………………	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)…………	Well-Graded Gravel (GW)
Fill material description (ASTM D2487)………	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure………	8-inch lifts tamped with a pneumatic compactor

Figure C-4. Static Soil Test, Test No. 34AGT-2

Appendix D. Vehicle Deformation Records

Date: 3/17/2017 Test Name: 34AGT-1 VIN: 1D7RB1GP5AS218232
Year: 2010 Make: D0dge Model: Ram 1500

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
1	29.709	-25.747	4.544	27.896	-23.350	5.084	-1.814	2.396	0.540	3.053
2	31.066	-20.821	2.015	30.696	-20.400	1.819	-0.370	0.421	-0.197	0.594
3	30.586	-15.333	1.209	30.358	-14.879	1.047	-0.228	0.454	-0.162	0.534
4	28.748	-11.727	2.155	28.380	-11.552	2.216	-0.368	0.175	0.060	0.412
5	28.179	-26.023	2.239	26.369	-23.779	2.863	-1.809	2.244	0.624	2.950
6	28.703	-21.139	0.851	28.469	-20.718	0.318	-0.234	0.421	-0.533	0.719
7	27.729	-15.798	-0.349	27.613	-15.317	-0.778	-0.116	0.481	-0.429	0.654
8	26.856	-12.509	-0.638	26.654	-12.230	-0.665	-0.203	0.279	-0.027	0.346
9	24.570	-26.199	-0.518	23.593	-24.652	-1.146	-0.977	1.547	-0.627	1.934
10	24.613	-21.477	-1.242	24.722	-21.014	-2.252	0.109	0.463	-1.009	1.116
11	23.832	-15.612	-2.369	24.004	-15.053	-3.019	0.172	0.559	-0.650	0.875
12	23.813	-12.637	-2.751	24.036	-12.103	-3.118	0.223	0.534	-0.367	0.686
13	20.023	-26.581	-2.706	20.267	-26.245	-4.451	0.243	0.336	-1.745	1.794
14	19.792	-21.778	-3.386	20.040	-21.134	-4.465	0.248	0.644	-1.080	1.281
15	19.725	-16.486	-4.116	19.945	-15.835	-4.768	0.220	0.651	-0.652	0.947
16	19.611	-12.881	-4.627	19.792	-12.207	-4.964	0.181	0.674	-0.337	0.775
17	15.137	-26.574	-3.076	15.498	-26.052	-4.288	0.362	0.523	-1.212	1.369
18	14.600	-21.946	-3.704	14.928	-21.357	-4.540	0.328	0.589	-0.836	1.073
19	14.711	-16.554	-4.437	14.947	-15.922	-4.904	0.237	0.632	-0.468	0.821
20	14.477	-12.820	-4.938	14.671	-12.165	-5.163	0.194	0.655	-0.225	0.719
21	9.071	-26.646	-3.066	9.500	-26.275	-3.777	0.429	0.371	-0.711	0.909
22	8.754	-21.970	-3.678	9.114	-21.513	-4.188	0.360	0.456	-0.510	0.773
23	8.670	-16.849	-4.373	9.013	-16.359	-4.618	0.343	0.490	-0.245	0.647
24	8.802	-12.693	-4.935	9.028	-12.216	-5.024	0.226	0.476	-0.089	0.535
25	0.043	-26.553	0.880	0.515	-26.176	0.808	0.471	0.377	-0.072	0.608
26	0.056	-21.473	0.223	0.459	-21.085	0.180	0.403	0.388	-0.043	0.561
27	-0.117	-16.504	-0.466	0.220	-16.137	-0.475	0.337	0.367	-0.009	0.499
28	-0.125	-12.129	-1.063	0.152	-11.751	-1.081	0.277	0.378	-0.018	0.469

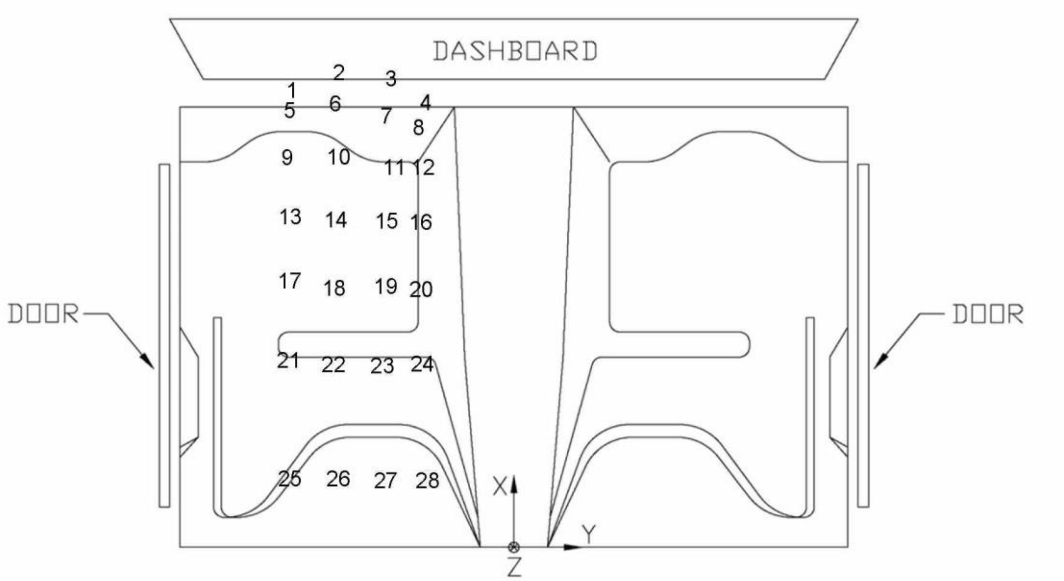


Figure D-1. Floor Pan Deformation Data – Set 1, Test No. 34AGT-1

Date: 3/17/2017 Test Name: 34AGT-1 VIN: 1D7RB1GP5AS218232
Year: 2010 Make: D0dge Model: Ram 1500

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
1	54.055	-30.306	3.022	52.179	-28.713	3.180	-1.876	1.593	0.158	2.466
2	55.462	-25.051	1.164	54.937	-25.300	0.321	-0.525	-0.249	-0.842	1.023
3	54.990	-19.484	1.080	54.656	-19.806	0.365	-0.334	-0.322	-0.715	0.853
4	53.167	-16.042	2.501	52.728	-16.686	2.026	-0.439	-0.644	-0.475	0.913
5	52.577	-30.215	0.697	50.581	-28.793	0.853	-1.996	1.422	0.156	2.456
6	53.100	-25.258	-0.057	52.770	-25.450	-1.161	-0.329	-0.191	-1.104	1.168
7	52.091	-19.758	-0.592	51.911	-19.876	-1.492	-0.180	-0.118	-0.901	0.926
8	51.317	-16.574	-0.383	51.014	-16.820	-0.913	-0.303	-0.247	-0.530	0.658
9	48.922	-29.989	-2.156	47.581	-29.313	-2.979	-1.341	0.676	-0.822	1.712
10	49.026	-25.243	-2.223	48.954	-25.295	-3.818	-0.072	-0.052	-1.595	1.598
11	48.299	-19.267	-2.551	48.387	-19.265	-3.653	0.088	0.001	-1.103	1.106
12	48.321	-16.247	-2.529	48.360	-16.300	-3.332	0.039	-0.053	-0.802	0.805
13	44.414	-30.051	-4.374	44.734	-30.055	-6.556	0.319	-0.004	-2.182	2.205
14	44.224	-25.214	-4.411	44.371	-25.061	-5.984	0.147	0.153	-1.573	1.587
15	44.176	-19.933	-4.441	44.325	-19.771	-5.509	0.148	0.162	-1.069	1.091
16	44.090	-16.249	-4.474	44.172	-16.110	-5.173	0.082	0.139	-0.699	0.717
17	39.590	-30.049	-4.775	39.816	-29.865	-6.549	0.226	0.184	-1.774	1.798
18	39.071	-25.328	-4.793	39.260	-25.271	-6.120	0.189	0.057	-1.327	1.342
19	39.135	-19.852	-4.794	39.294	-19.737	-5.671	0.159	0.115	-0.876	0.898
20	38.918	-16.162	-4.789	39.117	-16.180	-5.391	0.198	-0.018	-0.602	0.634
21	33.517	-30.075	-4.828	33.782	-30.046	-6.093	0.265	0.028	-1.265	1.293
22	33.192	-25.324	-4.824	33.427	-25.281	-5.794	0.235	0.043	-0.970	0.999
23	33.154	-20.109	-4.840	33.293	-20.070	-5.456	0.139	0.039	-0.615	0.632
24	33.287	-16.032	-4.849	33.342	-16.043	-5.261	0.055	-0.011	-0.412	0.416
25	24.433	-30.378	-0.987	24.748	-30.600	-1.555	0.315	-0.222	-0.569	0.687
26	24.454	-25.327	-0.970	24.718	-25.476	-1.430	0.264	-0.148	-0.460	0.551
27	24.307	-20.333	-1.000	24.515	-20.479	-1.352	0.208	-0.146	-0.352	0.434
28	24.329	-15.912	-1.016	24.495	-15.949	-1.308	0.166	-0.037	-0.292	0.338

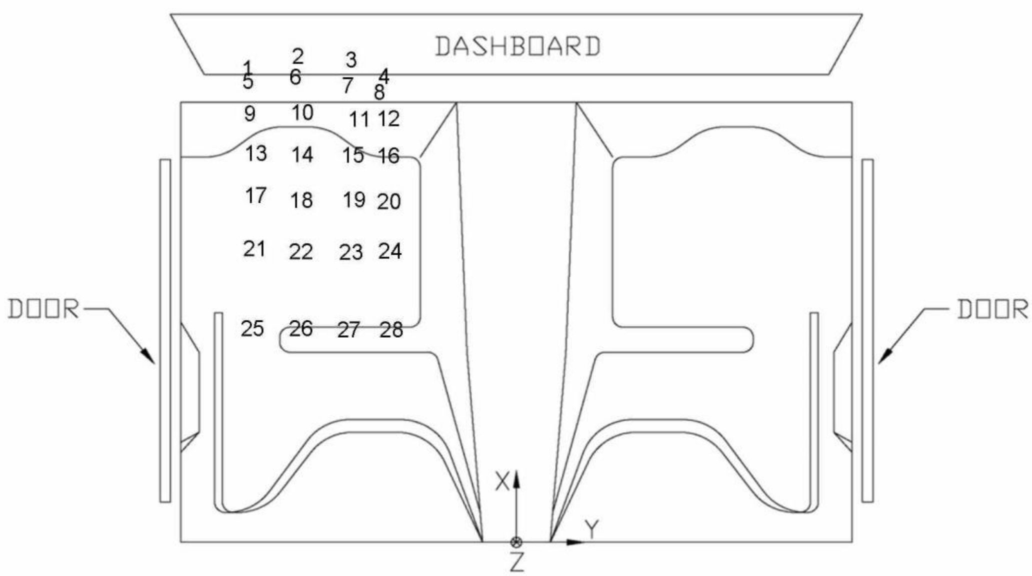


Figure D-2. Floor Pan Deformation Data – Set 2, Test No. 34AGT-1

Date:	3/17/2017	Test Name:	34AGT-1	VIN:	1D7RB1GP5AS218232
Year:	2010	Make:	D0dge	Model:	Ram 1500

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	14.585	-26.739	28.001	14.042	-25.218	28.526	-0.543	1.521	0.525	1.698
	2	12.388	-14.702	30.123	12.296	-13.209	30.716	-0.092	1.493	0.594	1.610
	3	11.023	3.569	24.966	11.412	4.799	25.007	0.390	1.230	0.041	1.291
	4	11.737	-27.765	17.844	10.854	-24.972	18.404	-0.883	2.794	0.561	2.983
	5	9.685	-16.565	16.202	8.580	-15.165	16.070	-1.105	1.401	-0.133	1.789
	6	8.350	2.020	13.796	8.224	3.185	13.915	-0.126	1.165	0.119	1.178
SIDE PANEL	7	20.698	-31.345	8.109	19.257	-25.343	8.225	-1.441	6.002	0.116	6.173
	8	23.692	-31.394	8.263	22.175	-24.919	8.375	-1.517	6.475	0.111	6.651
	9	22.347	-31.758	4.734	21.069	-25.910	4.989	-1.277	5.849	0.255	5.992
IMPACT SIDE DOOR	10	-14.519	-30.949	26.115	-15.198	-34.248	26.555	-0.678	-3.299	0.439	3.396
	11	-2.566	-30.788	25.695	-3.444	-32.500	26.461	-0.877	-1.712	0.766	2.071
	12	10.230	-30.488	25.498	9.148	-29.828	26.426	-1.082	0.660	0.927	1.570
	13	-14.688	-32.958	13.549	-14.754	-33.315	14.107	-0.066	-0.357	0.558	0.666
	14	0.473	-33.552	13.899	-0.238	-32.861	14.382	-0.711	0.691	0.482	1.102
	15	12.151	-32.458	12.550	10.493	-28.780	13.036	-1.659	3.678	0.487	4.064
ROOF	16	2.850	-20.241	43.660	2.980	-19.824	44.305	0.131	0.416	0.645	0.779
	17	5.131	-13.398	43.054	5.282	-12.841	43.508	0.150	0.557	0.454	0.734
	18	6.070	-8.223	42.581	6.254	-7.693	42.897	0.184	0.530	0.316	0.644
	19	7.144	-0.142	41.594	7.318	0.341	41.739	0.174	0.482	0.145	0.533
	20	7.113	4.971	41.033	7.294	5.440	41.071	0.181	0.469	0.038	0.504
	21	-2.994	-17.889	46.330	-2.726	-17.375	46.801	0.268	0.515	0.471	0.747
	22	-1.966	-12.799	45.996	-1.782	-12.285	46.391	0.184	0.514	0.395	0.673
	23	-0.916	-6.859	45.425	-0.780	-6.406	45.729	0.136	0.453	0.304	0.562
	24	0.115	0.513	44.515	0.217	1.009	44.688	0.103	0.496	0.173	0.535
	25	0.905	5.582	43.707	1.120	6.028	43.765	0.215	0.446	0.058	0.499
	26	-7.875	-17.155	46.992	-7.647	-16.682	47.433	0.228	0.473	0.441	0.686
	27	-8.165	-11.611	46.671	-8.040	-11.038	47.022	0.125	0.573	0.351	0.683
	28	-8.177	-6.522	46.259	-8.012	-6.032	46.529	0.165	0.490	0.270	0.583
	29	-5.574	0.500	45.380	-5.557	0.894	45.568	0.016	0.394	0.188	0.437
	30	-5.087	5.566	44.697	-5.006	6.053	44.778	0.081	0.487	0.081	0.500
A PILLAR	31	3.119	-21.825	42.556	3.370	-21.398	43.154	0.251	0.427	0.597	0.776
	32	9.043	-23.584	39.428	9.175	-23.123	39.968	0.133	0.460	0.540	0.722
	33	13.613	-24.944	36.680	13.705	-24.512	37.167	0.092	0.432	0.487	0.657
	34	18.313	-26.383	33.251	18.316	-25.886	33.644	0.004	0.497	0.393	0.634
B PILLAR	35	-17.909	-31.341	11.268	-17.499	-30.534	11.370	0.410	0.807	0.102	0.911
	36	-22.254	-31.346	11.521	-21.894	-30.319	11.597	0.360	1.027	0.076	1.091
	37	-18.449	-30.248	18.768	-18.100	-29.412	18.861	0.349	0.836	0.093	0.911
	38	-22.422	-30.251	19.088	-22.144	-29.288	19.264	0.278	0.963	0.177	1.018
	39	-19.760	-27.612	31.576	-19.565	-26.945	31.843	0.195	0.667	0.267	0.744
	40	-23.103	-27.699	31.531	-22.885	-26.988	31.674	0.217	0.711	0.142	0.757

Figure D-3. Occupant Compartment Deformation Data – Set 1, Test No. 34AGT-1

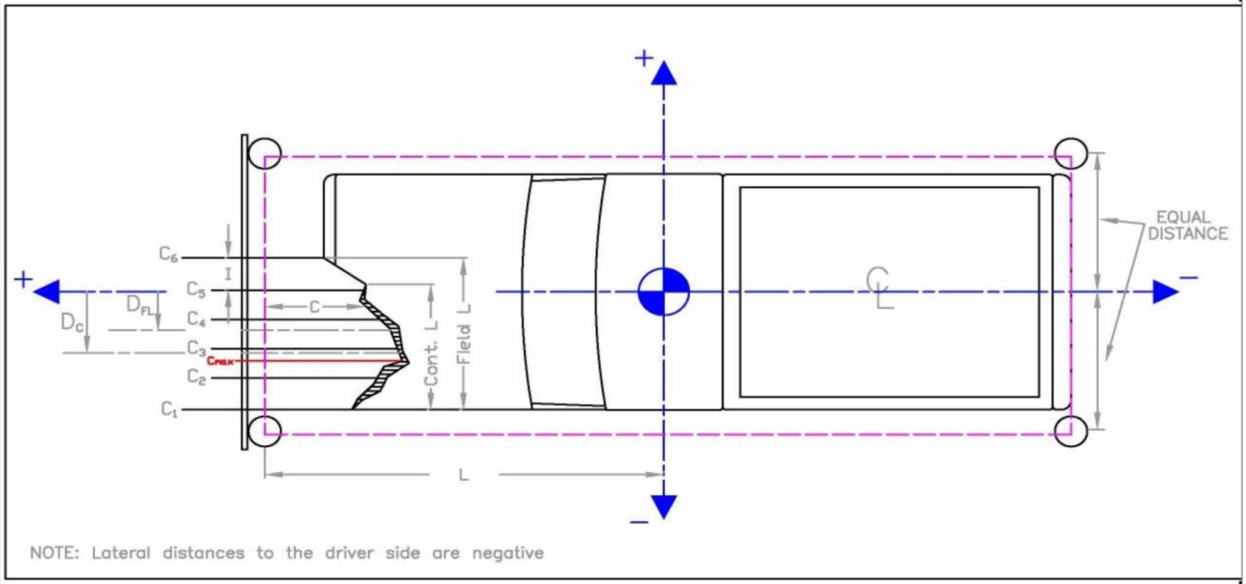
Date: 3/17/2017 Test Name: 34AGT-1 VIN: 1D7RB1GP5AS218232
Year: 2010 Make: D0dge Model: Ram 1500

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	38.684	-34.333	25.936	38.180	-33.816	26.050	-0.504	0.517	0.115	0.731
	2	36.527	-22.673	29.650	36.522	-22.254	29.962	-0.005	0.419	0.311	0.522
	3	35.309	-3.867	26.925	35.845	-3.538	26.965	0.536	0.329	0.040	0.630
	4	35.979	-33.974	15.682	35.032	-32.114	16.045	-0.947	1.860	0.363	2.118
	5	33.953	-22.636	15.613	32.825	-22.010	15.243	-1.128	0.625	-0.370	1.342
	6	32.719	-3.885	15.597	32.694	-3.540	15.706	-0.025	0.346	0.109	0.363
SIDE PANEL	7	45.037	-36.280	5.706	43.426	-31.047	5.922	-1.612	5.233	0.216	5.480
	8	48.022	-36.361	5.877	46.358	-30.688	6.154	-1.664	5.673	0.278	5.918
	9	46.703	-36.251	2.323	45.195	-31.189	2.662	-1.508	5.062	0.339	5.293
IMPACT SIDE DOOR	10	9.645	-38.121	23.220	8.871	-42.197	22.747	-0.774	-4.076	-0.472	4.175
	11	21.574	-37.922	23.064	20.619	-40.578	22.853	-0.955	-2.656	-0.211	2.830
	12	34.446	-37.679	22.910	33.251	-38.045	23.166	-1.194	-0.366	0.256	1.275
	13	9.606	-38.440	10.620	9.431	-39.469	10.446	-0.175	-1.029	-0.174	1.058
	14	24.741	-39.138	10.996	23.932	-39.181	10.861	-0.809	-0.043	-0.135	0.822
	15	36.411	-37.924	9.892	34.684	-35.051	10.187	-1.726	2.873	0.296	3.365
ROOF	16	26.848	-29.937	42.270	27.141	-30.653	42.392	0.293	-0.716	0.123	0.783
	17	29.198	-22.984	42.580	29.495	-23.778	42.628	0.297	-0.794	0.048	0.849
	18	30.111	-17.802	42.822	30.619	-18.564	42.744	0.508	-0.762	-0.078	0.919
	19	31.216	-9.696	42.906	31.695	-10.450	42.822	0.480	-0.754	-0.083	0.897
	20	31.241	-4.538	43.008	31.686	-5.373	42.930	0.445	-0.835	-0.078	0.949
	21	21.025	-27.864	45.161	21.335	-28.685	45.236	0.310	-0.821	0.075	0.881
	22	22.073	-22.803	45.511	22.458	-23.580	45.562	0.385	-0.777	0.051	0.869
	23	23.206	-16.842	45.728	23.521	-17.584	45.777	0.315	-0.742	0.049	0.808
	24	24.127	-9.377	45.834	24.559	-10.196	45.842	0.432	-0.819	0.007	0.926
	25	25.087	-4.218	45.679	25.443	-5.003	45.689	0.356	-0.785	0.010	0.862
	26	16.117	-27.265	45.872	16.488	-27.948	45.930	0.371	-0.683	0.058	0.779
	27	15.891	-21.578	46.295	16.234	-22.415	46.332	0.343	-0.837	0.037	0.905
	28	15.873	-16.600	46.556	16.242	-17.422	46.585	0.369	-0.822	0.028	0.901
	29	18.408	-9.503	46.640	18.886	-10.226	46.655	0.478	-0.723	0.015	0.867
	30	18.912	-4.292	46.631	19.345	-5.154	46.645	0.433	-0.863	0.014	0.965
A PILLAR	31	27.188	-31.321	40.909	27.421	-32.086	41.107	0.232	-0.764	0.198	0.823
	32	33.044	-32.645	37.658	33.294	-33.422	37.659	0.250	-0.776	0.001	0.816
	33	37.669	-33.665	34.812	37.773	-34.391	34.607	0.104	-0.727	-0.205	0.762
	34	42.374	-34.644	31.274	42.427	-35.311	30.989	0.053	-0.667	-0.285	0.728
B PILLAR	35	6.434	-36.518	8.445	6.666	-36.262	8.194	0.231	0.255	-0.251	0.427
	36	2.072	-36.550	8.650	2.234	-36.038	8.388	0.162	0.513	-0.261	0.598
	37	5.750	-36.430	16.019	5.992	-36.247	15.800	0.242	0.183	-0.220	0.374
	38	1.748	-36.456	16.348	1.956	-36.144	16.148	0.209	0.312	-0.200	0.425
	39	4.342	-35.488	29.150	4.536	-35.688	29.066	0.194	-0.200	-0.083	0.291
	40	1.032	-35.567	28.992	1.221	-35.679	28.836	0.190	-0.112	-0.157	0.270

Figure D-4. Occupant Compartment Deformation Data – Set 2, Test No. 34AGT-1

Date:	3/23/2017	Test Name:	34AGT-1	VIN:	1D7RB1GP5AS218232
Year:	2010	Make:	D0dge	Model:	Ram 1500



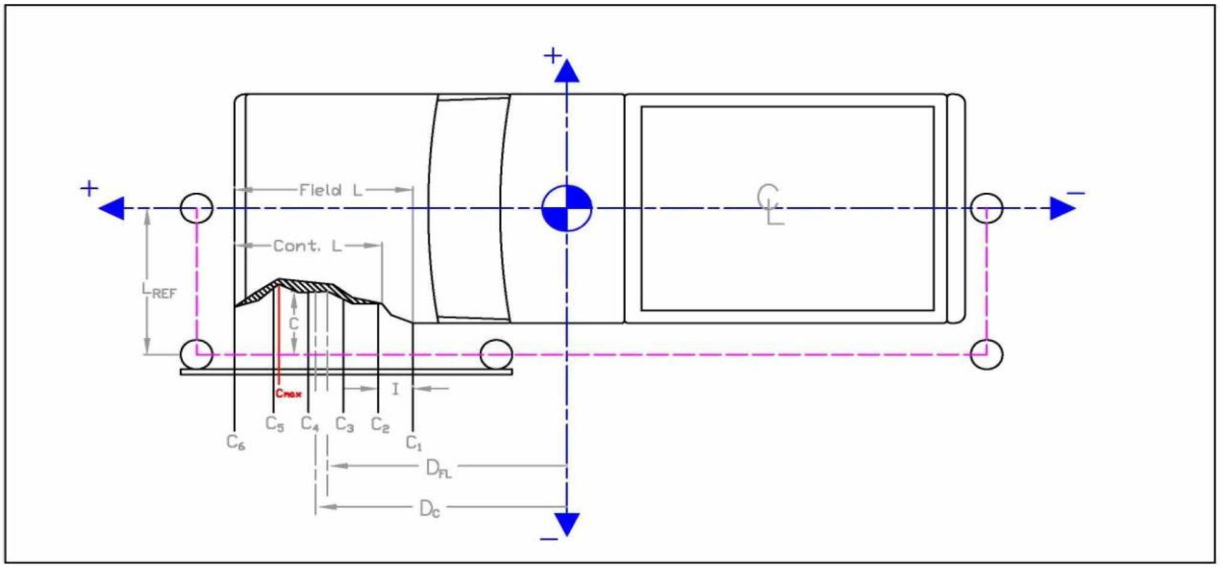
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	97	(2464)
Total Vehicle Width:	77 5/8	(1972)
Width of contact and induced crush - Field L:	77 5/8	(1972)
Crush measurement spacing interval (L/5) - I:	15 1/2	(394)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	77 5/8	(1972)
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	-38 7/8	-(987)	22 1/2	(572)	-9 1/5	-(233)	NA	NA
C_2	19 1/2	(495)	-23 3/8	-(594)	6 5/8	(168)			22	(560)
C_3	6 1/2	(165)	-7 7/8	-(200)	4 1/4	(108)			11 4/9	(291)
C_4	5	(127)	7 5/8	(194)	4 1/4	(108)			10	(252)
C_5	5 3/4	(146)	23 1/8	(587)	6 1/8	(156)			8 4/5	(224)
C_6	NA	NA	38 5/8	(981)	20 1/2	(521)			NA	NA
C_{MAX}	25 1/2	(648)	-30	-(762)	9 1/4	(235)			25 4/9	(646)

Figure D-5. Exterior Vehicle Crush (NASS) - Front, Test No. 34AGT-1

Date:	3/23/2017	Test Name:	34AGT-1	VIN:	1D7RB1GP5AS218232
Year:	2010	Make:	D0dge	Model:	Ram 1500



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	48	(1219)
Total Vehicle Length:	229 1/4	(5823)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-12 4/7	-(319)
Width of contact and induced crush - Field L:	229 1/4	(5823)
Crush measurement spacing interval (L/5) - I:	45 7/8	(1165)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-12 4/7	-(319)
Width of Contact Damage:	229 1/4	(5823)
Distance from vehicle c.g. to center of contact damage - D_C:	-12 4/7	-(319)

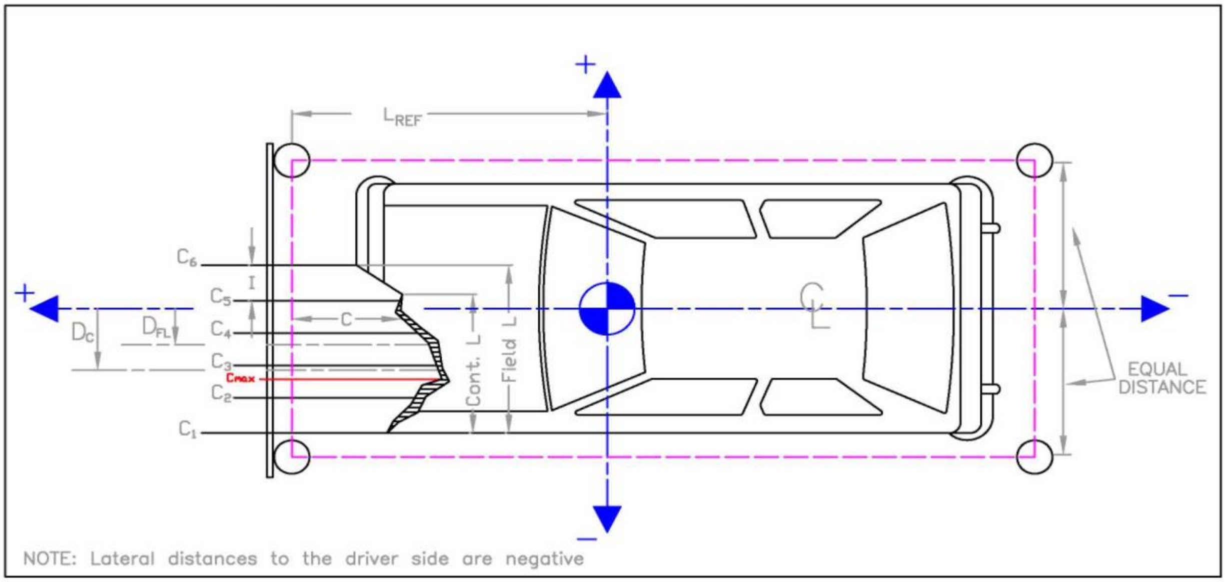
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been removed)
NOTE: All values must be filled out above before crush measurements are filled out.

	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	NA	NA	-127 1/4	-(3232)	33 1/2	(851)	4	(102)	NA	NA
C_2	9 1/4	(235)	-81 3/8	-(2067)	5 1/4	(133)			0	()
C_3	9 1/4	(235)	-35 1/2	-(902)	5 5/8	(143)			- 3/8	-(10)
C_4	5 1/2	(140)	10 3/8	(264)	5 1/8	(130)			-3 5/8	-(92)
C_5	NA	NA	56 1/4	(1429)	5	(127)			NA	NA
C_6	NA	NA	102 1/8	(2594)	33 1/2	(851)			NA	NA
C_{MAX}	28	(711)	85 1/2	(2172)	6 1/4	(159)			17 3/4	(451)

Figure D-6. Exterior Vehicle Crush (NASS) - Side, Test No. 34AGT-1

Date: 5/12/2017 **Test Number:** 34AGT-2

Year: 2011 **Make:** Kia **Model:** Rio



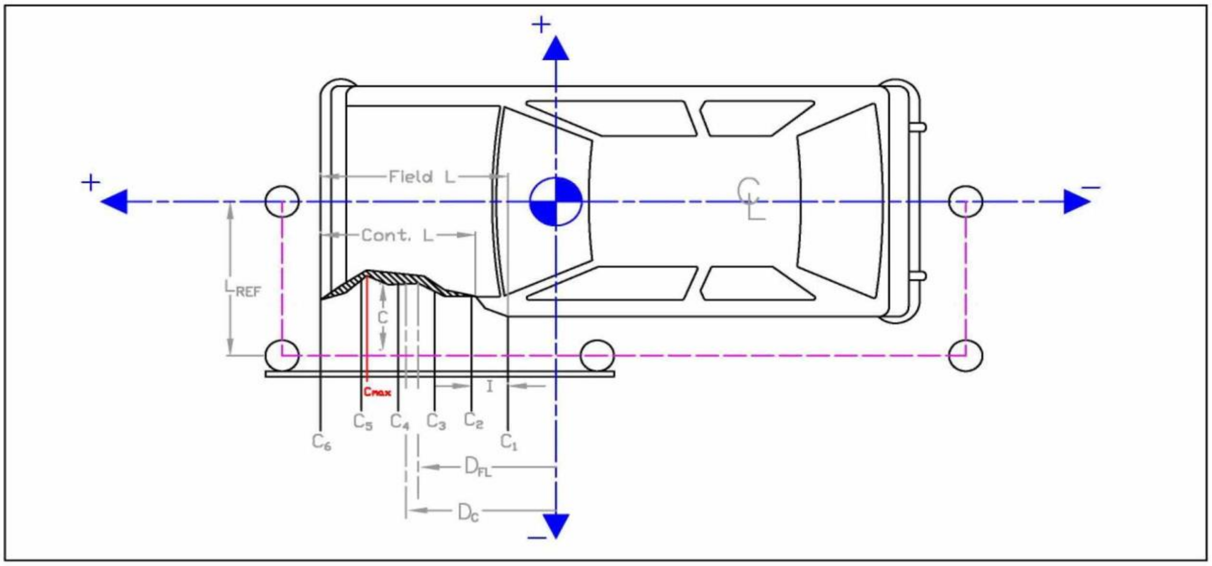
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	77	(1956)
Total Width of Vehicle:	65 1/4	(1657)
Width of contact and induced crush - Field L:	65 1/4	(1657)
Crush measurement spacing interval (L/5) - I:	13	(330)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	38	(965)
Distance from center of vehicle to center of contact damage - D_C:	12 1/2	(318)

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	63	(1600)	-32 5/8	-(829)	24	(610)	-2 1/3	-(59)	41 1/3	(1049)
C_2	29	(737)	-19 5/8	-(498)	8 1/2	(216)			22 4/5	(579)
C_3	18 1/2	(470)	-6 5/8	-(168)	6 1/8	(156)			14 2/3	(373)
C_4	7 1/2	(191)	6 3/8	(162)	6 1/8	(156)			3 2/3	(94)
C_5	3 1/2	(89)	19 3/8	(492)	8 3/8	(213)			-2 4/7	-(65)
C_6	10 1/2	(267)	32 3/8	(822)	24	(610)			-11 1/5	-(284)
C_{MAX}	27 3/4	(705)	-11	-(279)	6 5/8	(168)			23 4/9	(595)

Figure D-7. Exterior Vehicle Crush (NASS) - Front, Test No. 34AGT-2

Date:	5/12/2017	Test Number:	34AGT-2		
Year:	2011	Make:	Kia	Model:	Rio



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	45 1/2	(1156)
Total Vehicle Length:	167	(4242)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-9 4/7	-(243)
Width of contact and induced crush - Field L:	167	(4242)
Crush measurement spacing interval (L/5) - I:	33 3/8	(848)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-9 4/7	-(243)
Width of Contact Damage:	167	(4242)
Distance from vehicle c.g. to center of contact damage - D_C:	-9 4/7	-(243)

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	31 1/2	(800)	-93 1/8	-(2365)	26	(660)	9 1/2	(241)	-4	-(102)
C_2	11 3/4	(298)	-59 3/4	-(1518)	4	(102)			-1 3/4	-(44)
C_3	10 1/2	(267)	-26 3/8	-(670)	3 5/8	(92)			-2 5/8	-(67)
C_4	9	(229)	7	(178)	3 3/4	(95)			-4 1/4	-(108)
C_5	23	(584)	40 3/8	(1026)	3 1/4	(83)			10 1/4	(260)
C_6	N/A	#VALUE!	73 3/4	(1873)	20 1/4	(514)			#VALUE!	#VALUE!
C_{MAX}	37	(940)	56	(1422)	4	(102)			23 1/2	(597)

Figure D-8. Exterior Vehicle Crush (NASS) - Side, Test No. 34AGT-2

Appendix E. Accelerometer and Rate Transducer Data Plots, Test No. 34AGT-1

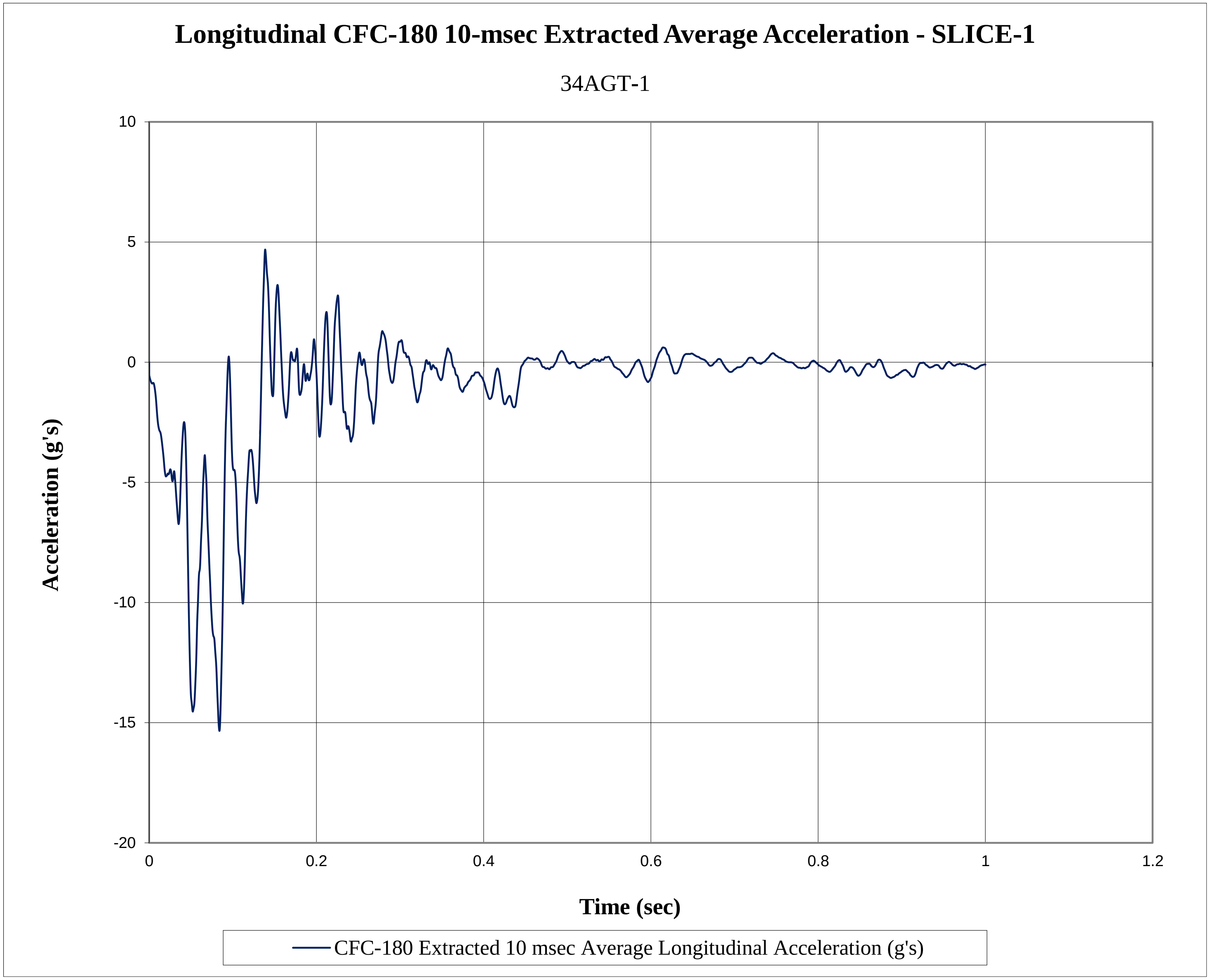


Figure E-1. 10-ms Average Longitudinal Acceleration (SLICE-1), Test No. 34AGT-1

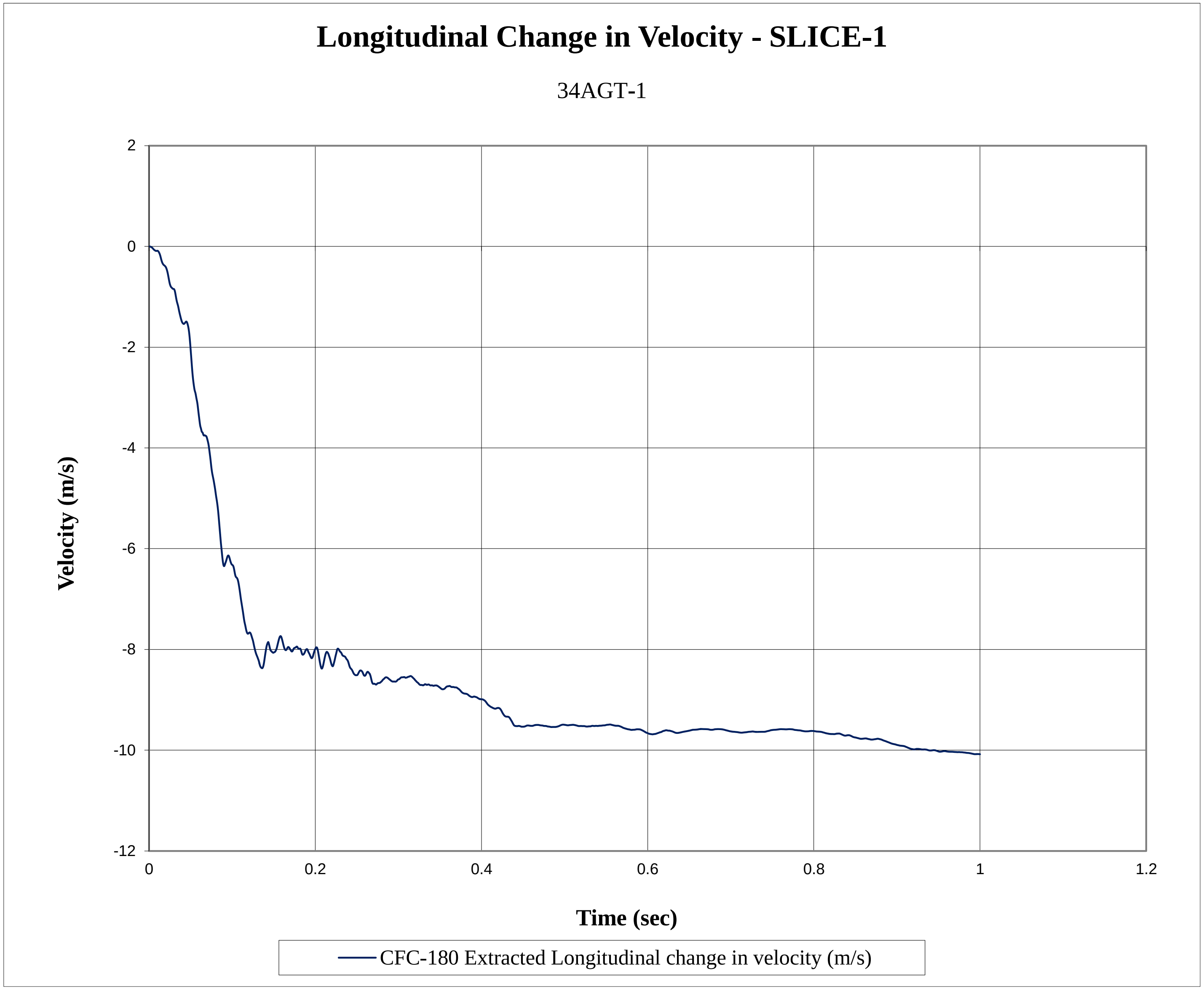


Figure E-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. 34AGT-1

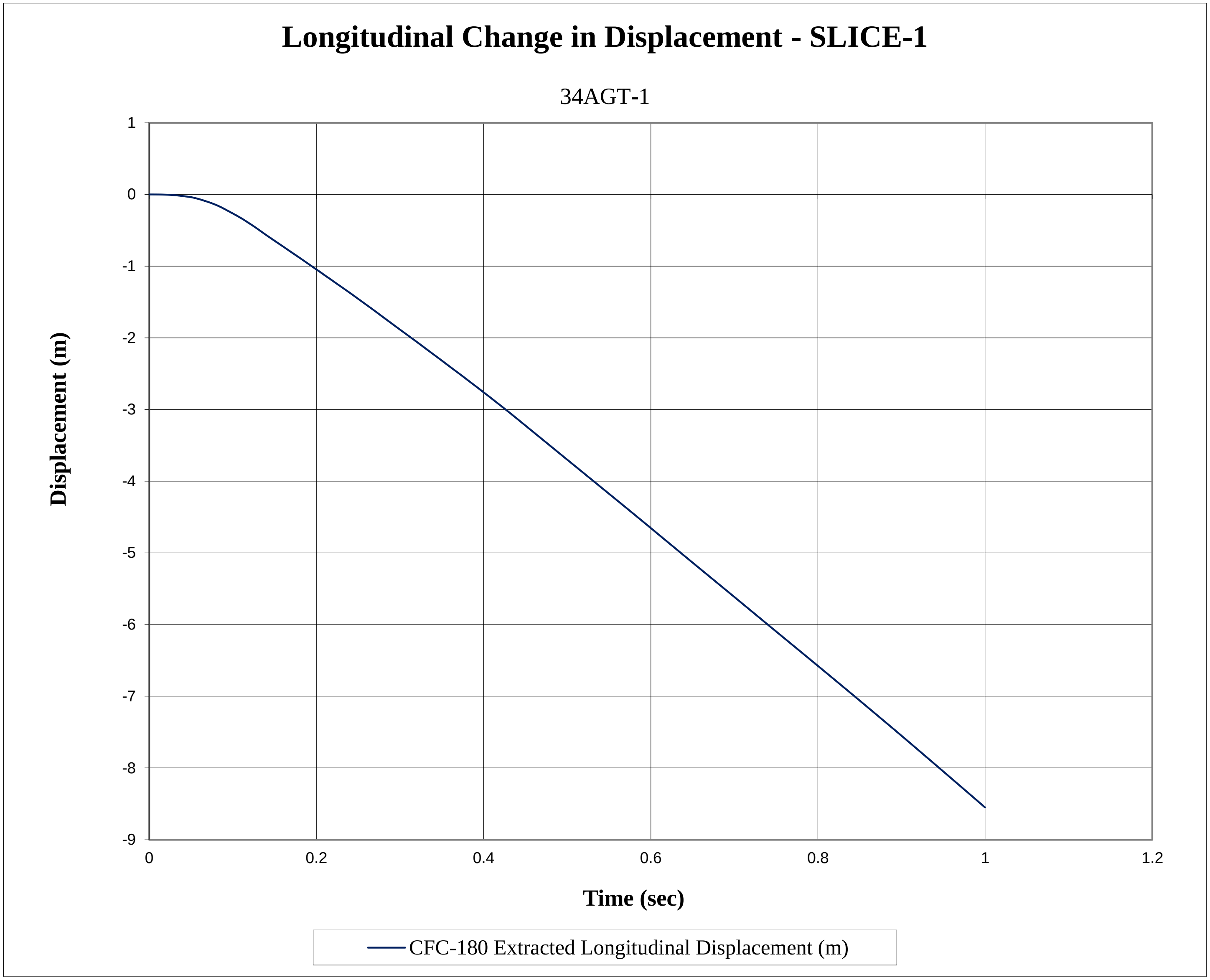


Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. 34AGT-1

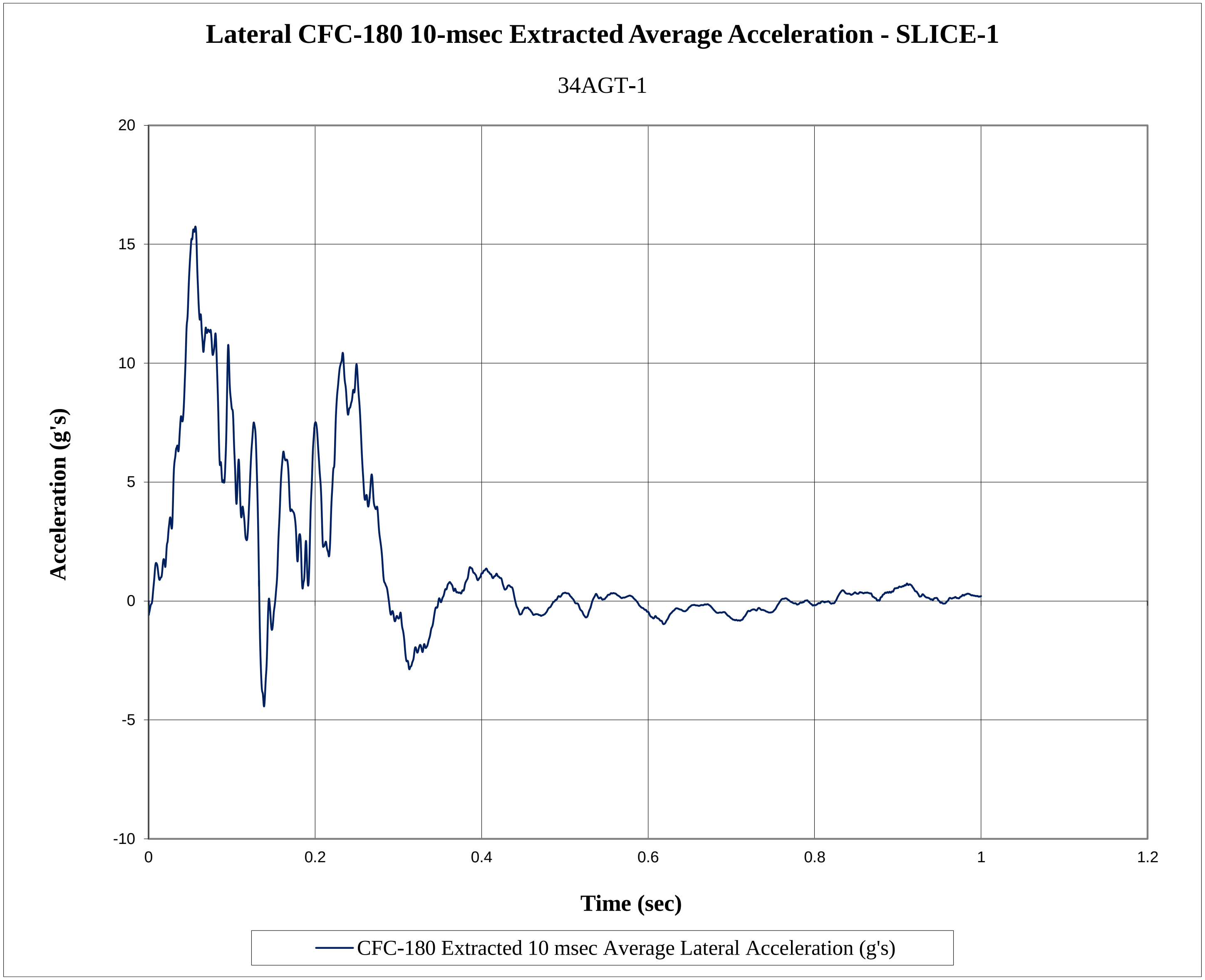


Figure E-4. 10-ms Average Lateral Acceleration (SLICE-1), Test No. 34AGT-1

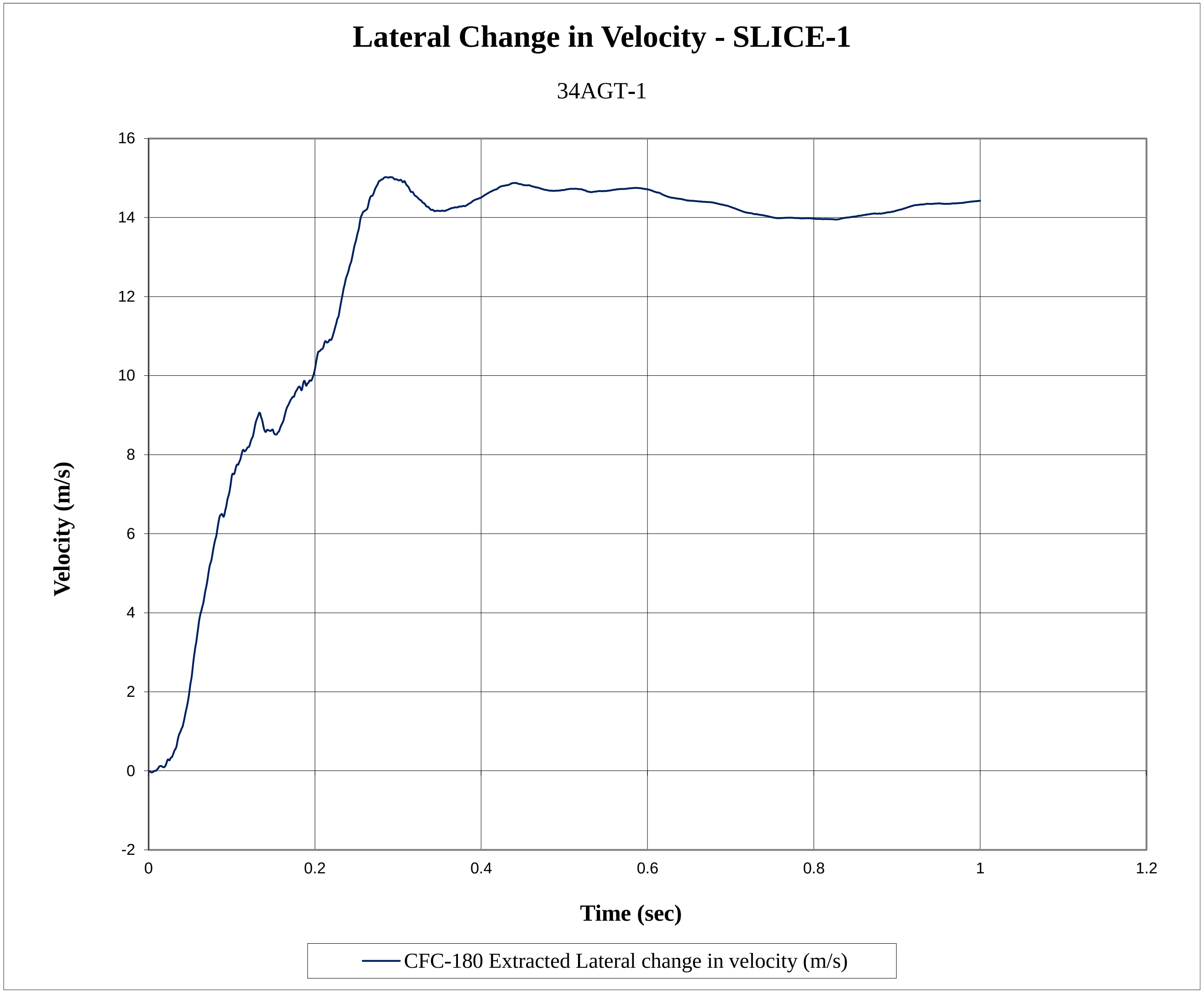


Figure E-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. 34AGT-1

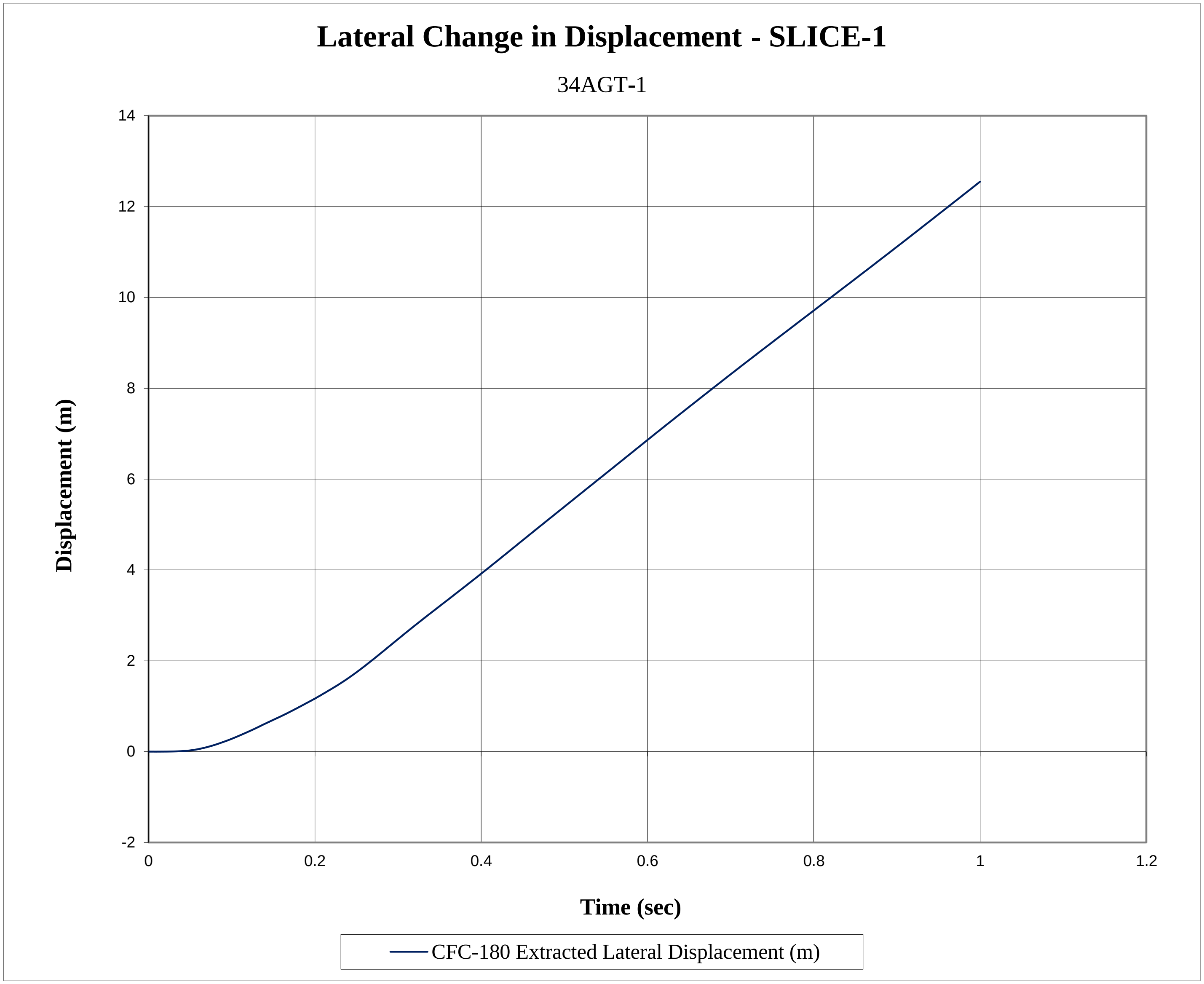


Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. 34AGT-1

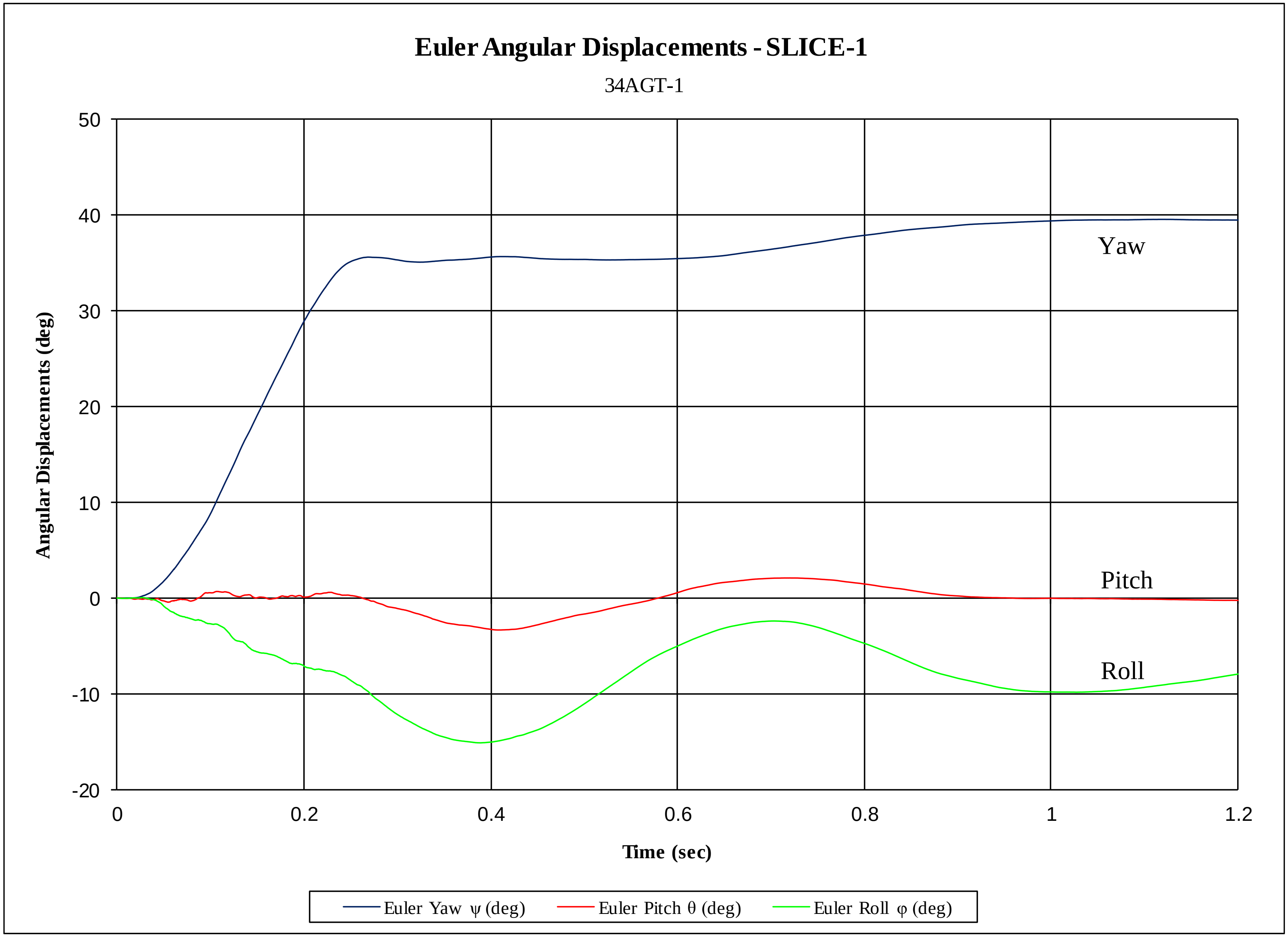


Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. 34AGT-1

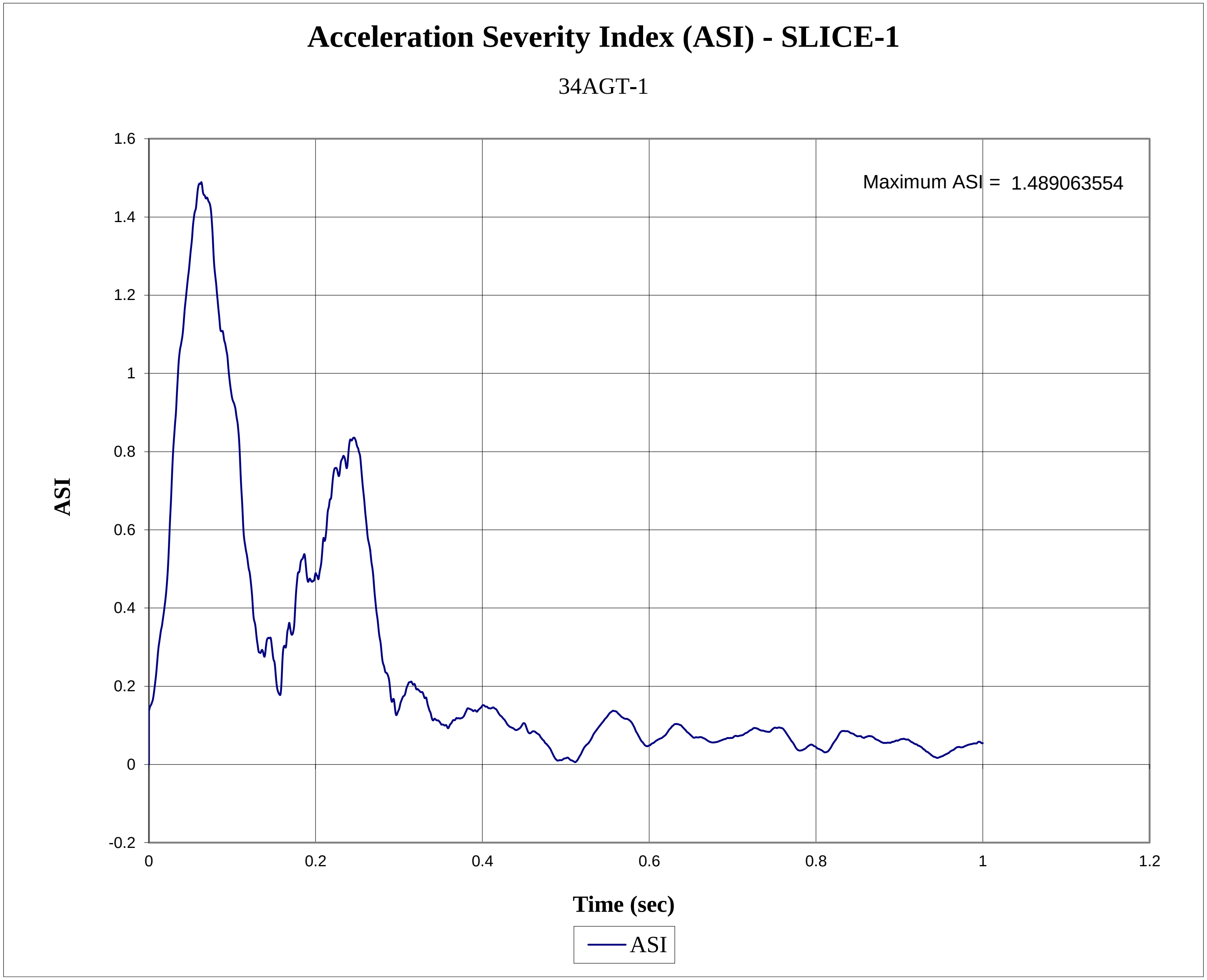


Figure E-8. Acceleration Severity Index (SLICE-1), Test No. 34AGT-1

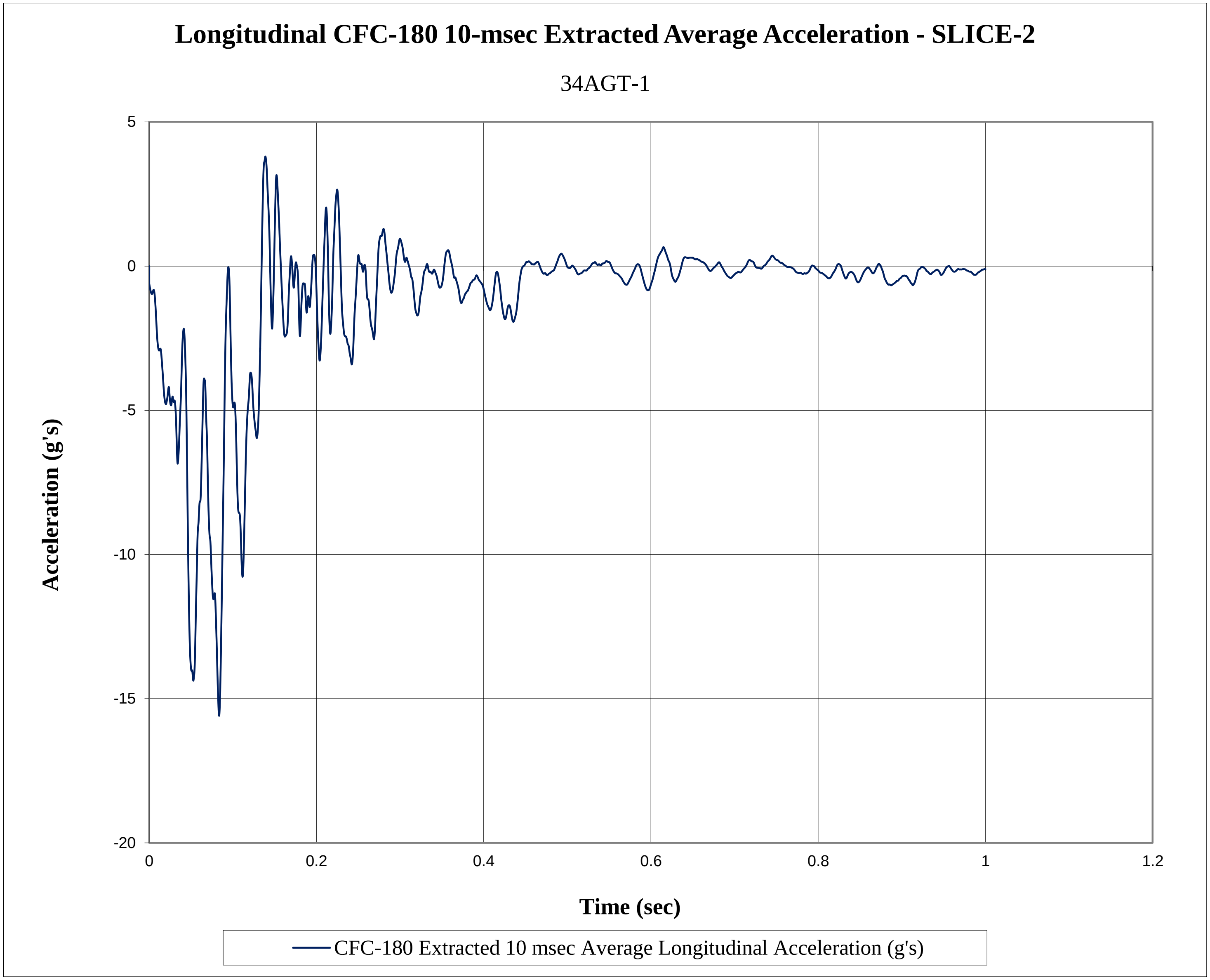


Figure E-9. 10-ms Average Longitudinal Acceleration (SLICE-2), Test No. 34AGT-1

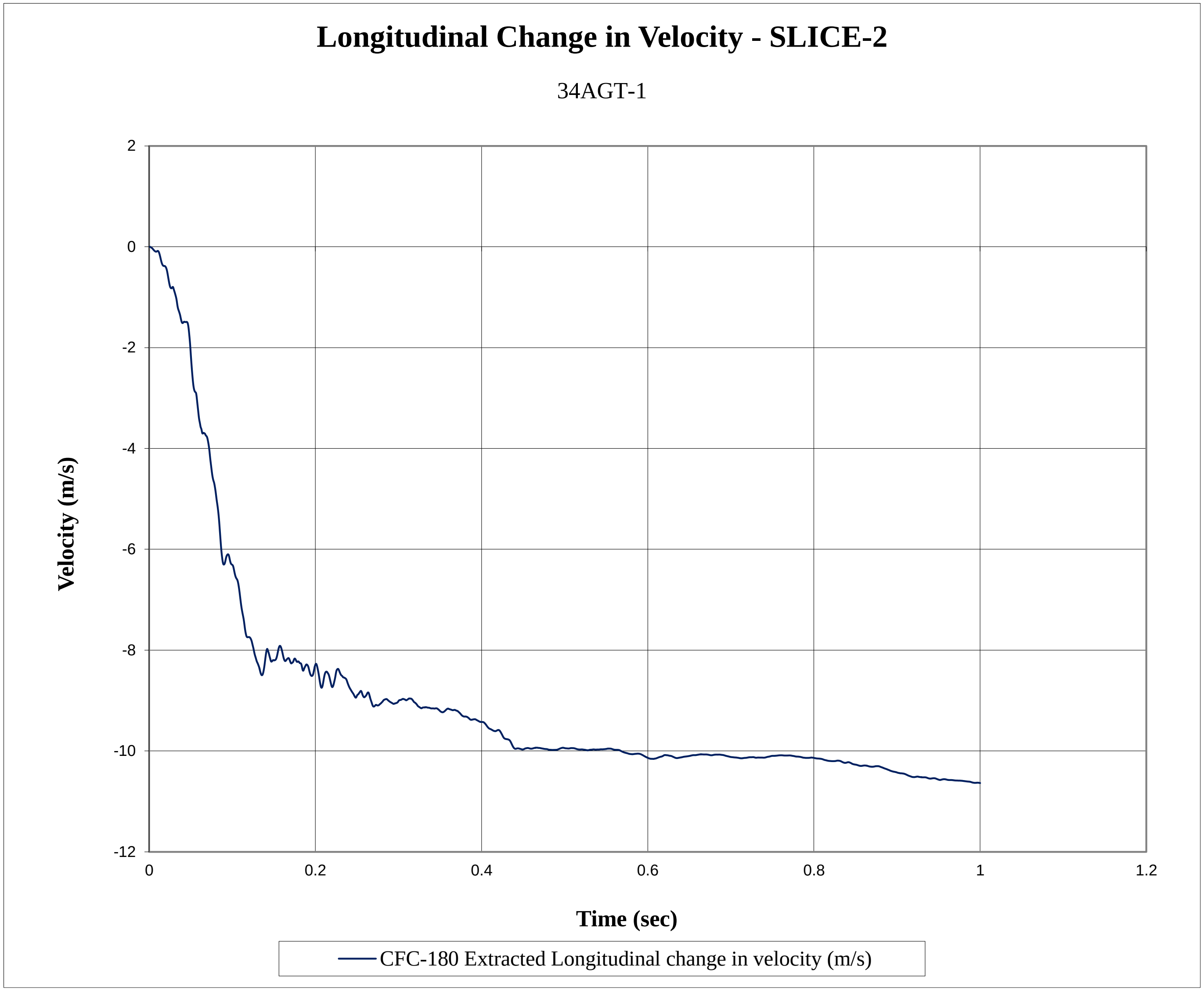


Figure E-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. 34AGT-1

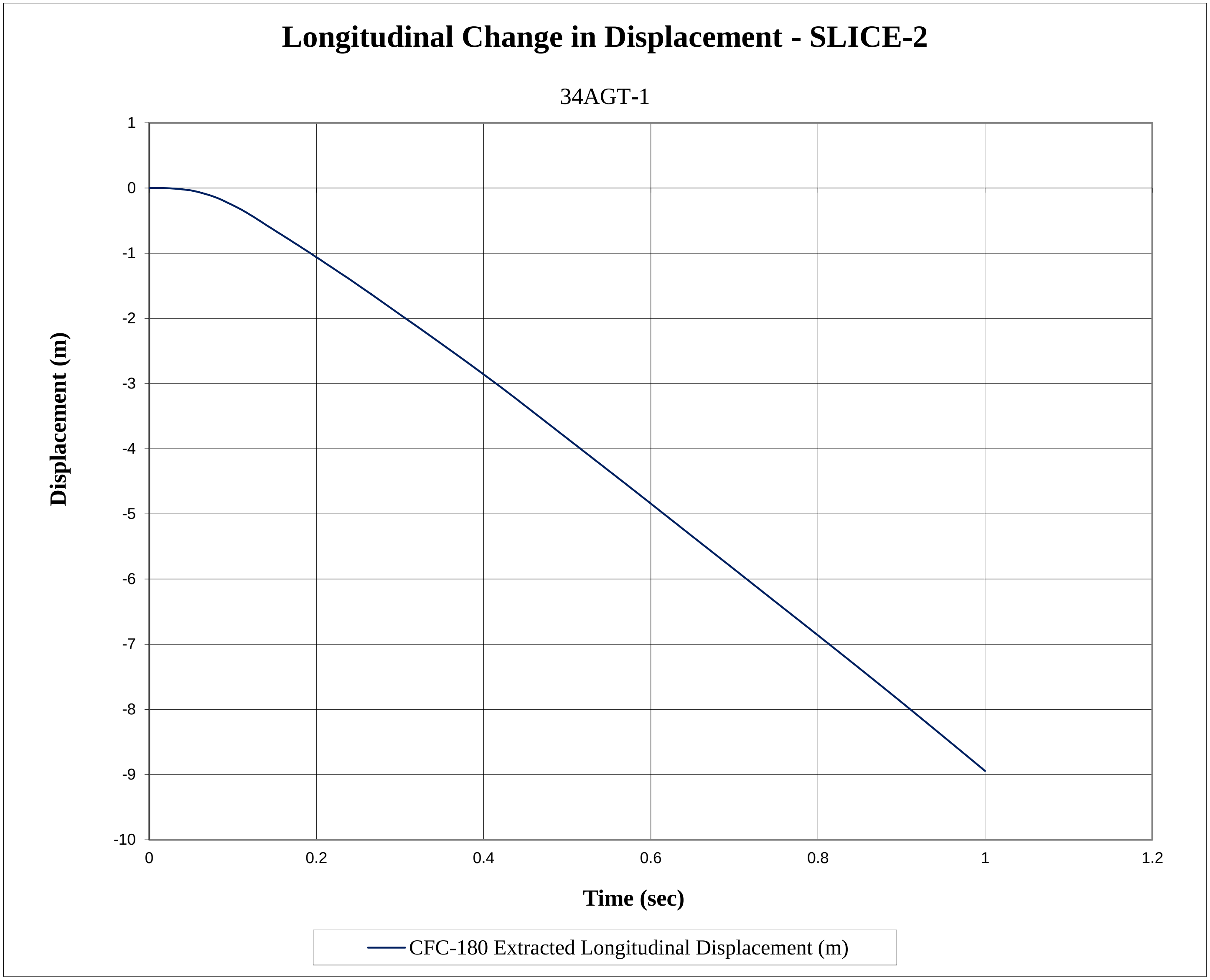


Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. 34AGT-1

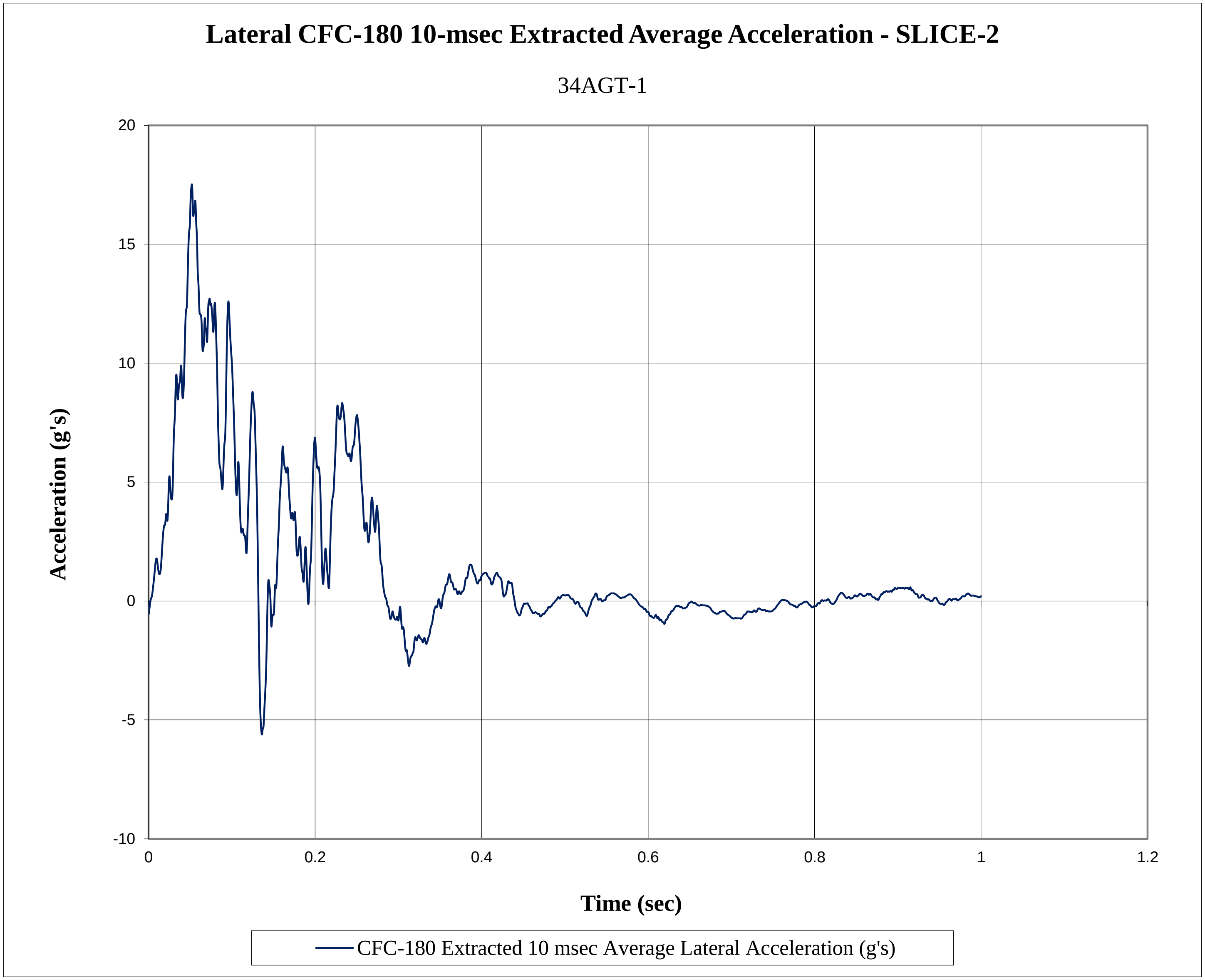


Figure E-12. 10-ms Average Lateral Acceleration (SLICE-2), Test No. 34AGT-1

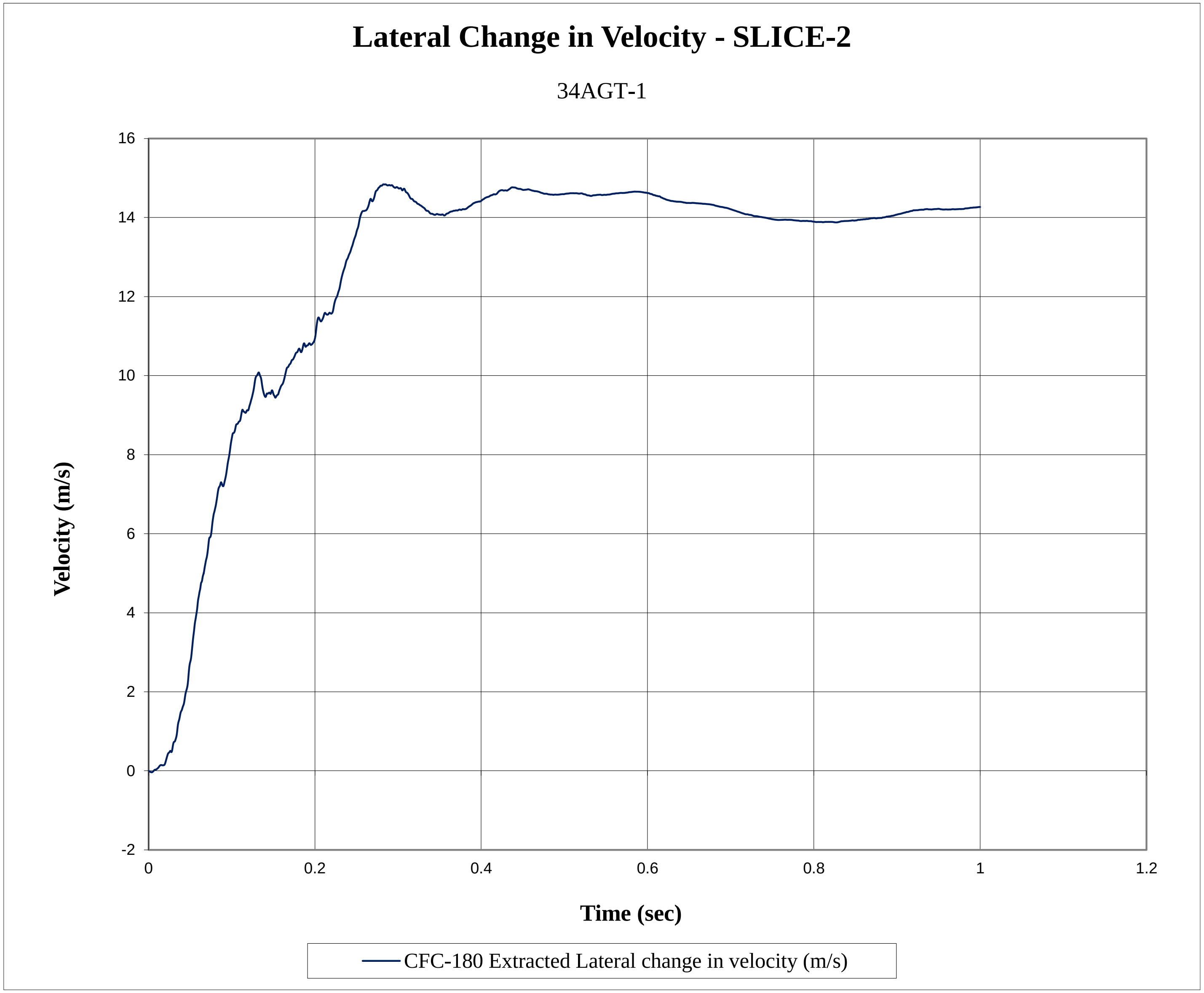


Figure E-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. 34AGT-1

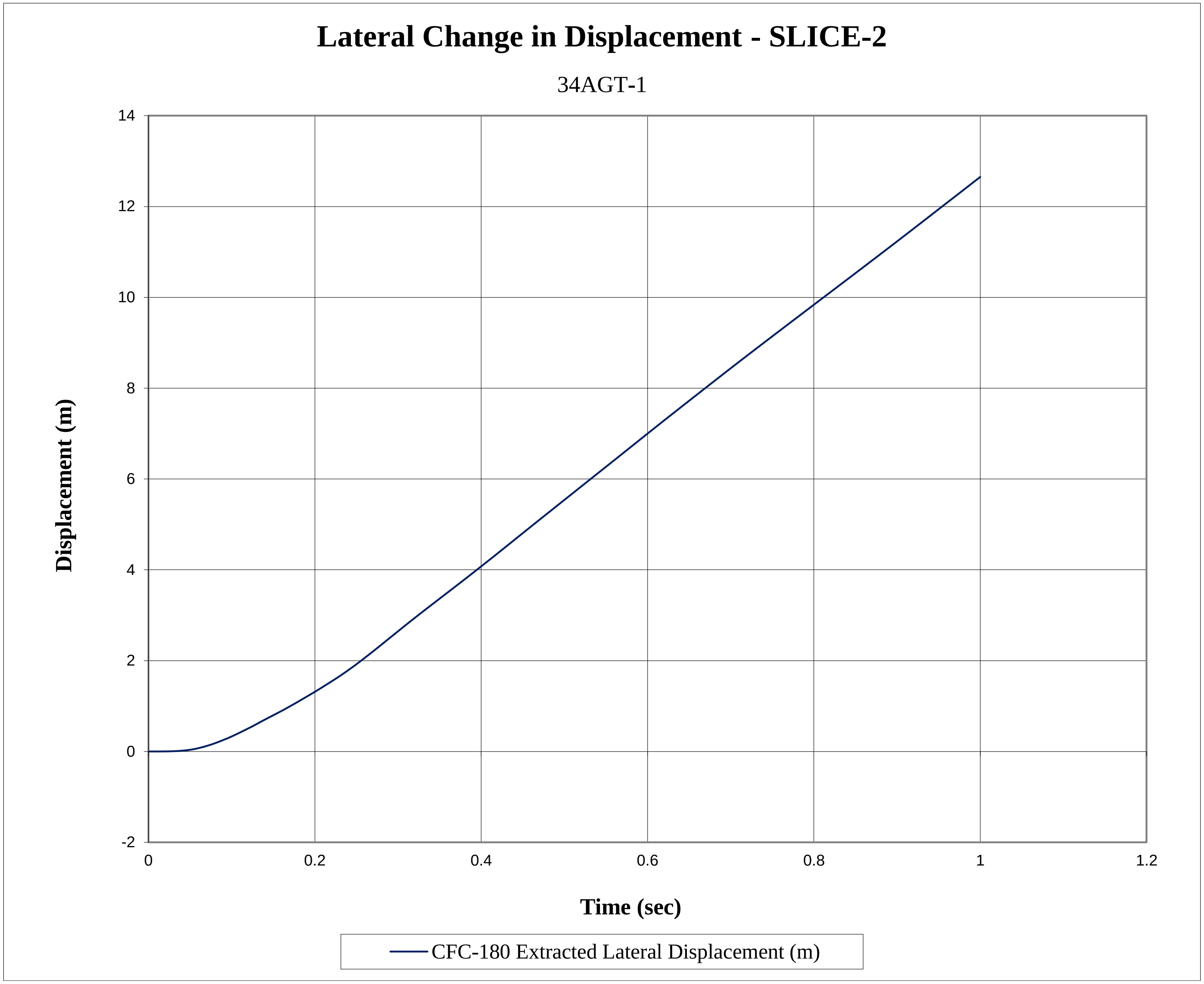


Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. 34AGT-1

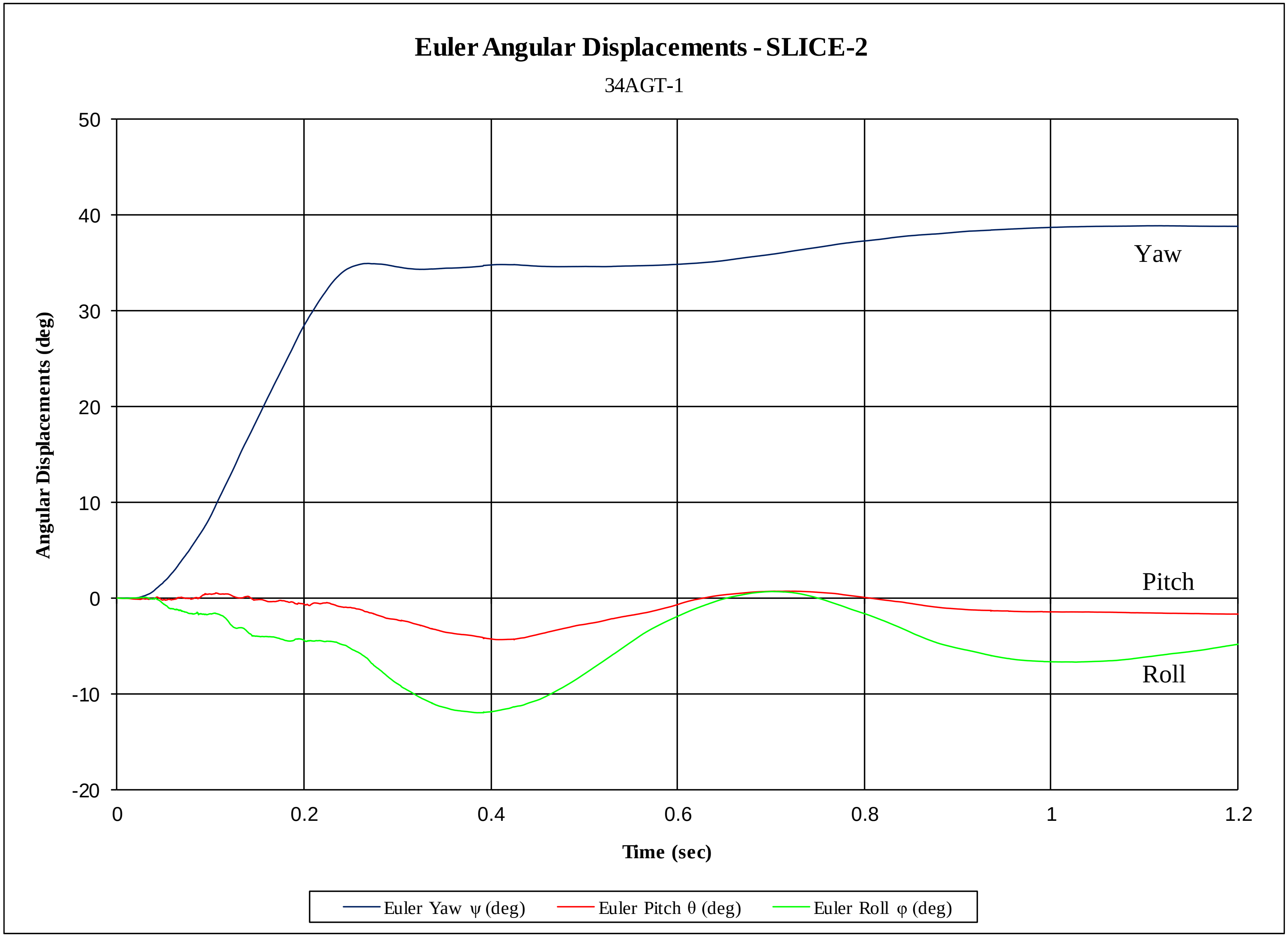


Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. 34AGT-1

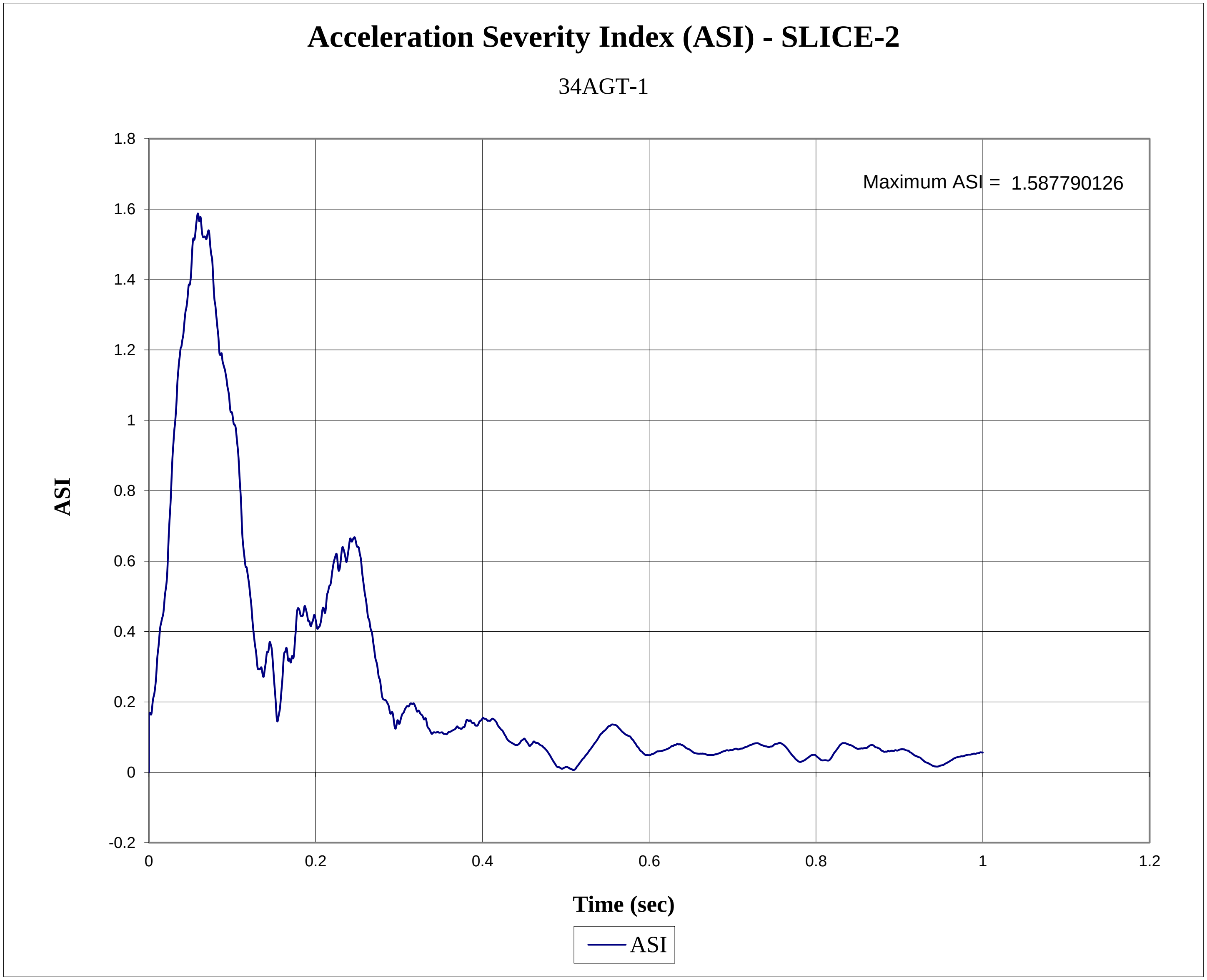


Figure E-16. Acceleration Severity Index (SLICE-2), Test No. 34AGT-1

Appendix F. Accelerometer and Rate Transducer Data Plots, Test No. 34AGT-2

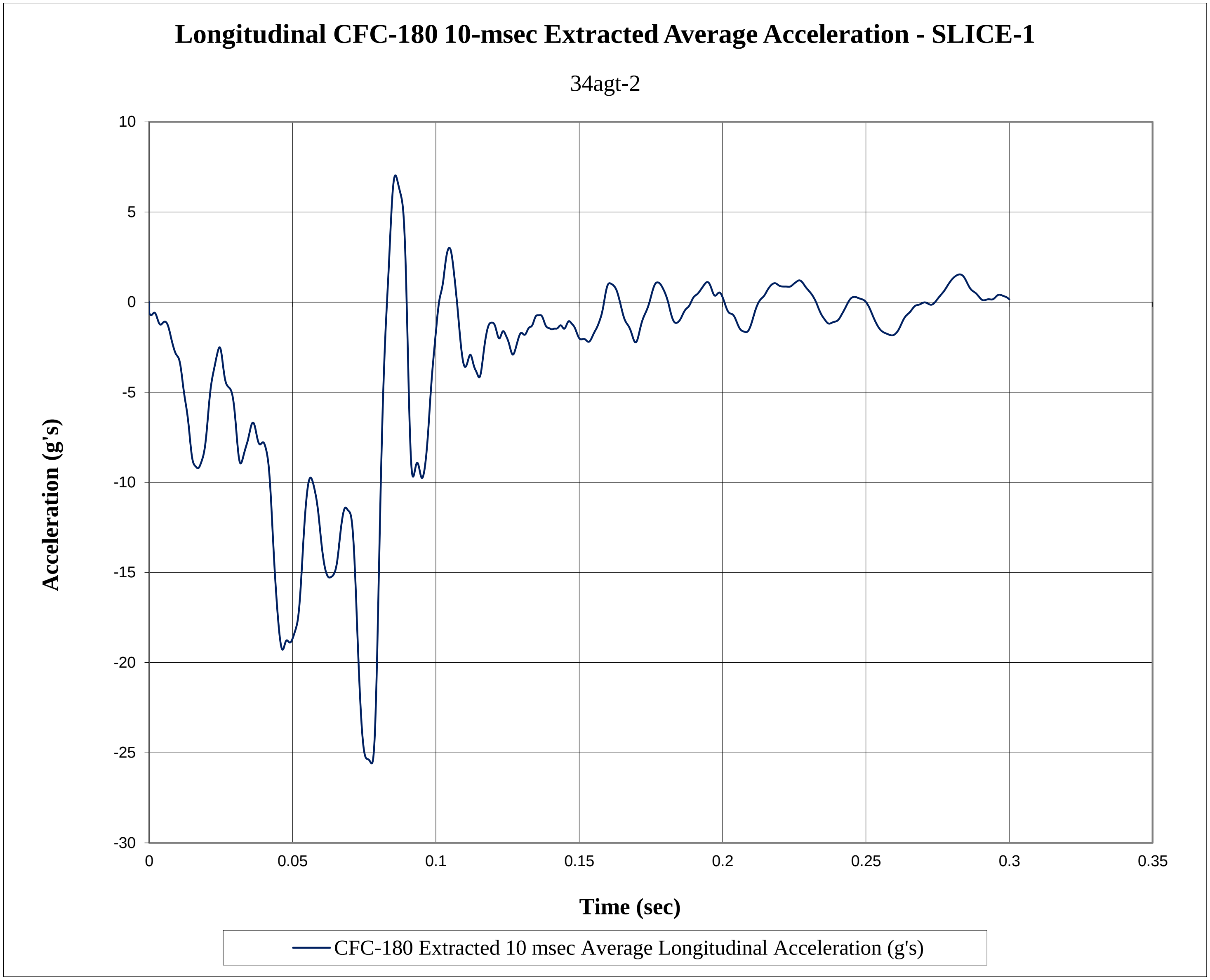


Figure F-1. 10-ms Average Longitudinal Acceleration (SLICE-1), Test No. 34AGT-2

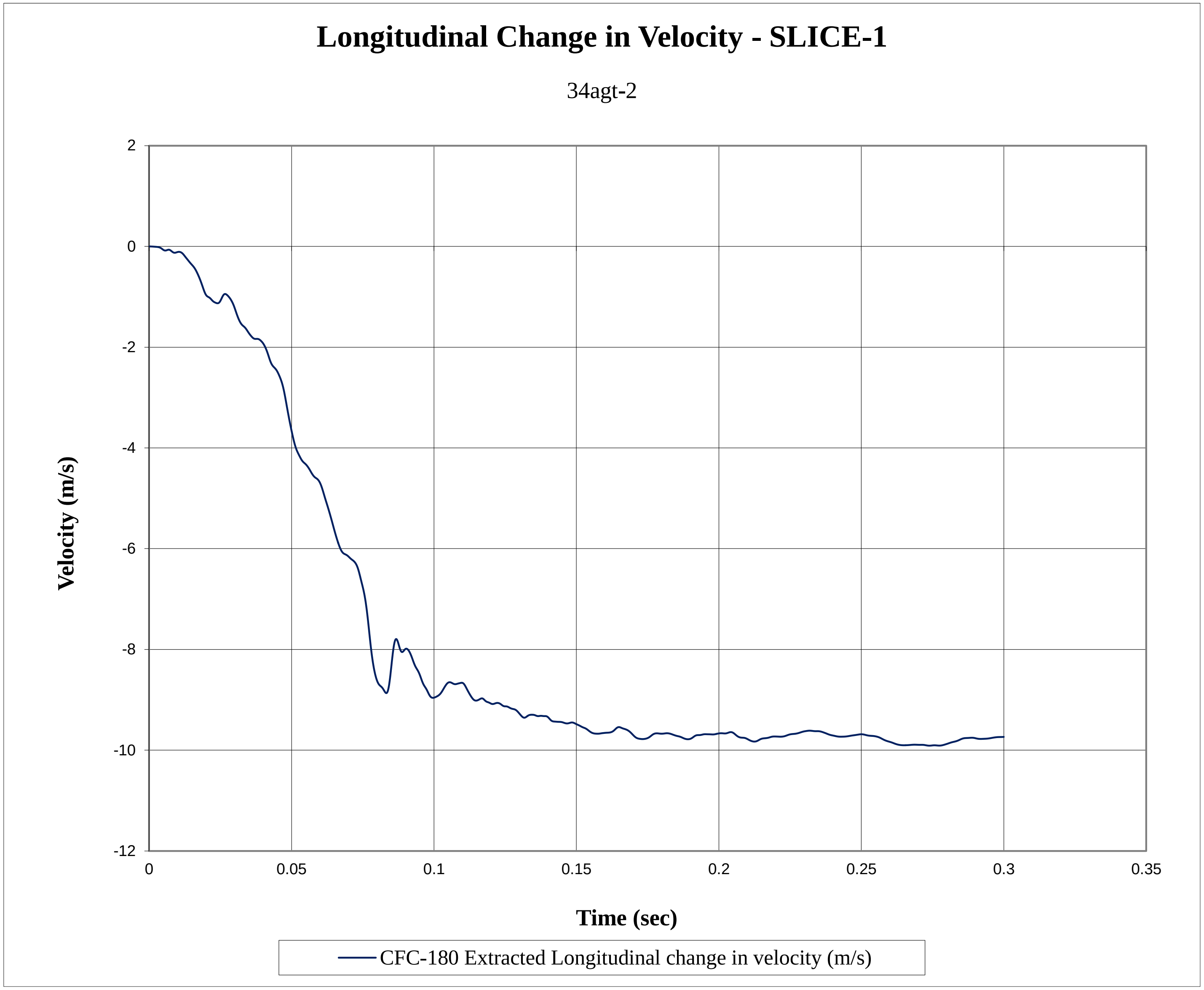


Figure F-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. 34AGT-2

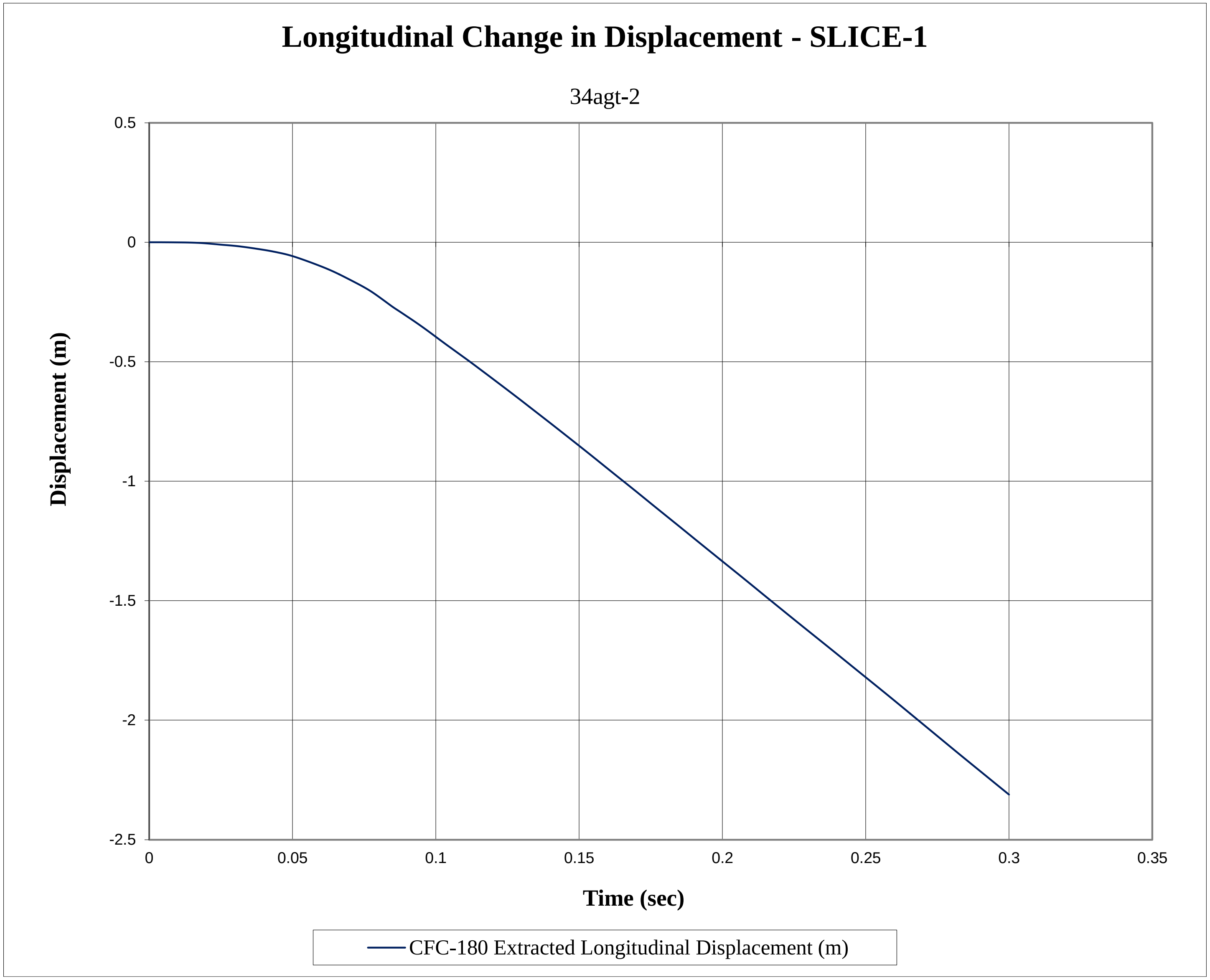


Figure F-3. Longitudinal Occupant Displacement (SLICE-1), Test No. 34AGT-2

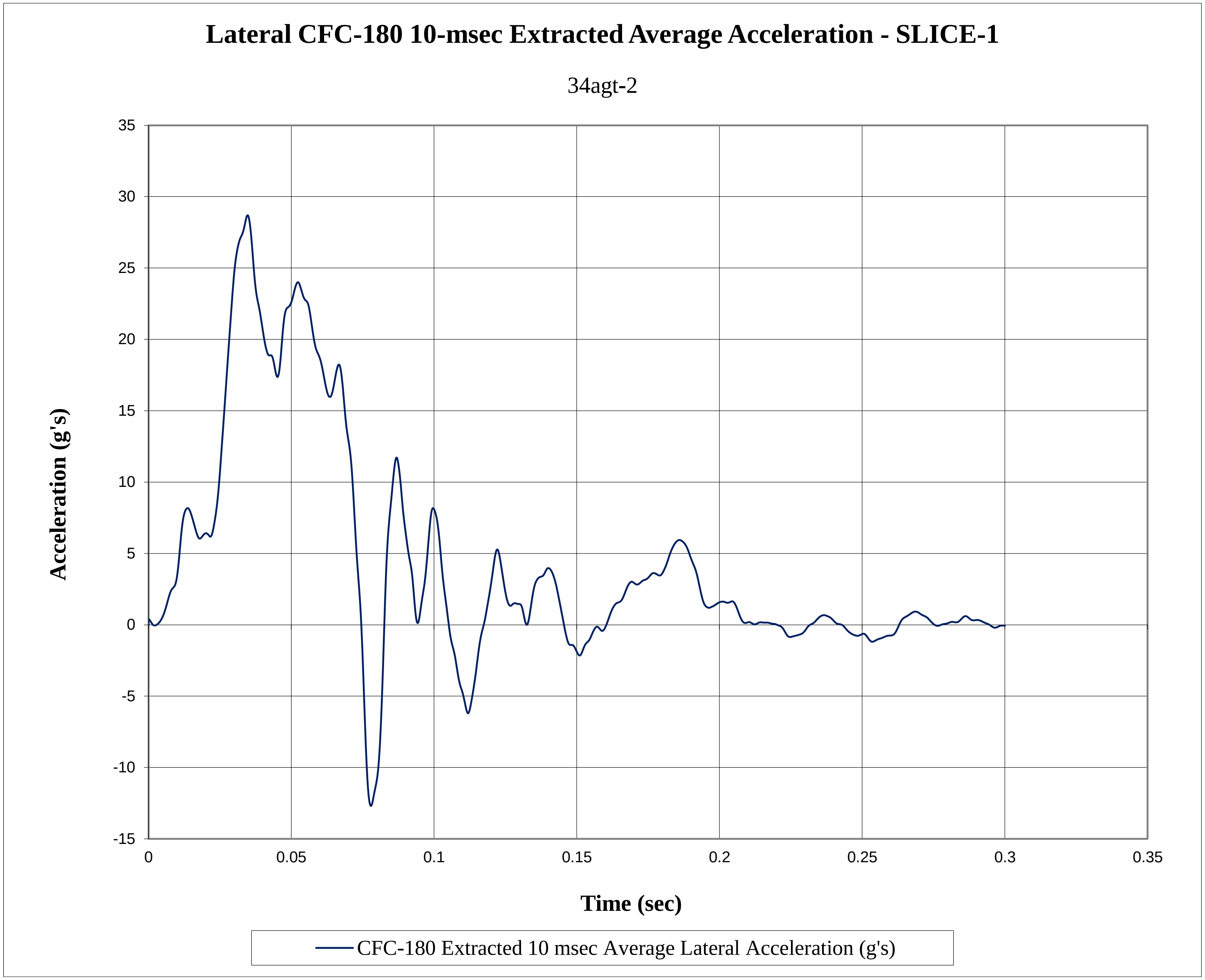


Figure F-4. 10-ms Average Lateral Acceleration (SLICE-1), Test No. 34AGT-2

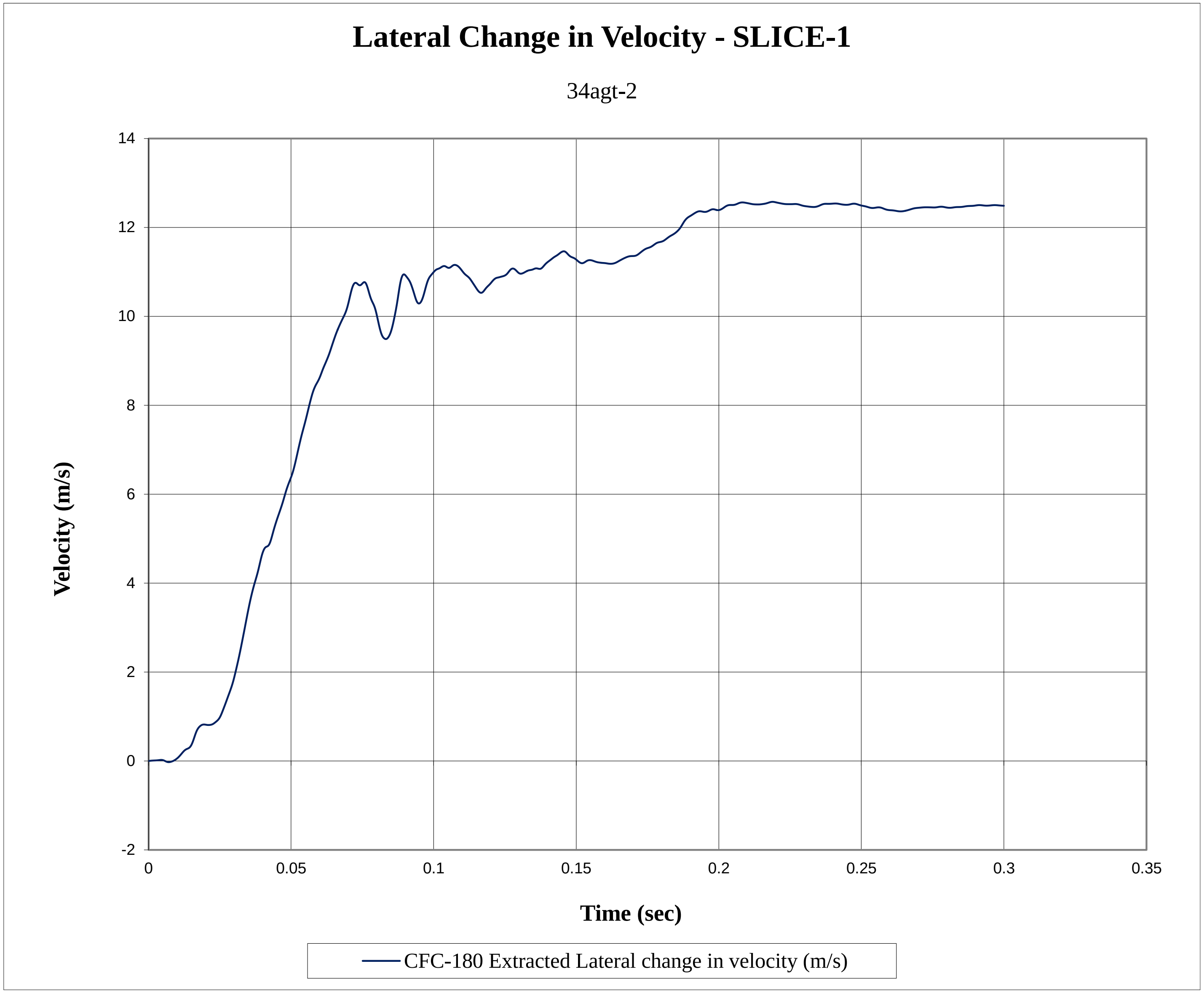


Figure F-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. 34AGT-2

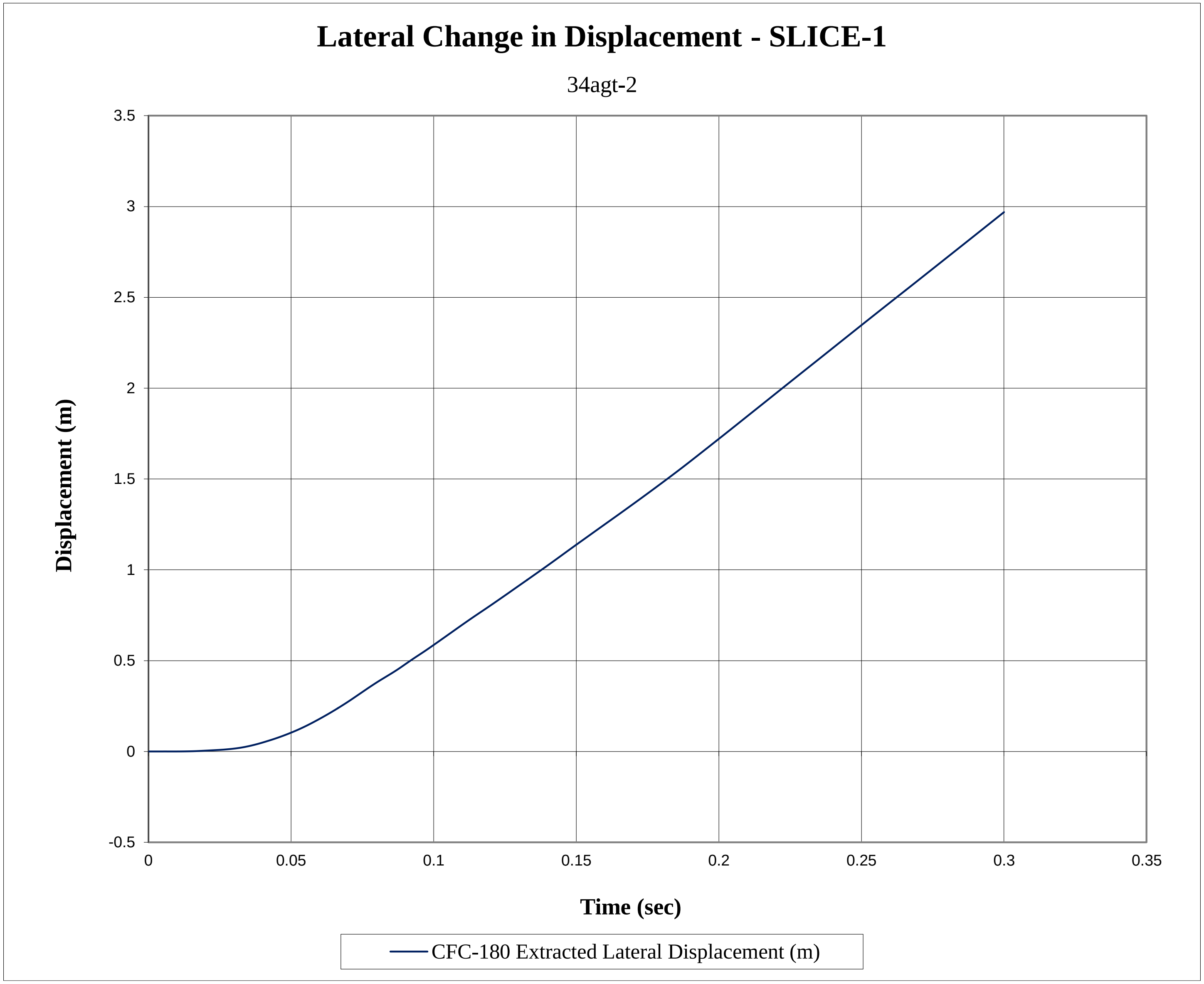


Figure F-6. Lateral Occupant Displacement (SLICE-1), Test No. 34AGT-2

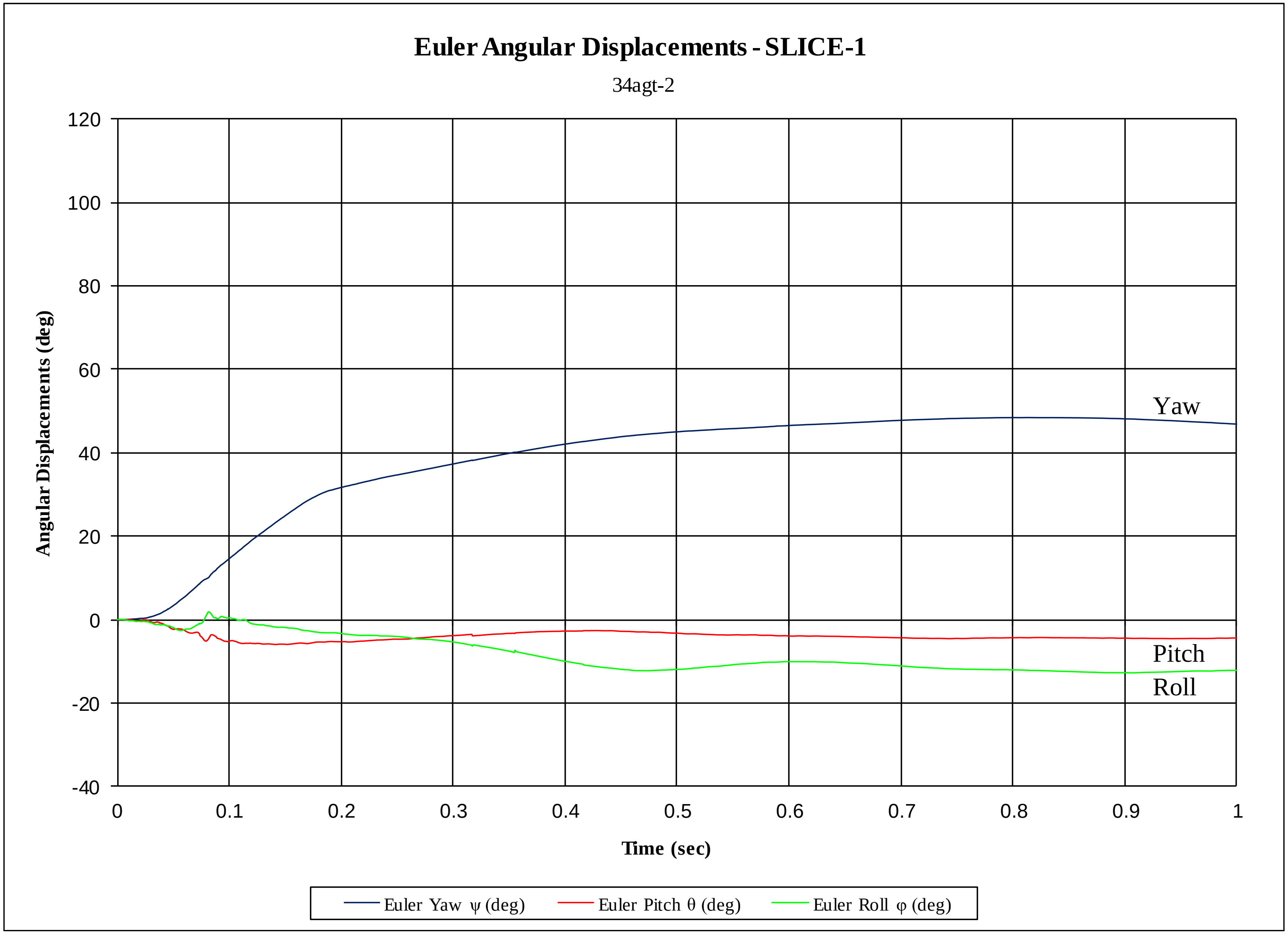


Figure F-7. Vehicle Angular Displacements (SLICE-1), Test No. 34AGT-2

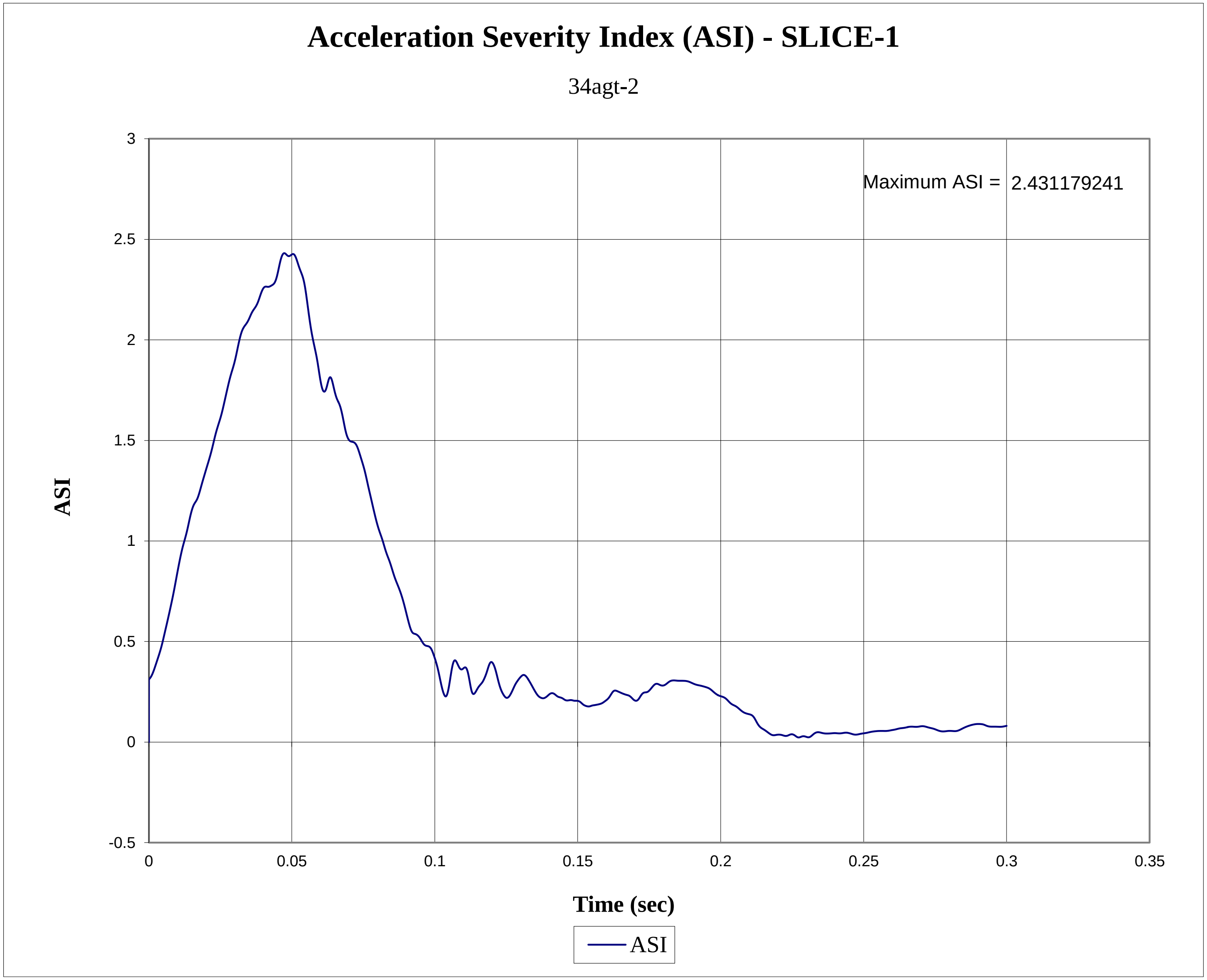


Figure F-8. Acceleration Severity Index (SLICE-1), Test No. 34AGT-2

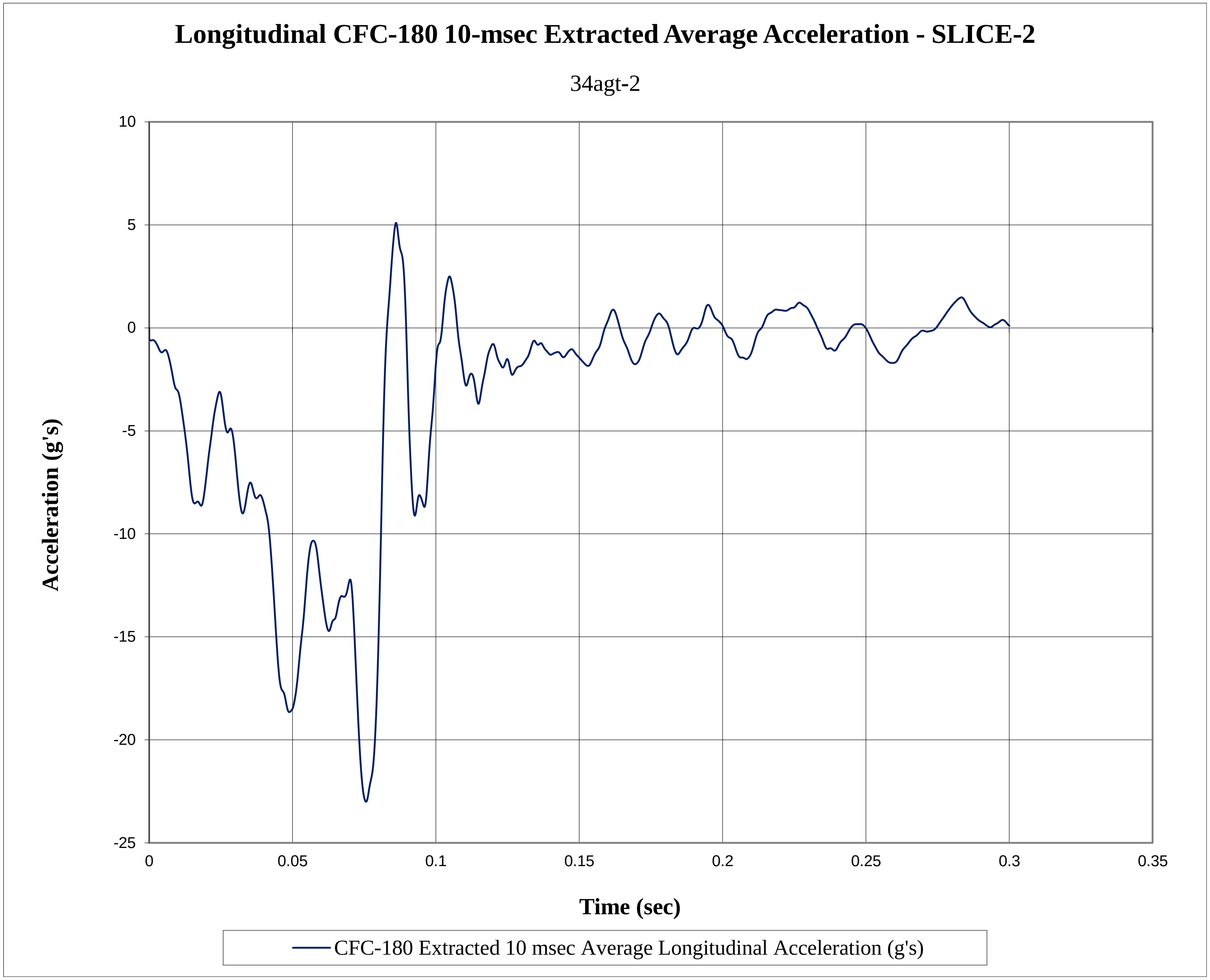


Figure F-9. 10-ms Average Longitudinal Acceleration (SLICE-2), Test No. 34AGT-2

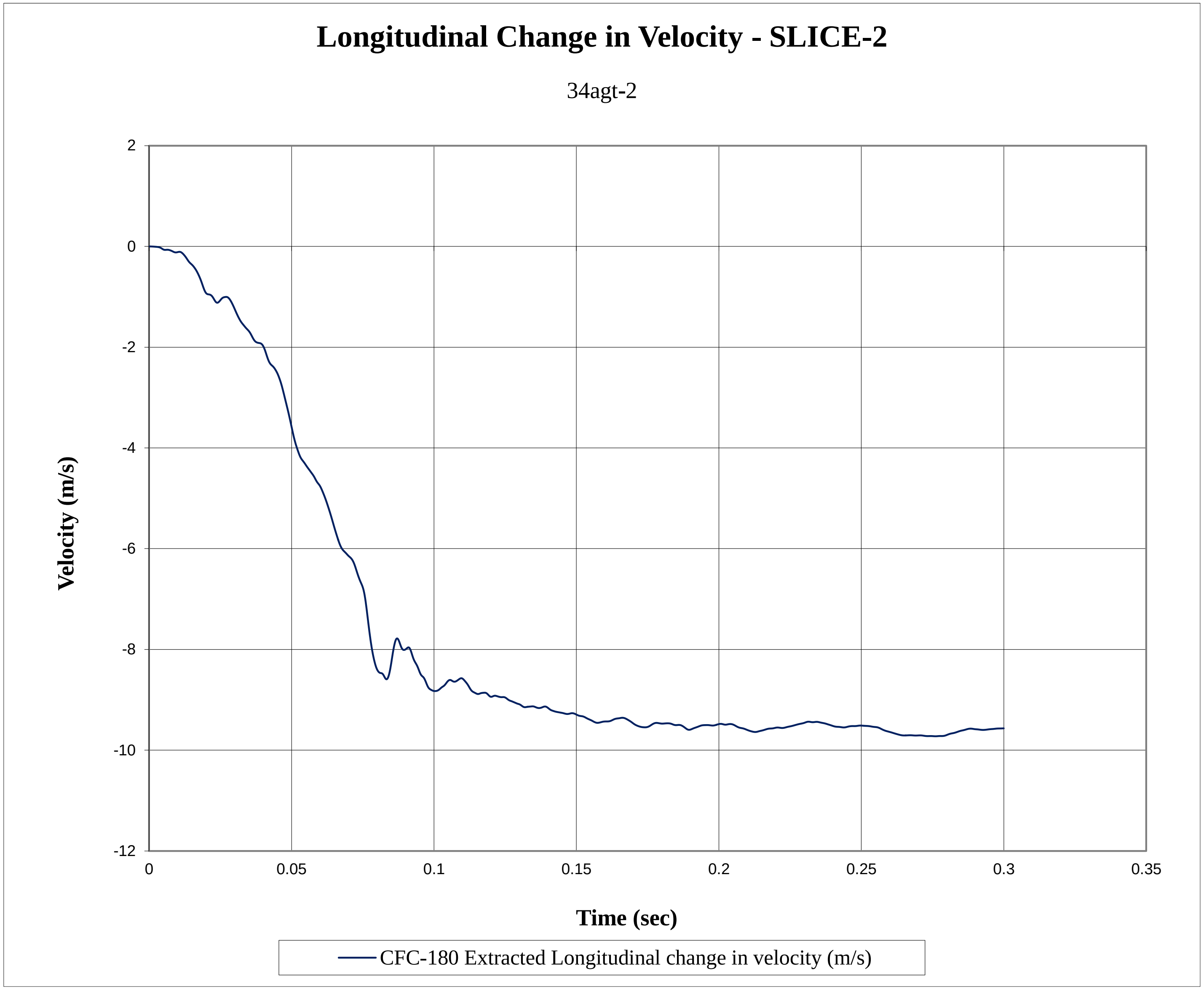


Figure F-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. 34AGT-2

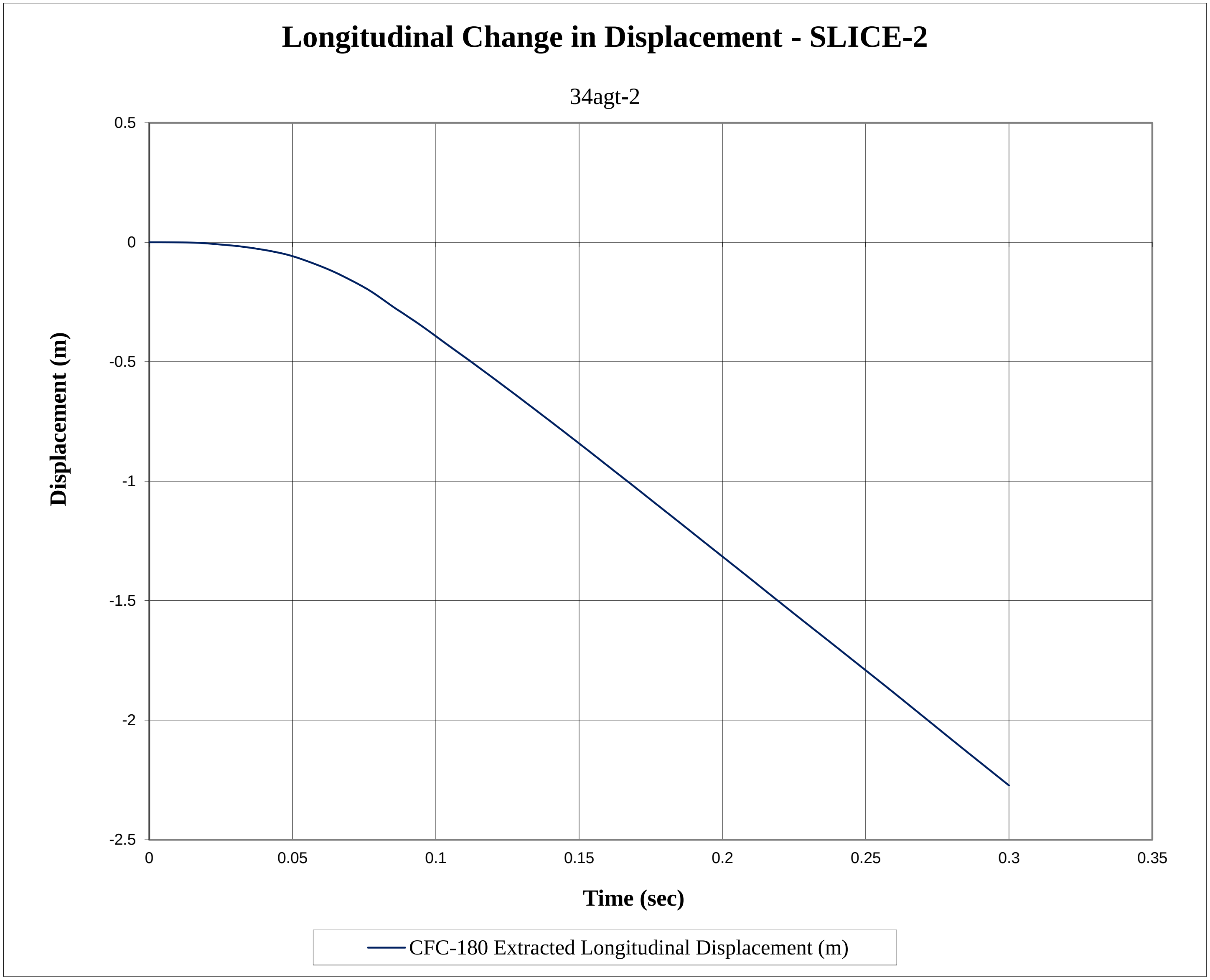


Figure F-11. Longitudinal Occupant Displacement (SLICE-2), Test No. 34AGT-2

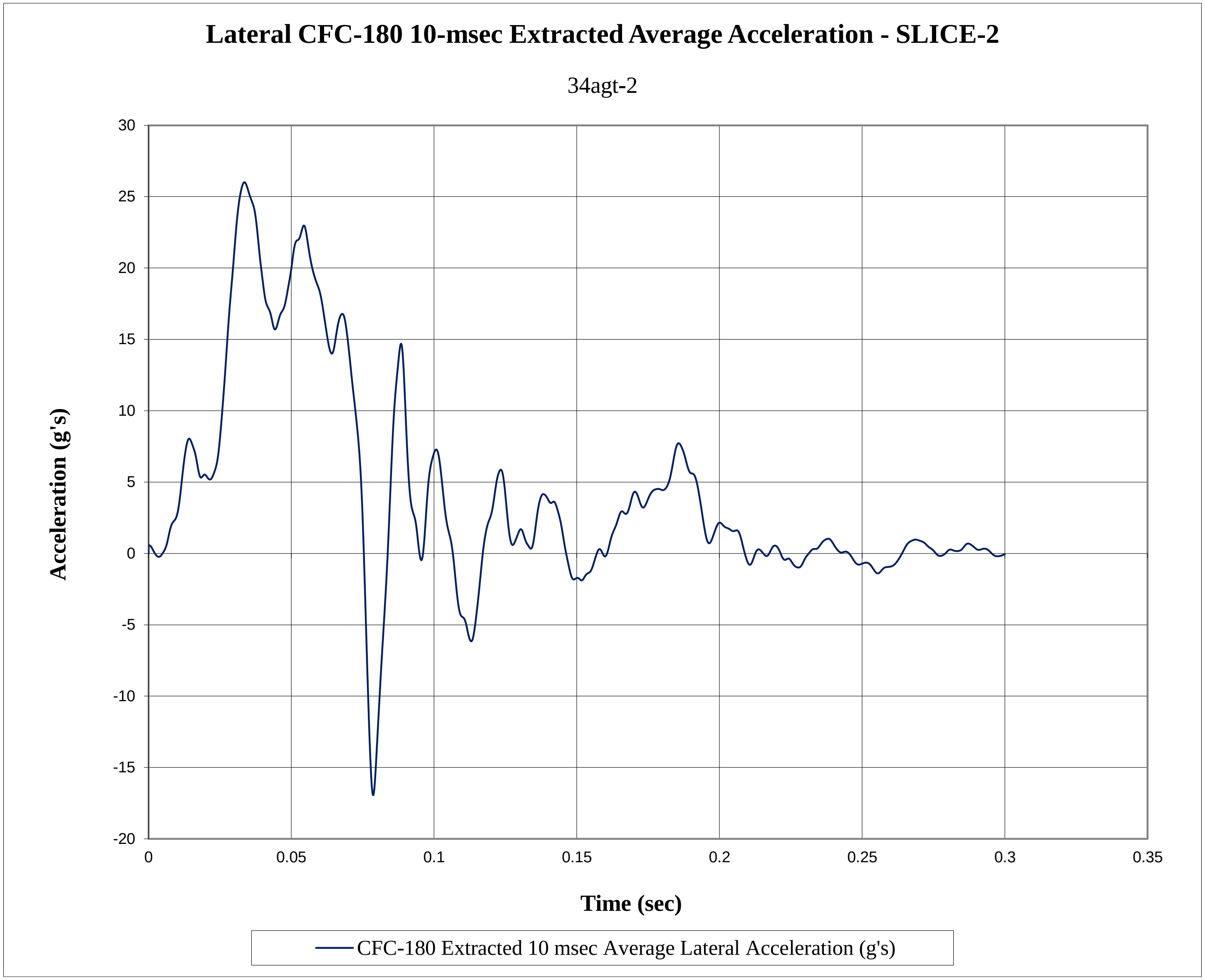


Figure F-12. 10-ms Average Lateral Acceleration (SLICE-2), Test No. 34AGT-2

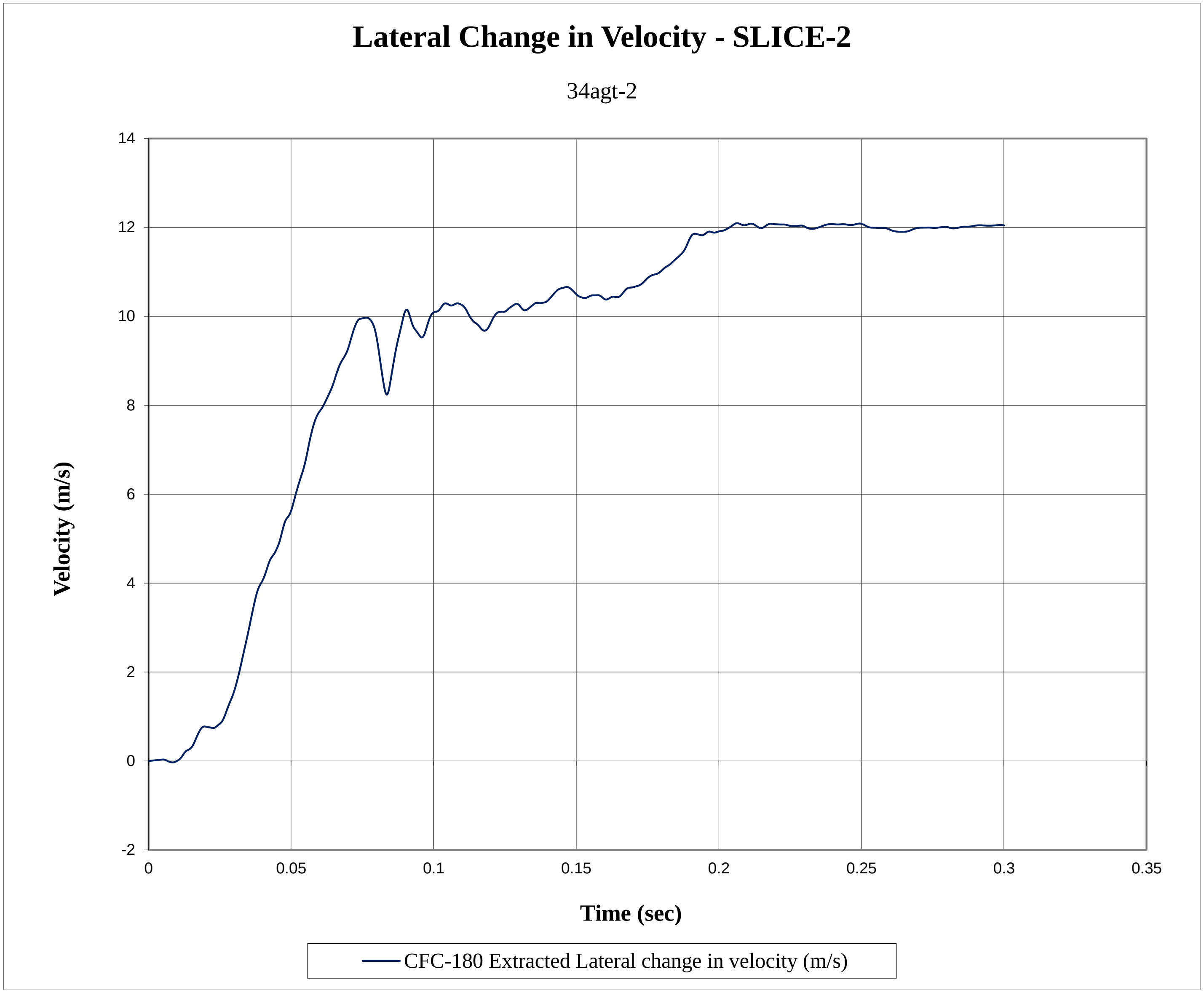


Figure F-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. 34AGT-2

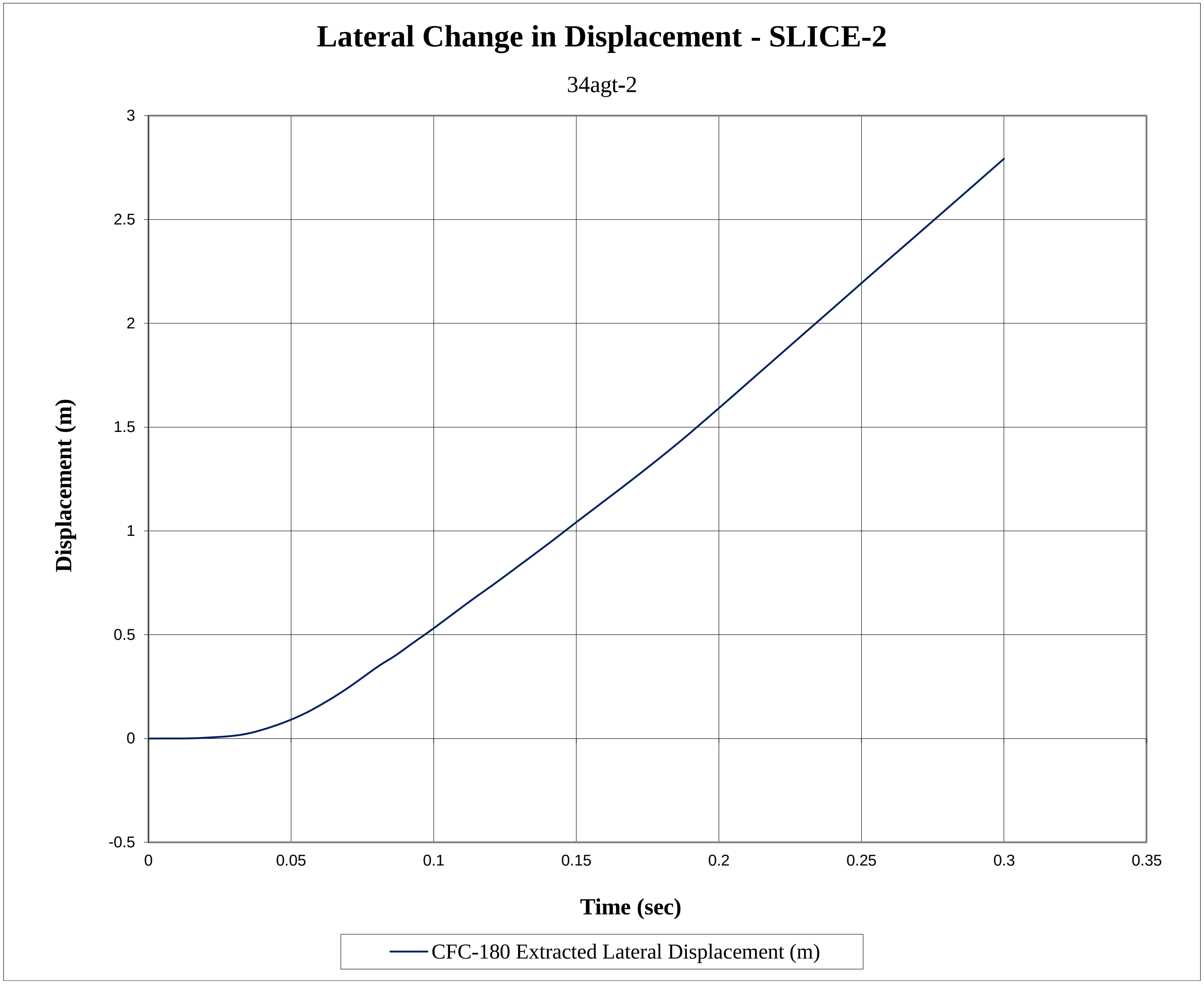


Figure F-14. Lateral Occupant Displacement (SLICE-2), Test No. 34AGT-2

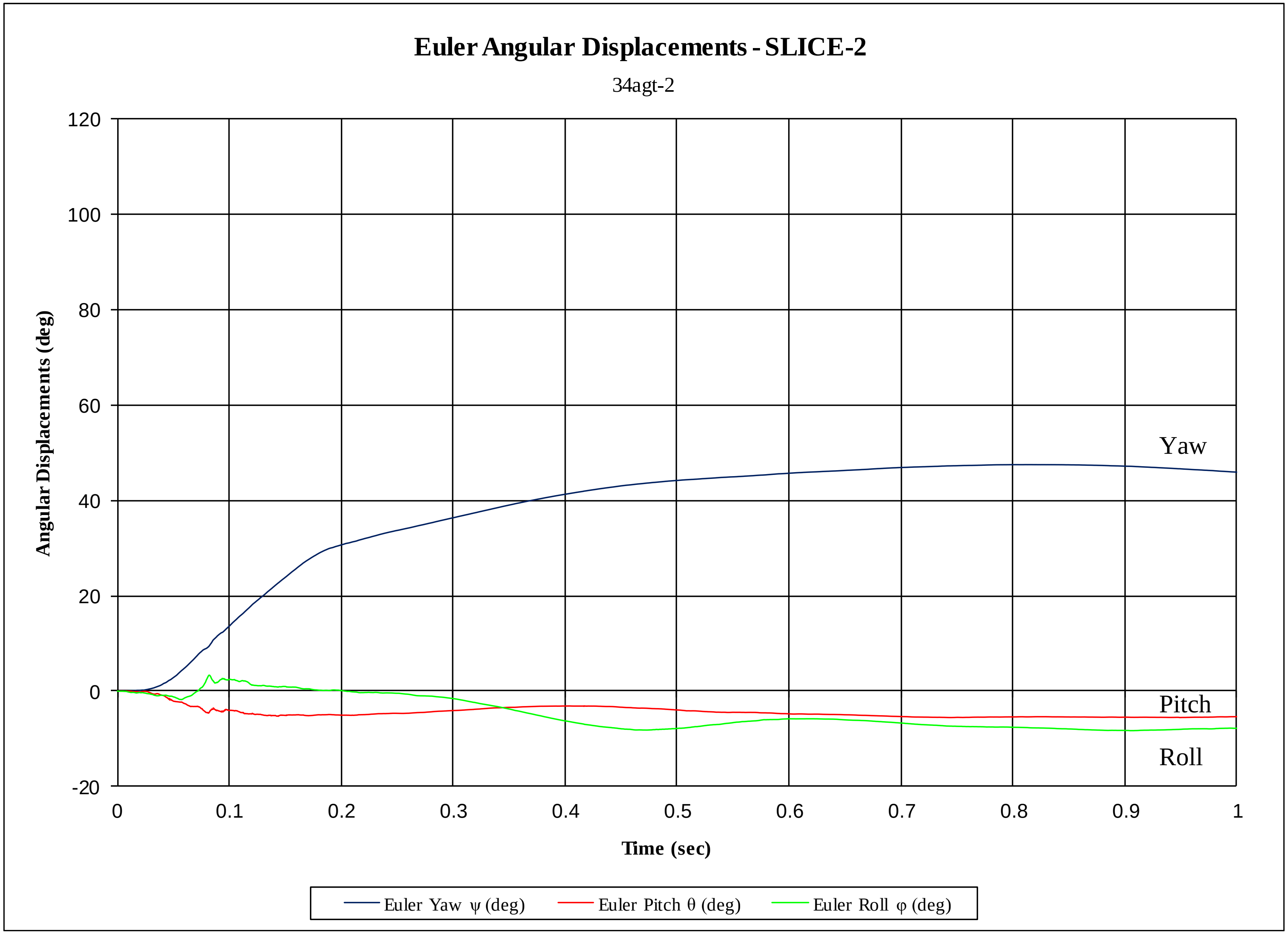


Figure F-15. Vehicle Angular Displacements (SLICE-2), Test No. 34AGT-2

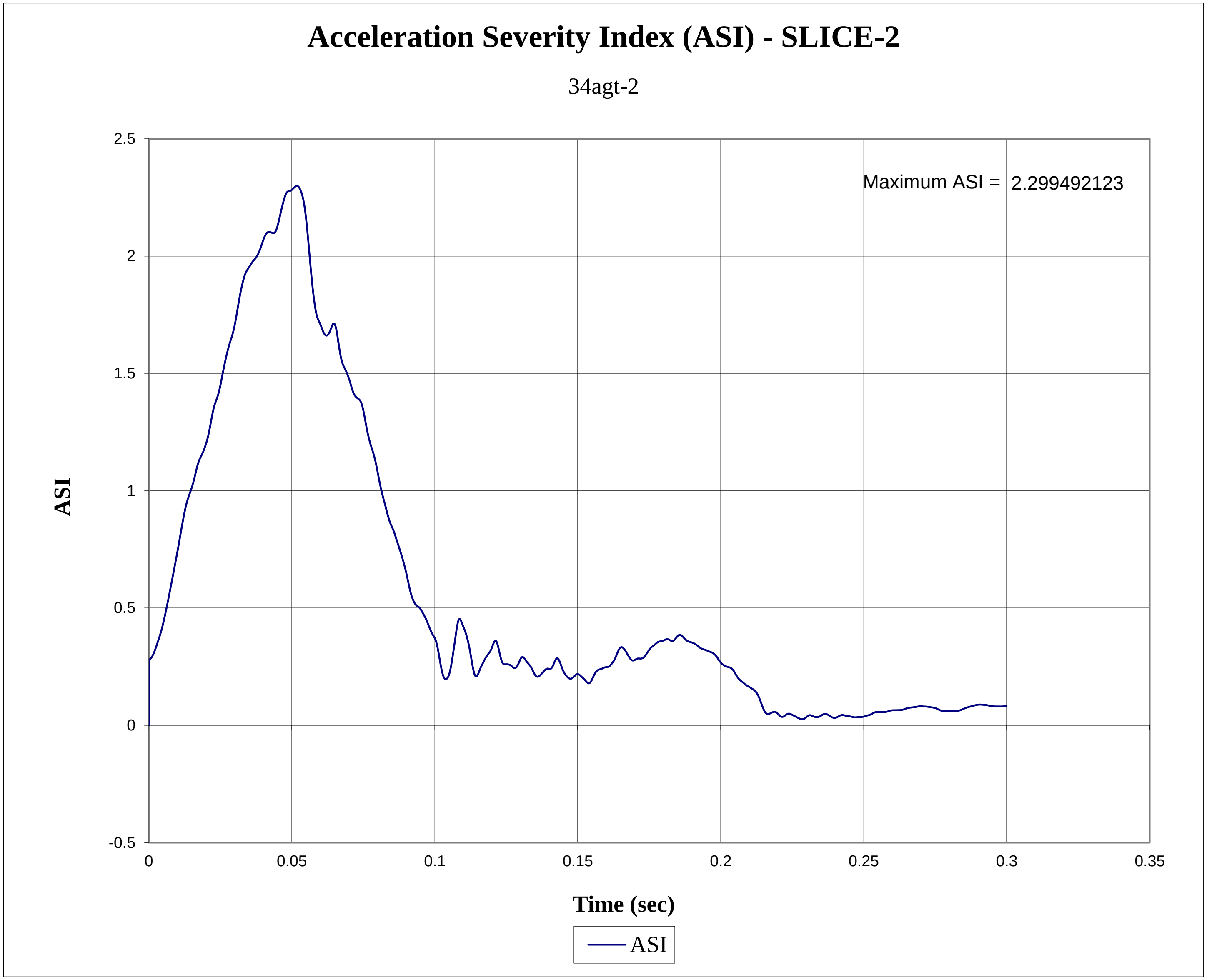


Figure F-16. Acceleration Severity Index (SLICE-2), Test No. 34AGT-2

Appendix G. Final System Design Details

The following pages depict the finalized system details, including the nominal 26¼-in. (667-mm) distance from the center of the first transition post to the upstream face of the buttress. This drawing set is intended for use by practitioners for future implementation of the AGT system.

END OF DOCUMENT