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Development and Evaluation of Crashworthy Approach Guardrail Transition with Increased Span Length between Concrete Bridge Rail and First Transition Post – Phase I

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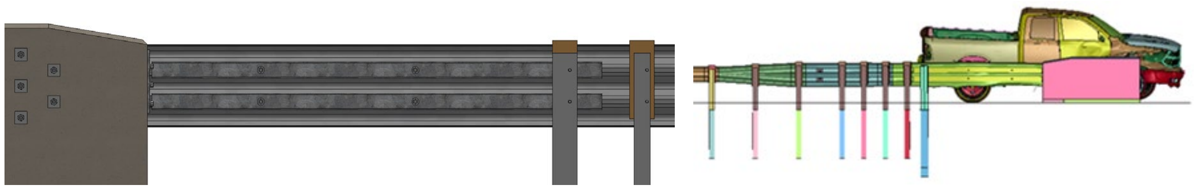

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16. Abstract

This study developed and evaluated a 34-in.-tall Nebraska Department of Transportation (NDOT) thrie-beam approach guardrail transition (AGT) with an increased span between the concrete buttress end and the first transition post. The objective was to accommodate a wide range of common obstructions near bridge ends, including abutments, wing walls, drainage features, and utilities. A survey of NDOT districts identified critical obstruction geometries and informed design criteria. Most NDOT districts indicated that a maximum span of about 4 ft would be sufficient, and some preferred spans up to 6 ft. To accommodate a wider range of obstructions, the first transition post was set 8 ft-5$^1/_4$ in. from the concrete buttress, more than twice the post spacing used in other MASH transitions. A validated LS-DYNA model of the standard 34 in. NDOT AGT system supported concept design screening under the *Manual for Assessing Safety Hardware* (MASH) Test Level 3 (TL-3). The selected configuration used a double-tube design with HSS 4 in. × 4 in. × 1/4 in. members based on performance, handling weight, and connection demand. Simulations for MASH test designation nos. 3-21 and 3-20 showed stable vehicle behavior, acceptable occupant risk measures, and component stresses below yield and ultimate limits. Critical impact points were 89 in. upstream of the concrete buttress for MASH test designation no. 3-21 and 65 in. upstream of the concrete buttress for MASH test designation no. 3-20. Reverse direction and upstream impacts showed no significant pocketing or snag. Overall performance matched the standard NDOT 34-in. tall AGT system. The long-span design provides a crashworthy and practical option for non-ideal sites. Full-scale vehicle crash testing is required to confirm compliance and support FHWA eligibility.

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Chapter 1 Introduction

1.1 Problem Statement

Approach guardrail transitions (AGTs) are commonly used to shield the ends of bridge rails and concrete buttresses, as well as provide a safe transition in lateral stiffness between semi-rigid approach guardrails and rigid bridge rails. In order to achieve a safe transition in lateral stiffness, AGTs typically utilize thicker and/or nested guardrail segments, increased post sizes, increased post embedment depths, and decreased post spacings as compared to semi-rigid W-beam guardrails. A typical AGT is shown in Figure 1.1. A gradual increase in lateral barrier stiffness along the transition length can be critical to its safety performance. Improper designs or abrupt changes in lateral stiffness can result in guardrail pocketing, vehicle instabilities, and vehicle snag on the end of a rigid bridge rail (i.e., parapet, buttress, etc.). Minor changes to prior crashworthy guardrail transitions (e.g., shape of the parapet end, addition or removal of a curb below the rail, and/or removal of a single post within the system) have led to failed crash tests [1].

Figure 1.1 AGT Installation [2]

Obstructions are frequently present near the downstream end of concrete bridge rails where the AGT begins. Typical elements include wing walls, abutments, intake tops, underground piles, surface flumes, and other drainage or utility structures. These features occupy the same envelope as closely spaced transition posts and can preclude proper post installation or force nonstandard placement. The result is a localized change in system stiffness and strength. Loss or misplacement of transition posts increases barrier deflection under vehicle impacts and increases safety risks. Prior studies show that omission of even a single post degrades performance [1]. A weakened transition may result in vehicle pocketing within the system, wheel snag on the end of a rigid bridge rail, and even vehicle instabilities.

Previous efforts addressed these obstructions with crashworthy retrofits or design alterations [3-4]. These research projects mainly focused on issues that obstruct AGT posts from being properly installed, including wing walls, drainage structures, utilities, and reduced grading. However, designing and evaluating an American Association of State Highway and Transportation Officials *Manual for Assessing Safety Hardware* (MASH) crashworthy AGT that incorporates an increased span length between the concrete bridge rail end and the first transition post would avoid these obstructions and prevent the need for in-field retrofits. Common obstructions near the bridge end and associated installation deviations are illustrated in Figure 1.2.

Figure 1.2 Common Obstructions Near Concrete Bridge End and Deviations in Installation [3-4]

As such, there is a need to develop and evaluate the standard 34-in. tall Nebraska Department of Transportation (NDOT) thrie-beam AGT system with an increased span length (shown in Figure 1.3) between the concrete buttress end and first transition post to meet MASH impact safety requirements. Omitting the first transition post and redesigning the AGT would enable the system to accommodate obstructions within the 5-ft 3¼-in. span length between the end of the AGT and the adjacent transition post. There may also be a possibility of designing the standard 34-in. tall NDOT AGT to have an 8-ft 9¼-in. span length between the end of the concrete buttress and adjacent transition post by omitting the first two posts to accommodate a wide range of obstructions. However, increasing the span length to accommodate larger obstructions may be challenging.

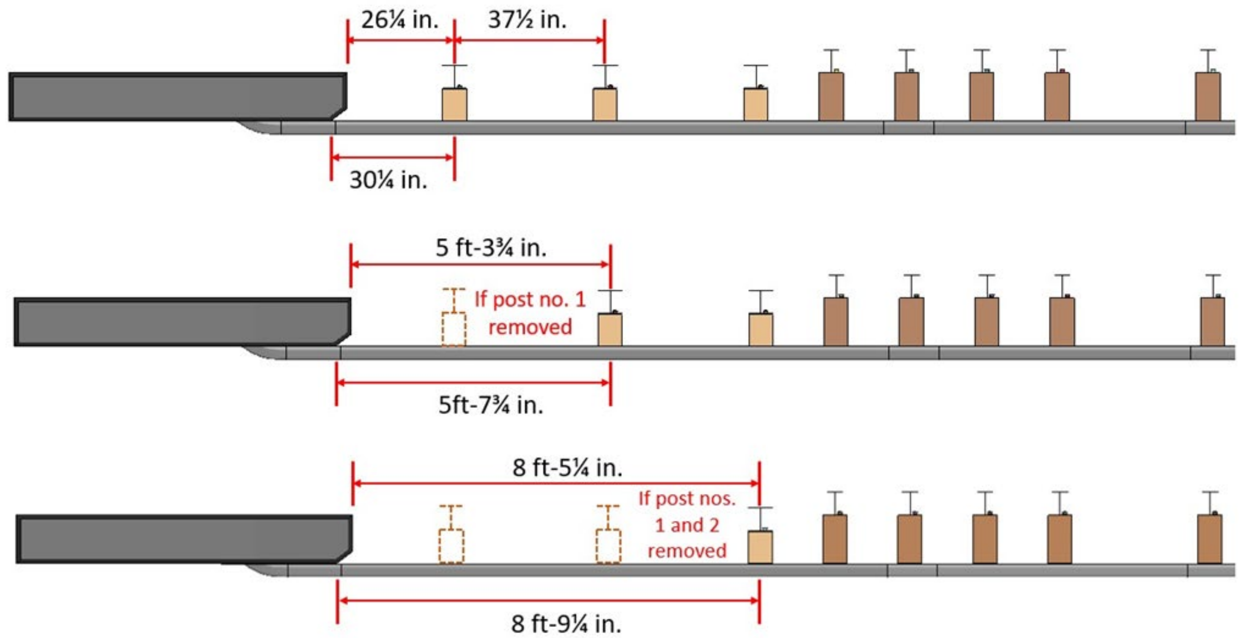


Figure 1.3 Schematics of the 34-in. tall NDOT Standard AGT (i.e., 26¼-in. Span Length) and with 5 ft–3¾-in. and 8 ft–5¼-in. Span Lengths between Concrete Buttress End and First Transition Post

1.2 Objective

The objective of this project was to develop and evaluate the standard 34-in. tall NDOT thrie-beam AGT system with increased span length between the concrete buttress end and the first transition post. The aim was to accommodate a wide range of obstructions that prevent proper post installation, including bridge abutments, wing walls, drainage structures, and utilities. A survey of NDOT District Construction Engineers and District Operations and Maintenance Managers identified critical obstructions near bridge ends and informed the target span. Most districts indicated a maximum span near 4 ft, and some preferred up to 6 ft. To serve a wider set of sites, the first transition post was set 8 ft–5¼ in. from the concrete buttress, more than twice the post spacing used in other MASH transitions. The project explored surrogate post mechanisms, including continuous horizontal tubes and cantilever beams, and increased the moment capacity of AGT rail elements to control deflection, pocketing, snag, and vehicle instability associated with a longer span. Dynamic evaluations using the LS-DYNA finite element program assessed impacts near the upstream W-to-thrie transition and the downstream thrie-to-buttress transition. The system was designed to meet MASH Test Level 3 (TL-3) impact safety requirements.

1.3 Scope

The scope of this project included a literature and practice review of AGT systems and AGT retrofit concepts, an NDOT district survey to document obstruction types and geometries, and the translation of survey findings into design criteria for the new long-span AGT system. Concept development focused on increasing lateral stiffness and resisting impact loads through surrogate post configurations and rail stiffening. A validated LS-DYNA model of the 34-in. NDOT AGT system supported simulations for MASH test designation 3-21 and 3-20 with upstream, downstream, and reverse-direction impacts. Analyses tracked occupant risk metrics, vehicle kinematics, system deflection, pocketing, snag, and component stresses, and identified critical impact points. The preferred configuration used a dual-tube system with HSS 4-in. × 4-in. × ¼-in. members and the 8 ft–5¼-in. span from buttress to last transition post. The work concluded with simulation findings that support Phase II full-scale crash testing to confirm MASH TL-3 compliance and support Federal Highway Administration (FHWA) Federal-aid eligibility.

Chapter 2 Review of Relevant AGT Systems

A literature review was performed on previously crash-tested AGT systems, long-span AGTs, and retrofit concepts deemed pertinent to the development and evaluation of a long-span AGT system. The review focused on the foundational AGT system pertinent to the current research and development effort, specifically the 34-in. tall NDOT thrie-beam AGT system, alongside prior investigations into long-span MASH TL-3 AGT systems. The subsequent sections discuss these relevant systems.

2.1 Base AGT System

Historically, thrie beam AGTs have been designed, evaluated, and installed with 31-in. top mounting heights. Unfortunately, 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. NDOT employs a MASH TL-3 crashworthy guardrail transition system that incorporates a nested thrie-beam, a W-to-thrie connection section, W-beam guardrail, and support posts consisting of W6x15 members spaced at 37.5 in. on-center along with W6x8.5 posts at varying intervals. The system was originally configured with a rail height of 34 in., intentionally designed to remain compliant with MASH crashworthiness requirements even after roadway overlays of up to 3 in. thick.

Following the placement of an overlay, the symmetric W-to-thrie transition piece is substituted with an asymmetric version, and the W-beam rails are elevated by 3 in. on the standard posts. This adjustment effectively maintains a 31-in. system height for both the transition and the upstream Midwest Guardrail System (MGS) without the need to remove or reinstall the existing posts. The NDOT 34-in. transition configuration at installation and after overlay modification are illustrated in Figure 2.1 through Figure 2.3.

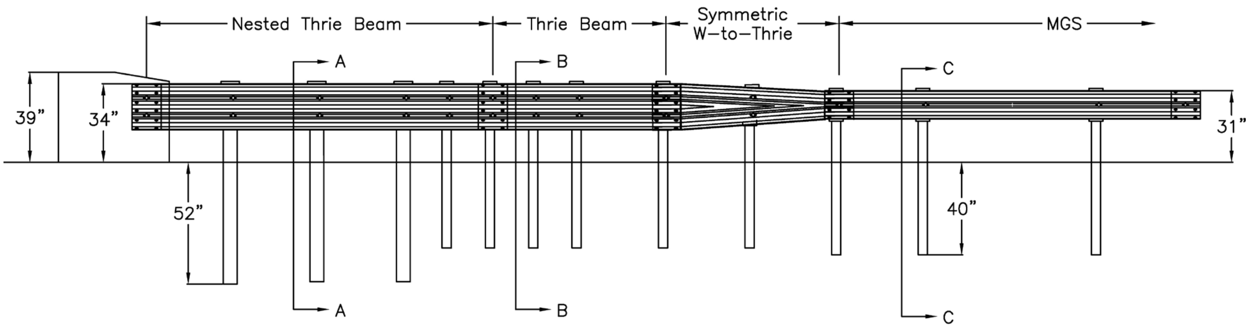


Figure 2.1 Initial 34-in. AGT Installation Prior to Overlay [2]

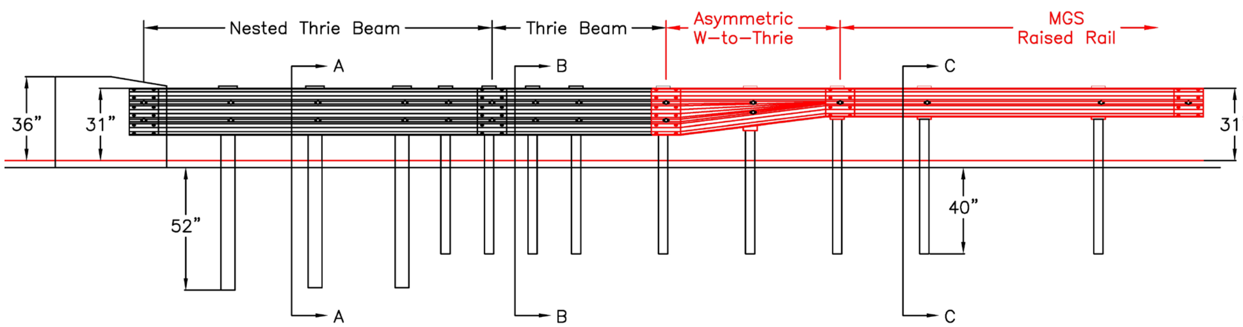


Figure 2.2 34-in. AGT Configuration Following 3-in. Roadway Overlay [2]

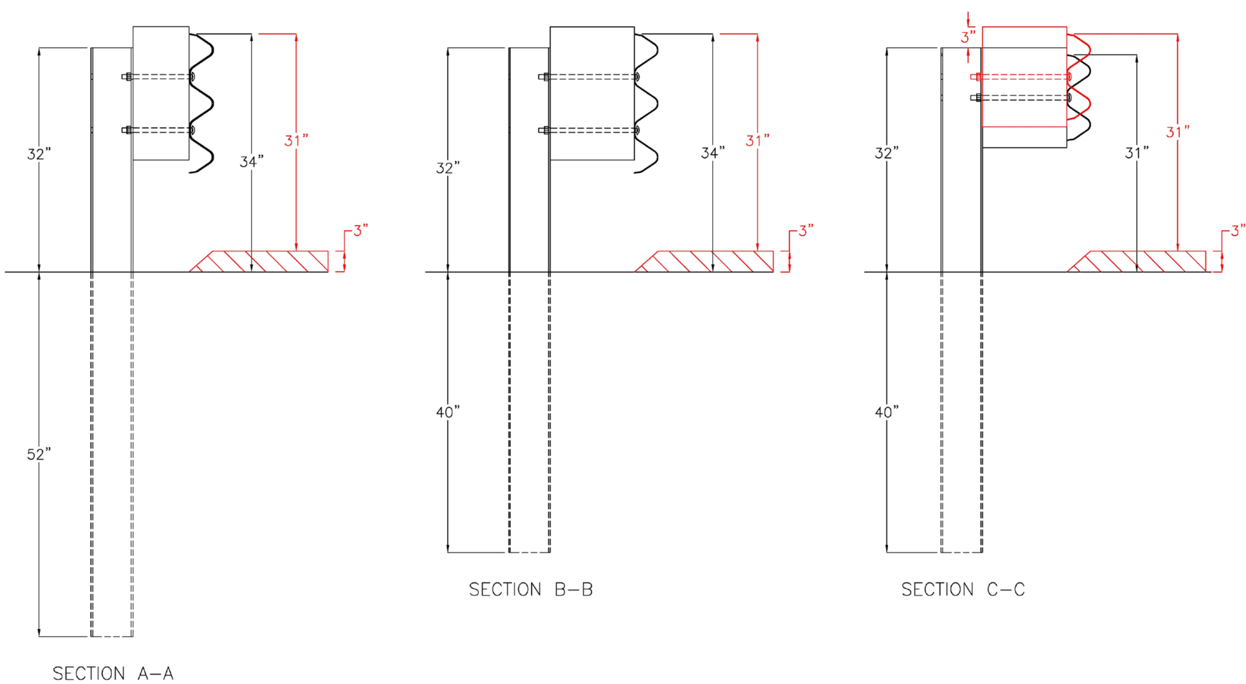


Figure 2.3 Cross-Sections of AGT Before and After 3-in. Overlay [2]

As discussed previously, the NDOT 34-in. tall AGT system was designed to be crashworthy both before and after the placement of a 3-in. thick overlay, and it was specifically developed for use with a standardized concrete buttress to facilitate the attachment of new long-span AGT systems. Therefore, the NDOT 34-in. tall AGT was selected as the base configuration for the long-span AGT system. Additionally, the NDOT 34-in. tall AGT utilized W6x15 posts spaced at 37.5 in. on-center. This post configuration was thought to be more conducive to maximizing the span length between the first transition post and the concrete buttress as compared to the other AGTs with smaller W6x9 posts spaced at 18.75 in. on-center.

2.2 Previous Research on Long Span AGT Systems

Historically, researchers have utilized various mechanisms to mitigate large barrier deflections, vehicle instabilities, and vehicle pocketing and snag risks associated with AGTs that have an increased span length between the bridge rail end and the first transition post. These mechanisms can be broadly categorized into: (1) a surrogate post, such as a continuous horizontal beam, cantilever beam, and grade-mounted post, and (2) stiffening and increasing the moment capacity of the AGT rail elements.

2.2.1 Nebraska Prototype Thrie Beam Transition

The Nebraska thrie beam AGT was previously crash tested at the University of Nebraska-Lincoln (UNL) in 1987 [5]. This system was re-evaluated in 1998 by researchers at the Midwest Roadside Safety Facility (MwRSF) according to National Cooperative Highway Research Program (NCHRP) Report No. 350 criteria [6-7]. Following a BARRIER VII computer simulation analysis, the dimensions and flare rate of the upstream end of the bridge rail were slightly modified to minimize the propensity for wheel snag and better ensure that adequate safety was provided. Further, a 4-in. thick concrete mow-strip with 13-in. x 15$^{3}/_{4}$-in. leave outs filled with a 2-in. thick layer of ‘weak’ fill material was utilized for vegetation control purposes, as shown in Figure 2.4. In addition, comparably-sized steel posts were specified for a modified design. This design modification was considered based on the Nebraska Department of Road's (NDOR) desire to utilize steel posts instead of wood posts in guardrail installations. As a result, an alternate steel-post transition system was developed to replace the wood-post configuration with a missing post.

Figure 2.4 Nebraska Thrie-Beam AGT System [6]

During test no. NEBT-1, a 4,418-lb pickup truck traveling at 64.1 mph impacted the transition at an angle of 24.9 degrees between post nos. 1 and 2. The system was able to adequately contain and redirect the vehicle. However, the vehicle experienced wheel snag in excess of 3 in. during the impact event, causing severe occupant compartment deformations.

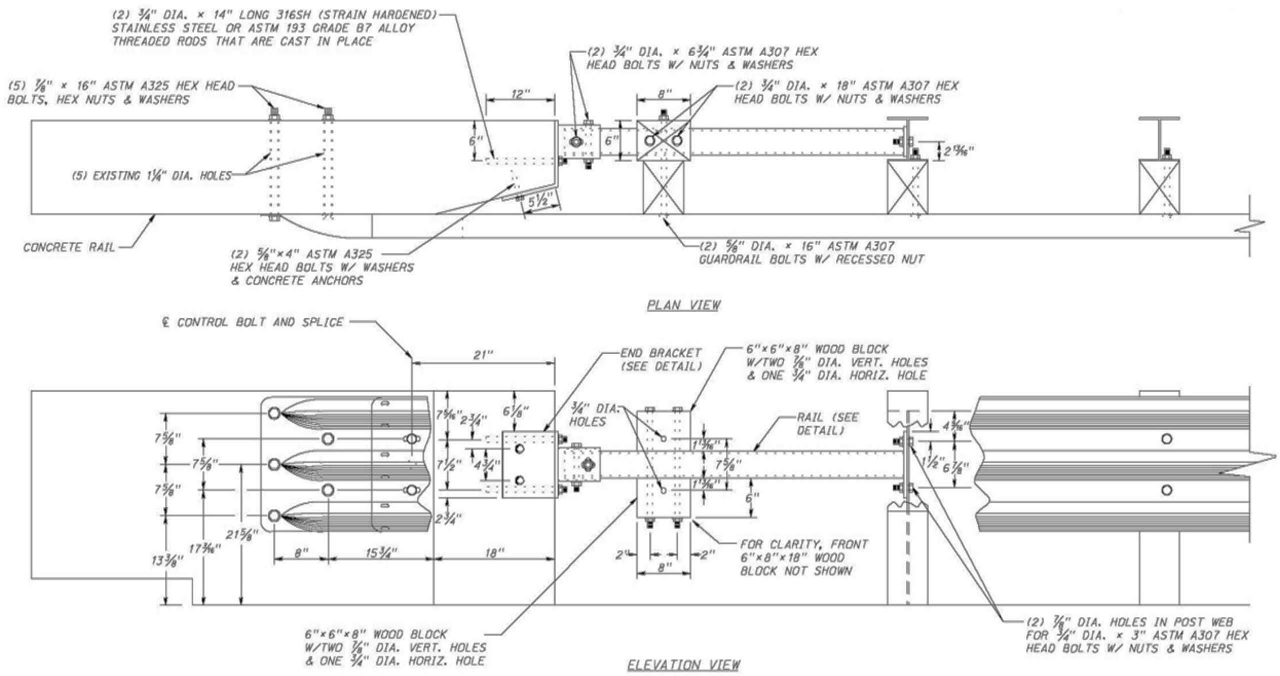
Therefore, the full-scale crash test was deemed unsuccessful according to NCHRP Report No. 350 TL-3 criteria. Still, the researchers concluded that the addition of a rubrail would likely prevent wheel snag and reduce subsequent occupant compartment deformations to an acceptable level.

2.2.2 Modified Nebraska Thrie Beam Transition with Hidden Post

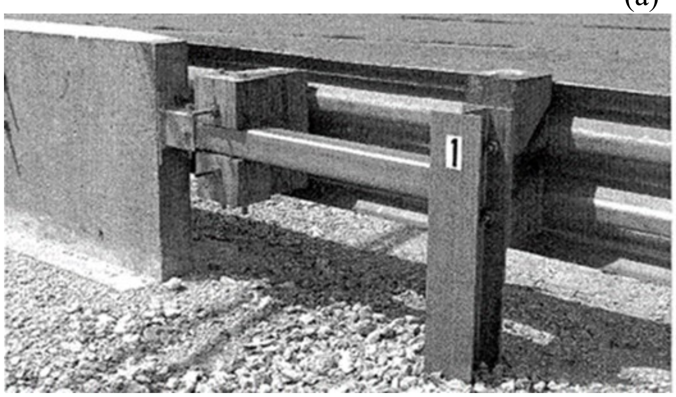
In 2000, researchers at the Texas Transportation Institute (TTI) re-evaluated the Nebraska thrie-beam transition under NCHRP Report No. 350 TL-3 safety performance criteria [8] For this study, the transition design incorporated an additional feature referred to as a hidden post.

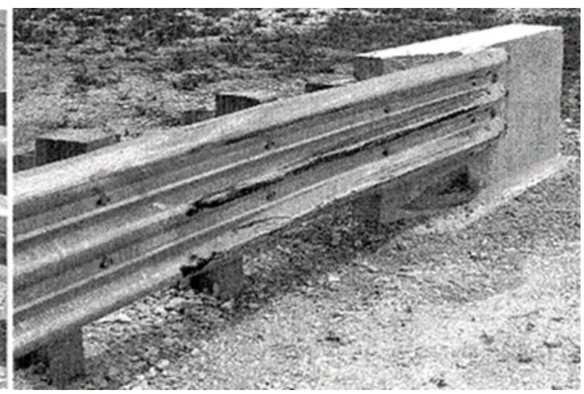
The hidden post consisted of a TS 4-in. × 4-in. × $^{5}/_{16}$-in. steel tube rail, which was connected at one end to the upstream face of the concrete parapet and at the other end to the side of post no. 1 (Figure 2.5). A 6-in. × 8-in. × 15¾-in. wood block was mounted on this tube, serving as the support element for the nested thrie-beam at the location where a standard post would normally be installed. This modification effectively replaced the need for an embedded post at that position. The connection of the steel tube to the parapet was achieved using a ½-in. ASTM A36 steel plate, anchored by two ⅝-in. diameter A325 mechanical anchors and two ¾-in. diameter ASTM A193 Grade B7 chemically bonded threaded rods.

Crash test no. 404211-7 involved a 4,409-lb pickup truck striking the transition at a speed of 61.9 mph and an angle of 24.6 degrees, with the impact point located 6 ft–4 in. upstream from the end of the parapet. The system successfully contained and redirected the vehicle, thereby satisfying the TL-3 performance requirements outlined in NCHRP Report No. 350.



(a)





(b) (c)

Figure 2.5 Modified Nebraska Thrie-Beam Transition with a Surrogate or 'Hidden' Post: (a) Transition Plan, (b) Test Article, and (c) Tested Transition System [8]

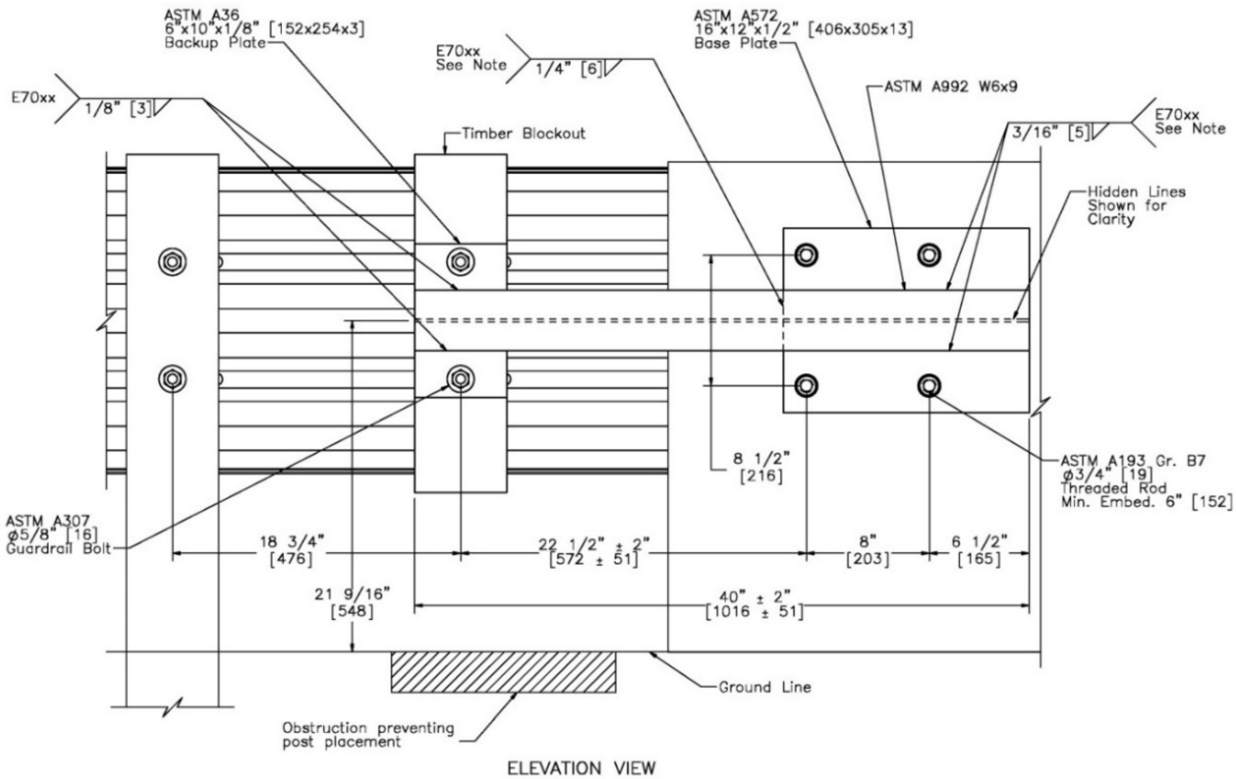
2.2.3 Wisconsin DOT Retrofit Strategies for Existing AGTs

In 2012, MwRSF conducted a study for the Wisconsin Department of Transportation (WisDOT) to investigate retrofit solutions for existing wood-post AGTs that deviated from their as-tested configurations [3]. Among the deficiencies, missing transition posts were identified as the most critical, especially near the bridge rail end where the absence of a post could cause snagging and compromise system performance. To mitigate this concern, researchers designed retrofit concepts involving a horizontal cantilever beam mounted to the back side of the parapet, with two variations tailored to blunt-end and sloped-end parapets. Building on these concepts, the study then expanded to evaluate retrofit strategies for posts positioned directly at the parapet ends, followed by solutions for posts located farther upstream and other deficiencies that affected overall system performance.

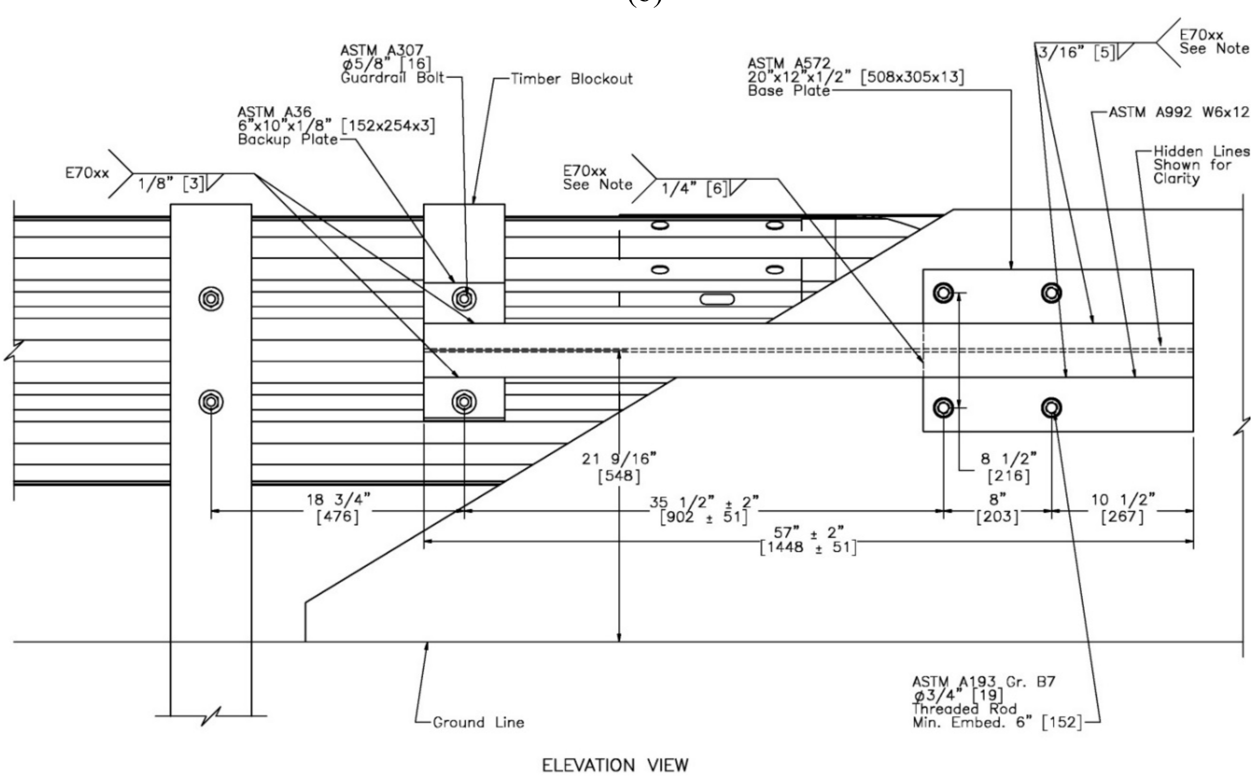
2.2.3.1 Retrofit Option 1: Positions Adjacent to the End of Parapets

Instead of modifying the bridge rail shape, this retrofit introduced a horizontal beam that served as a surrogate post by connecting the transition rail to the parapet. The design, conceptually similar to the Nebraska thrie-beam hidden-post solution studied at TTI [8], was vertically aligned with the thrie-beam rail and intended to plastically deform under impact, absorbing part of the impact energy while reducing anchor forces [3]. Different beam sizes were applied to blunt-end and sloped-end parapets to address their unique geometries, as shown in Figure 2.6.

Component tests, including test nos. WAGTMP-1 and WAGTMP-4, used a 1,720-lb bogie vehicle and demonstrated that the retrofit could sustain impact forces during initial deflection, although performance declined as the beam experienced buckling and twisting. The anchor and parapet remained undamaged, and simulations suggested that the retrofit reduced vehicle wheel snag on the upstream bridge rail edge by nearly 30% compared with the configuration with a missing first post. While installation challenges were noted, particularly regarding conflicts with thrie-beam anchor bolts and blockout placement, the retrofit was generally considered practical for parapet-end post replacements. Building on these results, researchers then evaluated retrofit strategies for posts positioned farther upstream where drainage structures and other obstructions commonly limited standard post installation.



(a) Blunt-End Parapet Retrofit
(b)



(c) Sloped-End Parapet Retrofit

Figure 2.6 Retrofit Adjacent to (a) Blunt-End Parapet and (b) Sloped-End Parapet [3]

2.2.3.2 Retrofit Option 2: Positions Not Adjacent to Concrete Bridge Parapets

For locations where transition posts conflicted with drainage structures, one option considered was relocating the drainage feature upstream of the W-to-thrie element. Although effective, this solution was not deemed economically feasible. Instead, a straddle in retrofit concept was developed, as illustrated in Figure 2.7. The design incorporated two W6x9 surrogate steel posts embedded in the ground and spaced 3 ft apart, connected by a horizontal beam attached to the thrie beam with multiple blockouts [3]. This configuration allowed the surrogate posts to act together to replicate the resistance of a single transition post [9-10].

The system included a lateral offset created with wood blockouts, which minimized the likelihood of vehicle snag and ensured compatibility with adjacent posts. Previous crash data confirmed that this spacing was sufficient, as transition posts typically deflected only a few inches relative to one another [9-10]. The design was suitable for both level terrain and sloped embankments, with adjustments in post length and embedment depth to maintain adequate soil resistance [11-12]. After developing retrofit options for obstructed and missing posts, researchers also examined additional AGT deficiencies that could reduce system performance in service conditions.

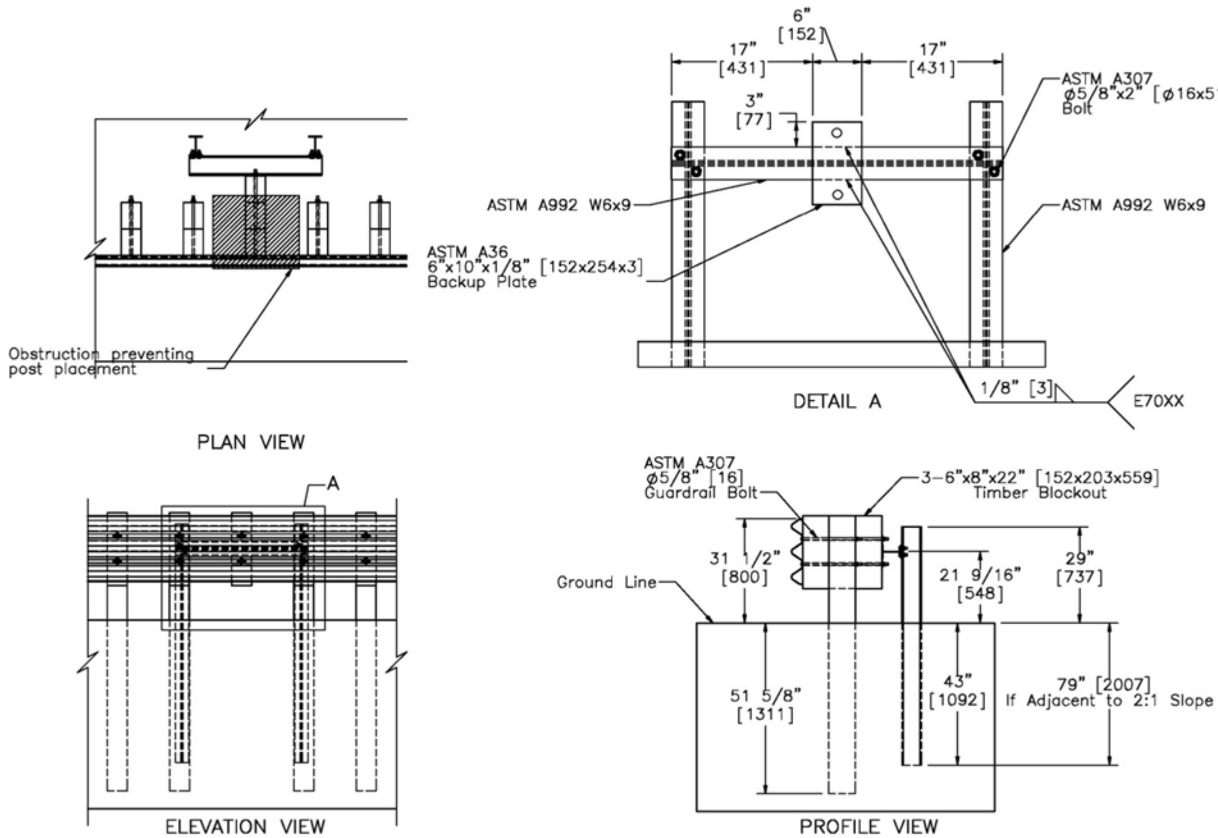


Figure 2.7 Surrogate Post Installation Detail [3]

2.2.3.3 Other AGT Systems Deficiencies

Beyond missing or obstructed posts, the WisDOT study evaluated other deficiencies in AGT systems, including posts placed at slope break points, insufficient soil backfill, and installations where wood posts were set in asphalt [3]. Two component tests, test nos. WITB-1 and WITB-2, showed that posts installed on a 2H:1V slope provided less than half the resistance of posts installed on level terrain, leading to greater barrier deflections and higher risks of snagging and pocketing. Simulation results confirmed these trends, suggesting that additional backfill to flatten slopes was the most effective solution, although supplemental steel posts or stronger replacements were also considered viable alternatives.

Post exposure due to erosion or settlement was another concern, as it reduced embedment depth and soil resistance. Analytical and simulation studies indicated that exposures greater than

3 in. across multiple posts led to excessive dynamic deflections, making corrective backfilling necessary. Finally, four dynamic component tests, test nos. WIA-1 through WIA-4, evaluated wood posts installed in asphalt overlays on sloping terrain. Results showed that posts embedded in asphalt exhibited lower soil resistance, and in some cases fractured prematurely under load. These findings indicated that such installations should be treated similarly to posts installed on sloped terrain. Collectively, the WisDOT study highlighted that retrofit devices could mitigate the most severe deficiencies but also emphasized the importance of proper installation and site conditions for maintaining AGT performance.

2.2.4 IL-OH Long Span AGT to Steel Tube Rail

Recently, a MASH TL-3 AGT was designed to connect the MGS to a MASH Test Level 4 (TL-4) steel post, steel tube, bridge rail Type IL-OH. The feasibility of the design was initially evaluated using the LS-DYNA finite element analysis computer program [13]. Two HSS 8-in. x in. x 6-in. x ¼-in. tubes, each 119⅝ in. long, were used to connect the thrie-beam terminal connector to the bridge rail. A 2-in. tall step near the midspan was included to match the AGT and bridge rail elevations, and a 6H:1V vertical taper was applied to limit snag at that step. A 36-in. HSS 6-in. x 4-in. x ¼-in. tube was placed between the lower and middle transition rails, with a 3:1 lateral taper on the downstream end to reduce contact with the terminal connector during reverse-direction impacts. The top transition assembly measured 44¼ in. and used HSS 12-in. x 4-in. x ¼-in. segments with a ¼-in. bent plate. The top member was sloped at 2H:1V and welded to the plate, which bore against the top and back faces of the middle transition rail and was fastened with two ¾-in. bolts. The three transition tubes were connected to the bridge rail tubes using the same splice hardware as the bridge rail. To avoid interference with wingwalls and abutments, the last transition post was set 9 ft from the first bridge post, more than twice the post spacing used in other MASH transitions. Photographs of the AGT are provided in Figure 2.8.

Test nos. STBRT-1 (i.e., MASH 3-20) and STBRT-2 (i.e., MASH 3-21) were conducted on the AGT system. Both tests were determined to be successful according to MASH test designation nos. 3-20 and 3-21.

Figure 2.8 Photographs of the AGT to Steel Railing, Type IL-OH [13]

2.2.5 Long Span Structure Connection (LSSC)

Road Safe R&D developed and patented a proprietary AGT system known as the Long Span Structure Connection (LSSC) [14]. The system was designed for situations where conventional short-span transitions are impractical. Unlike standard AGTs, which typically rely on closely spaced posts and a short unsupported guardrail span to increase stiffness near the barrier end, the LSSC accommodates an unsupported distance of approximately 9 ft between the final guardrail post and the face of a reinforced concrete barrier wall (RCBW). This configuration could address installation challenges that arise when subsurface utilities, bridge decks, or other site constraints limit the available space for post placement. The LSSC was conceived to provide a longer unsupported span while maintaining crashworthy performance in accordance with MASH.

The initial prototype employed a tri-chord spanning configuration, in which three tubular members were used to bridge the gap between the last guardrail post and the barrier anchorage (Figure 2.9). This prototype was evaluated through development testing under MASH test designation no. 3-21, which requires redirection of a 5,000-lb pickup truck impacting at approximately 62 mph and 25 degrees. In test no. 18030-1, the prototype met the criteria for containment and redirection, but video analysis showed that the transition stiffness and resulting pocketing angle were relatively high [14]. These findings raised concerns regarding potential performance under MASH test designation no. 3-20, which involves a smaller passenger vehicle and more stringent stability demands. To address these concerns, the design was revised to reduce the overall rigidity of the system.

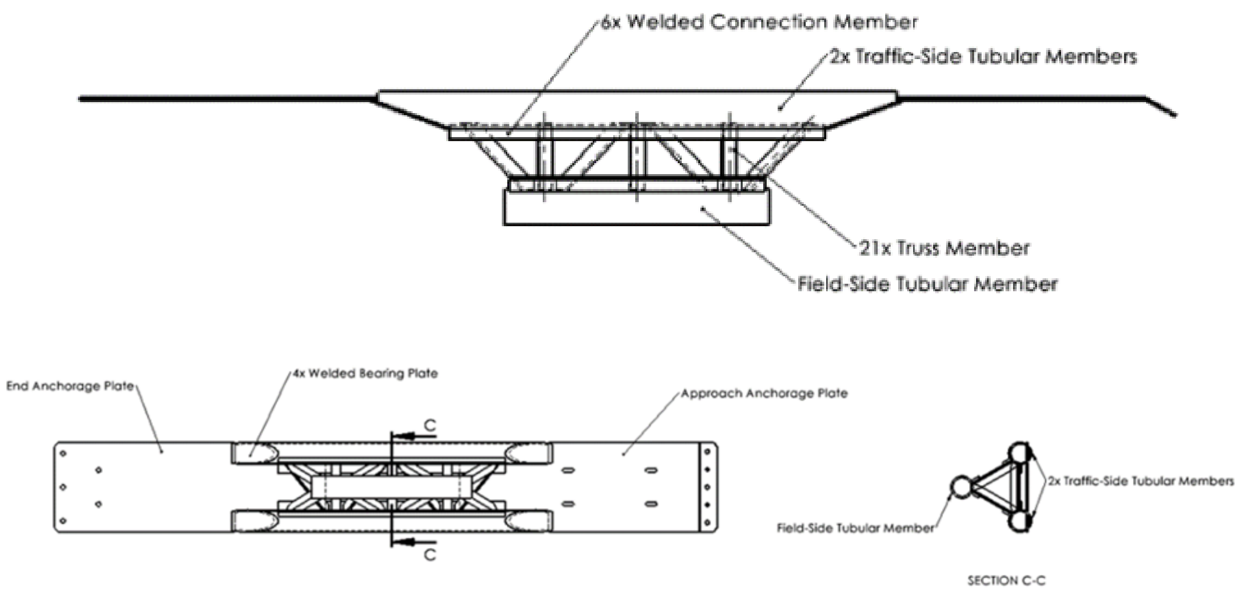


Figure 2.9 Schematics of Prototype AGT Tri-Chord: (a) Plan View and (b) Elevation View [14]

The final design adopted a two-tube configuration, which lowered both the stiffness and weight relative to the tri-chord prototype, producing a more gradual stiffness transition between the flexible guardrail and the rigid barrier wall. The configuration consisted of two vertically aligned tubular HSS members spanning between upstream and downstream anchorage plates. Each plate was bent to create angled bearing faces that helped guide impacting vehicles while minimizing snagging. Peripheral welds connected the tubular members to the anchorage plates, providing structural continuity across the unsupported span. On the traffic side, nested thrie-beam segments were incorporated to shield the tubular members and reduce hardware snag potential, while a custom thrie-beam element on the field side limited vertical spreading during impact. For improved constructability, the final five wooden offset blocks were replaced with steel HSS blocks, providing more uniform stiffness and eliminating timber variability. Several stiffening components included in the tri-chord prototype were also eliminated, simplifying fabrication while maintaining structural adequacy (Figure 2.10).

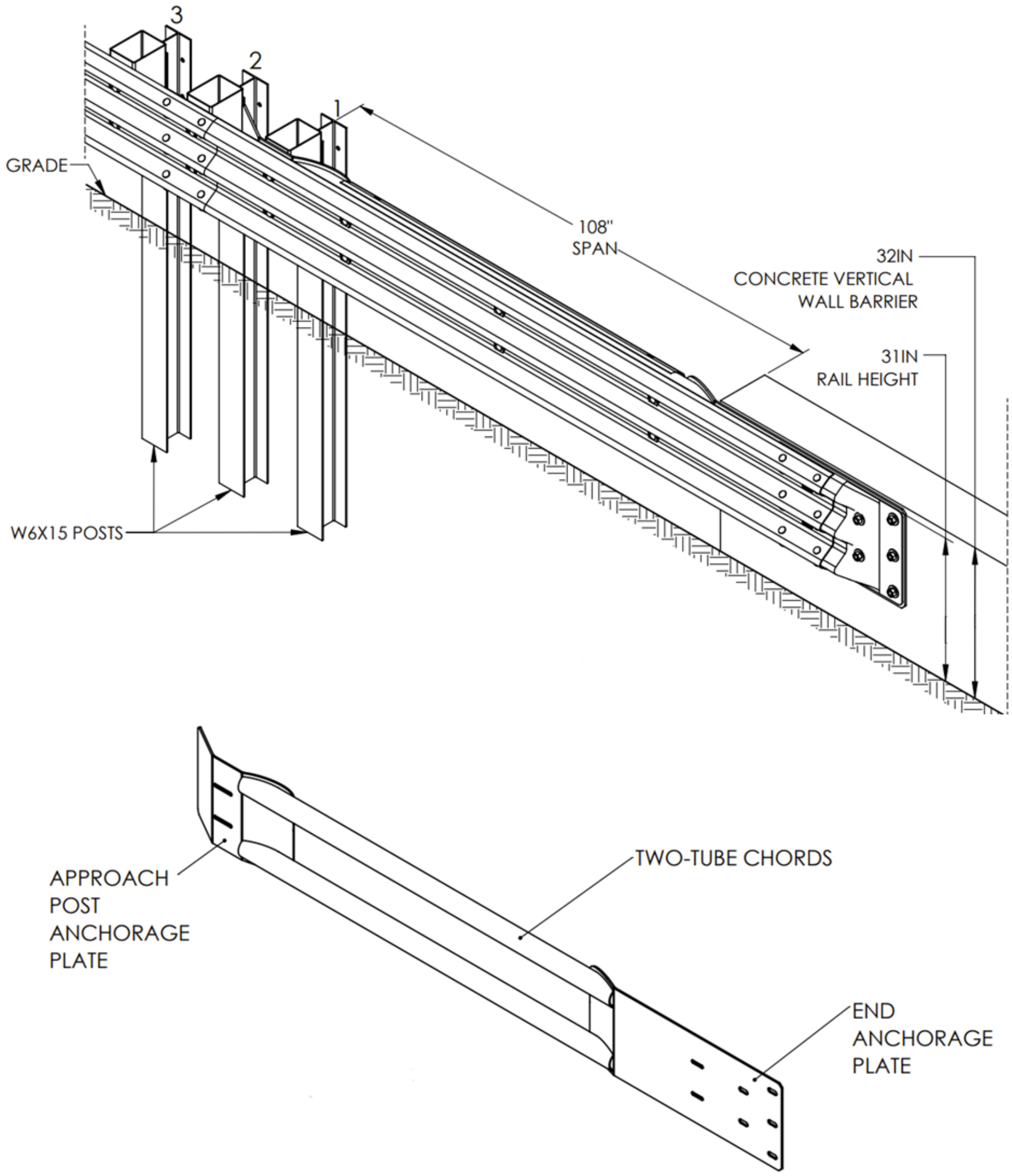


Figure 2.10 Schematics of Final Long Span Structure Connection [14]

Full-scale compliance testing was conducted at the Applus IDIADA Karco Engineering facility [14]. In MASH test designation no. 3-20, a 2,427-lb passenger car impacted the LSSC at 63.1 mph and 24.3 degrees, as shown in Figure 2.11. The system successfully contained and redirected the vehicle, with a dynamic deflection of 4.1 in. and a working width of 17.6 in. Occupant risk measures, including ridedown accelerations and occupant impact velocities, were within MASH limits. Video analysis confirmed stable redirection without rollover, limited wheel interaction with the tubular region, and no compromise of the occupant compartment.

0.000 sec 0.060 sec 0.0120 sec 0.180 sec

Figure 2.11 Sequential Photographs of MASH Test Designation No. 3-20 [14]

Under MASH test designation no. 3-21, a 5,020-lb pickup truck impacted the LSSC at 62.4 mph and 25.6 degrees, as depicted in Figure 2.12. The system again contained and redirected the vehicle, with a measured dynamic deflection of 10.1 in. and a working width of 25.0 in. Although the pickup experienced measurable roll and yaw during redirection, overall stability was maintained. Post-test inspection revealed localized plastic deformation in the tubular members and anchorage plates but no evidence of fracture, tearing, or structural separation.

0.000 sec 0.150sec 0.300 sec 0.450sec

Figure 2.12 Sequential Photographs of MASH Test Designation No. 3-21 [14]

Chapter 3 NDOT Districts Survey Data

3.1 Overview

A survey was conducted among NDOT District Operations and Maintenance Managers, as well as District Construction Engineers from Districts 1 through 8 (Figure 3.1). The objective of this survey was to document the most common types of obstructions that prevent the installation of AGT posts near bridge rail ends. Additional questions focused on the geometries of these obstructions, fill slope conditions, the number and location of omitted posts, and the desired maximum span length between the concrete bridge rail end and the first transition post. This chapter summarizes the survey responses and synthesizes them into findings relevant to the design of the new long-span AGT system. The survey questionnaire sent to the NDOT Districts is documented in Appendix A.

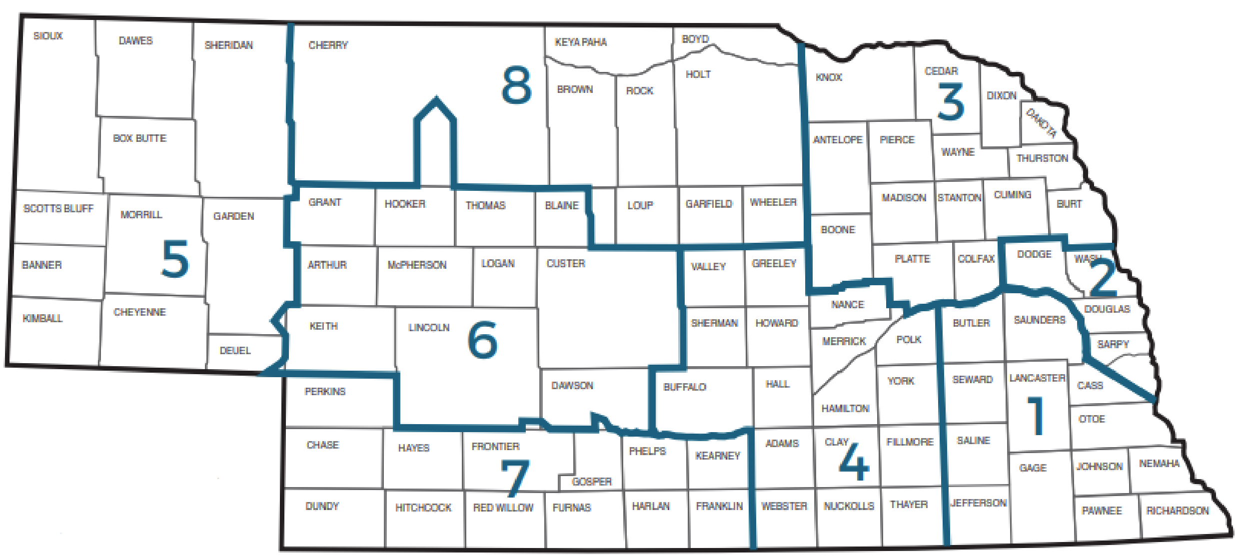


Figure 3.1 NDOT Districts 1 Through 8 [15]

3.2 Survey Results and Analysis

3.2.1 Challenges with Subsurface Obstructions

Survey participants were first asked whether their Districts experienced challenges with subsurface obstructions such as drainage structures, utility lines, wingwalls, and other concrete obstructions below grade, as well as site constraints including soil fill and grading. Nearly all respondents reported encountering such challenges, as illustrated in Figure 3.2, confirming the widespread nature of this issue.

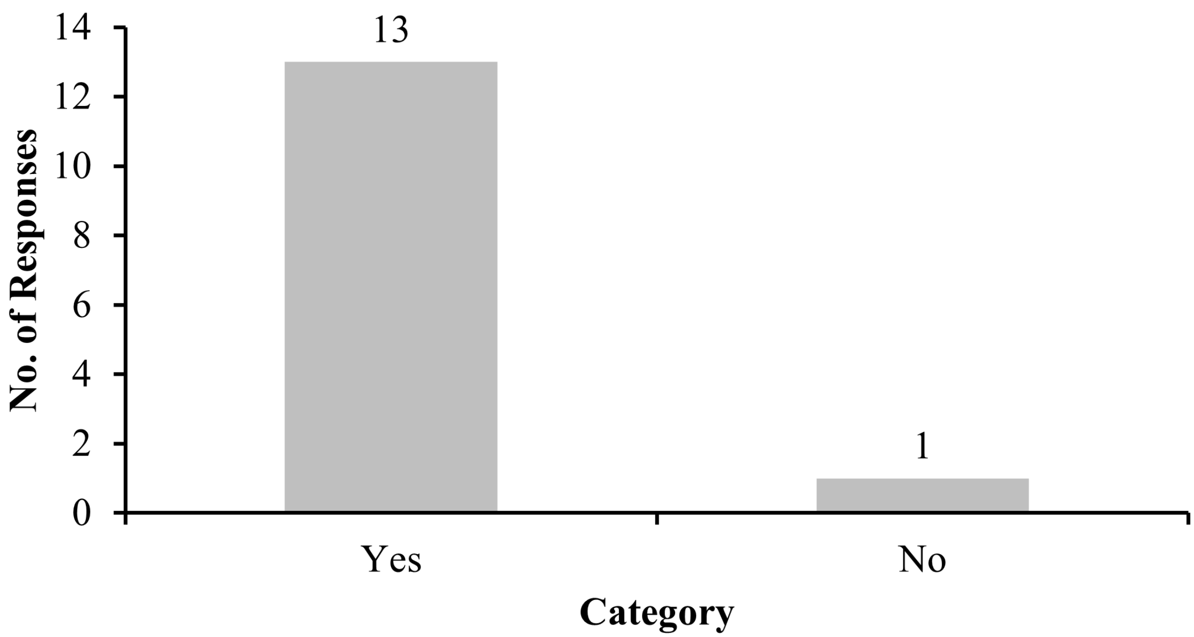


Figure 3.2 District Responses Regarding Subsurface Obstruction Challenges

3.2.2 Type and Size of Obstructions

When asked to describe the types of obstructions encountered near concrete bridge rail ends, the most commonly reported categories included drainage structures (culverts, pipes, and inlets), wingwalls, and soil-related issues, such as erosion or grading limitations. These findings are illustrated in Figure 3.3.

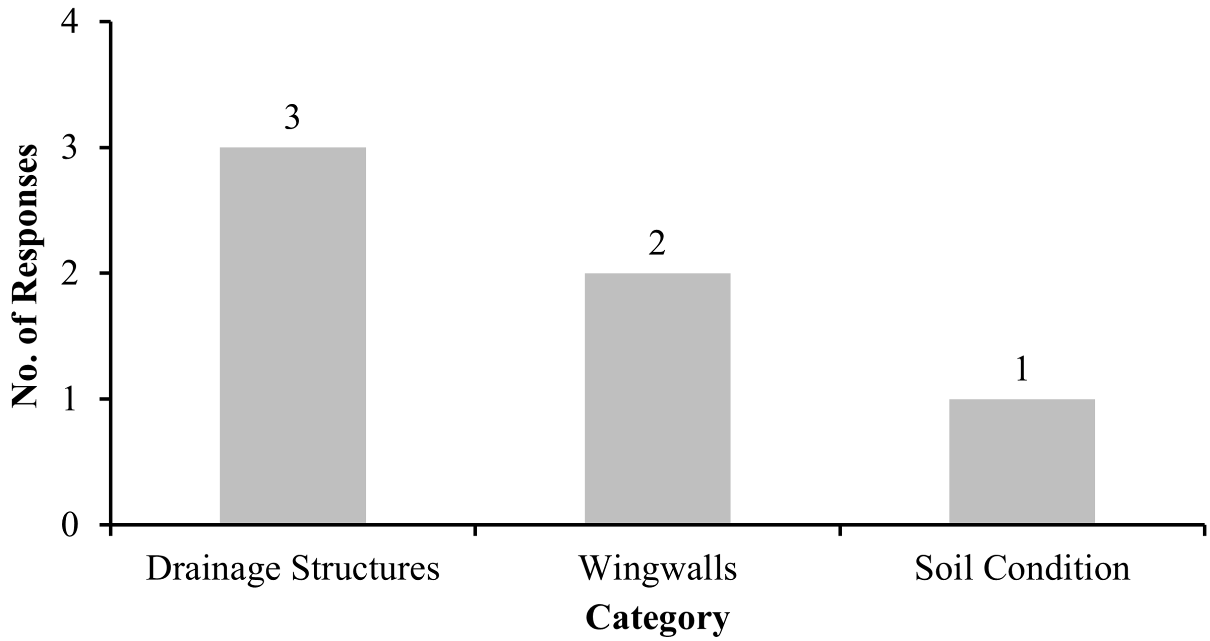


Figure 3.3 Reported Obstruction Categories Near Concrete Bridge Rail Ends

Respondents also provided information about the dimensions of these obstructions. Reported lengths were typically between 3 and 5 ft, widths were between 3 and 5 ft, and depths ranged from 1.5 to 10 ft. These values suggest that obstructions often extend through a significant portion of the post installation zone, limiting feasible post placement.

3.2.3 Slope Conditions

Several districts reported slope conditions affecting AGT installations. Reported slopes ranged from 1V:2H to 1V:3H, with offsets between 1 ft and 4 ft from the posts. The reported slope gradients and slope offsets are summarized in Figure 3.4 and Figure 3.5.

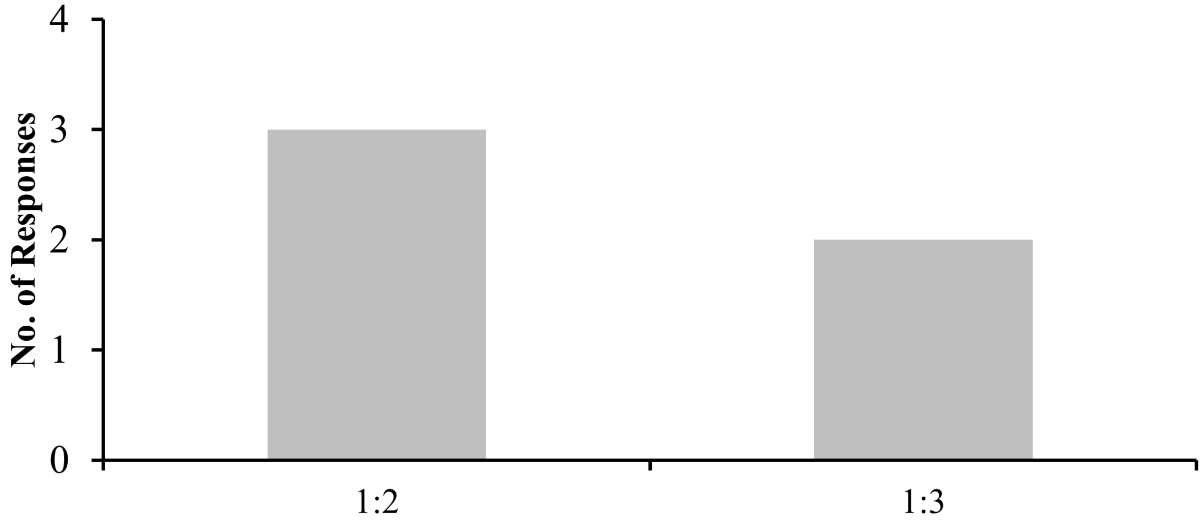


Figure 3.4 Reported Slope Ratios Affecting AGT Post Installation

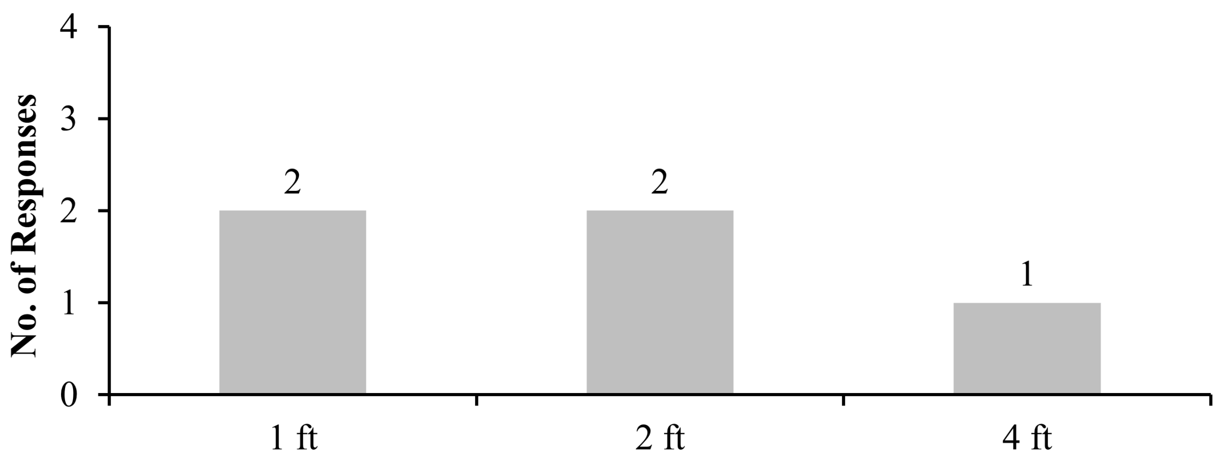


Figure 3.5 Reported Slope Offsets from AGT Post Locations

3.2.4 Post Omission Due to Obstructions

Survey responses indicated that obstructions often require the omission of one or more AGT posts. As shown in Figure 3.6, the typical number of omitted posts was reported as one or two, with fewer cases involving three or more posts. The maximum number of omitted posts was also most frequently two. The omitted posts were most commonly located at post no. 1 or post no. 2 (the first and second transition posts adjacent to the bridge rail end), as shown in Figure 3.7.

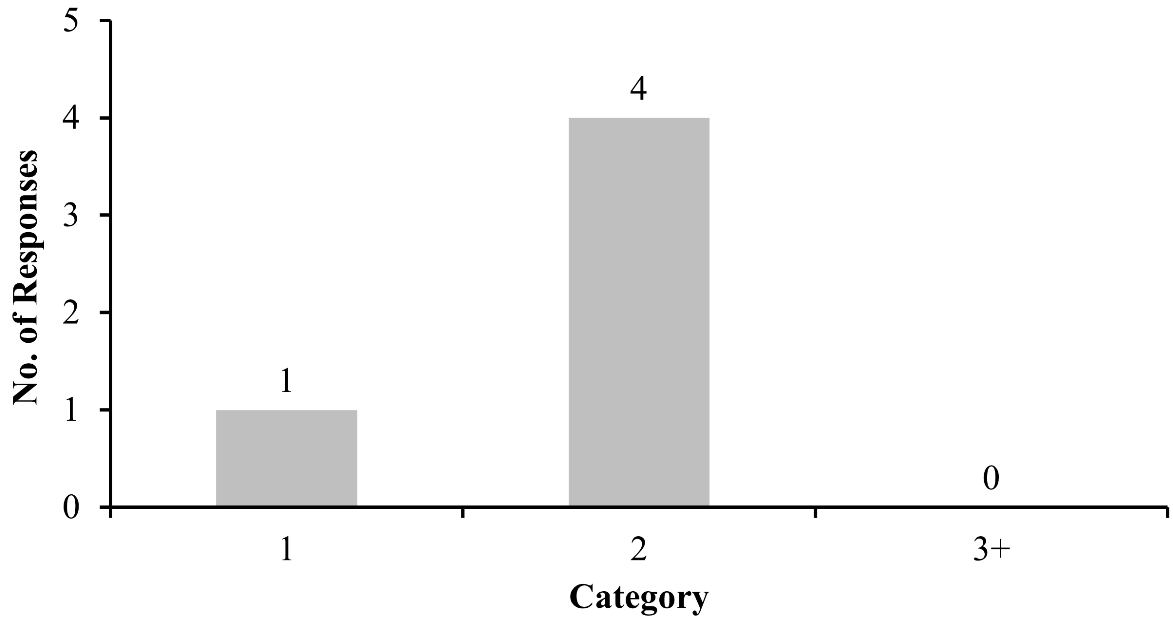


Figure 3.6 Typical Number of Omitted Posts Due to Obstructions

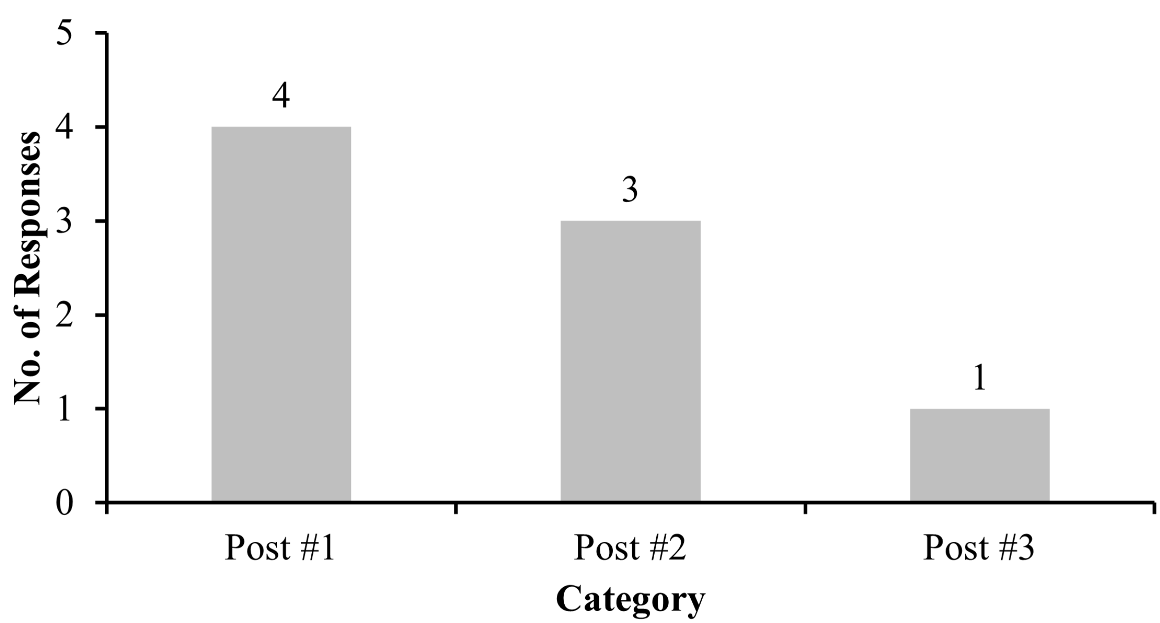


Figure 3.7 Location of Omitted Posts Within the AGT System

3.2.5 Mitigation Strategies

In response to challenges posed by obstructions and site constraints, all districts emphasized coordination with roadway design and manufacturers when developing site-specific solutions. Commonly reported mitigation strategies included the use of mid-span rail supports to bridge gaps created by omitted posts.

3.2.6 Desired Maximum Span Length

Finally, participants were asked to provide the desired maximum span length between the bridge rail end and the first transition post that would enable accommodation of obstructions. Responses ranged from 3 ft to 6 ft, with the majority favoring 4 ft, as shown in Figure 3.8.

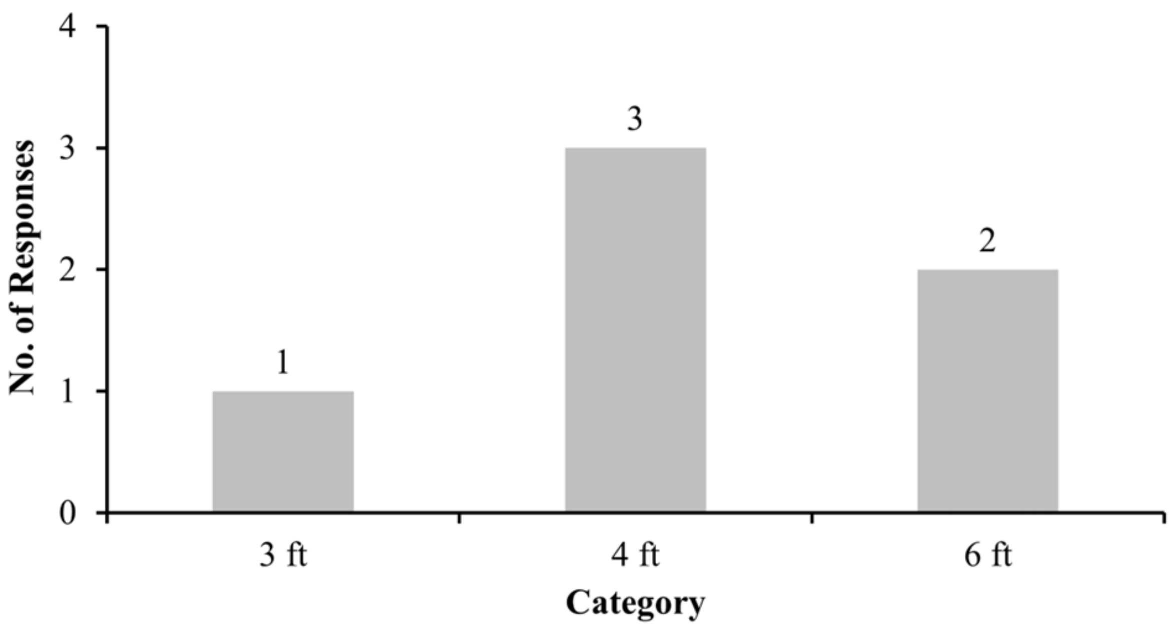


Figure 3.8 Desired Maximum Span Length between Concrete Bridge Rail End and First Transition Post

3.3 Summary

The NDOT District survey revealed consistent challenges across the state related to subsurface obstructions, slope conditions, and omitted posts near concrete bridge rail ends.

Districts reported that drainage structures and wingwalls are the most frequent obstructions, with typical obstruction sizes preventing post installation in the first two transition positions. Most districts suggested that a maximum span length of 4 ft would be sufficient to accommodate these constraints, although some responses indicated a preference for spans up to 6 ft.

Chapter 4 Long-Span AGT System Design Concepts

4.1 Design Criteria

The objective of this study was to develop a new long-span AGT system based on the standard NDOT 34-in. thrie-beam system that increases the clear distance between the concrete buttress end and the first transition post. This new long-span AGT system would allow installation where conventional posts cannot be placed properly due to site conditions, such as bridge abutments, wing walls, drainage inlets, and utility structures. MwRSF researchers consolidated prior work on crash-tested AGT systems, long-span AGTs, and retrofit concepts deemed pertinent to the development and evaluation of the new long-span AGT system. Input from NDOT Districts was also reviewed. Together, these sources established design criteria for a new AGT system with an increased span between the concrete bridge rail end and the first transition post.

The standard NDOT 34-in. AGT, which includes a standardized buttress, served as the base configuration for development. The new long-span system must satisfy MASH TL-3 impact safety criteria. The system must provide sufficient lateral strength to redirect vehicles and must preserve geometry that avoids vehicle instabilities, including snag at the bridge rail end. NDOT District feedback identified a preferred maximum span length of 6 ft for typical sites. A target span of 8 ft–5 in. was selected to accommodate a wide range of obstructions at post nos. 1 and 2 locations and to increase applicability at constrained locations.

Following establishment of the design criteria, the research team generated and screened multiple long-span AGT system concepts aimed at increasing lateral stiffness and improving impact performance within the modified region. Mechanisms considered included a surrogate post formed by a continuous horizontal member, a cantilever member near the buttress to control end rotations and shear, and local rail stiffening to increase moment capacity and reduce lateral deflection. The next section presents these design concepts with their expected advantages and limitations based on the criteria noted above.

4.2 Design Concepts

4.2.1 Design Concept #1

Design concept #1 placed a tubular backup member behind nested thrie-beam through the transition region, as shown in Figure 4.1. The layout follows the Modified Nebraska thrie-beam transition [5-6] and removes embedded posts at post nos. 1 and 2. The backup member was rectangular steel tubing, 8 in. x 4 in. x $^1/_4$ in., ASTM A500 Grade B. It ran from the upstream face of the concrete buttress to post no. 3, as depicted in Figure 4.1. Timber blockouts measuring 6 in. x 9 in. x 19 in. were fastened to the top and bottom faces of the tube. A timber spacer set the required rail offset from the tube and preserved the thrie-beam geometry.

The tube, spacer, and blockouts acted as a surrogate support where posts cannot be installed near the concrete bridge rail end. Impact loads would enter the thrie-beam, pass through the spacer and blockouts, and transfer into the steel tube. The tube would then transfer these forces to the buttress and post no. 3. The maximum unsupported span, as shown in Figure 4.1, was 8 ft–5 in. The tube connected to the web of post no. 3 with a bolted plate. This arrangement-maintained rail height and offset while providing a continuous load path across the long span. It also concentrated a larger share of demand at post no. 3 during vehicle impacts. The design concept noted the effect of higher demand on post no. 3 for checks on the post section, the bolted web connection, and the anchor design at the concrete buttress.

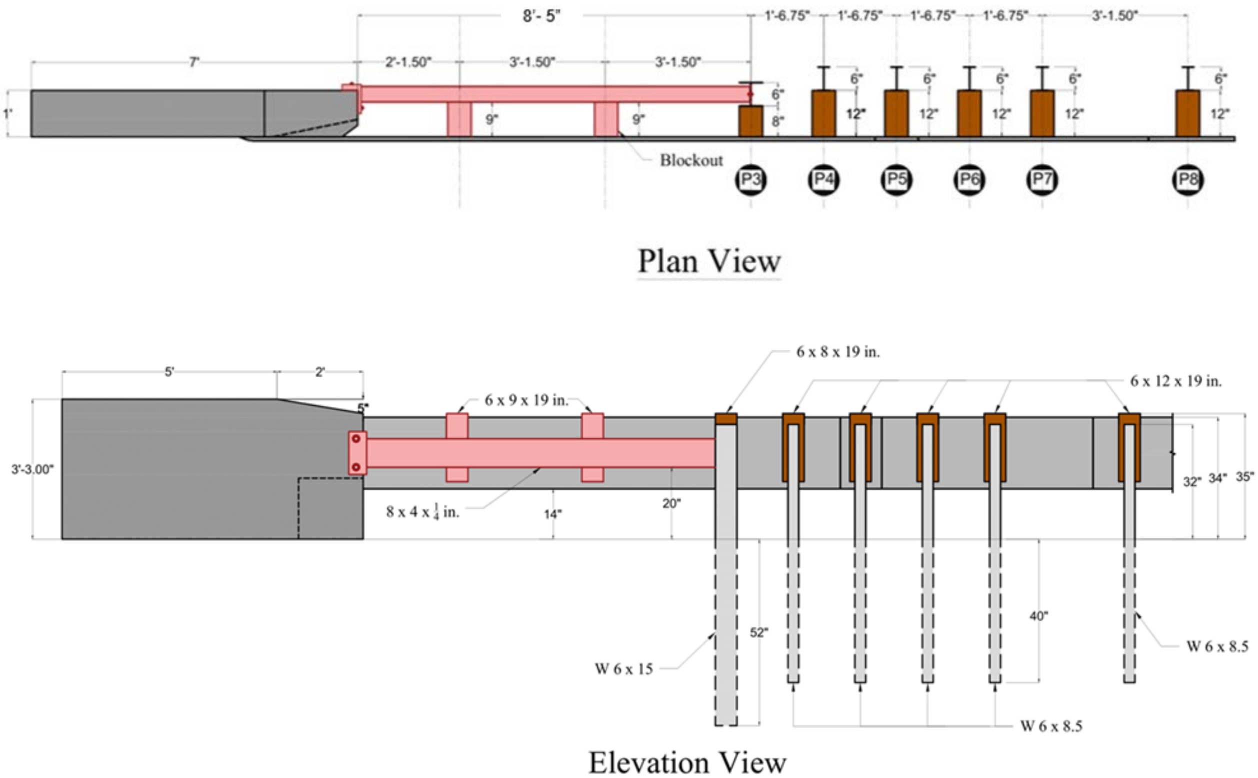


Figure 4.1 Schematics of Design Concept #1

4.2.2 Design Concept #2

This concept added a horizontal cantilever beam on the base side of the concrete buttress, similar to the Nebraska thrie-beam transition evaluated at TTI in 2000 [8]. The member used in this design was a W6x15 section with its center aligned with the thrie-beam rail at 24 in. The beam connected to the back of the thrie beam with 6-in. x 9-in. x 19-in. blockouts and standard attachment hardware, as shown in Figure 4.2.

The layout preserved basic AGT functions while shifting lateral resistance from the post-soil system to the steel beam and its anchor. Impact loads would enter the thrie-beam, pass through the timber blockouts, and transfer into the W6x15. The anchor at the buttress would resist cantilever reactions and return the load to the concrete buttress. A known concern for this design concept was the higher demand on post no. 3 during vehicle impacts. Removing nearby buttress posts places more force on the post no. 3 connection and foundation. The design noted the effect of higher demand on post no. 3 for checks of post capacity, web connection details, and local stability at that location.

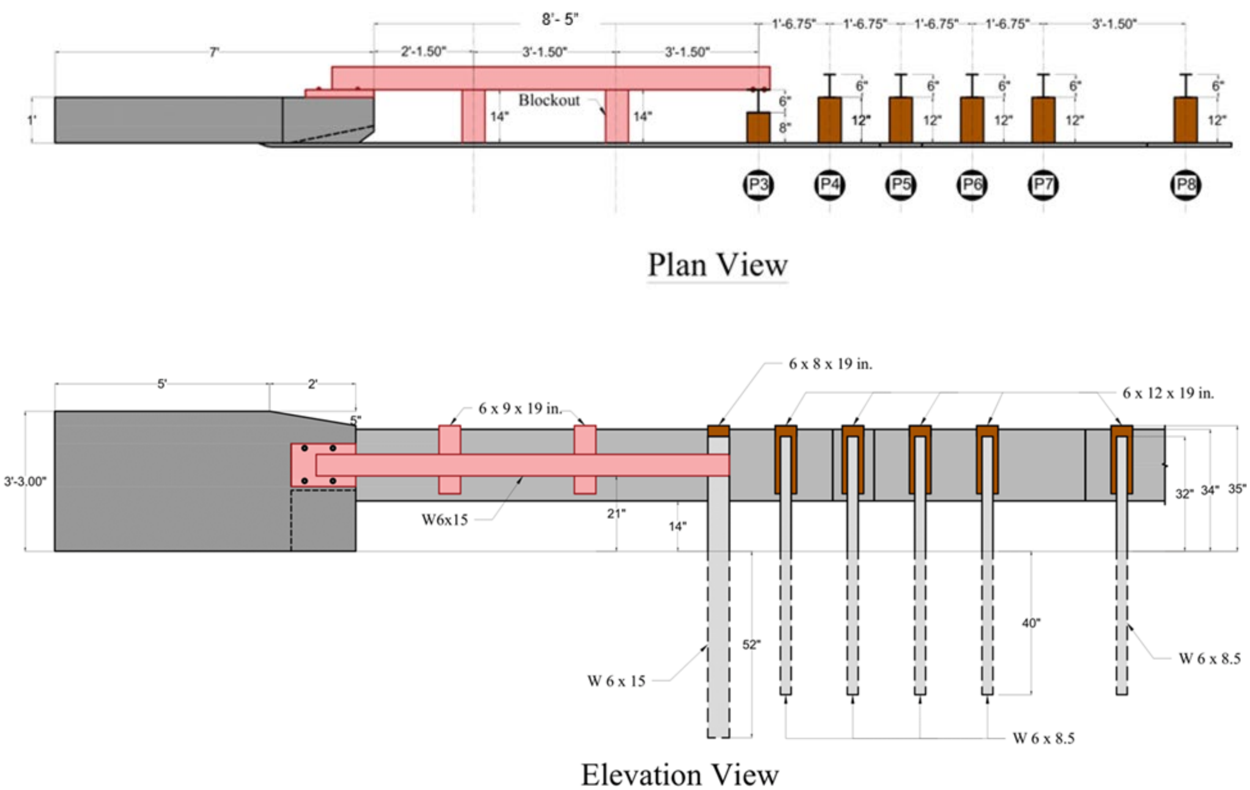


Figure 4.2 Schematics of Design Concept #2

4.2.3 Design Concept #3

This concept used a horizontal cantilever beam on the base side of the concrete buttress, consistent with Design Concept #2. The member was a W6x15 section and its center was aligned with the thrie-beam rail at 24 in. The beam connected to the back of the nested thrie-beam using 6-in. x 9-in. x 19-in. timber blockouts and standard attachment hardware, as shown in Figure 4.3. The anchor at the buttress developed cantilever reactions and returned the load to the concrete buttress.

To reduce the demand on post no. 3, an additional W6x15 post was placed 19 in. from the centerline of post no. 3. This auxiliary post provided a secondary load path in the long-span region. Impact forces would enter the thrie beam, pass through the blockouts, and split between the cantilever beam and the added post. The intent was to lower bending and shear at post no. 3 and to moderate foundation actions at that location.

The layout maintained the required rail height and offset while preserving basic AGT functions and fit within the clearance near the buttress while keeping the traffic face unchanged. Adding the auxiliary post required additional design evaluation for connection details. This design concept reduced the maximum span length between the concrete buttress and first transition post to 6 ft–9½ in. and introduced additional hardware compared to the previous two concepts.

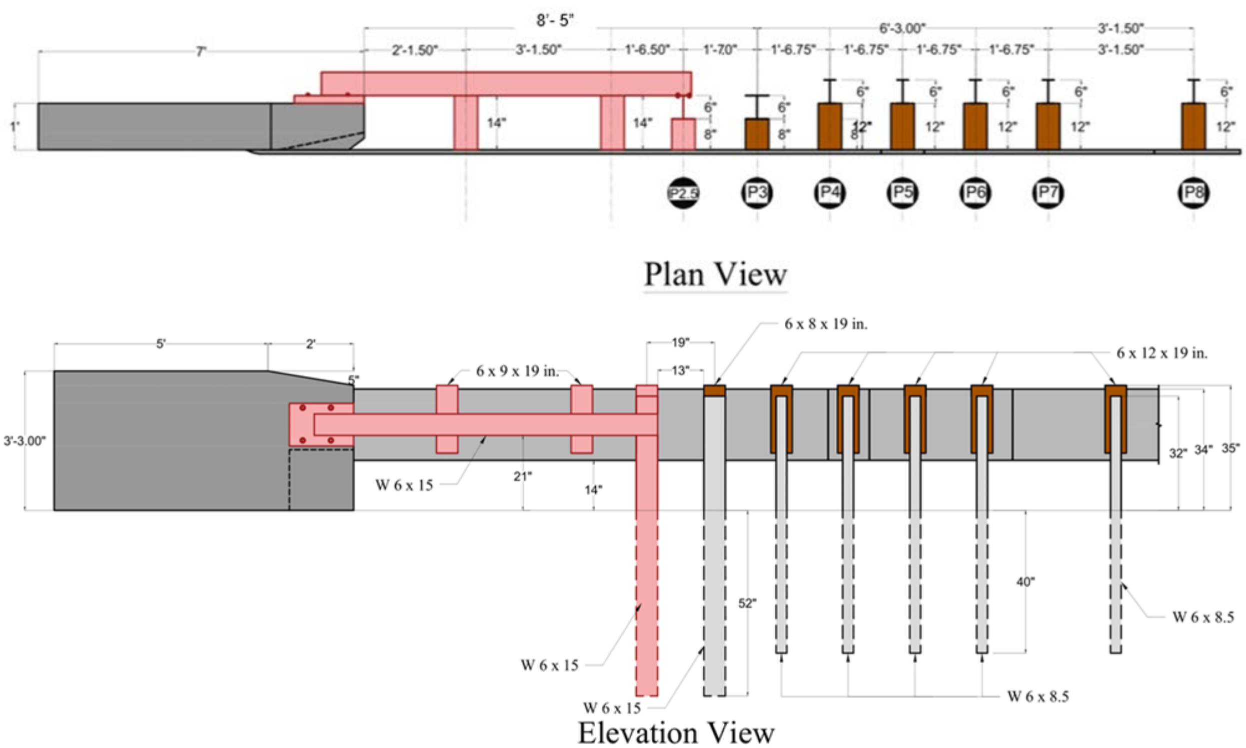


Figure 4.3 Schematics of Design Concept #3

4.2.4 Design Concept #4

This concept utilized two independent cantilever beams with moment connections, as shown in Figure 4.4. Each beam was intended to act on its own under impact loading. Candidate sections were HSS 4 in. x 4 in. x ¼ in. and HSS 6 in. x 6 in. x ¼ in., which are common in roadside hardware design.

Both beams were vertically centered with the thrie-beam at 24 in. Each beam connected to the back of the thrie-beam using timber blockouts and standard hardware. Two blockout sizes were considered, 6 in. x 9 in. x 19 in. and 6 in. x 4.5 in. x 19 in., as shown in Figure 4.4. This layout preserved the rail offset and maintained the required geometry in the transition region. The concept was viewed as innovative. However, this design increased the hardware count and expected costs compared with concepts 1, 2, and 3. Further evaluation would need to weigh the added complexity against potential performance gains.

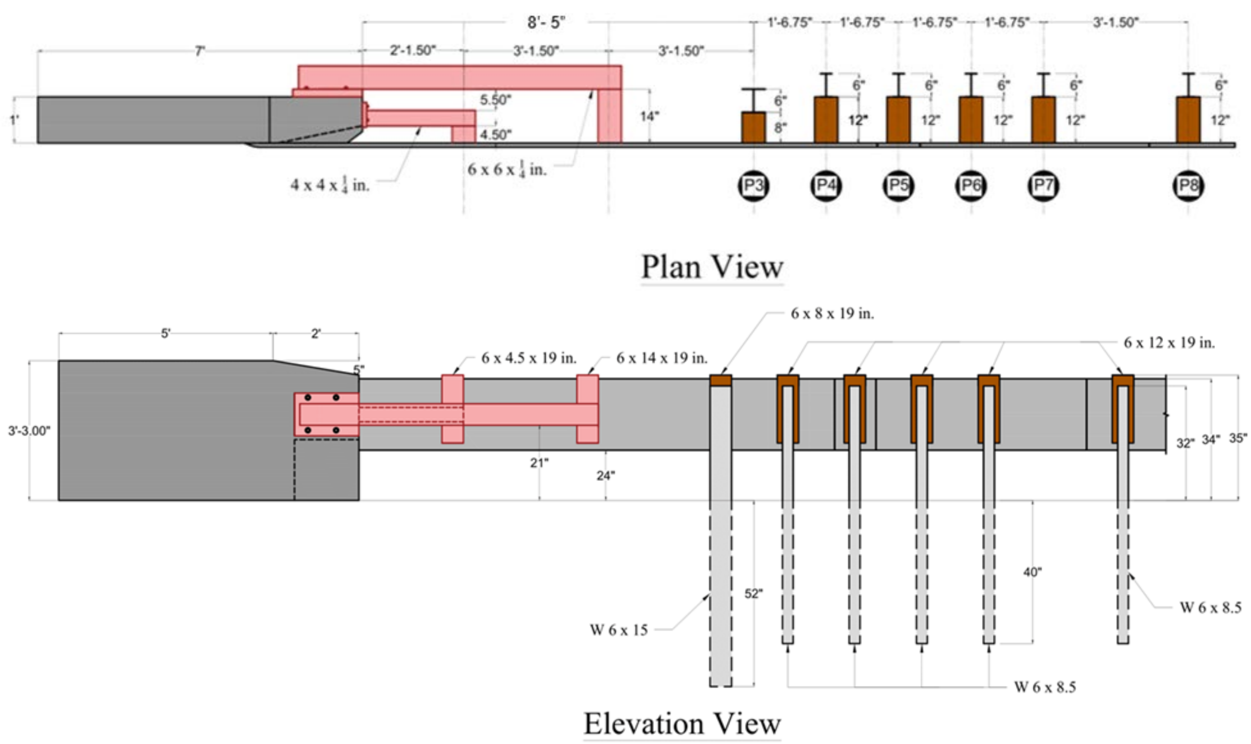


Figure 4.4 Schematics of Design Concept #4

4.2.5 Design Concept #5

This concept used a double-beam system to increase lateral stiffness and improve impact performance in the long-span region. Two rectangular steel tubes, HSS 8 in. x 6 in. x ¼ in., ran parallel behind the nested thrie-beam. Tube top elevations were 16 in. and 25 in. to engage the rail at two heights and limit rotation near the buttress. The tubes anchored to the concrete buttress and extended toward the approach rail, as shown in Figure 4.5.

The layout followed the continuous transition tube AGT used in the IL-OH bridge railing and AGT study, which employed a 9-ft span from the final AGT post to the first bridge rail post [13]. That prior configuration was shown to be crashworthy when connecting steel tube bridge rails to AGTs. The present design adapted the concept to NDOT's details by fixing the tubes at the concrete buttress rather than at a bridge rail post line. The result is a compact substructure that fits common bridge corners and preserves standard rail geometry.

The hardware count was low compared with concepts 1 through 4. Each tube served as a continuous surrogate support that carried impact loads from the thrie-beam through the blockouts and attachments into the buttress anchorage. The dual tube arrangement would reduce local demand at any single elevation, limit lateral deflection at rail height, and distribute forces to the buttress with predictable load paths. This simplicity, along with prior positive performance history, motivated the selection of Concept 5 for detailed analysis.

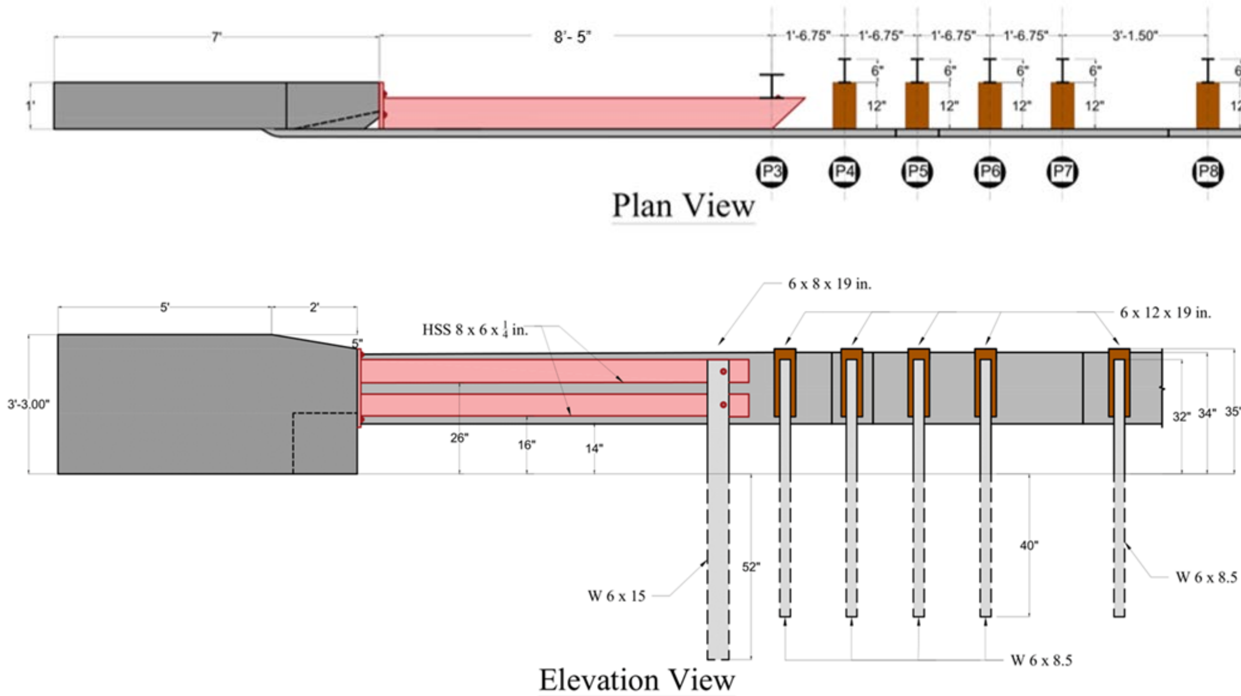


Figure 4.5 Schematics of Design Concept #5

4.2.6 Design Concept #6

This concept shifted the entire AGT and added a rigid extension downstream of the bridge rail end, as shown in Figure 4.6. The intent was to create a stiff region with higher moment capacity near the buttress. The extension used two HSS 8-in. x 6-in. x ¼-in. steel tubes, a ¼-in. plate, and a W8x24 post. These components formed a stiff assembly that increased resistance at the downstream end and maintained the required rail height and offset. The layout required more hardware than other concepts and increased the expected cost. The research team recorded this approach as a possible alternative during brainstorming, but it was not identified as the preferred path for development.

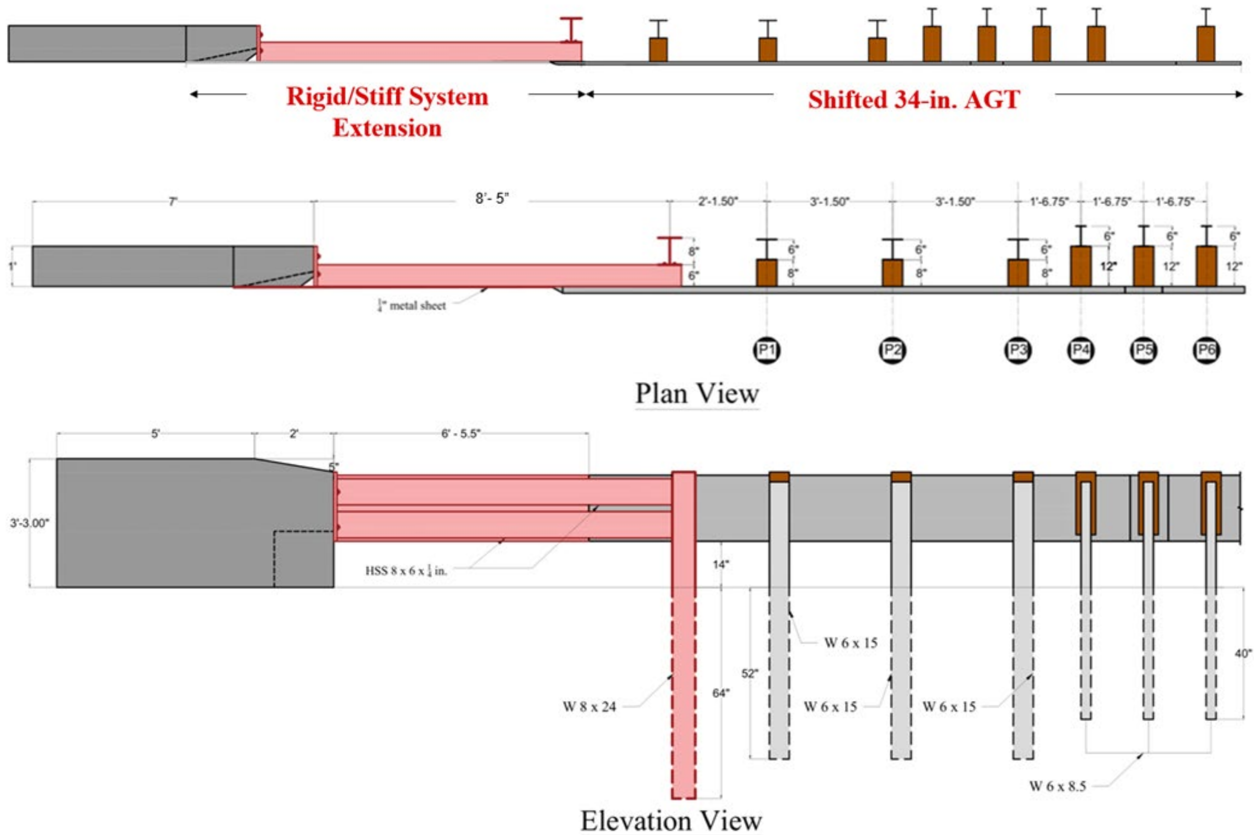


Figure 4.6 Schematics of Design Concept #6

4.3 Summary

As discussed, multiple long-span AGT design concepts were developed through structured brainstorming sessions, incorporating a range of rail stiffening mechanisms intended to enhance lateral system stiffness and minimize impact-related deflections, pocketing, and vehicle instability. Each concept was evaluated based on structural performance, constructability, and potential field application, with their strengths and limitations thoroughly documented. These design concepts were presented to Technical Advisory Committee (TAC) members. Following discussion and feedback, Design Concept #5 was selected by the TAC members as the preferred configuration for further engineering analysis and development.

Chapter 5 LS-DYNA Model Development

The preferred long-span AGT system design concept (Design Concept #5) was assessed using LS-DYNA [16] finite element analysis to evaluate crashworthiness, optimize the design, and select Critical Impact Points (CIPs) for the future full-scale crash testing effort.

5.1 Validation of the AGT Model

An LS-DYNA model of the NDOT 34-in. tall AGT consisting of a trailing end anchor, MGS section, thrie-beam approach guardrail transition, and standardized concrete buttress was developed in a previous research effort at MwRSF [17]. The model was validated against test nos. 34AGT-1 and 34AGT-2 [2]. The modification of the AGT model for the current study included incorporating the symmetric W-beam-to-thrie-beam section, as shown in Figure 5.1.

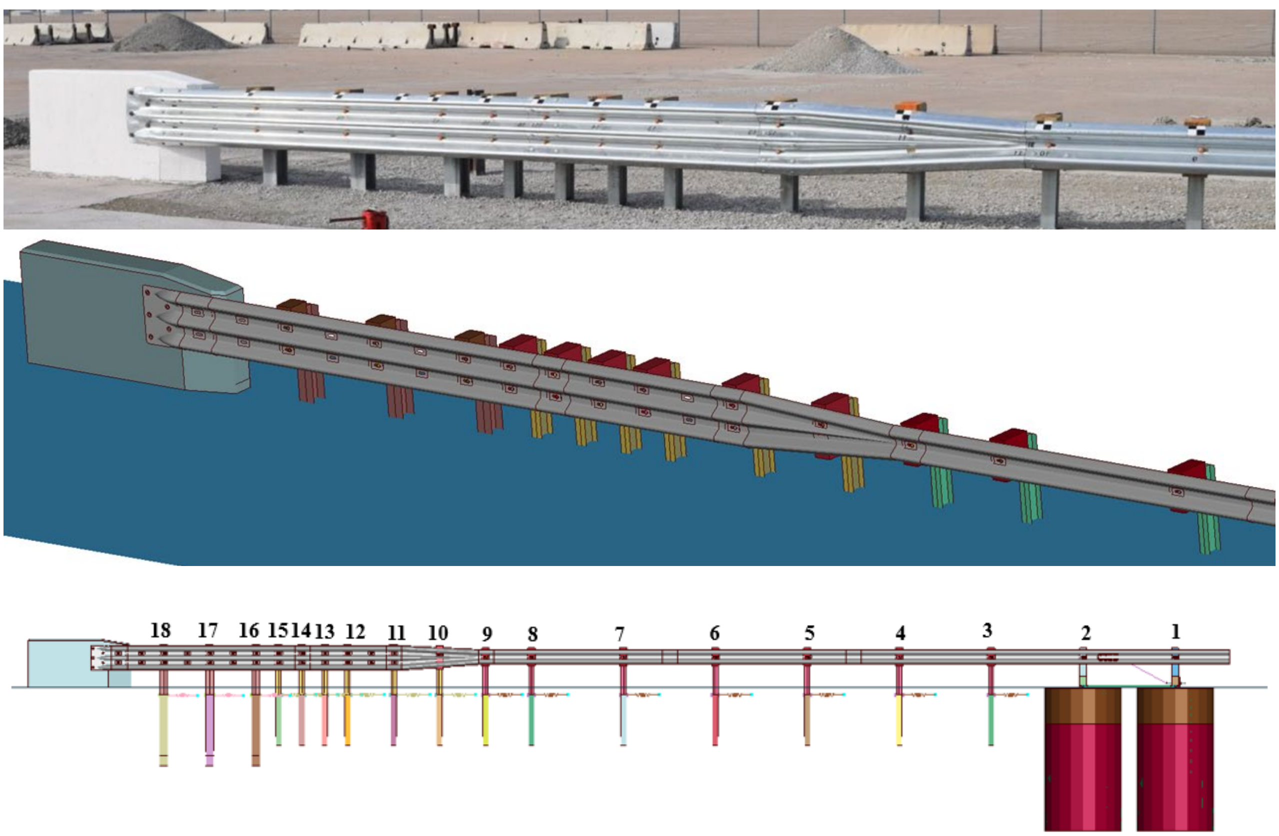


Figure 5.1 NDOT 34-in. Tall AGT System Installation for Test Nos. 34AGT-1 and 34AGT-2 (top) and LS-DYNA Simulation Model (middle, bottom)

The total system length of the LS-DYNA model was 6.25 ft shorter than the length of actual test installations, which was due to a shorter length of MGS being placed upstream of the MGS. Thus, the LS-DYNA model had 18 posts, while the test installations for test nos. 34AGT-1 and 34AGT-2 utilized 19 posts.

A vehicle model of a 2018 Ram pickup truck was used for the simulation of test no. 34AGT-1 (MASH test designation no. 3-21). The Ram vehicle model was originally developed by the Center for Collision Safety and Analysis Team at George Mason University [18] and was modified by MwRSF researchers for use in roadside safety applications. A 2010 Toyota Yaris vehicle model was used in the simulation of test no. 34AGT-2 (MASH test designation no. 3-20). The Yaris vehicle model was originally created by the National Crash Analysis Center [19] and later modified by MwRSF researchers for use in roadside safety applications. The vehicle models of the 2018 Dodge Ram and 2010 Toyota Yaris are shown in Figure 5.2.

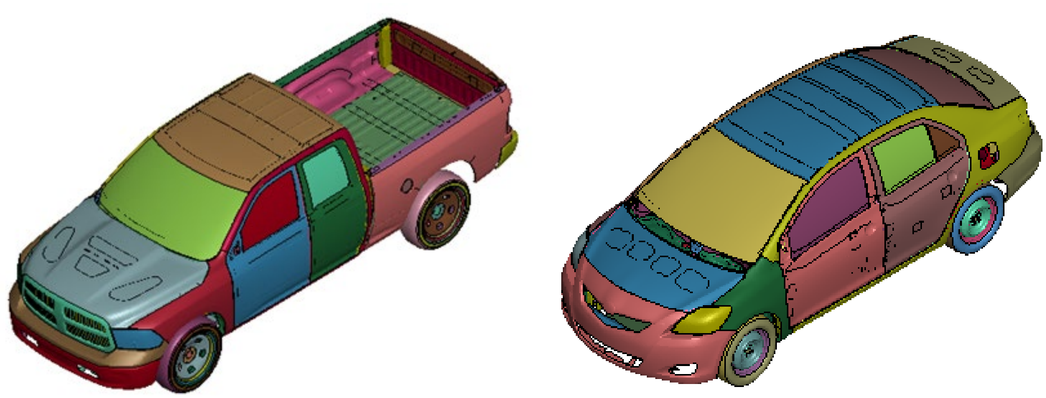


Figure 5.2 LS-DYNA Model of 2018 Dodge Ram Pickup Truck and 2010 Toyota Yaris

The updated NDOT 34-in. tall AGT model was validated by comparing simulations with full-scale test nos. 34AGT-1 and 34AGT-2. Occupant impact velocities (OIV), occupant ridedown accelerations (ORA), angular displacements, and dynamic deflections for the pickup truck case, MASH test designation no. 3-21, and the small car case, MASH test designation no.

3-20, are reported in Table 5.1 and Table 5.2. Sequential comparisons are shown in Figure 5.3 and Figure 5.4.

For test no. 34AGT-1, the model slightly overpredicted OIV. The longitudinal OIV was 27.2 ft/s versus 21.2 ft/s and the lateral OIV was 26.6 ft/s versus 25.9 ft/s in the simulation and crash test, respectively. The ORA agreed well. The longitudinal ORA was 11.8 g versus 10.8 and the lateral ORA matched at 8.9 g. Vehicle roll and pitch were lower in the model at 5.5 degrees versus 12.0 degrees and 2.5 degrees versus 4.4 degrees, respectively. Yaw was higher in the model, 47.9 degrees versus 38.9 degrees, which has no MASH limit. The maximum dynamic deflection agreed closely, at 8.0 in. versus 7.8 in. in the model and crash test, respectively.

For test no. 34AGT-2, the model again matched trends and limits. The simulated longitudinal OIV was higher than in the crash test, 28.20 ft/s versus 22.65 ft/s. The lateral OIV was within 1.5%, 32.24 ft/s versus 32.71 ft/s. The longitudinal ORA essentially matched, 10.85 g versus 10.84 g, but the lateral ORA was slightly lower, 13.45 g versus 14.70 g in the simulation and crash test, respectively. The vehicle's roll and pitch were lower in the model, 5.5 degrees versus 10.0 degrees and 5.1 degrees versus 5.5 degrees, and the yaw was higher, 104.7 degrees versus 94.9 degrees. The maximum dynamic deflection differed by 0.2 in., 2.9 in versus 2.7 in. in the model and crash test, respectively.

Overall, validation against test nos. 34AGT-1 and 34AGT-2 showed close agreement across primary occupant risk and structural response metrics. OIV trends were consistent, with the model slightly overpredicting the longitudinal component, while the lateral component tracked the tests closely. The ORA matched well in both configurations. Longitudinal values aligned with the measurements, and lateral values showed small, stable differences across the two tests. These patterns indicate that contact pulse timing and energy dissipation were captured with adequate fidelity. The angular displacements and structural responses followed a repeatable pattern. The model underpredicted roll and pitch and overpredicted yaw, which points to a modest bias in global rotational response rather than random scatter. The maximum dynamic deflection agreed within a narrow margin in both evaluations. The direction of the differences remained consistent across configurations. Taken together, the validation results support the use of the model to evaluate crashworthiness, optimize the design, and select CIPs for the preferred design concept of the 34-in. tall NDOT long-span AGT system.

Table 5.1 Comparison of Test No. 34AGT-1 and Simulation

Evaluation Criteria		**Test No. 34AGT-1 (MASH 3-21)**	**Simulation**	**MASH Limits**
OIV (ft/s)	Longitudinal	21.2	27.2	±40
	Lateral	25.9	26.6	±40
ORA (g's)	Longitudinal	10.8	11.8	±20.49
	Lateral	8.9	8.9	±20.49
Maximum Angular Displacement (deg.)	Roll	12.0	5.5	±75
	Pitch	4.4	2.5	±75
	Yaw	38.9	47.9	N/A
Max. dynamic deflection (in.)		7.8	8.0	N/A

N/A = not applicable

Table 5.2 Comparison of Test No. 34AGT-2 and Simulation

Evaluation Criteria		**Test No. 34AGT-2 (MASH 3-20)**	**Simulation**	**MASH Limits**
OIV (ft/s)	Longitudinal	22.65	28.20	±40
	Lateral	32.71	32.24	±40
ORA (g's)	Longitudinal	10.84	10.85	±20.49
	Lateral	14.70	13.45	±20.49
Maximum Angular Displacement (deg.)	Roll	10.0	5.5	±75
	Pitch	5.5	5.1	±75
	Yaw	94.9	104.7	N/A
Max. dynamic deflection (in.)		2.7	2.9	N/A

N/A = not applicable

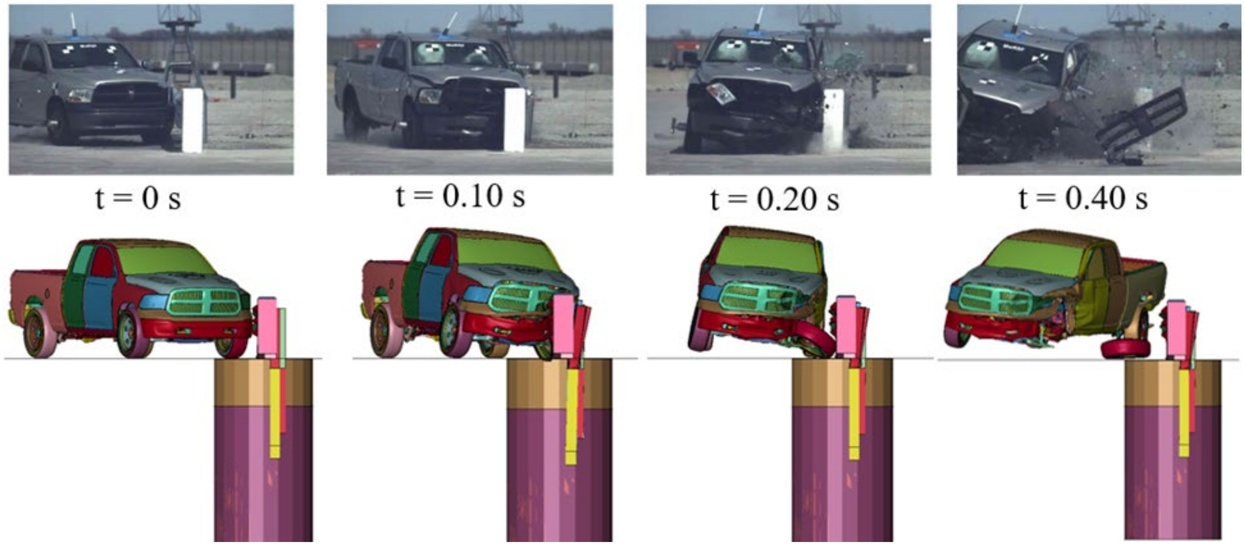


Figure 5.3 Sequential Comparison between Test No. 34AGT-1 and LS-DYNA Simulation

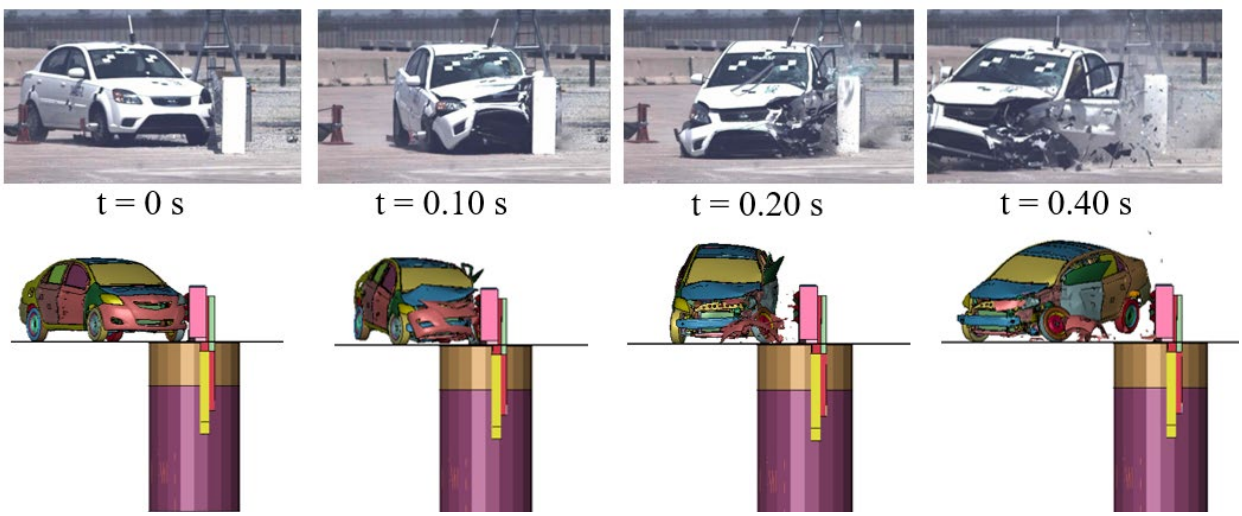


Figure 5.4 Sequential Comparison between Test No. 34AGT-2 and LS-DYNA Simulation

5.2 Development of Long Span AGT System Model

An existing LS-DYNA model was used to create the NDOT 34-in. tall, long-span AGT system with steel tube beams, as shown in Figure 5.5. The steel tube beams were modeled using shell elements with material properties consistent with the ASTM A500 steel material. MAT_PIECEWISE_LINEAR_PLASTICITY material formulation was used for simulating the steel-tube beams. The steel tube-rail bolts were simulated with constrained nodal rigid bodies. The steel tube beams were rigidly connected to the first transition post. Nodal constraints were defined to mimic the connection between the steel tube beams and concrete buttress.

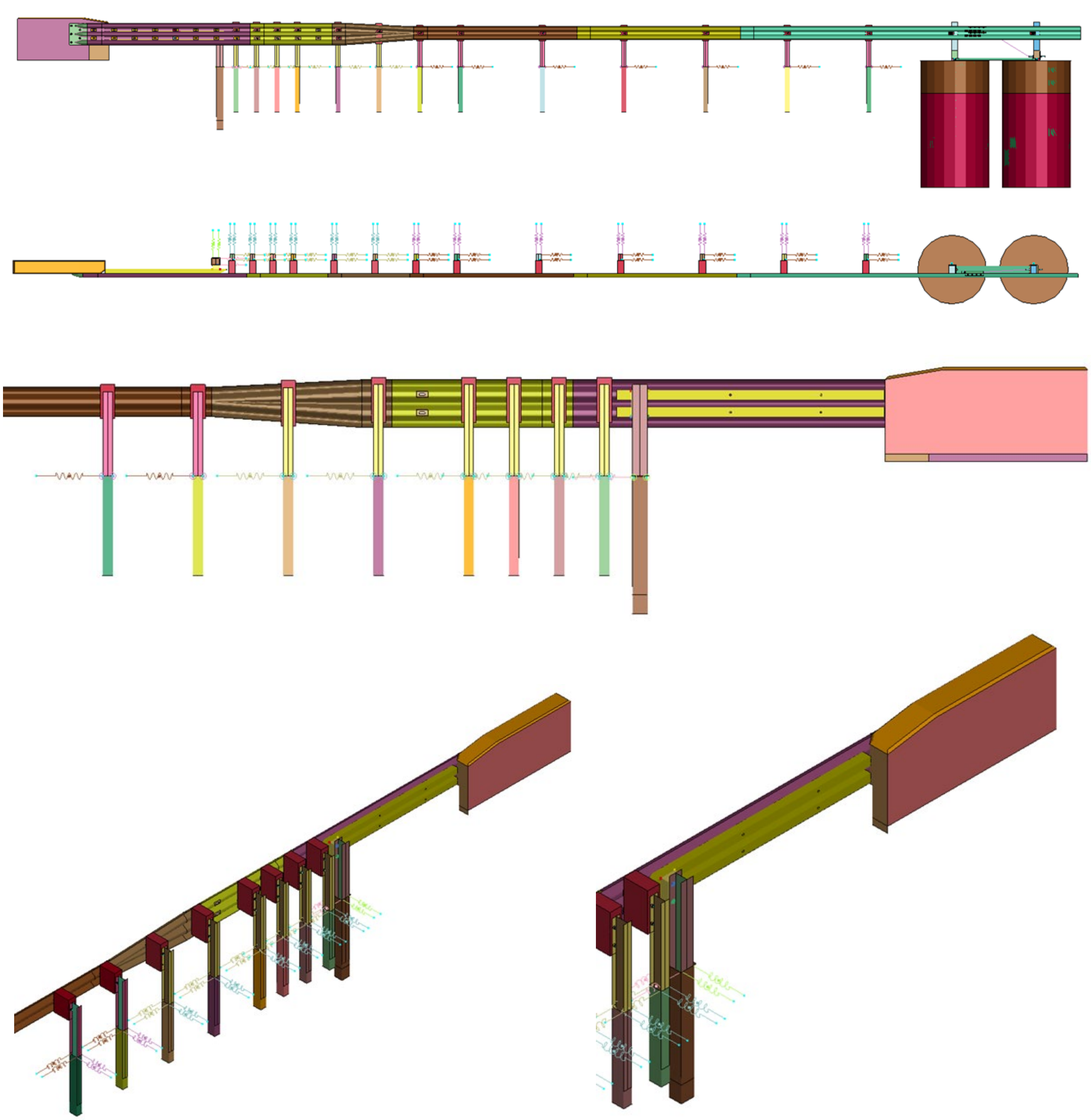


Figure 5.5 LS-DYNA Model of New Long-Span AGT System

The concrete buttresses were modeled using solid elements with a *MAT_RIGID material model. The modeled buttresses were fully constrained from displacements and rotations in the x, y, and z directions and therefore did not experience movement during simulations. Making the buttress models rigid was the worst-case scenario for vehicle snag. The buttresses and thrie-beam terminal connector were connected using modeled bolted connections. The bolts were modeled using fully integrated solid elements with a *MAT_PIECEWISE_LINEAR_PLASTICITY material formulation. The preload to bolts was determined through field testing and applied using *INITIAL_STRESS_SECTION at a cross section near the center of each bolt. The nuts and washers were simulated using fully integrated solid elements and were given a *MAT_RIGID material model.

5.3 Structural Design and Analysis of Selected Design Concept

As noted previously, the TAC members met with the research team to review long-span AGT concepts for the existing NDOT 34-in. thrie-beam AGT system. The committee selected Design Concept #5, a double-tube system, for further engineering analysis and development. The selection criteria included constructability, compatibility with the standard buttress, maintainability, and the likelihood of achieving MASH TL-3 impact safety performance. This section documents the selection basis, the structural demand estimation and member design, and the simulation-based evaluation that determined the final configuration.

The selected concept introduced a long-span AGT region at the concrete buttress. A parallel double-tube steel structure supported nested 34-in. thrie-beam rails. The buttress connection limited fixity to control end moments and shear, and the layout shifted plastic hinging away from the buttress face. The system geometry preserved the rail height and lateral offset required by NDOT.

Two performance criteria governed the horizontal beam design. First, the beam must resist vehicle impact loads. Second, it must transfer those loads efficiently to the anchors. To balance strength and weight, the selection focused on steel tubes and wide flange sections commonly used in roadside hardware. The design of the member was intentionally detailed to ensure it yielded in flexure. Controlled plastic bending absorbs a portion of the impact energy in the beam, which lowers the force delivered to the anchors and reduces the risk of pullout or damage to the concrete buttress.

Design calculations used standard expressions for plastic flexural capacity with a dynamic magnification factor. Steel members under impact can carry higher effective demand than under static loading. Based on prior MwRSF experience with anchored steel components under dynamic loading, a factor of 1.5 was applied to shear and flexure. This value increased demand to reflect impact effects while avoiding unnecessary weight and overdesign.

5.3.1 Demand Estimation

Lateral impact demand was modeled as a 70-kip line load over a 4-ft span [20], as shown in Figure 5.6. The equivalent uniform load on the rail line was 17.5 kip/ft. A dynamic magnification factor of 1.5 was applied to shear and flexure based on prior MwRSF crash datasets for similar rail components. Loads acted on the double tube line to represent transfer from the nested thrie-beam through the attachment hardware and blockouts.

An influence line method located the critical 4-ft load position relative to the concrete buttress and the first viable post. Two bounding support cases were analyzed to bound the response. The first case involved a propped cantilever, which had a fixed buttress end and an intermediate prop near the first viable post. The analysis also included a simple span between the buttress connection and the first viable post. These cases represent the practical range of end restraint and field tolerances at installation.

Factored maximum bending moments were 103 kip-ft for the propped cantilever case and 111.5 kip-ft for the simple span case. Factored maximum shears were 53 kips and 35 kips, respectively. These demands governed preliminary sizing of the tubes and the buttress connection. The double-tube arrangement reduced end moment by sharing the load between the two members and by allowing controlled rotation at the buttress interface. Candidate HSS sections per ASTM A500 are listed in Table 5.3.

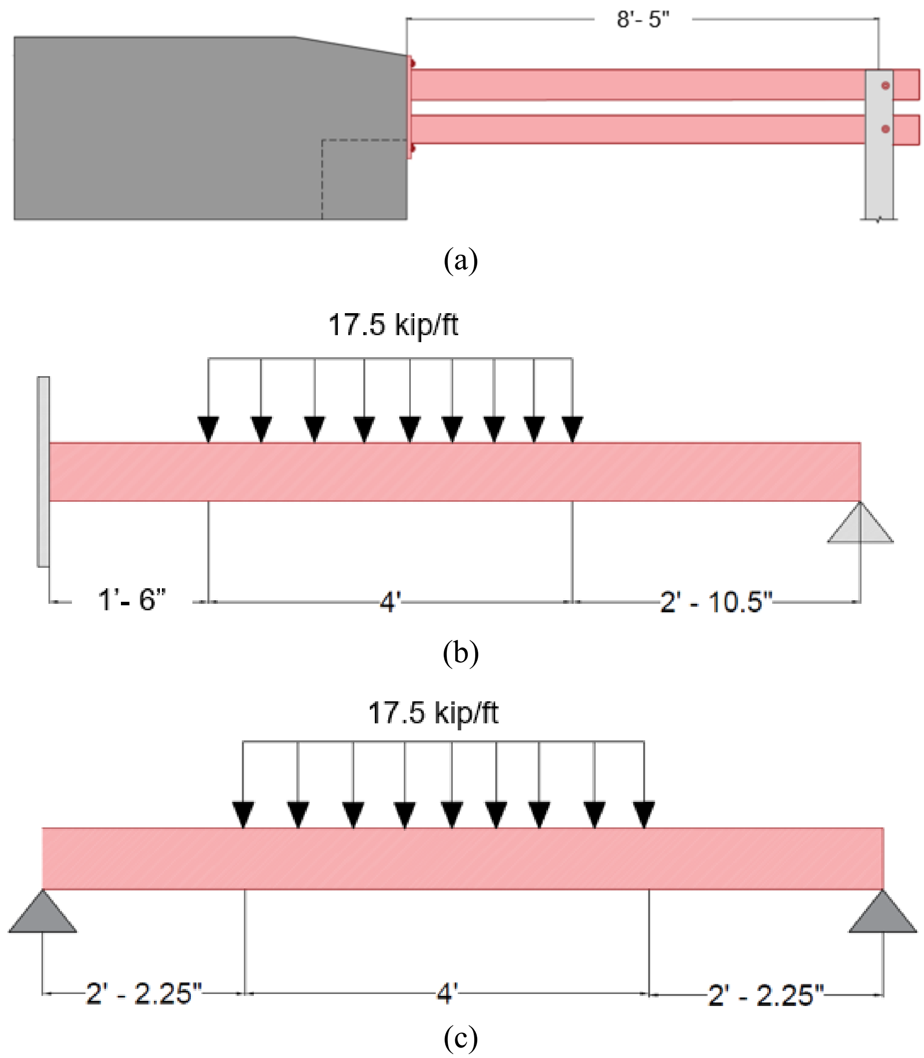


Figure 5.6 Double Tube System and Lateral Load Cases: (a) Double Tube Layout at the Buttress; (b) Lateral Line Load, 70 kips over 4 ft, Propped Cantilever Boundary Condition; and (c) Lateral Line Load, 70 kips over 4 ft, Simple Span Boundary Condition

Table 5.3 Section Properties of Candidate Square HSS for the Double Tube System

Section (in.)	Z_x (in.^{3})	Weight to Length Ratio (lb/ft)
HSS 4 x 4 x ¼	4.69	12.21
HSS 4 x 4 x ⅜	6.39	17.3
HSS 4 x 4 x ½	7.70	21.3
HSS 6 x 4 x ⅛	4.56	8.16

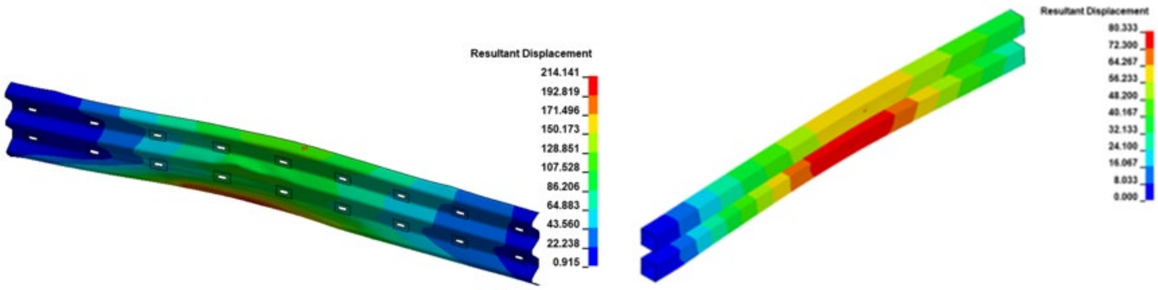
5.3.2 LS-DYNA Evaluation and Final selection

The baseline NDOT 34-in. tall thrie-beam AGT finite element model was validated against MASH TL-3 full-scale crash tests (Section 5.1). The near buttress support region was replaced with a double-tube long-span concept, while the upstream and downstream geometry and anchors remained unchanged. Vehicle models and impact conditions followed MASH test designation no. 3-21. Four tube options were evaluated under identical boundary conditions and attachments: HSS 4 in. x 4 in. x ¼ in., HSS 4 in. x 4 in. x ⅜ in., HSS 4 in. x 4 in. x ½ in., and HSS 6 in. x 4 in. x ⅛ in. Metrics tracked included OIV, ORA, roll, pitch, yaw, maximum dynamic rail deflection, tube plastic strain, and permanent set, as listed in Table 5.4.

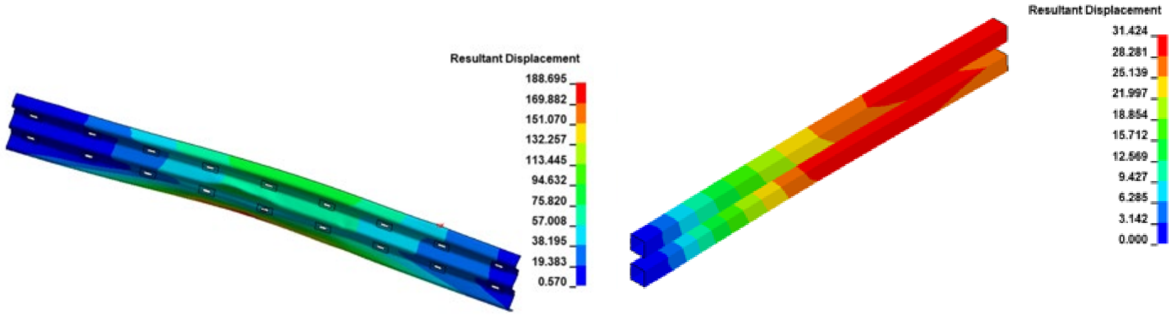
Thicker 4-in. x 4-in. walls reduced deflection but increased member weight and connection forces. The 6-in. x 4-in. x ⅛-in. section showed the largest deflection due to lower wall thickness and section modulus despite the larger depth. Plastic strain maps showed hinge formation away from the buttress interface. Vehicle kinematics remained stable without pocketing or snagging. Based on performance, handling weight, and connection demand, the research team selected the HSS 4-in. x 4-in. x ¼-in. double tube for development. The maximum dynamic deflection contours for all candidates are presented in Figure 5.7.

Table 5.4 LS-DYNA Summary for Long-Span AGT Variants

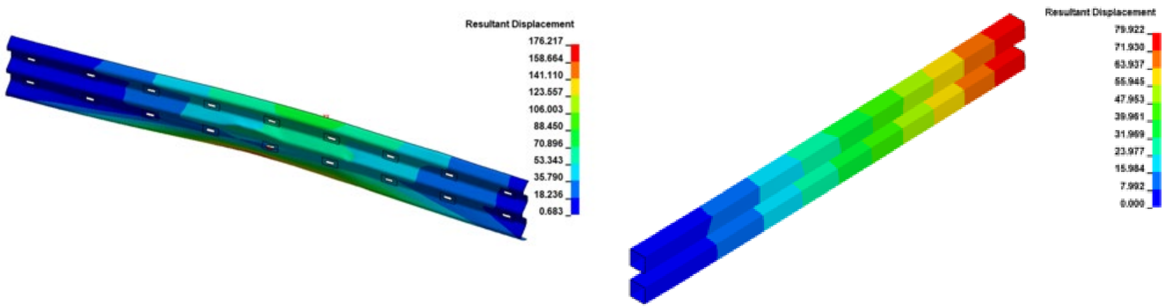
Evaluation Criteria		Tube Options for Long-Span AGT System				MASH Limits
		HSS 4 in. x 4 in. x ¼ in.	HSS 4 in. x 4 in. x 3/8 in.	HSS 4 in. x 4 in. x ½ in.	HSS 6 in. x 4 in. x 1/8 in.	
OIV (ft/s)	Longitudinal	24.3	23.1	24.6	24.2	±40
	Lateral	27.9	28.9	29.5	27.8	±40
ORA (g's)	Longitudinal	12.1	5.9	7.1	12.3	±20.49
	Lateral	10.2	11.0	11.4	10.2	±20.49
Max. Angular Displ. (Deg.)	Roll	10.4	6.3	6.4	10.5	±75
	Pitch	4.5	2.8	3.7	4.6	±75
	Yaw	41.5	34.1	35.2	41.6	N/A
Max. Dynamic Deflection (in.)		5.9	3.9	3.3	6.8	N/A



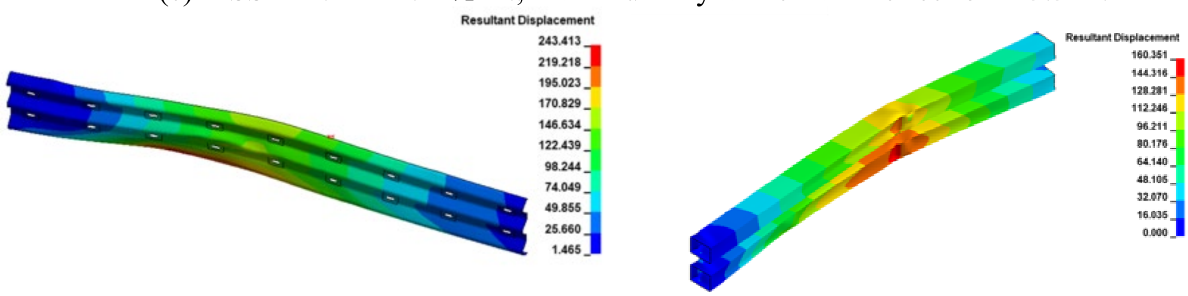
(a) HSS 4 in. x 4 in. x ¼ in., Maximum Dynamic Rail Deflection = 5.9 in.



(b) HSS 4 in. x 4 in. x 3/8 in., Maximum Dynamic Rail Deflection = 3.9 in.



(c) HSS 4 in. x 4 in. x ½ in., Maximum Dynamic Rail Deflection = 3.3 in.



(d) HSS 6 in. x 4 in. x 1/8 in., Maximum Dynamic Rail Deflection = 6.8 in.

Figure 5.7 Maximum Dynamic Rail Deflection Contours for the Candidate Tube Sections Under the Simulated MASH Test Designation No. 3-21 Impact: (a) HSS 4 in. x 4 in. x ¼ in.; (b) HSS 4 in. x 4 in. x 3/8 in.; (c) HSS 4 in. x 4 in. x ½ in.; (d) HSS 6 in. x 4 in. x $^{1}/_{8}$ in.

Chapter 6 LS-DYNA Simulation Results

6.1 Simulation of Design Concept #5

Design Concept #5 was evaluated according to MASH test designation nos. 3-21 (pickup truck) and 3-20 (small car) impacts. MASH test designation no. 3-21 was simulated with conventional impacts originating from the thrie-beam to the concrete buttress and reverse-direction impacts from the concrete buttress into the thrie-beam. Additional simulations placed pickup truck and small car impacts at multiple points upstream of the concrete buttress. These LS-DYNA computer simulations identified the critical impact point (CIP) for the long-span AGT system.

Several parameters were utilized to evaluate the feasibility of the concept:

1) General vehicle behavior and snag on any system components
2) Occupant risk – longitudinal and lateral OIV and ORA
3) Stresses in the double beam system as well as various components compared to yield and ultimate stresses
4) Other MASH metrics

6.1.1 Test Designation No. 3-21, Conventional Impact Direction

The study evaluated a thrie-beam to concrete buttress configuration under MASH test designation no. 3-21 at multiple impact points. Impact locations were measured in inches upstream of the concrete buttress, noted as US. The simulation matrix summarized the cases by simulation name and impact location, as shown in Table 6.1. Figure 6.1 illustrates how the impact points were measured relative to the buttress.

Table 6.1 Summary of Simulations, MASH Test Designation No. 3-21

Simulation Name	Impact Point
3-21_89US	89 in. US of Buttress
3-21_83US	83 in. US of Buttress
3-21_77US	77 in. US of Buttress
3-21_71US	71 in. US of Buttress
3-21_65US	65 in. US of Buttress
3-21_59US	59 in. US of Buttress
3-21_53US	53 in. US of Buttress
3-21_47US	47 in. US of Buttress

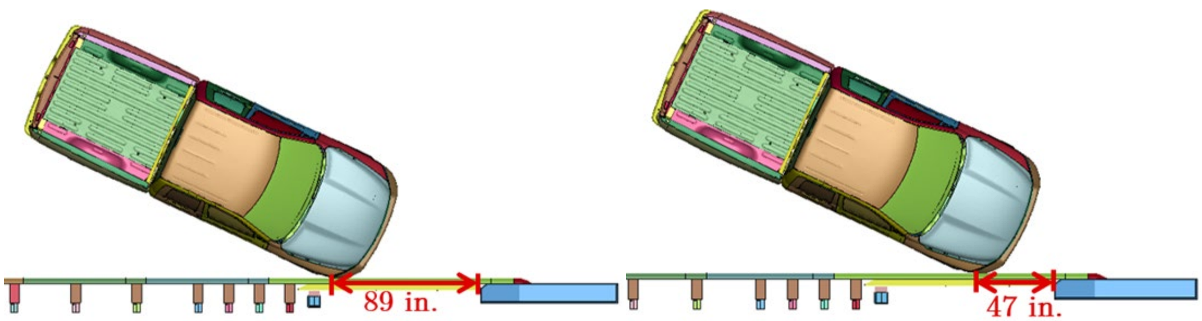


Figure 6.1 Impact Points for MASH Test Designation No. 3-21 Simulations, Conventional Impact Direction

Occupant risk values for each simulation are listed in Table 6.2, and Figure 6.2 through Figure 6.9 show the vehicle and system behavior for each simulation. The vehicle was smoothly redirected in all simulations. All occupant risk values were below MASH thresholds. Large maximum angular displacements and higher dynamic deflections were recorded for the simulation with impact 89 in. upstream from the concrete buttress, leading to that location being selected as the CIP to maximize the potential for wheel snag on the concrete buttress. It should be noted that the CIP for test no. 34AGT-1 was also located 89 in. upstream from the concrete buttress [2], meaning the impact performance of the long-span AGT system was comparable to the base AGT system crash test conducted in test no. 34AGT-1.

Table 6.2 Summary of Simulation Results, MASH Test Designation No. 3-21

Evaluation Criteria		**Impact Point Location Upstream from Buttress**							**MASH Limits**
		89 in.	**83 in.**	**77 in.**	**71 in.**	**65 in.**	**53 in.**	**47 in.**	
OIV (ft/s)	Long.	25.00	26.34	25.49	25.49	27.99	27.75	27.34	±40
	Lat.	27.29	28.67	29.34	29.34	29.31	29.99	28.52	±40
ORA (g’s)	Long.	11.97	12.53	9.82	9.82	5.97	4.00	3.83	±20.49
	Lat.	9.40	9.05	11.09	11.09	10.40	10.10	10.44	±20.49
Max. Angular Displacement (Deg.)	Roll	12.1	7.9	7.3	7.3	4.6	2.2	3.5	±75
	Pitch	4.4	4.5	3.3	3.3	5.1	5.1	2.8	±75
	Yaw	45.1	41.0	37.8	37.8	38.3	36.3	32.8	N/A
Max. Dynamic Deflection (in.)		6.9	6.8	6.3	5.5	4.6	3.4	2.6	N/A

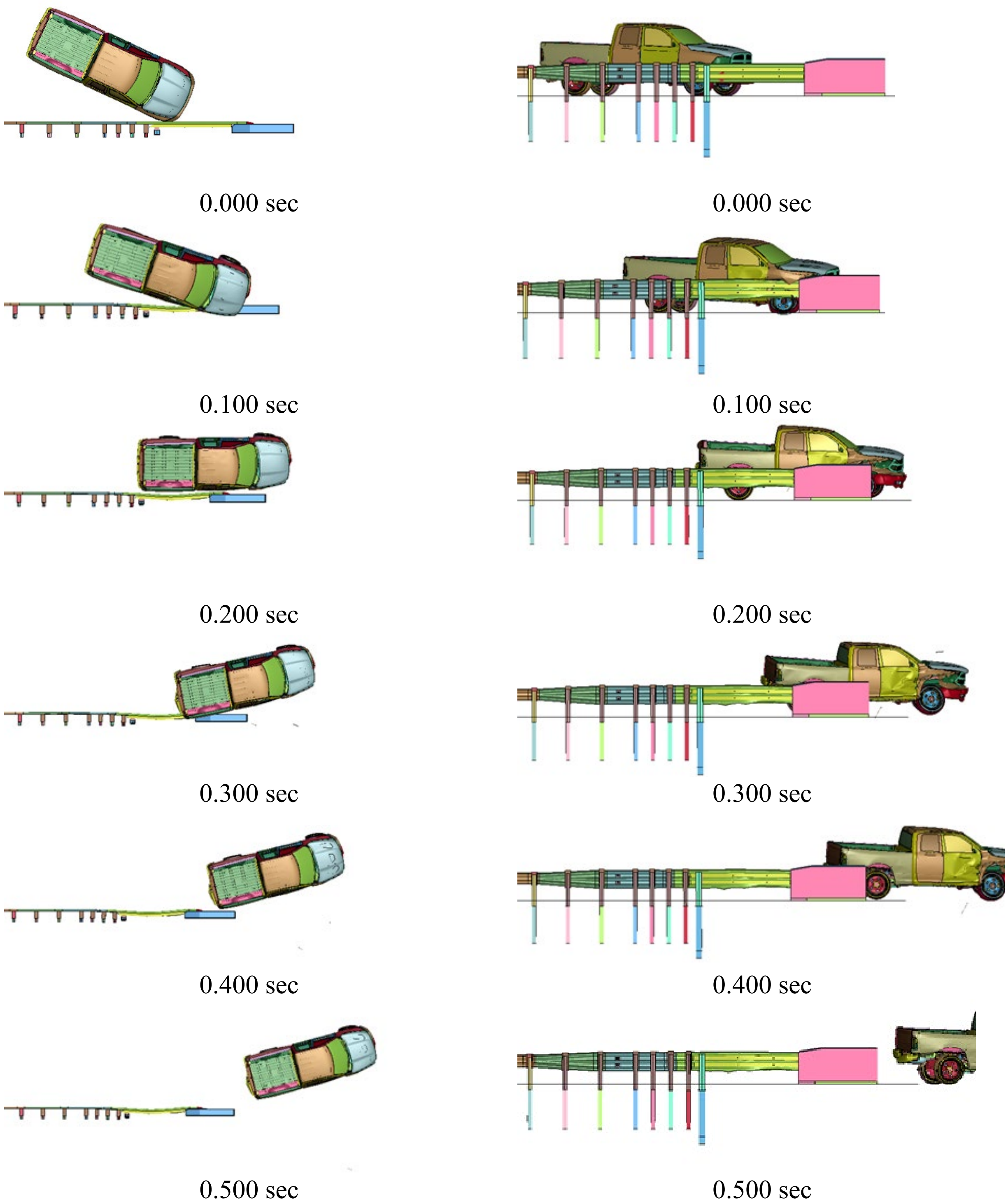


Figure 6.2 Sequential Images, 2270P Conventional Impact Direction (MASH Test Designation No. 3-21), Impact Point at 89 in. US from Buttress

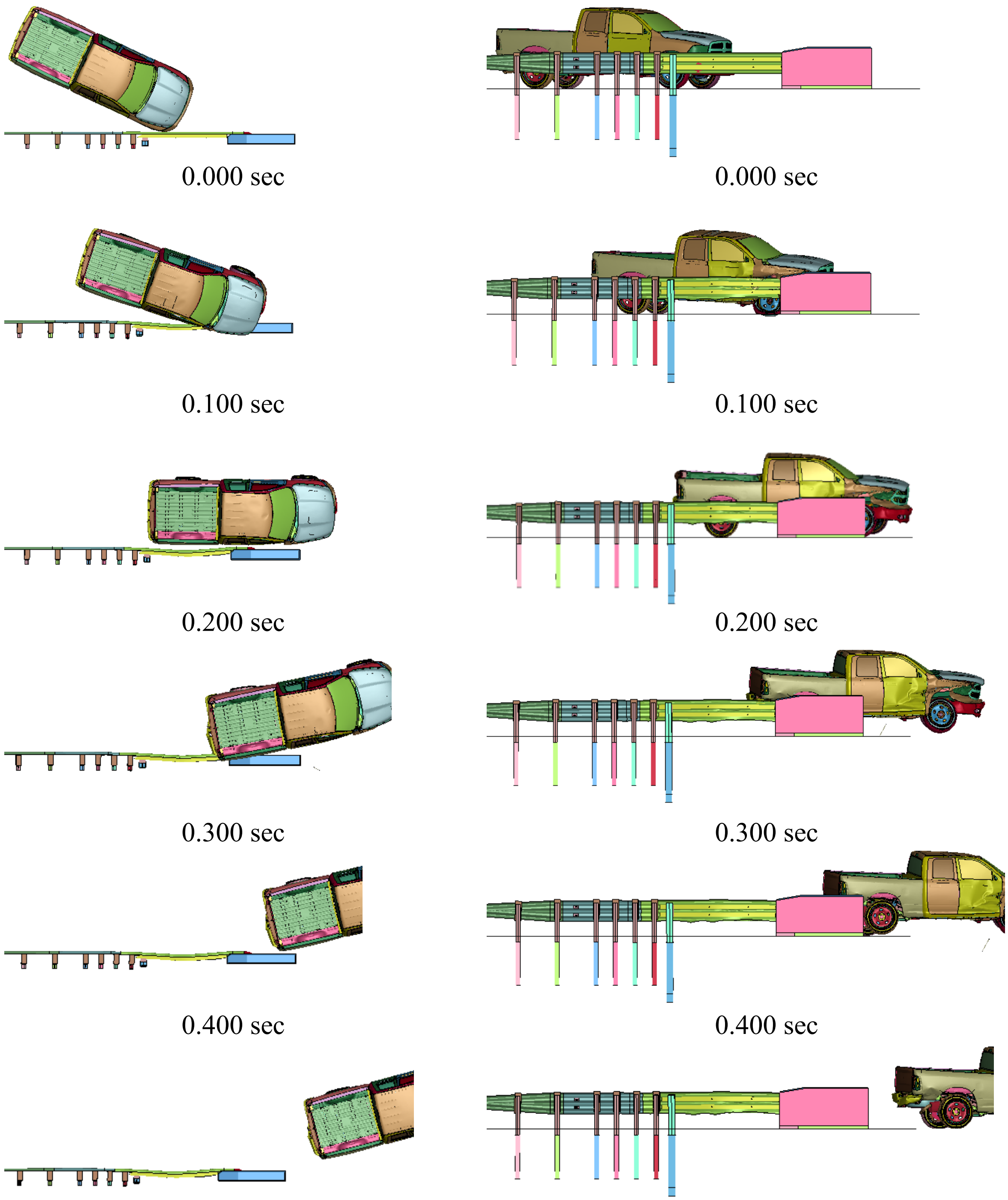


Figure 6.3 Sequential Images, 2270P Conventional Impact Direction (MASH Test Designation No. 3-21), Impact Point at 83 in. US from Buttress

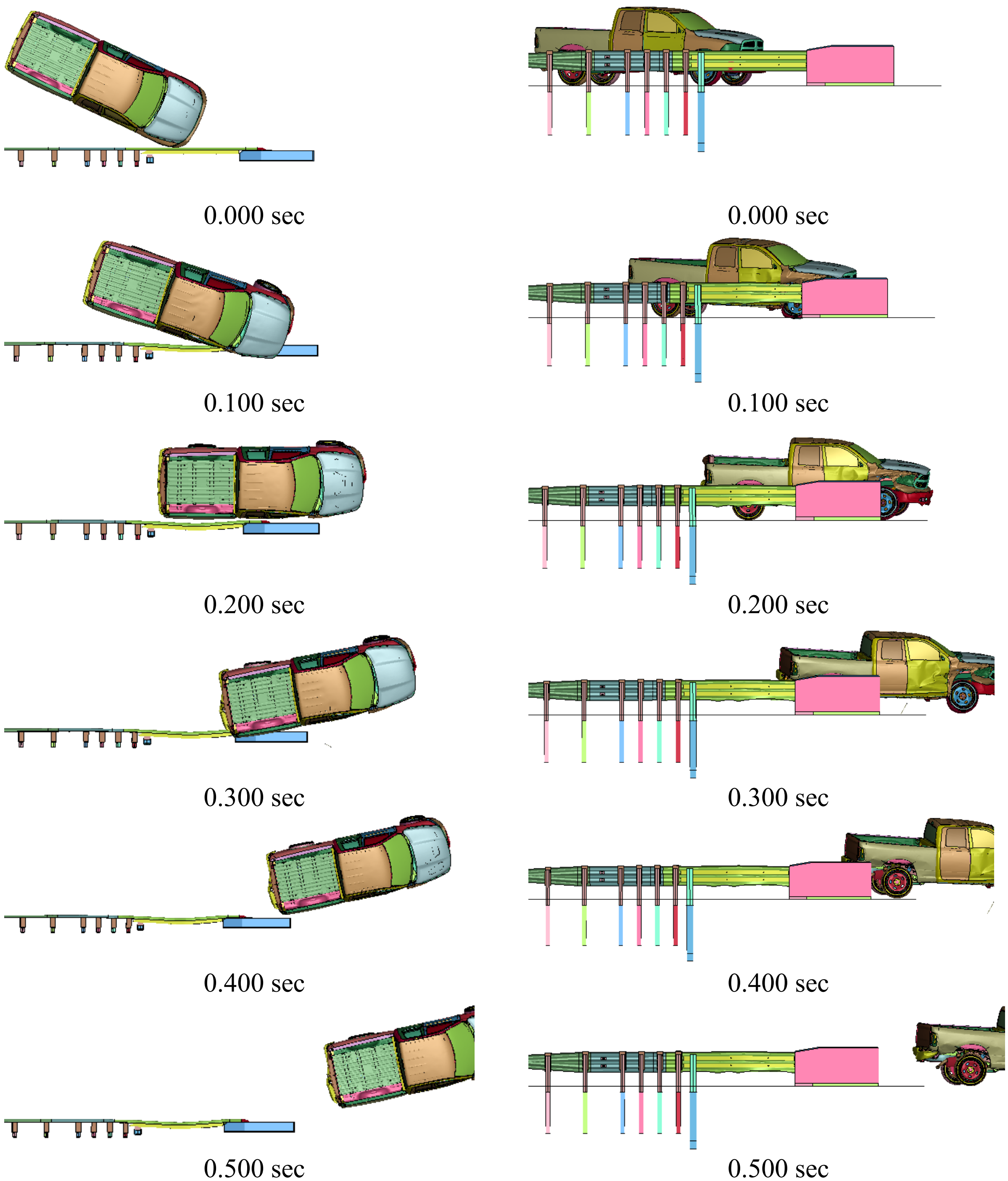


Figure 6.4 Sequential Images, 2270P Conventional Impact Direction (MASH Test Designation No. 3-21), Impact Point at 77 in. US from Buttress

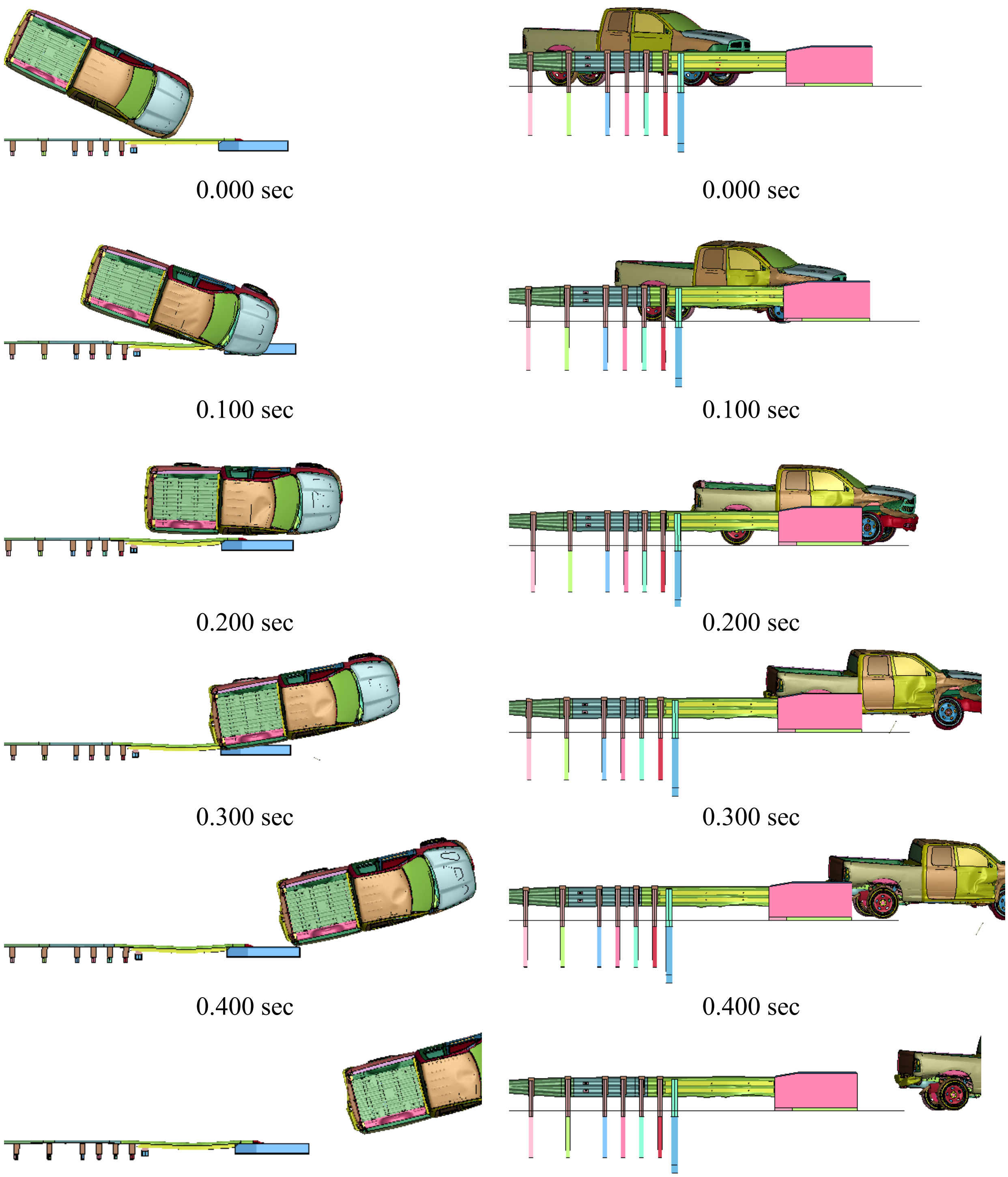


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Figure 6.5 Sequential Images, 2270P Conventional Impact Direction (MASH Test Designation No.3-21), Impact Point at 71 in. US from Buttress

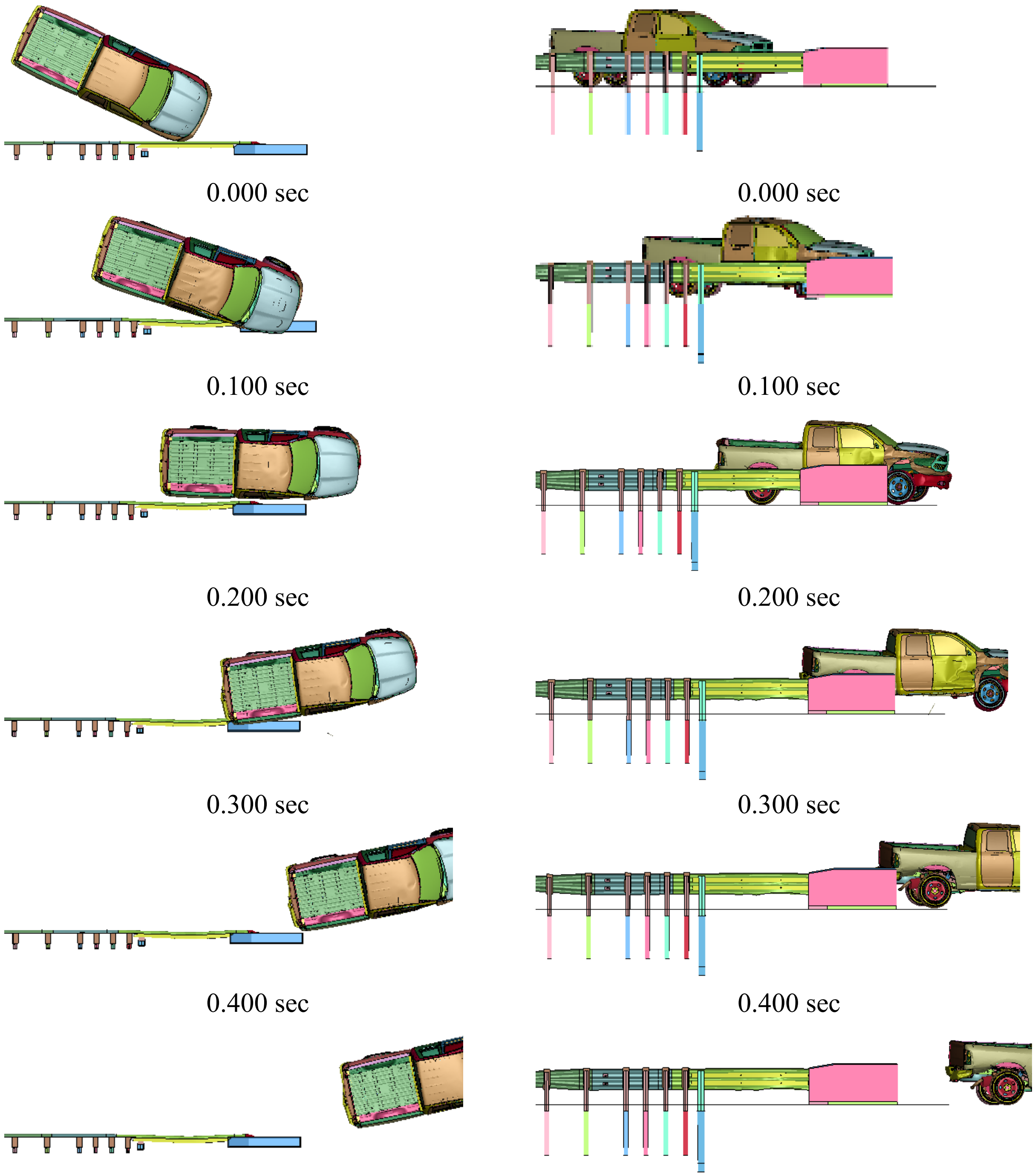


Figure 6.6 Sequential Images, 2270P Conventional Impact Direction (MASH Test Designation No. 3-21), Impact Point at 65 in. US from Buttress

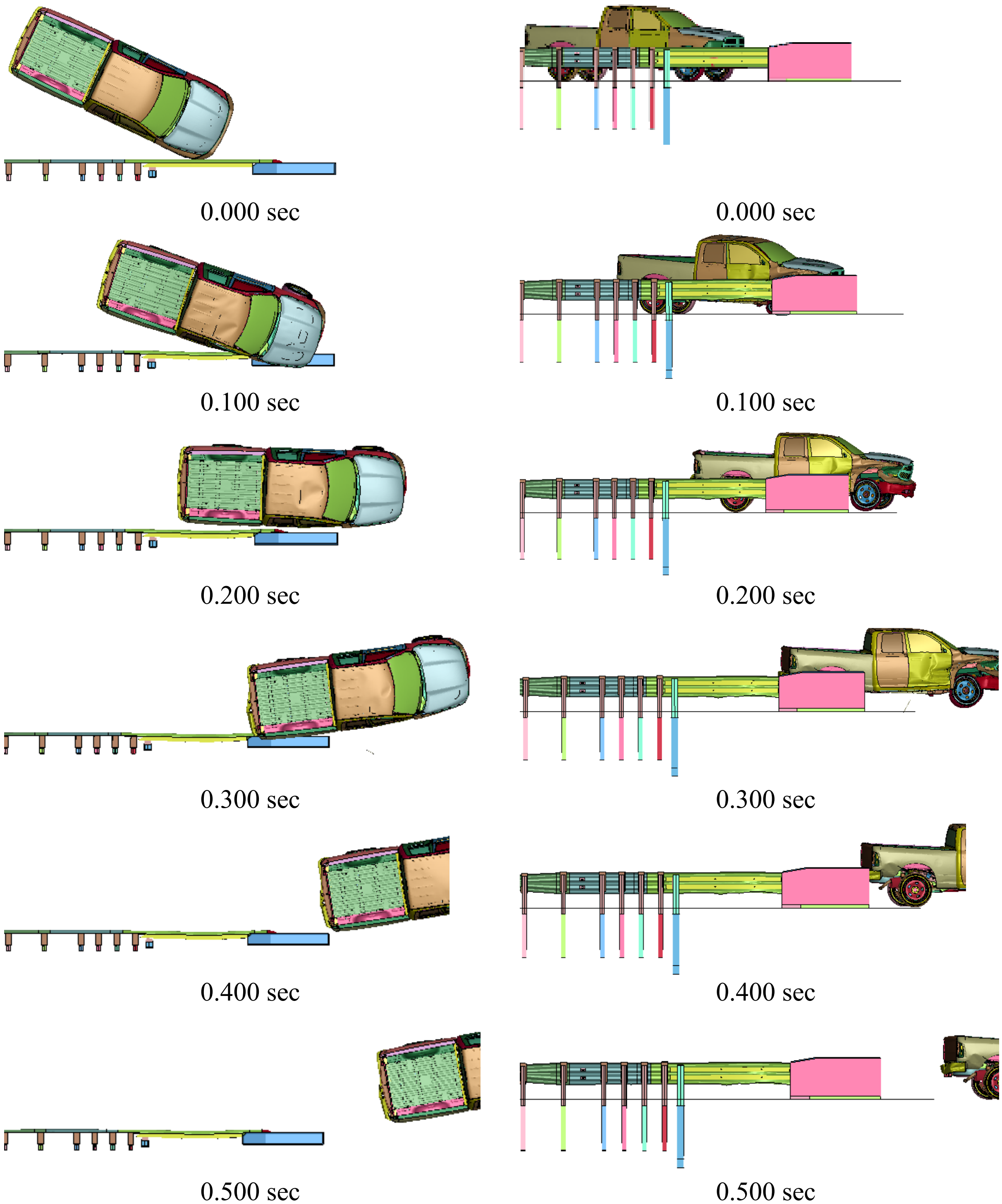


Figure 6.7 Sequential Images, 2270P Conventional Impact Direction (MASH Test Designation No. 3-21), Impact Point at 59 in. US from Buttress

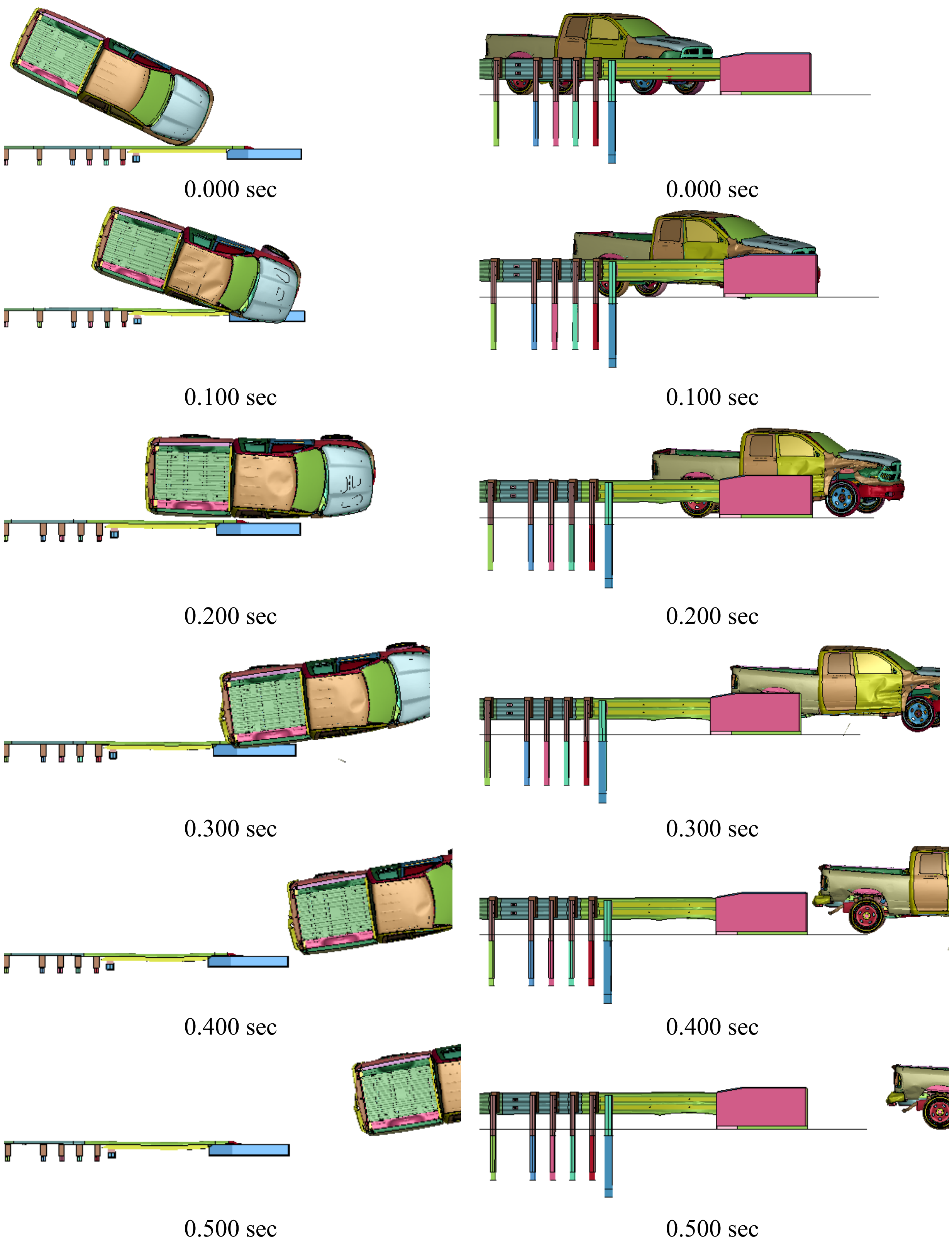


Figure 6.8 Sequential Images, 2270P Conventional Impact Direction (MASH Test Designation No. 3-21), Impact Point at 53 in. US from Buttress

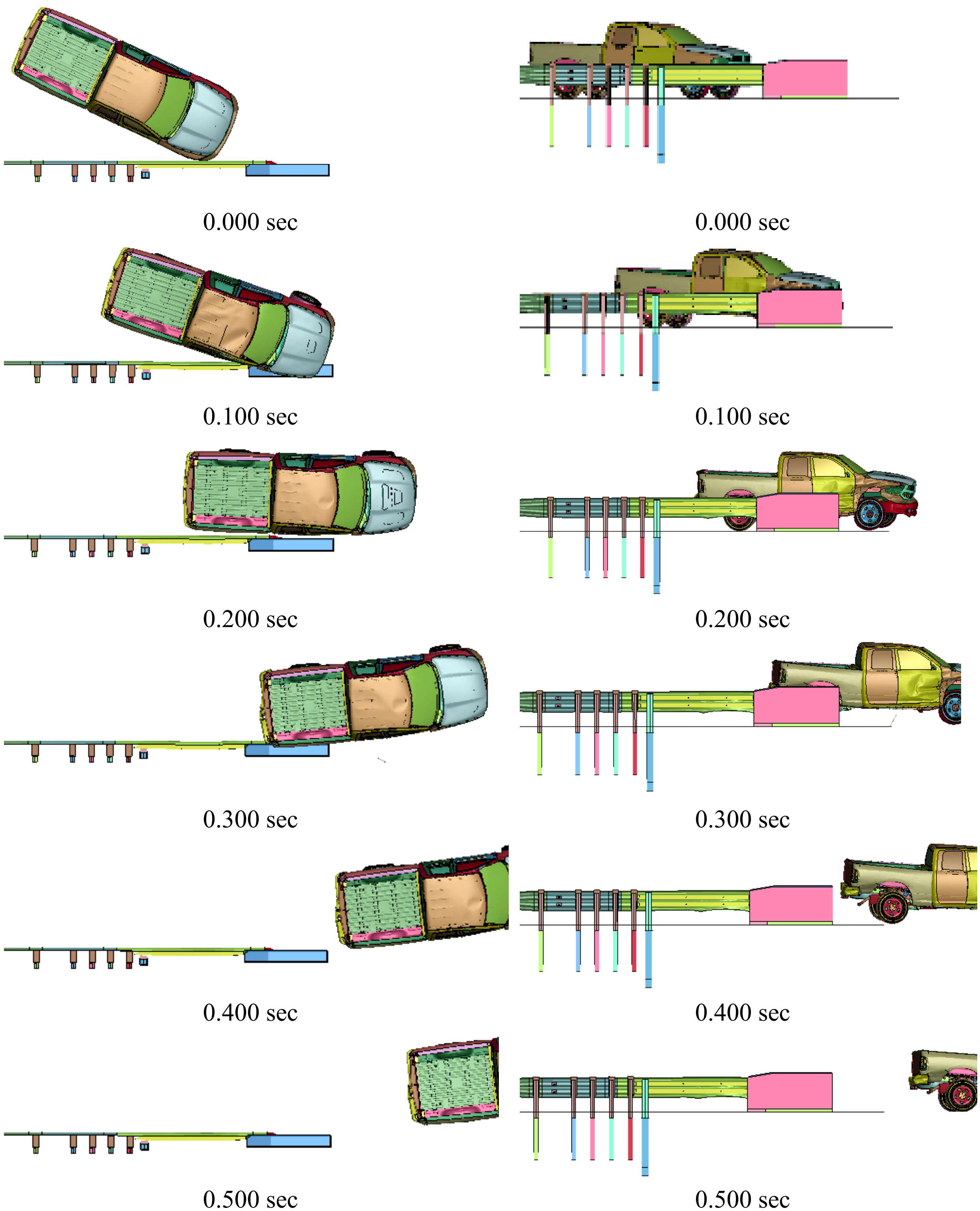


Figure 6.9 Sequential Images, 2270P Conventional Impact Direction (MASH Test Designation No. 3-21), Impact Point at 47 in. US from Buttress

6.1.2 Test Designation No. 3-21, Upstream Impact

The study defined the simulation matrix for MASH test designation no. 3-21. Simulations were run upstream of the concrete buttress at multiple impact points. Impact locations were measured in inches upstream, noted as US. Table 6.3 summarizes the cases by simulation name and impact location. Figure 6.10 shows how the impact points were measured.

Table 6.3 Summary of Upstream Impact Simulations on Concept #5, MASH Test Designation No. 3-21

Simulation Name	Impact Point
3-21_P1	Post No. 1
3-21_P2	Post No. 2
3-21_P3	Post No. 3
3-21_P4	Post No. 4
3-21_P5	Post No. 5
3-21_P6	Post No. 6
3-21_P7	Post No. 7

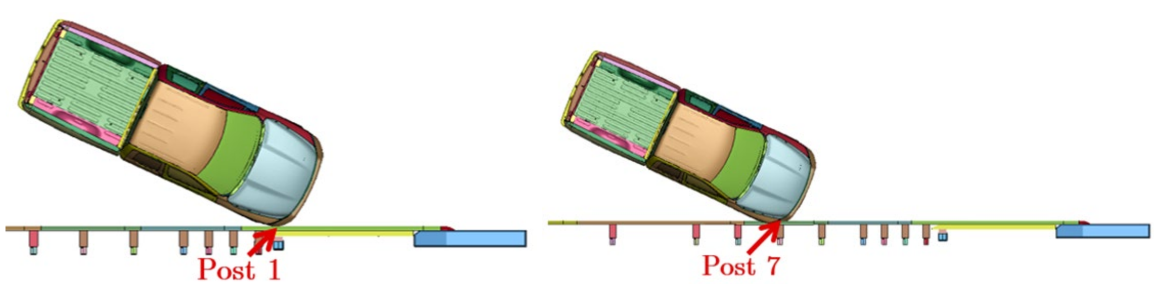


Figure 6.10 Upstream Impact Locations for MASH Test Designation No. 3-21 Simulations

Table 6.4 lists occupant risk values for all simulations. Figure 6.11 through Figure 6.17 show vehicle and system behavior. Every simulation produced smooth vehicle redirection. All occupant risk values were below MASH thresholds. The simulation showed no indication of significant pocketing or snag.

Table 6.4 Summary of Simulation Results, MASH Test Designation No. 3-21

Evaluation Criteria		**Impact Point Location**							**MASH Limits**
		Post 1	**Post 2**	**Post 3**	**Post 4**	**Post 5**	**Post 6**	**Post 7**	
OIV (ft/s)	Long.	24.39	21.77	21.12	21.83	21.31	26.63	22.61	±40
	Lat.	27.66	26.66	26.73	26.31	26.31	24.00	23.79	±40
ORA (g's)	Long.	9.62	7.08	6.61	5.03	5.03	16.97	14.86	±20.49
	Lat.	9.29	9.57	10.77	10.10	10.10	9.04	7.14	±20.49
Max. Angular Displacement (Deg.)	Roll	5.9	6.0	6.3	7.0	7.0	3.5	4.6	±75
	Pitch	2.6	2.1	1.8	2.7	2.7	4.6	3.4	±75
	Yaw	42.5	42.6	38.7	39.3	39.3	43.0	38.3	N/A
Max. Dynamic Deflection (in.)		7.1	7.6	8.3	8.8	9.2	11.7	12.8	N/A

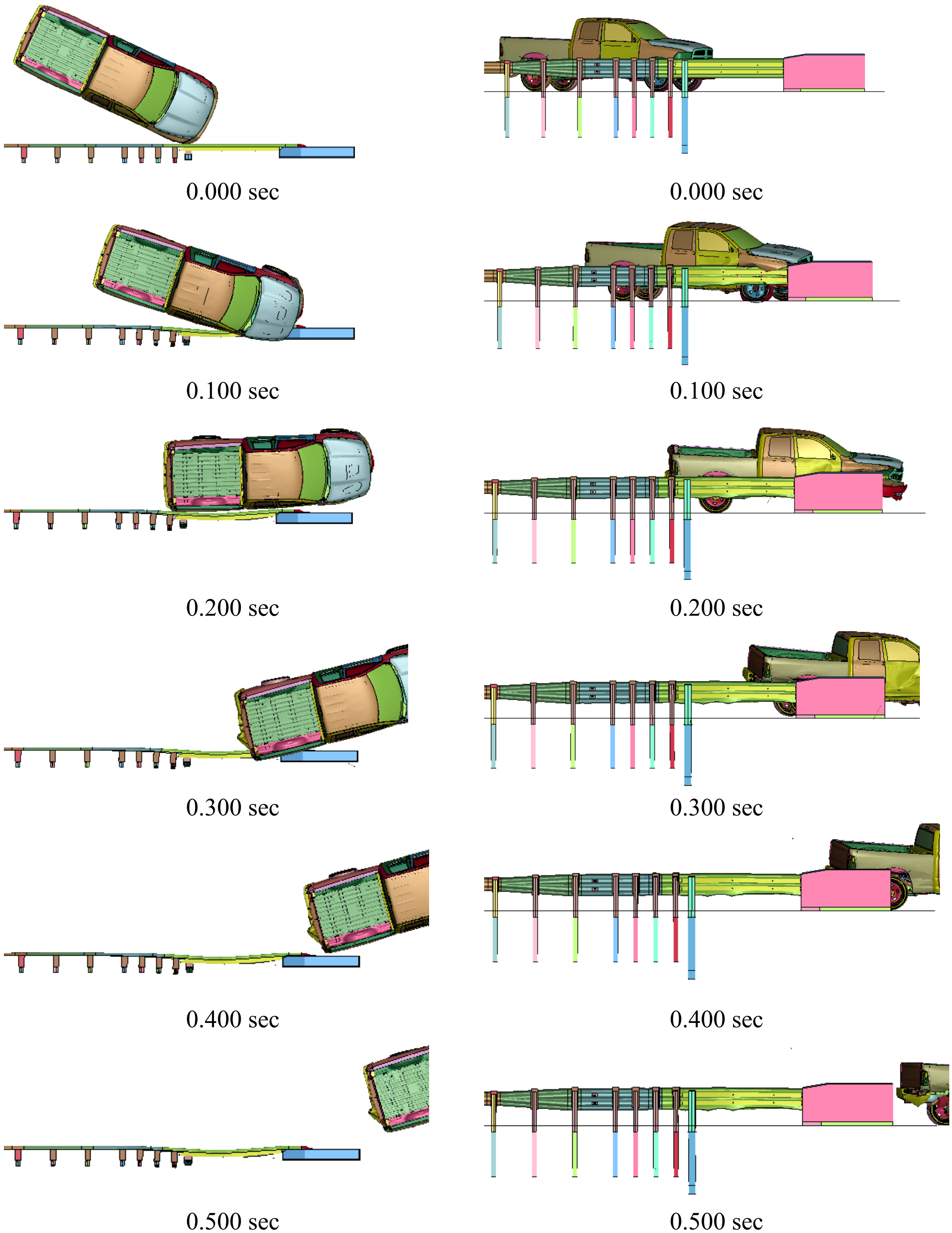


Figure 6.11 Sequential Images, 2270P Conventional Impact Direction (MASH Test Designation No. 3-21), Impact Point at Post No.1

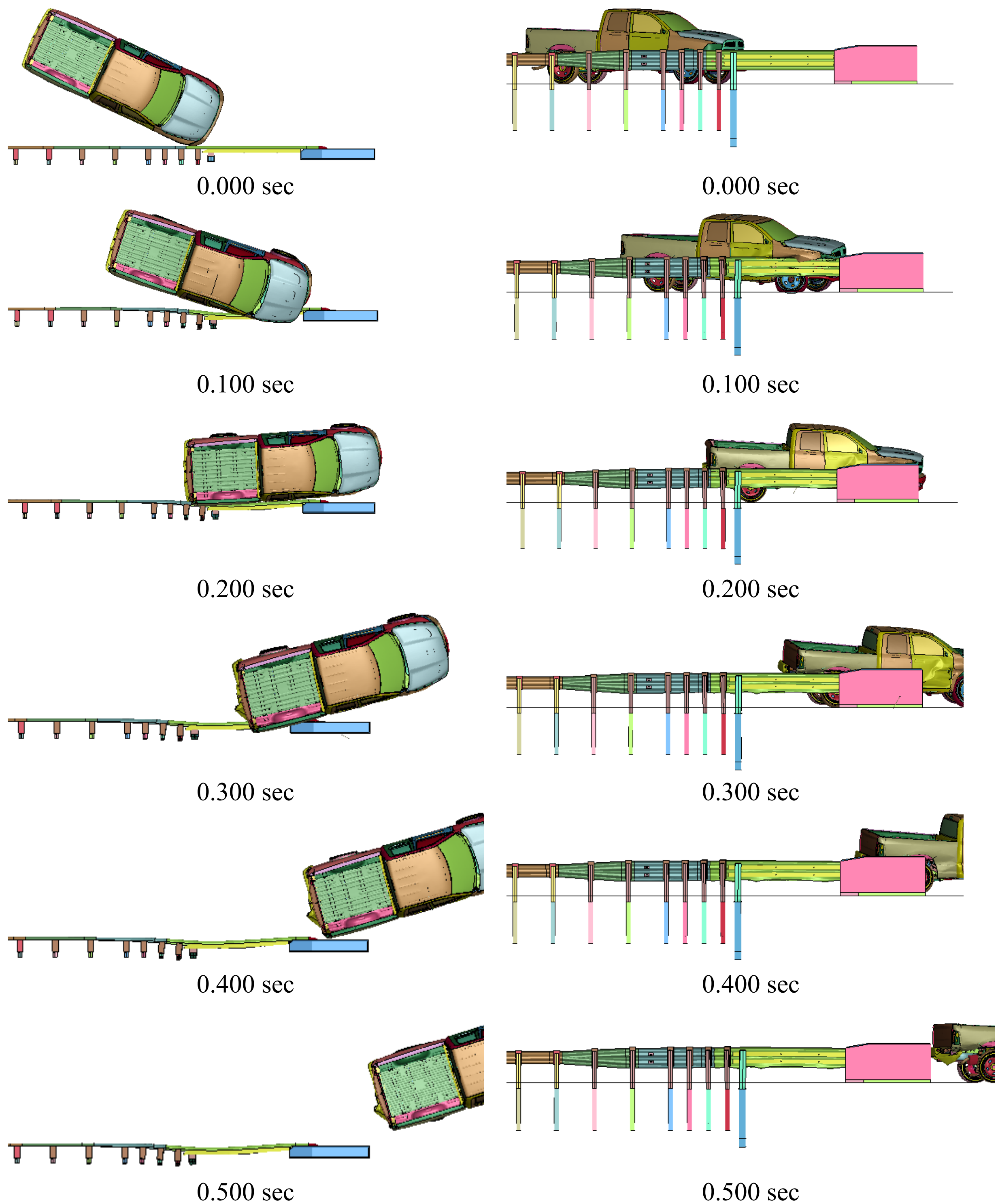


Figure 6.12 Sequential Images, 2270P Conventional Impact Direction (MASH Test Designation No. 3-21), Impact Point at Post No. 2

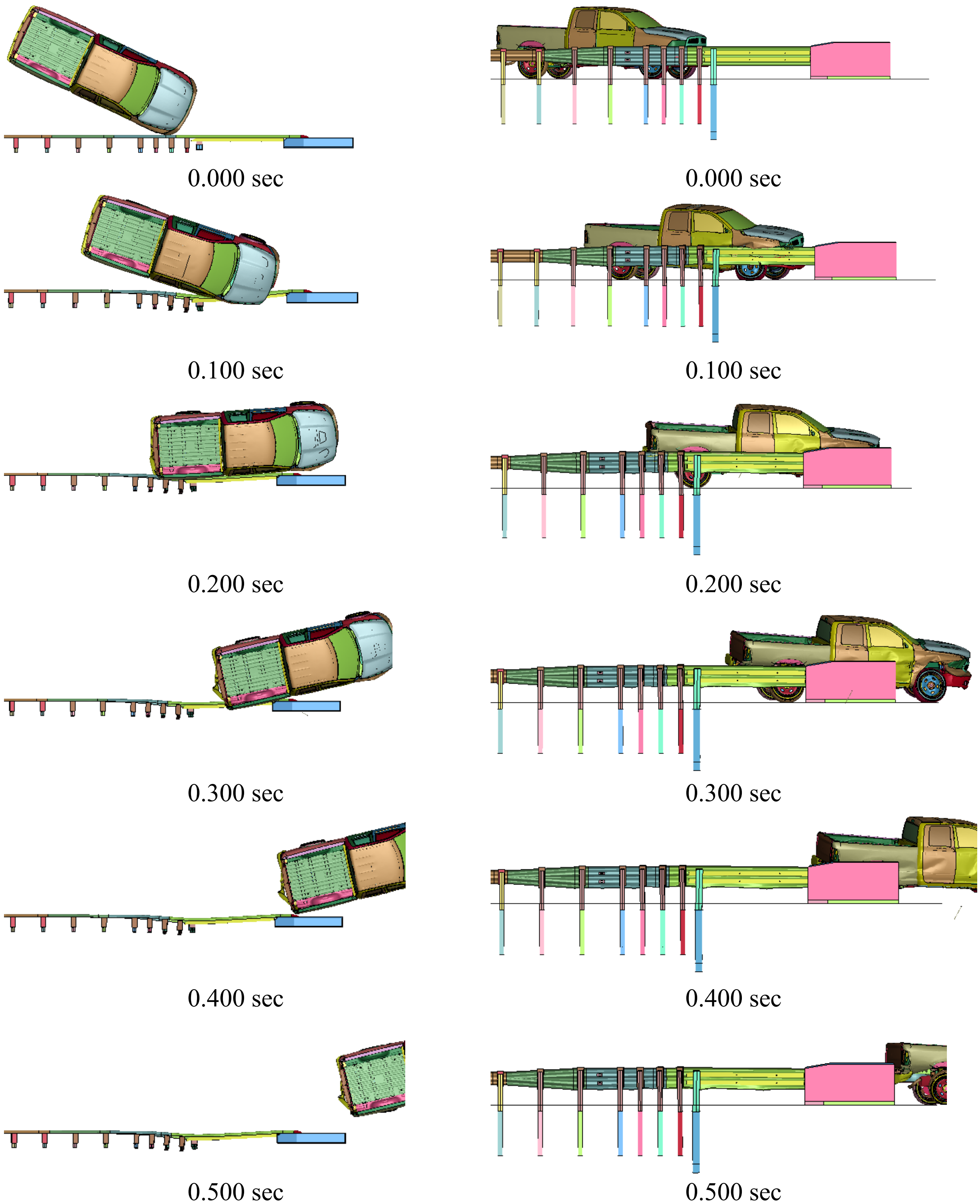


Figure 6.13 Sequential Images, 2270P Conventional Impact Direction (MASH Test Designation No. 3-21), Impact Point at Post No. 3

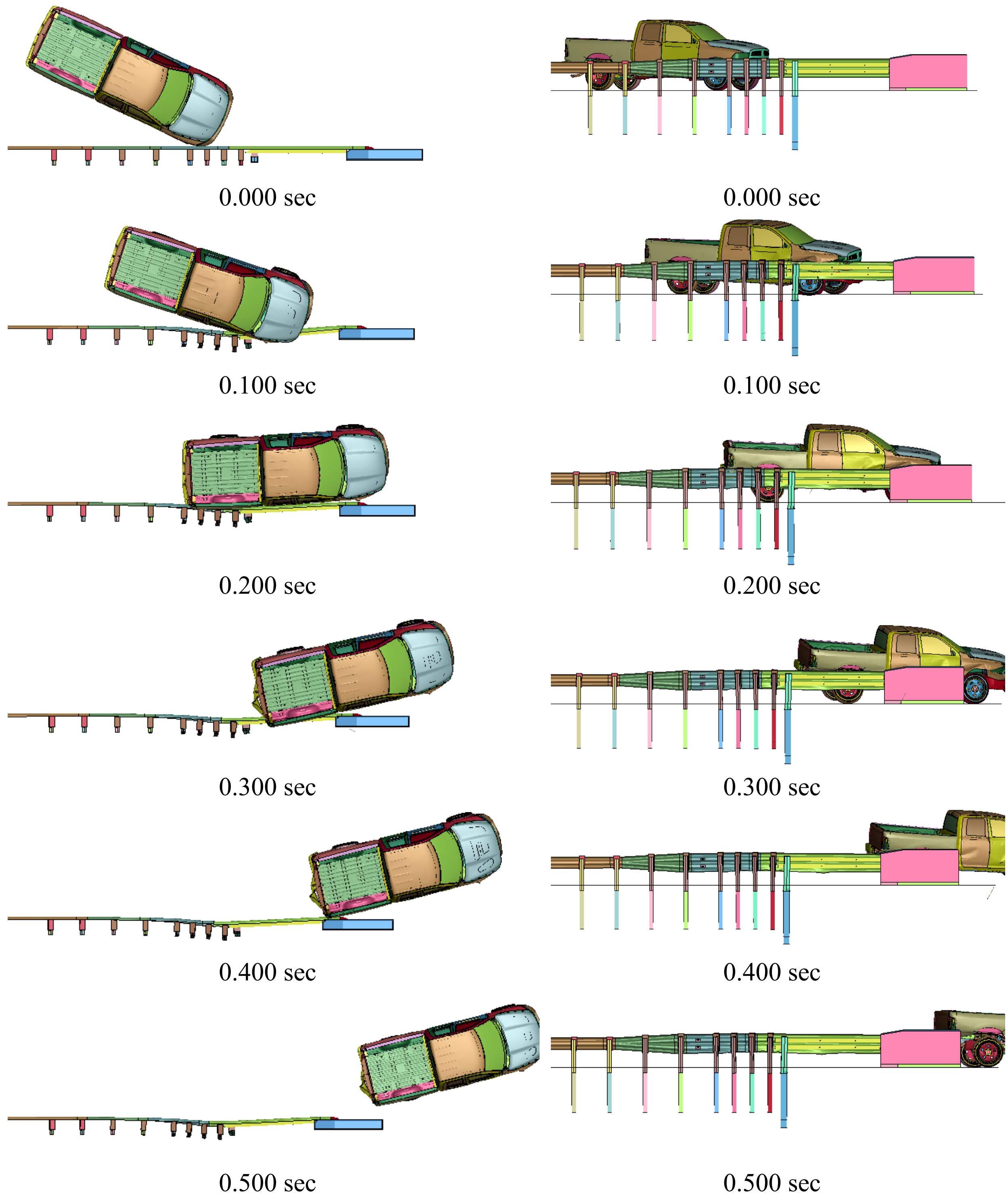


Figure 6.14 Sequential Images, 2270P Conventional Impact Direction (MASH Test Designation No. 3-21), Impact Point at Post No. 4

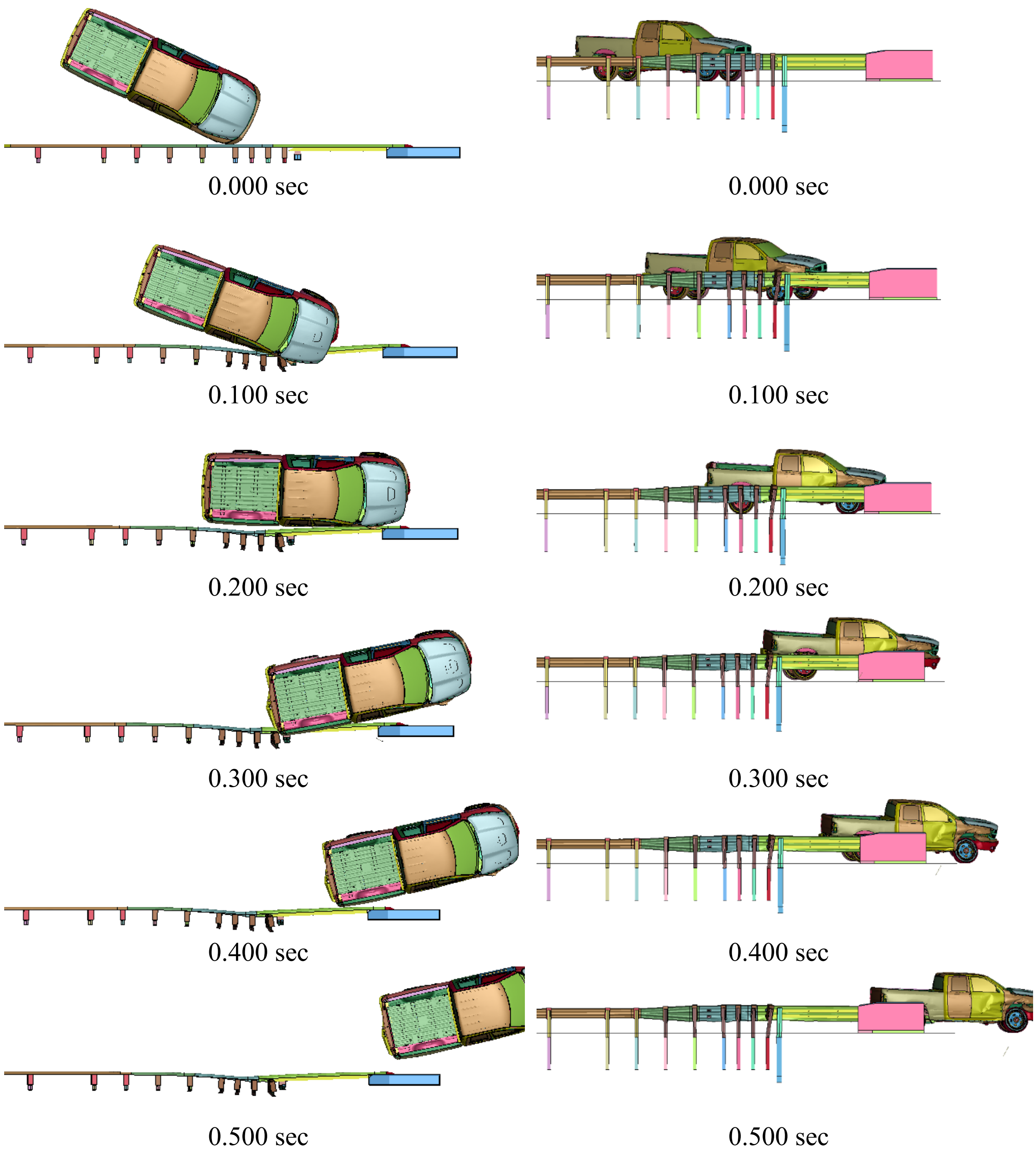


Figure 6.15 Sequential Images, 2270P Conventional Impact Direction (MASH Test Designation No. 3-21), Impact Point at Post No. 5

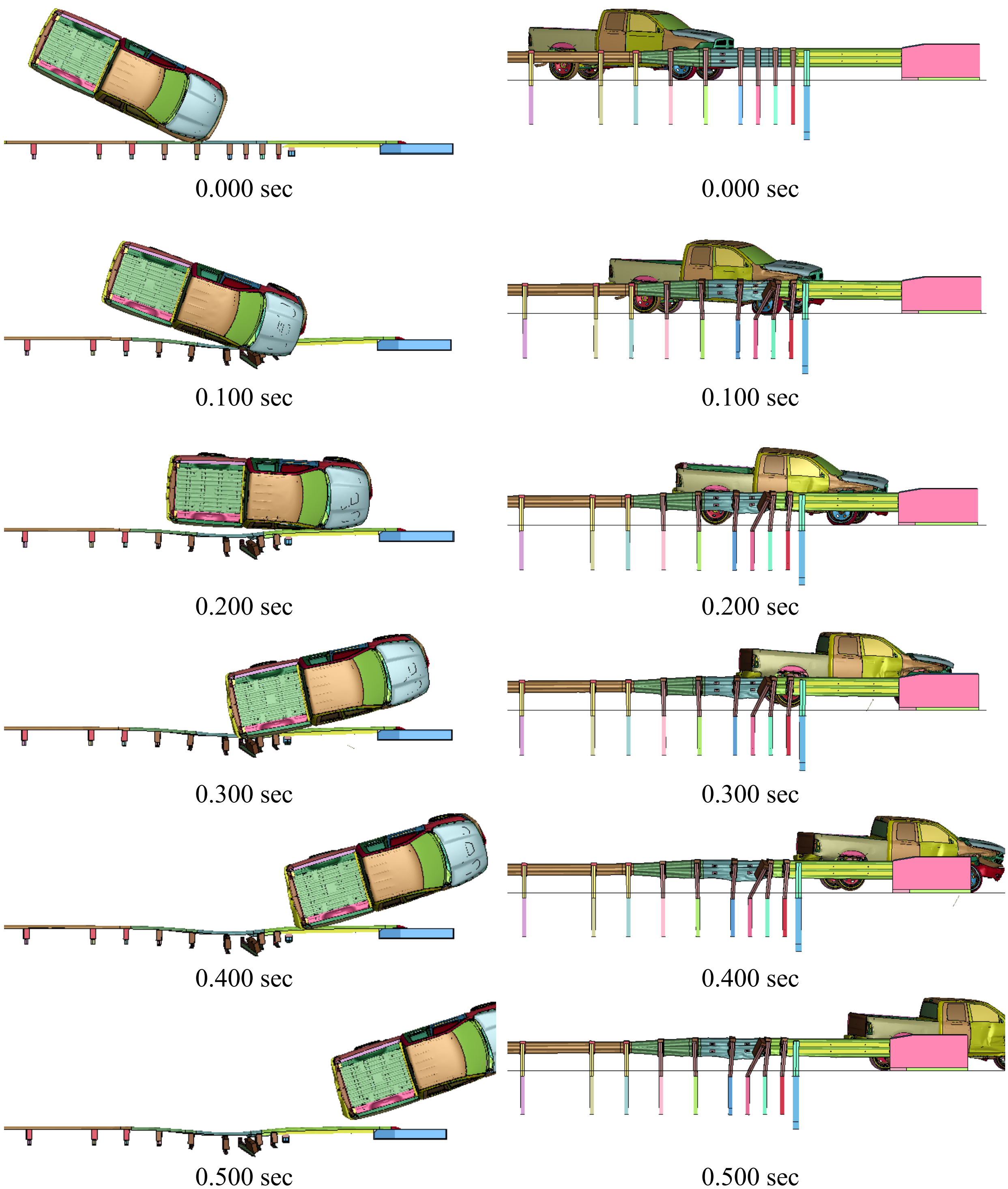


Figure 6.16 Sequential Images, 2270P Conventional Impact Direction (MASH Test Designation No. 3-21), Impact Point at Post No. 6

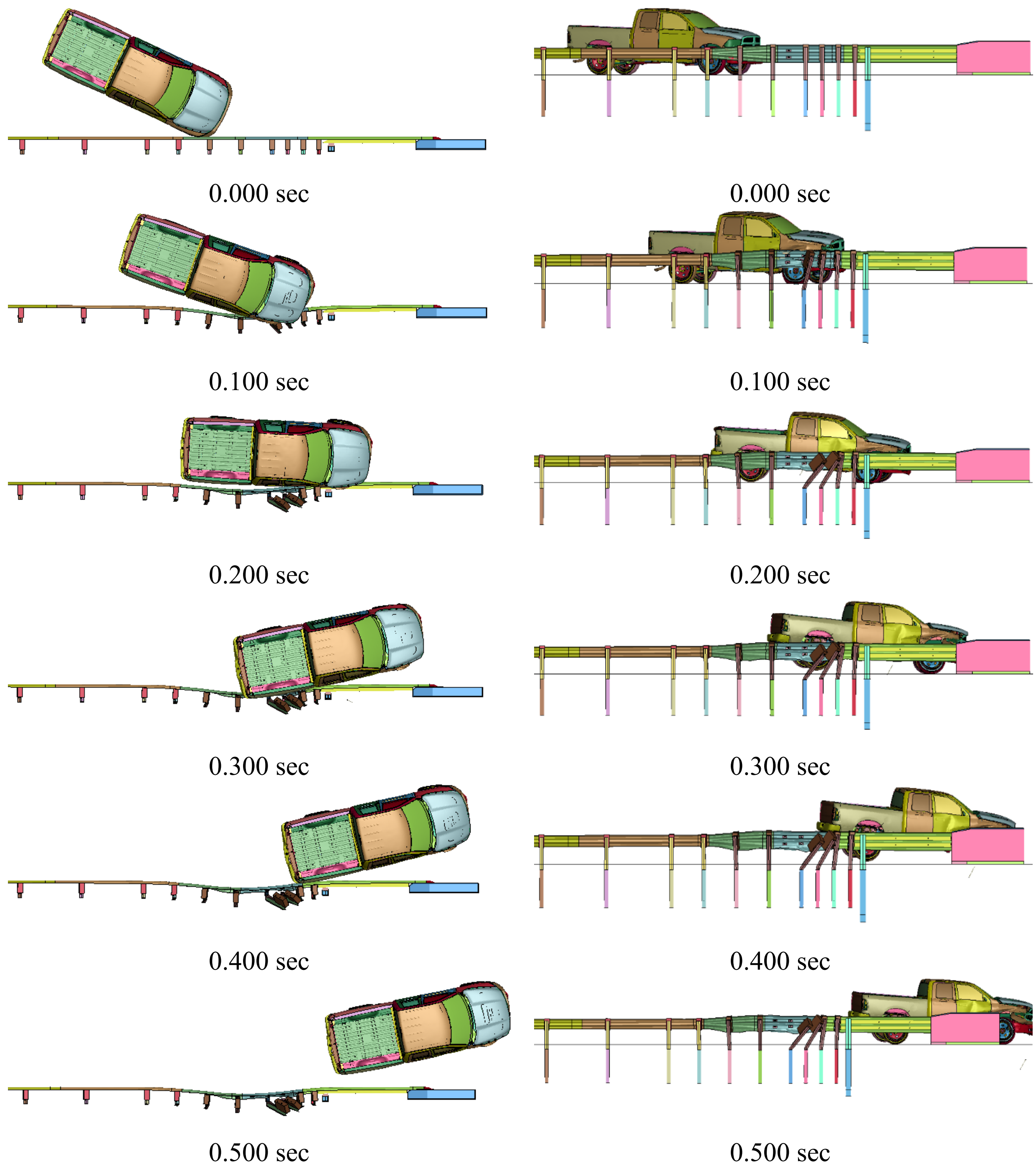


Figure 6.17 Sequential Images, 2270P Conventional Impact Direction (MASH Test Designation No. 3-21), Impact Point at Post No. 7

6.1.3 Test Designation No. 3-21, Reverse Impact Direction

The study examined the reverse direction, from the concrete buttress to the thrie beam transition, under MASH test designation no. 3-21. Simulations covered multiple impact points measured in inches upstream of the buttress, noted as US. The simulation matrix summarized each case by simulation name and impact location. Table 6.5 provides the matrix. Figure 6.18 shows the impact point measurements.

Table 6.5 Summary of Simulations, MASH Test Designation No. 3-21 (Reverse Direction)

Simulation Name	Impact Point
3-21_REV_12US	12 in. US of Buttress
3-21_REV_24US	24 in. US of Buttress
3-21_REV_36US	36 in. US of Buttress
3-21_REV_48US	48 in. US of Buttress
3-21_REV_60US	60 in. US of Buttress
3-21_REV_72US	72 in. US of Buttress
3-21_REV_84US	84 in. US of Buttress
3-21_REV_96US	96 in. US of Buttress
3-21_REV_108US	108 in. US of Buttress

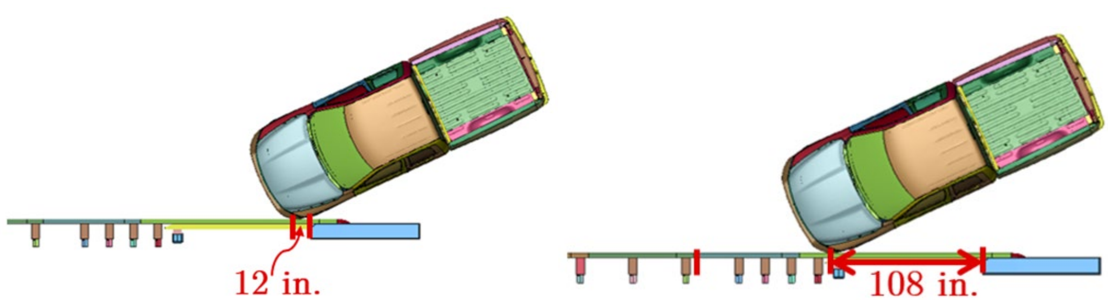


Figure 6.18 Impact Points for MASH Test Designation No. 3-21 Simulation, Reverse Direction

Occupant risk values for each simulation are shown in Table 6.6. General vehicle and system behavior for each simulation is shown in Figure 6.19 through Figure 6.27. The vehicle was smoothly redirected in all simulations. All occupant risk values were below MASH thresholds. The simulation showed no indication of significant pocketing or snag.

Table 6.6 Summary of Simulation Results, Test Designation No. 3-21, Reverse-Direction

Evaluation Criteria		Impact Point Location US from Buttress									MASH Limits
		12 in.	24 in.	36 in.	48 in.	60 in.	72 in.	84 in.	96 in.	108 in.	
OIV (ft/s)	Long.	19.90	20.50	21.92	22.18	23.15	21.60	20.10	19.45	18.79	±40
	Lat.	26.27	26.30	26.69	27.46	25.60	26.32	25.18	24.18	23.23	±40
ORA (g's)	Long.	5.75	5.75	6.68	6.51	7.05	9.01	6.34	7.61	7.37	±20.49
	Lat.	8.84	10.90	10.87	12.21	9.23	11.50	10.58	11.48	12.74	±20.49
Max. Angular Displ. (Deg.)	Roll	8.9	7.0	7.5	8.7	6.0	7.3	7.0	5.8	6.3	±75
	Pitch	2.6	1.5	2.0	2.0	2.7	3.2	2.4	1.8	2.4	±75
	Yaw	37.3	36.9	38.9	38.2	36.4	35.9	35.8	35.4	36.6	N/A
Max. Dynamic Deflection (in.)		5.3	6.1	6.6	7.4	7.5	7.5	7.8	8.5	9.3	N/A

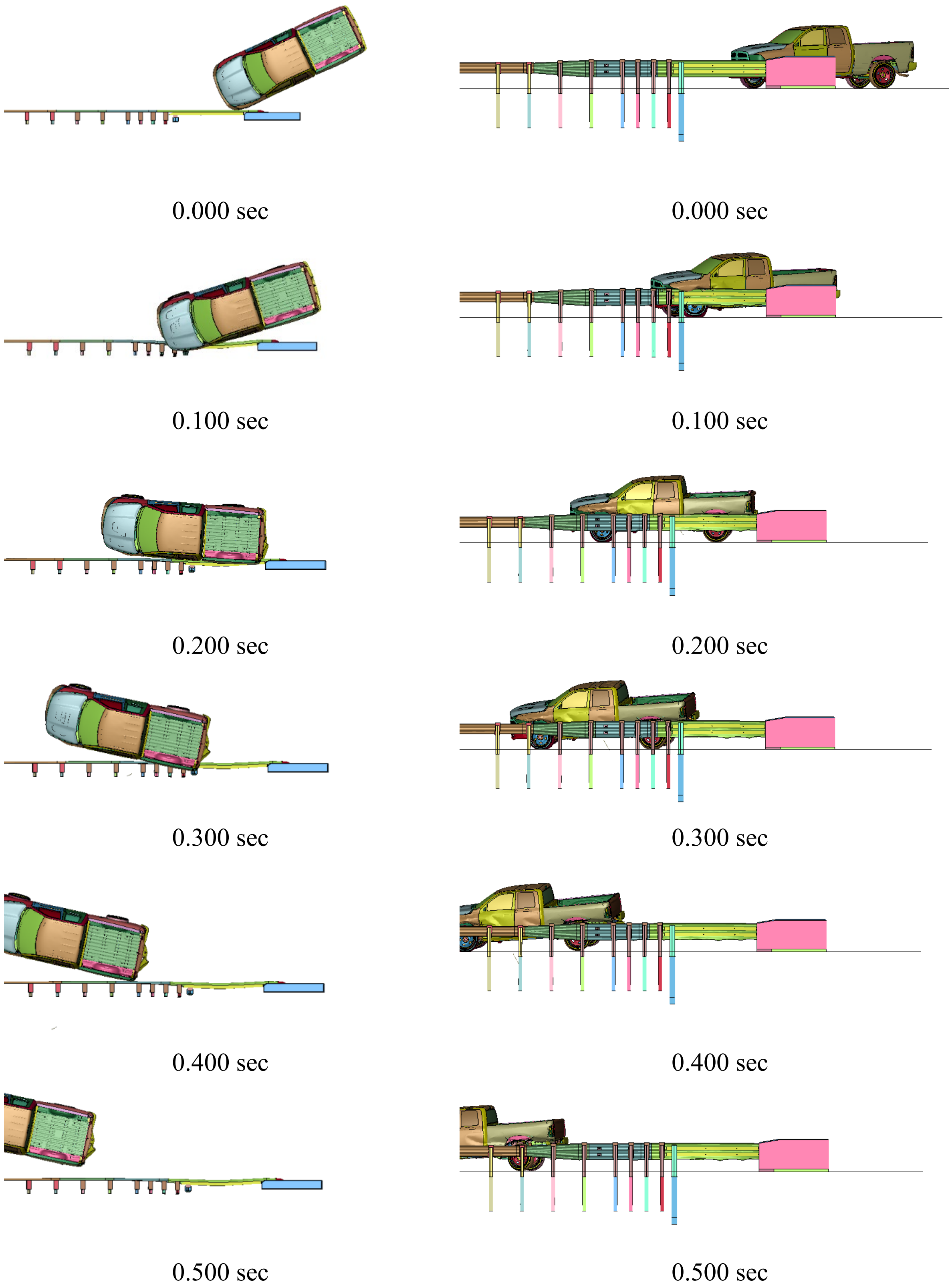


Figure 6.19 Sequential Images, 2270P Reverse-Direction (MASH Test Designation No. 3-21), Impact Point at 12 in. US from Buttress

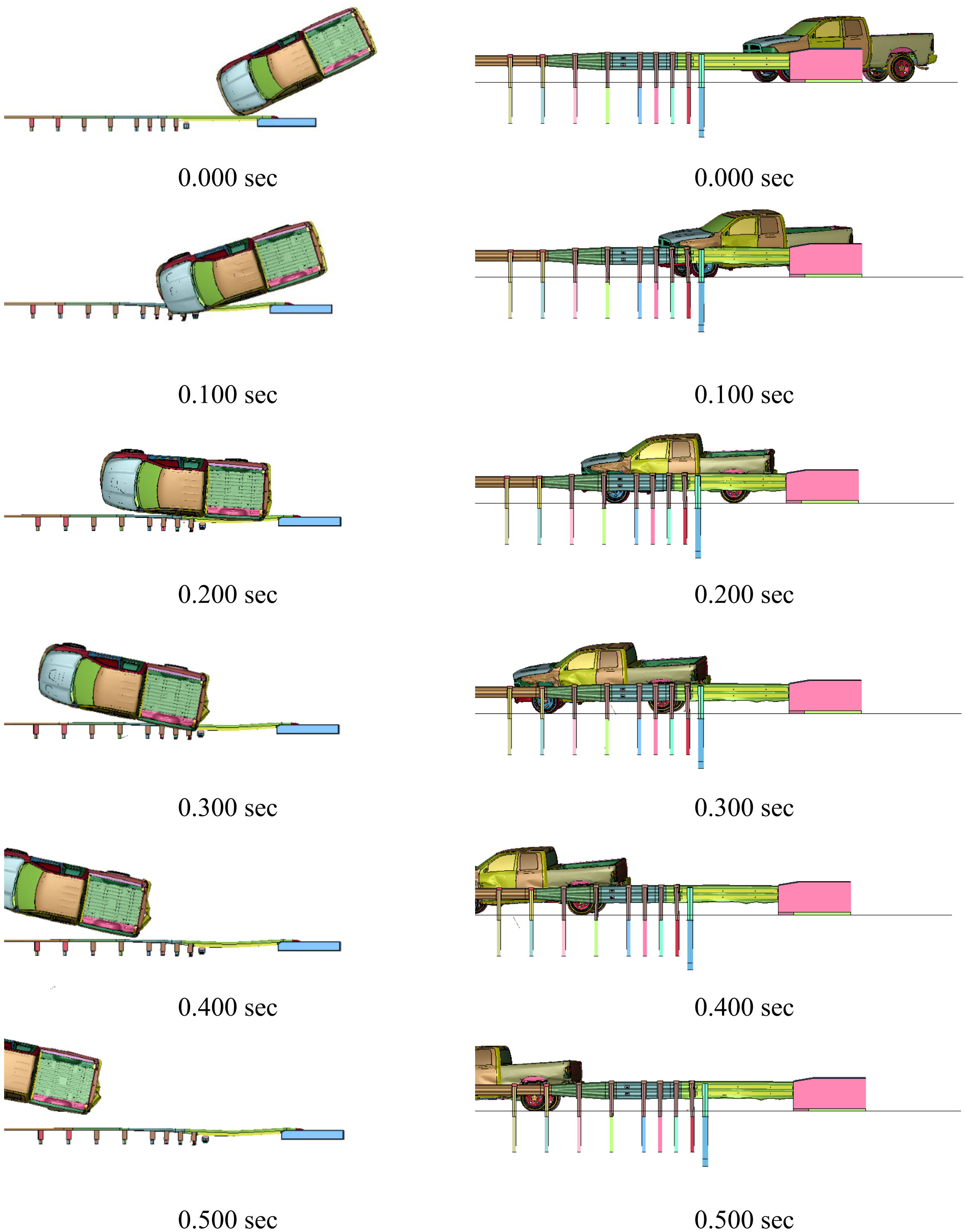


Figure 6.20 Sequential Images, 2270P Reverse-Direction (MASH Test Designation No. 3-21), Impact Point at 24 in. US from Buttress

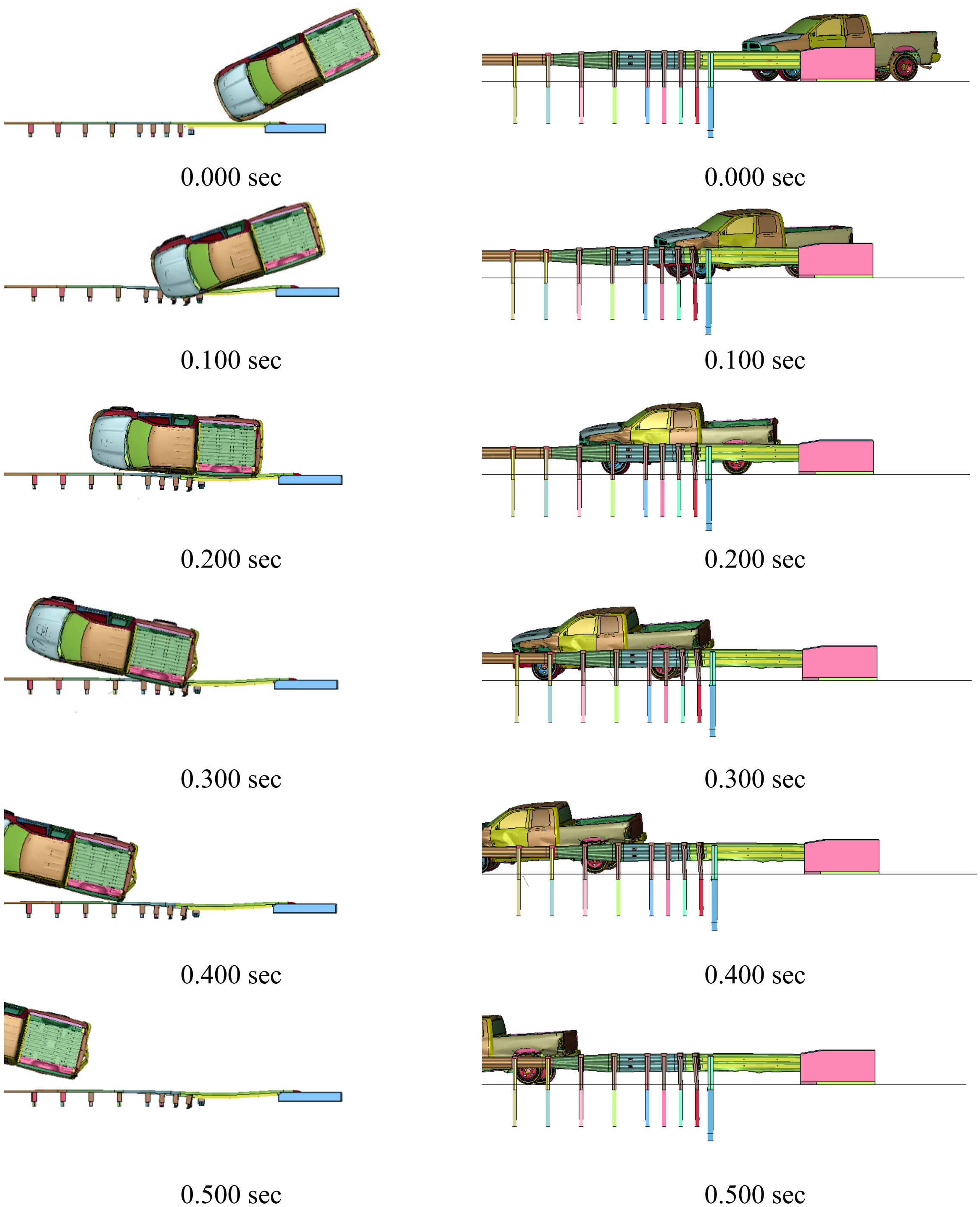


Figure 6.21 Sequential Images, 2270P Reverse-Direction (MASH Test Designation No. 3-21), Impact Point at 36 in. US from Buttress

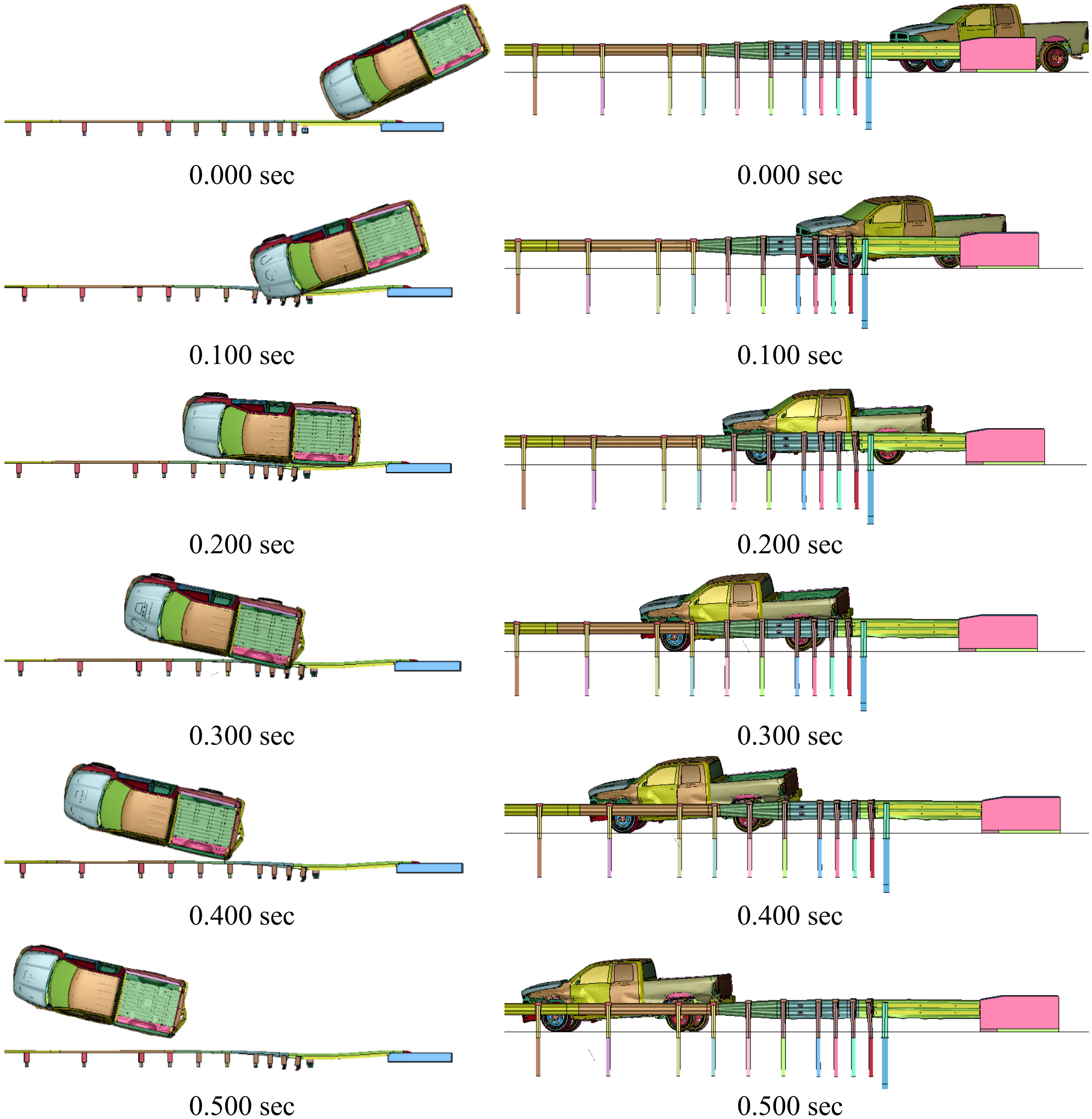


Figure 6.22 Sequential Images, 2270P Reverse-Direction (MASH Test Designation No. 3-21), Impact Point at 48 in. US from Buttress

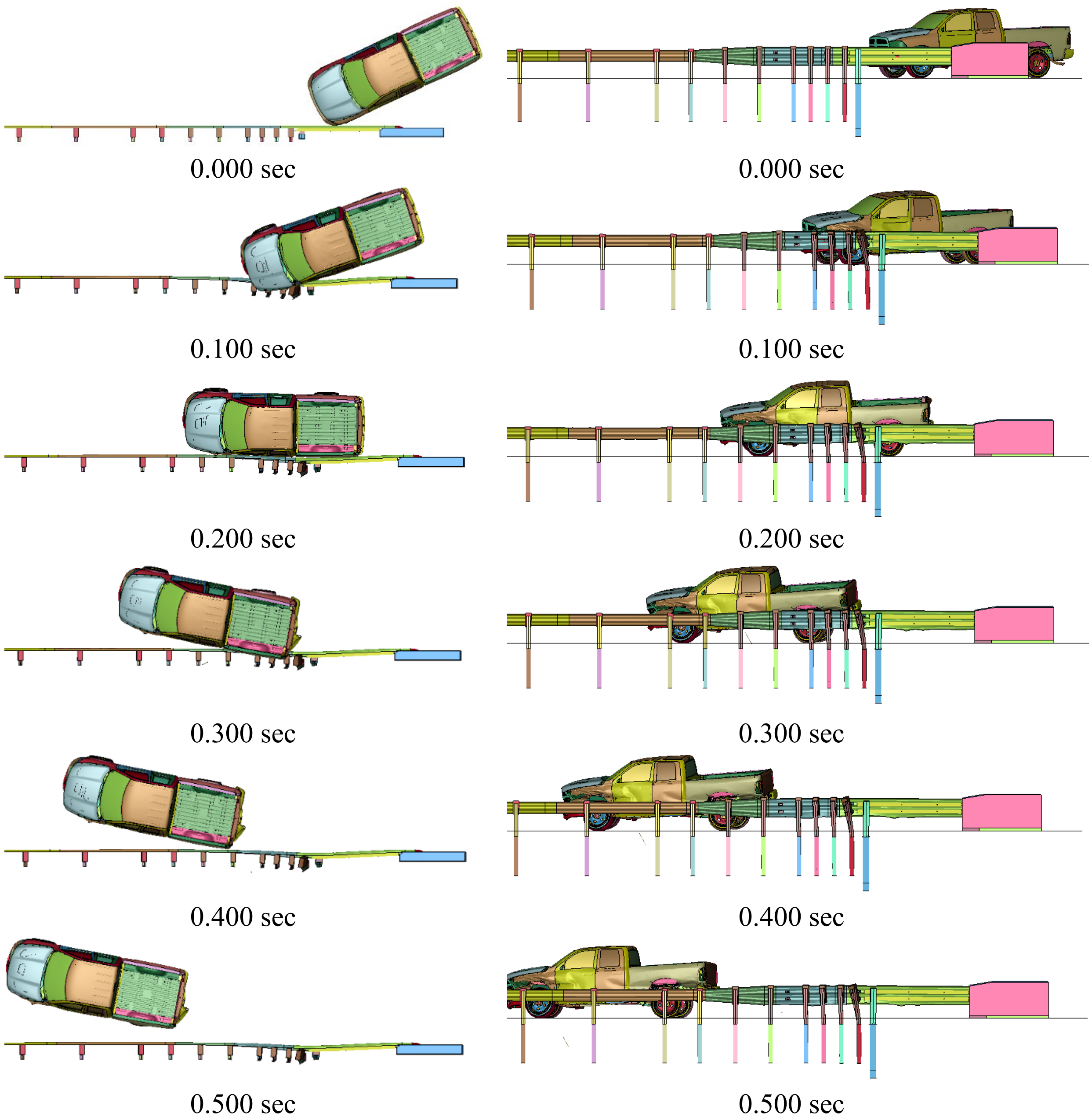


Figure 6.23 Sequential Images, 2270P Reverse-Direction (MASH Test Designation No. 3-21), Impact Point at 60 in. US from Buttress

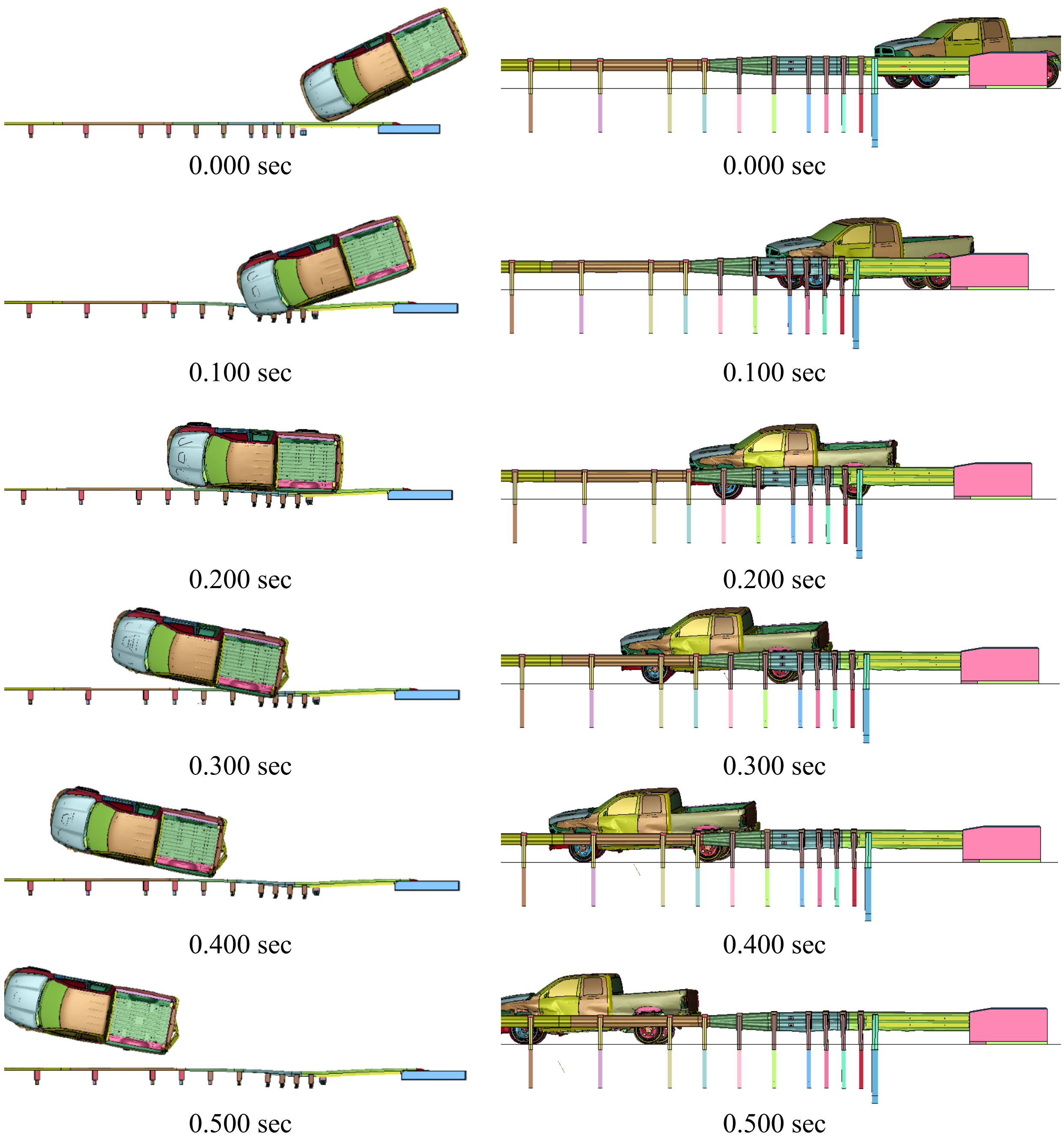


Figure 6.24 Sequential Images, 2270P Reverse-Direction (MASH Test Designation No. 3-21), Impact Point at 72 in. US from Buttress

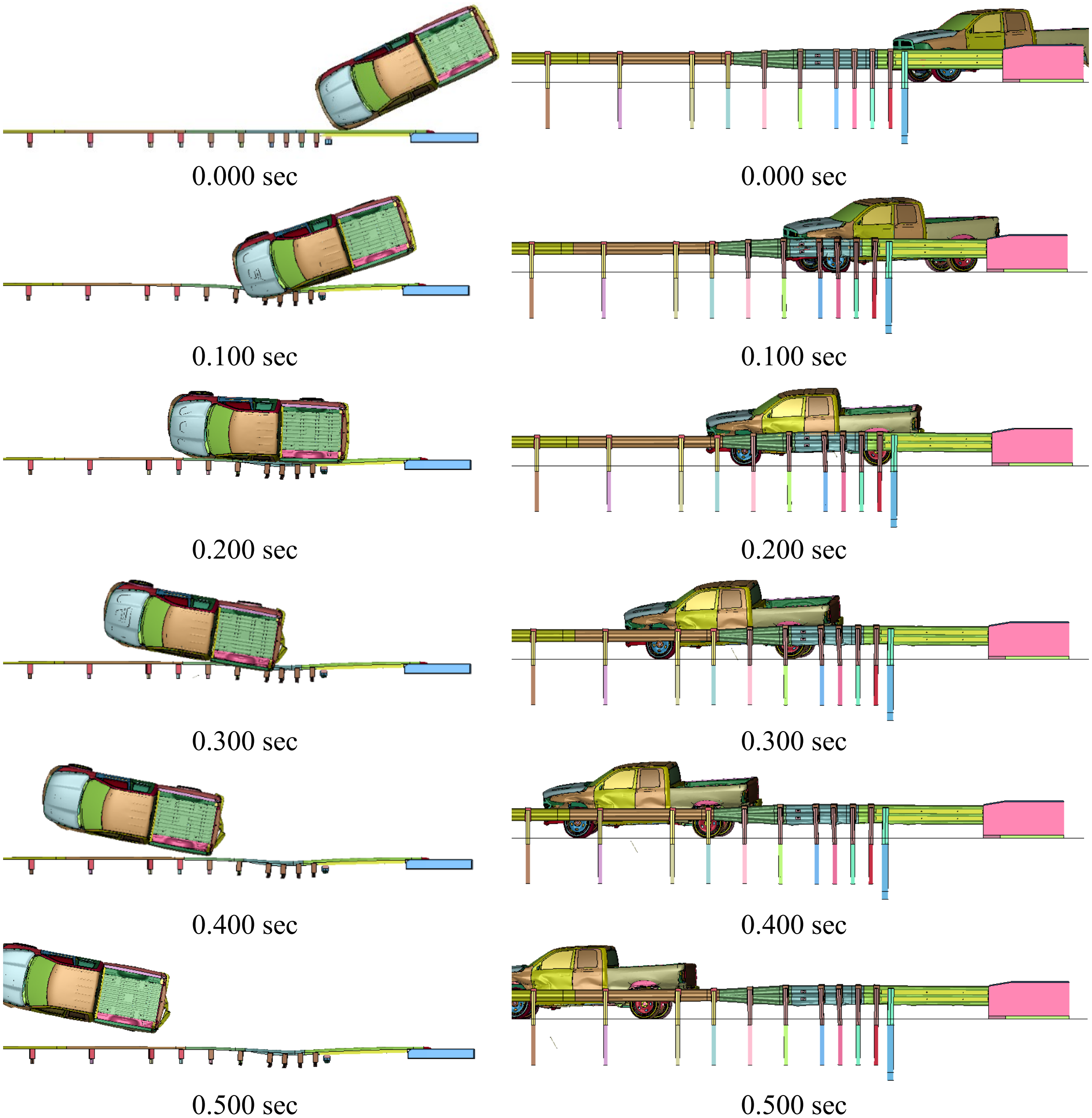


Figure 6.25 Sequential Images, 2270P Reverse-Direction (MASH Test Designation No. 3-21), Impact Point at 84 in. US from Buttress

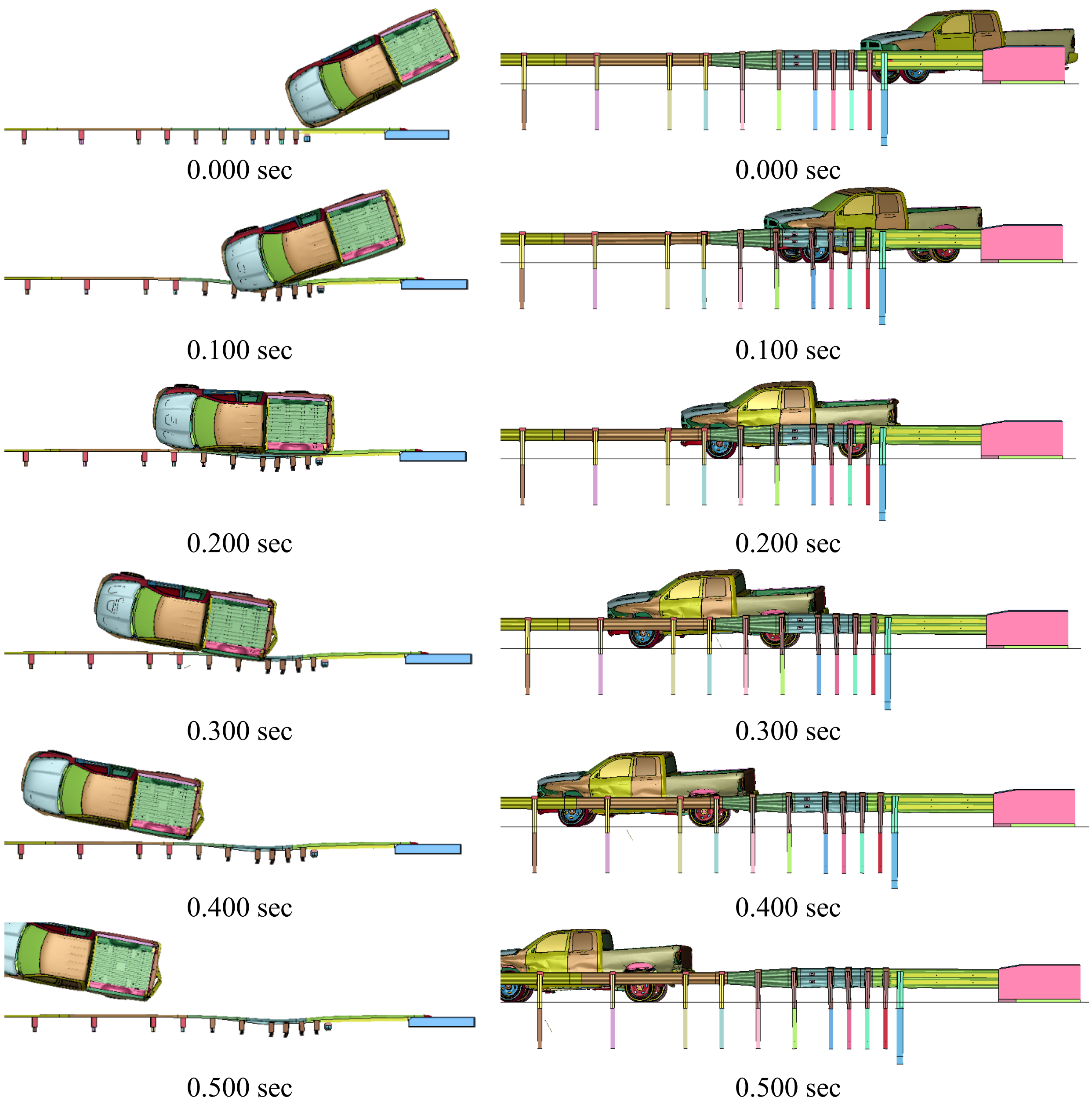


Figure 6.26 Sequential Images, 2270P Reverse-Direction (MASH Test Designation No. 3-21), Impact Point at 96 in. US from Buttress

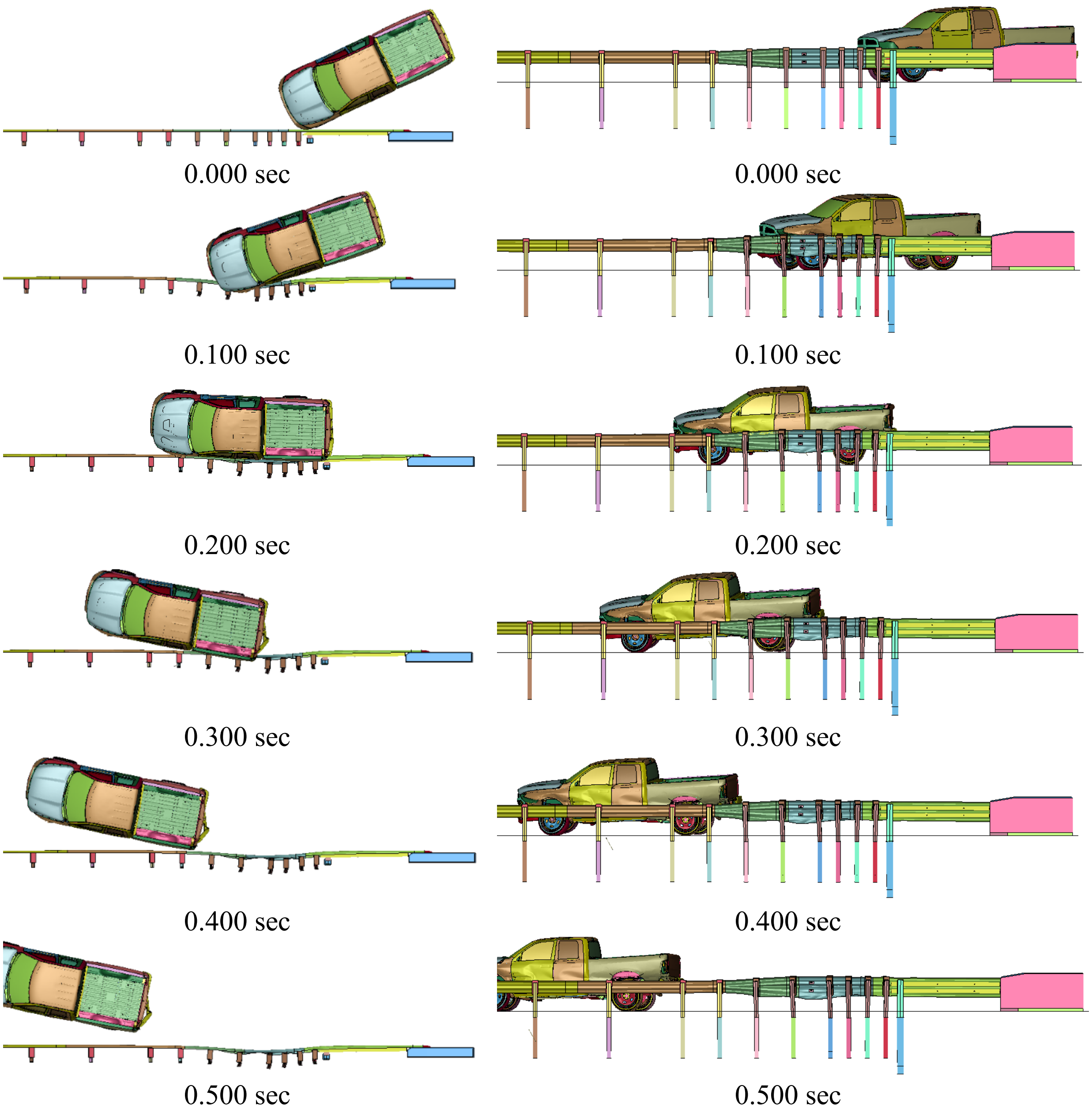


Figure 6.27 Sequential Images, 2270P Reverse-Direction (MASH Test Designation No. 3-21), Impact Point at 108 in. US from Buttress

6.1.4 Test Designation No. 3-20, Conventional Impact Direction

Table 6.7 summarizes the simulation matrix for MASH test designation no. 3-20.

Simulations modeled thrie-beam to concrete buttress impacts at multiple locations. The table lists each simulation name and the impact location in inches upstream (US) from the concrete buttress. Figure 6.28 shows the measurement of impact points relative to the concrete buttress.

Table 6.7 Summary of Simulations, Test Designation No. 3-20

Simulation Name	Impact Point
3-20_89US	89 in. US of Butress
3-20_83US	83 in. US of Butress
3-20_77US	77 in. US of Butress
3-20_71US	71 in. US of Butress
3-20_65US	65 in. US of Butress
3-20_59US	59 in. US of Butress
3-20_53US	53 in. US of Butress
3-20_47US	47 in. US of Butress
3-20_41US	41 in. US of Butress
3-20_35US	35 in. US of Butress
3-20_29US	29 in. US of Butress

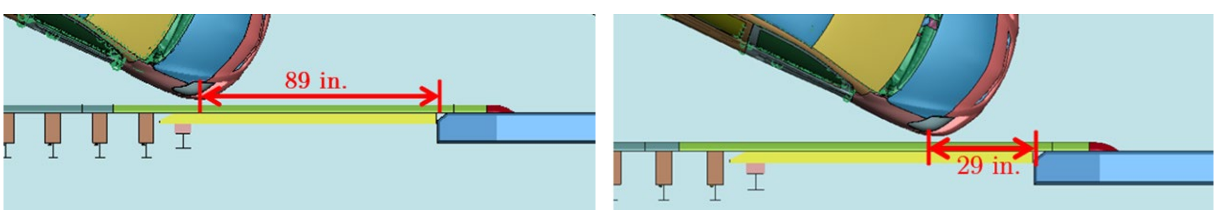


Figure 6.28 Impact Points for MASH Test Designation No. 3-20 Simulations, Conventional Impact Direction

Table 6.8 lists occupant risk values for all simulations and Figure 6.29 through Figure 6.39 show vehicle and system behavior. The vehicle was smoothly redirected in all simulations. Based on the simulation results, the impact point 65 in. upstream from the concrete buttress was selected as the CIP to maximize occupant risk metrics and snag potential on the concrete buttress.

Table 6.8 Summary of Simulation Results, Test Designation No. 3-20

Evaluation Criteria		Impact Point Location US from Buttress											MASH Limits
		89 in.	83 in.	77 in.	71 in.	65 in.	59 in.	53 in.	47 in.	41 in.	35 in.	29 in.	
OIV (ft/s)	Long.	26.83	27.35	27.47	28.61	29.97	32.81	34.14	33.16	32.44	31.53	31.38	±40
	Lat.	33.18	32.75	32.97	32.58	32.84	32.16	29.95	30.59	30.18	28.88	27.74	±40
ORA (g's)	Long.	14.75	15.20	16.19	17.28	17.57	13.58	10.56	5.75	5.04	7.62	5.53	±20.49
	Lat.	13.12	14.13	13.70	15.47	16.88	15.85	15.40	13.19	12.25	7.40	6.11	±20.49
Max. Angular Displ. (deg.)	Roll	6.8	3.6	5.2	12.3	7.7	14.9	14.7	10.1	5.4	5.9	5.8	±75
	Pitch	3.4	3.6	3.3	3.8	4.3	4.2	4.4	5.0	6.1	6.9	9.3	±75
	Yaw	66.3	78.0	84.7	73.9	70.2	51.1	48.6	55.2	55.8	56.2	63.9	N/A
Max. Dynamic Deflection (in.)		5.3	4.2	4.0	3.8	3.4	3.1	3.0	2.9	2.5	2.2	2.0	1.6

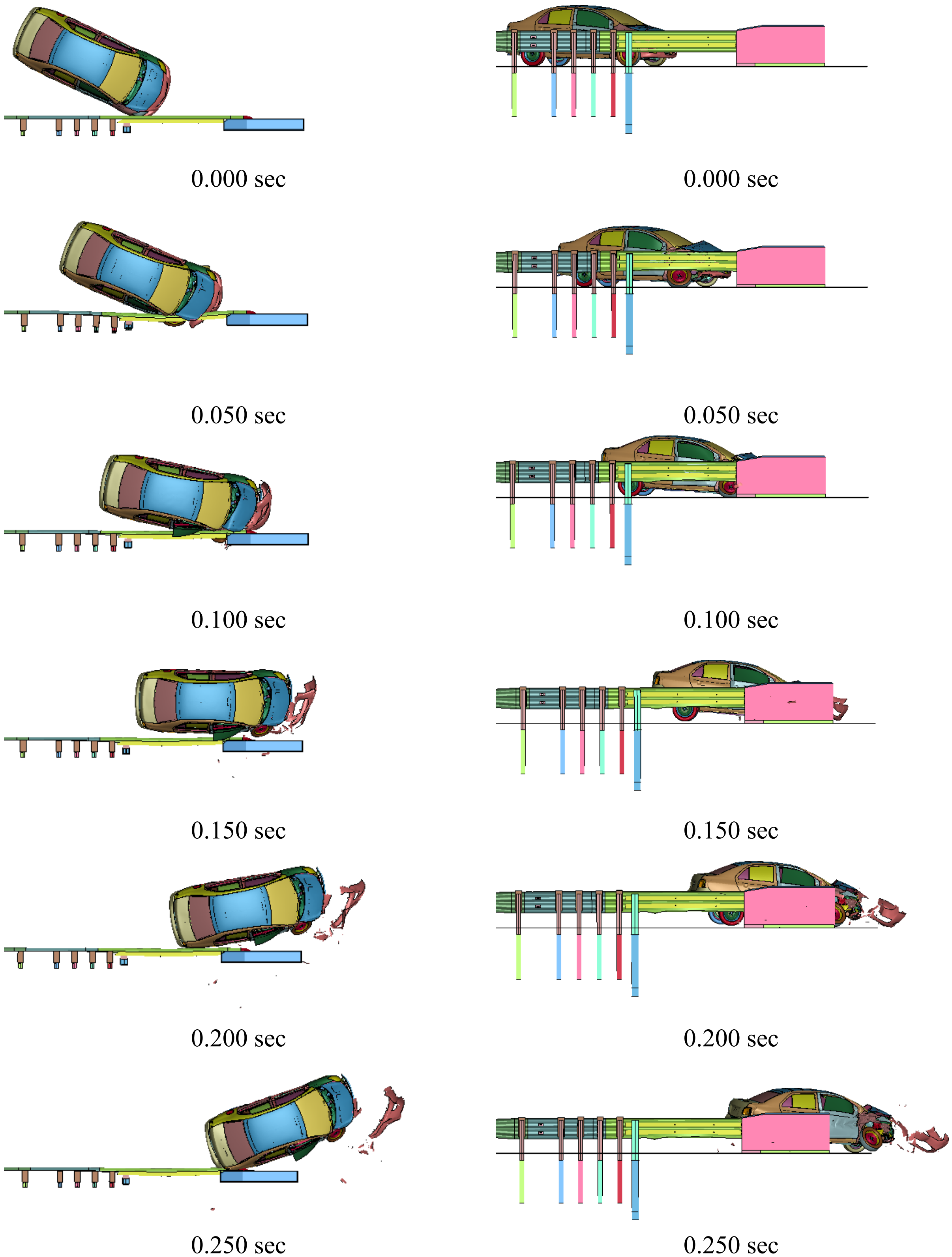


Figure 6.29 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at 89 in. US from Buttress

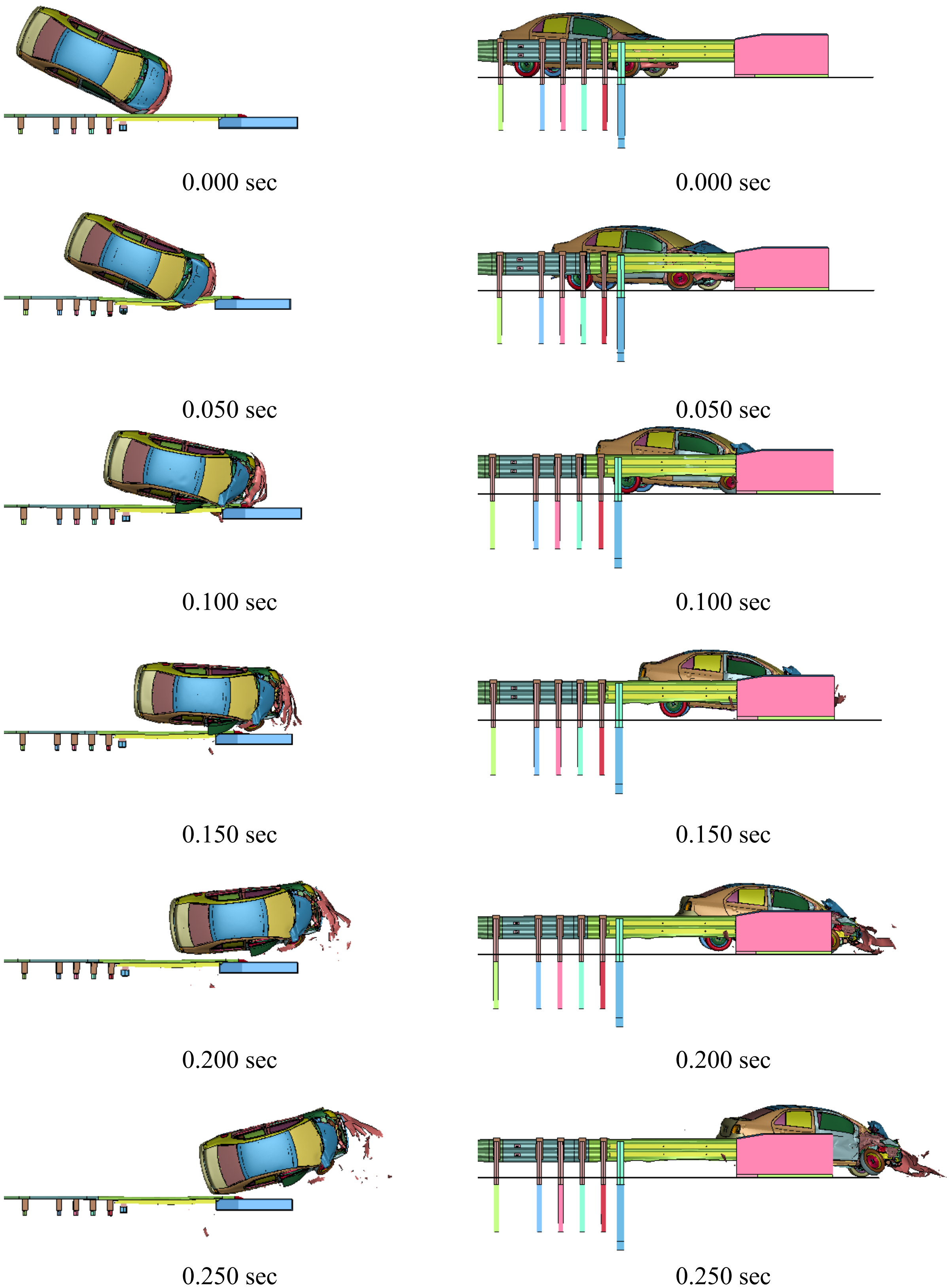


Figure 6.30 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at 83 in. US from Buttress

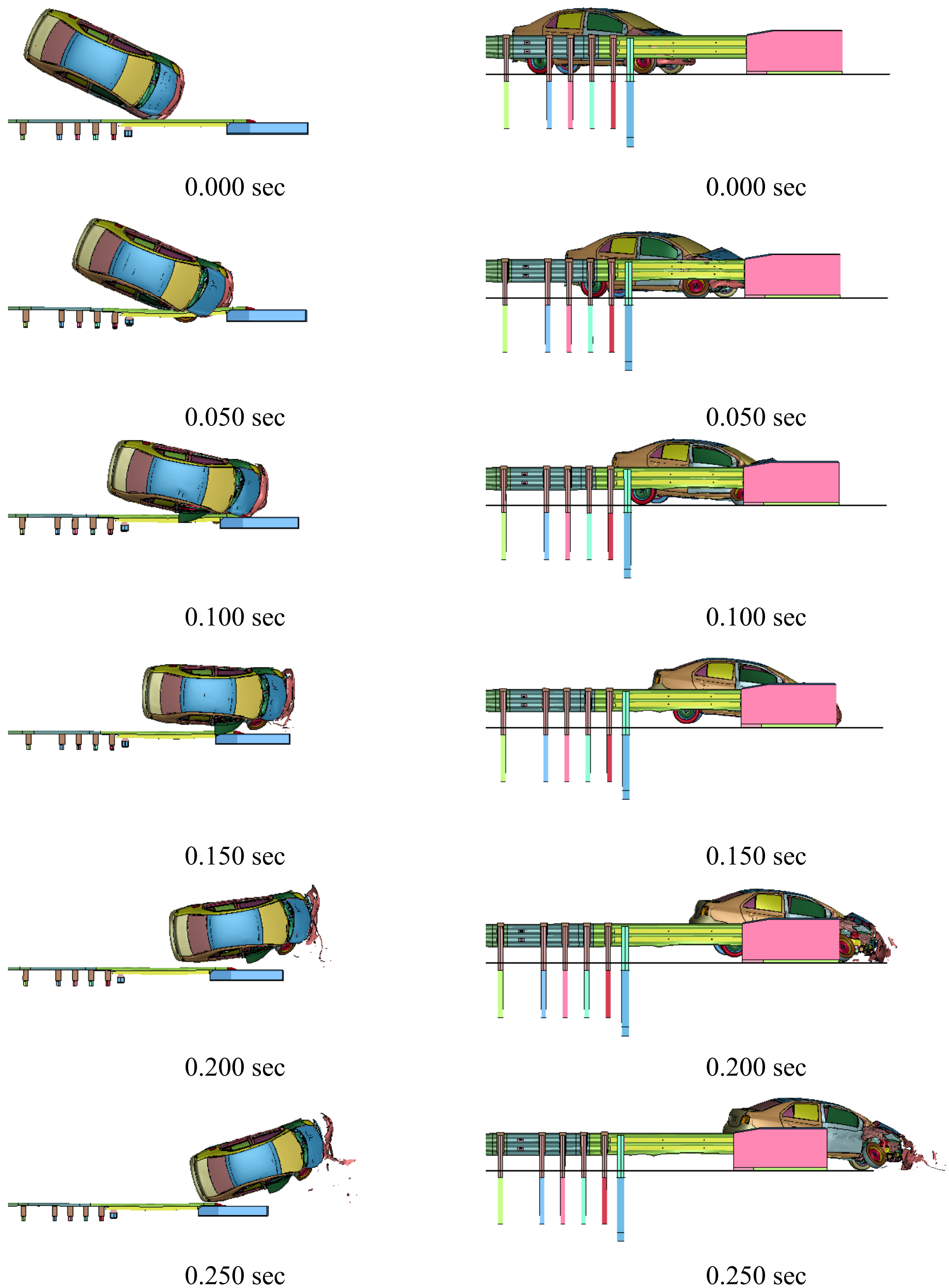


Figure 6.31 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at 77 in. US from Buttress

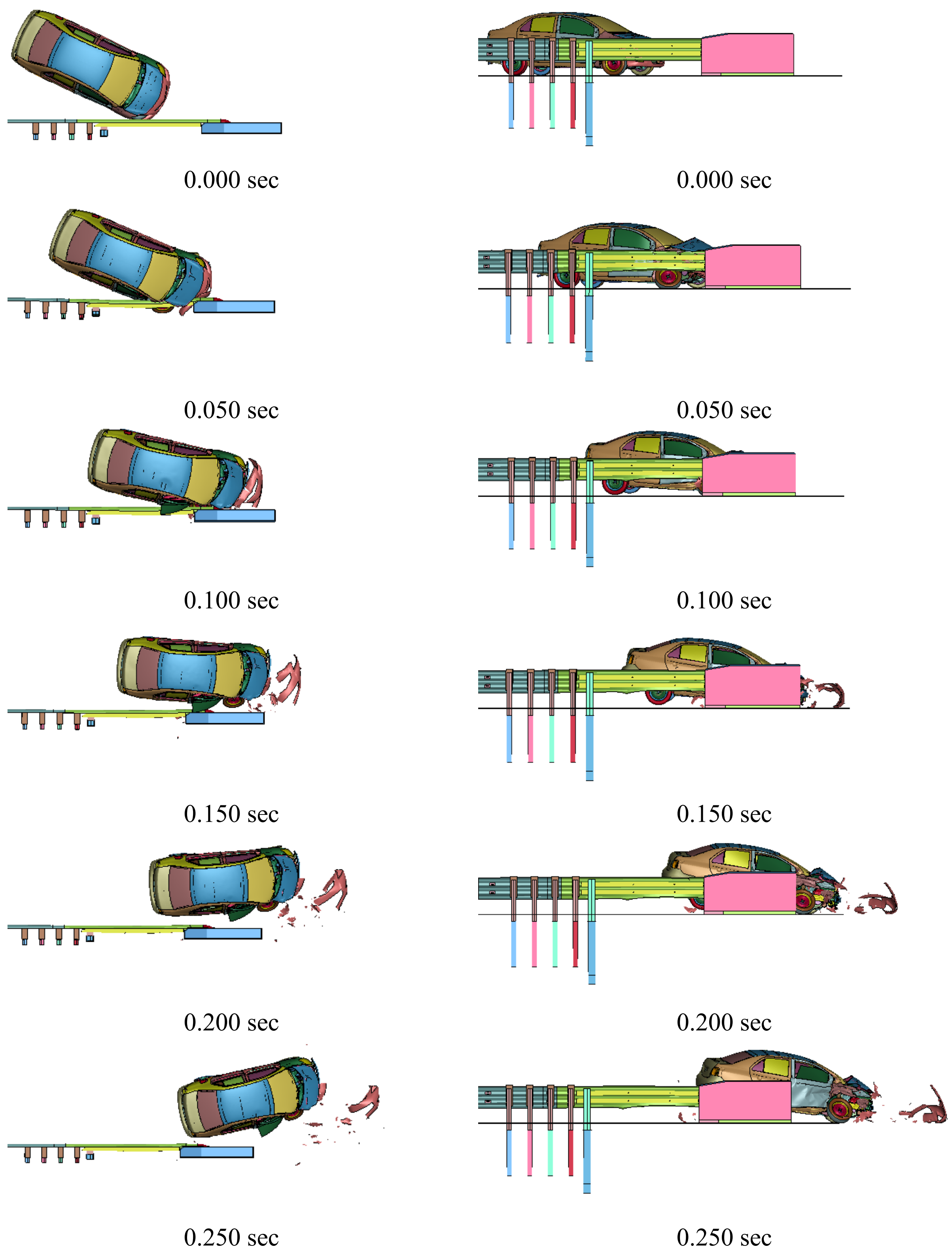


Figure 6.32 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at 71 in. US from Buttress

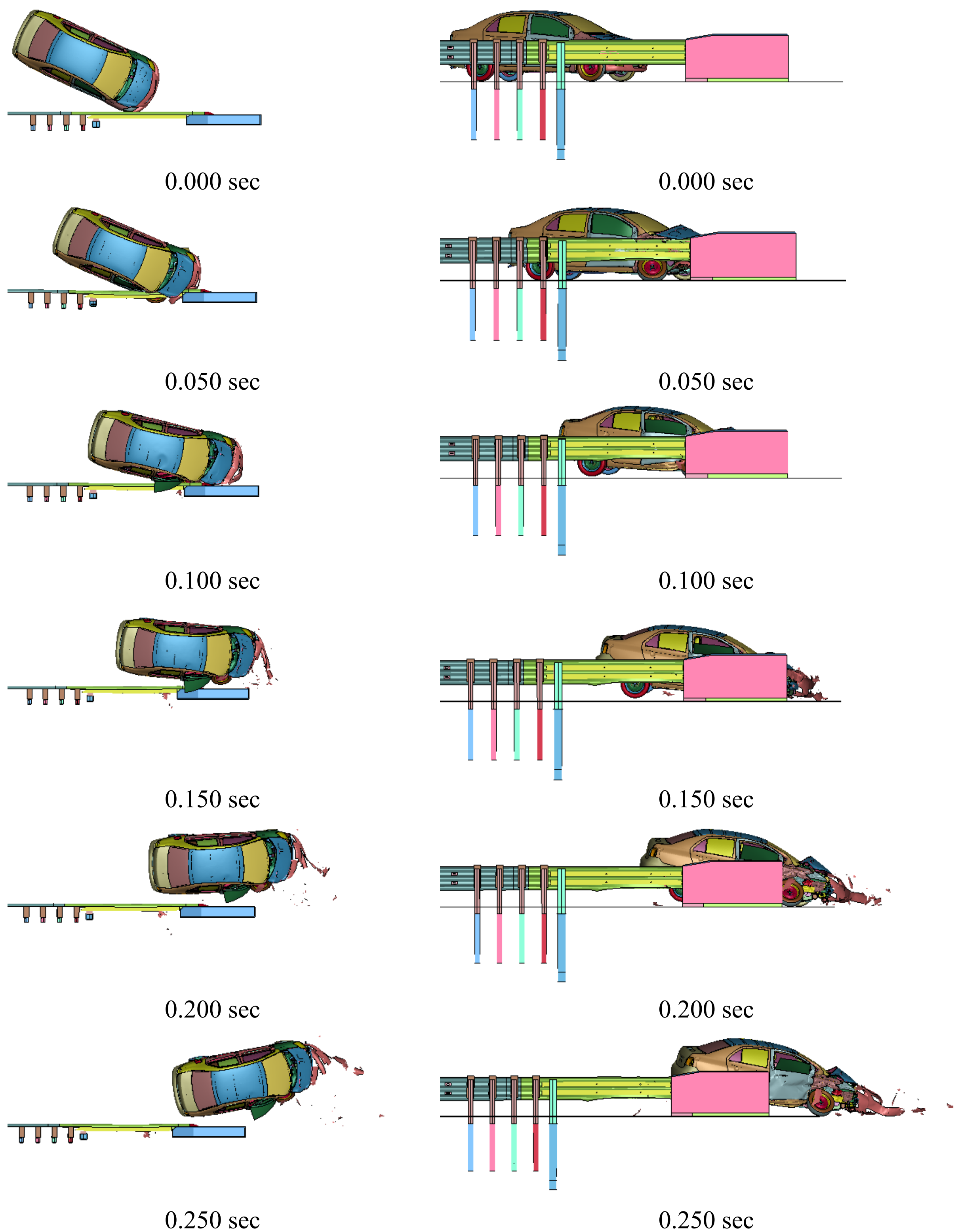


Figure 6.33 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at 65 in. US from Buttress

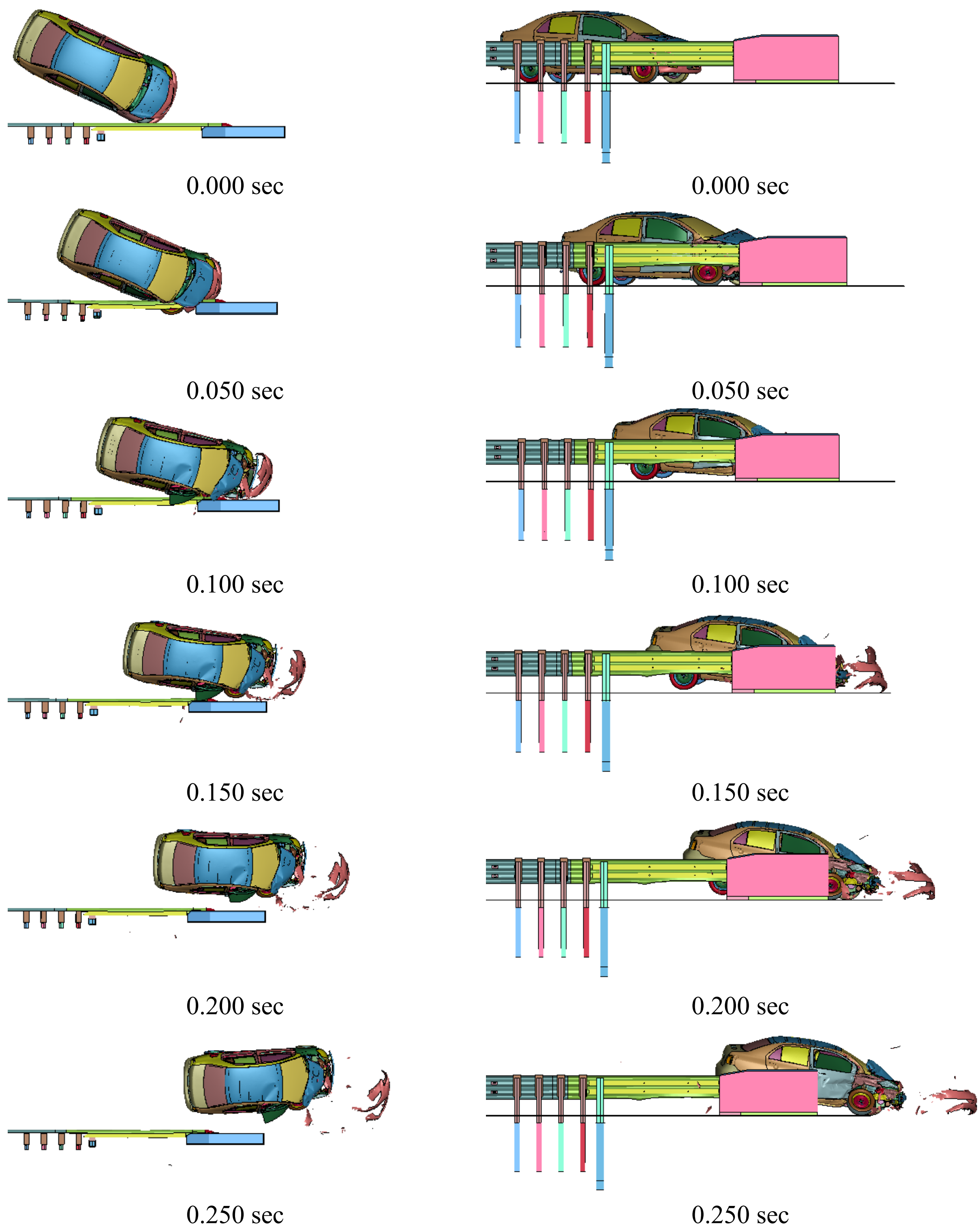


Figure 6.34 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at 59 in. US from Buttress

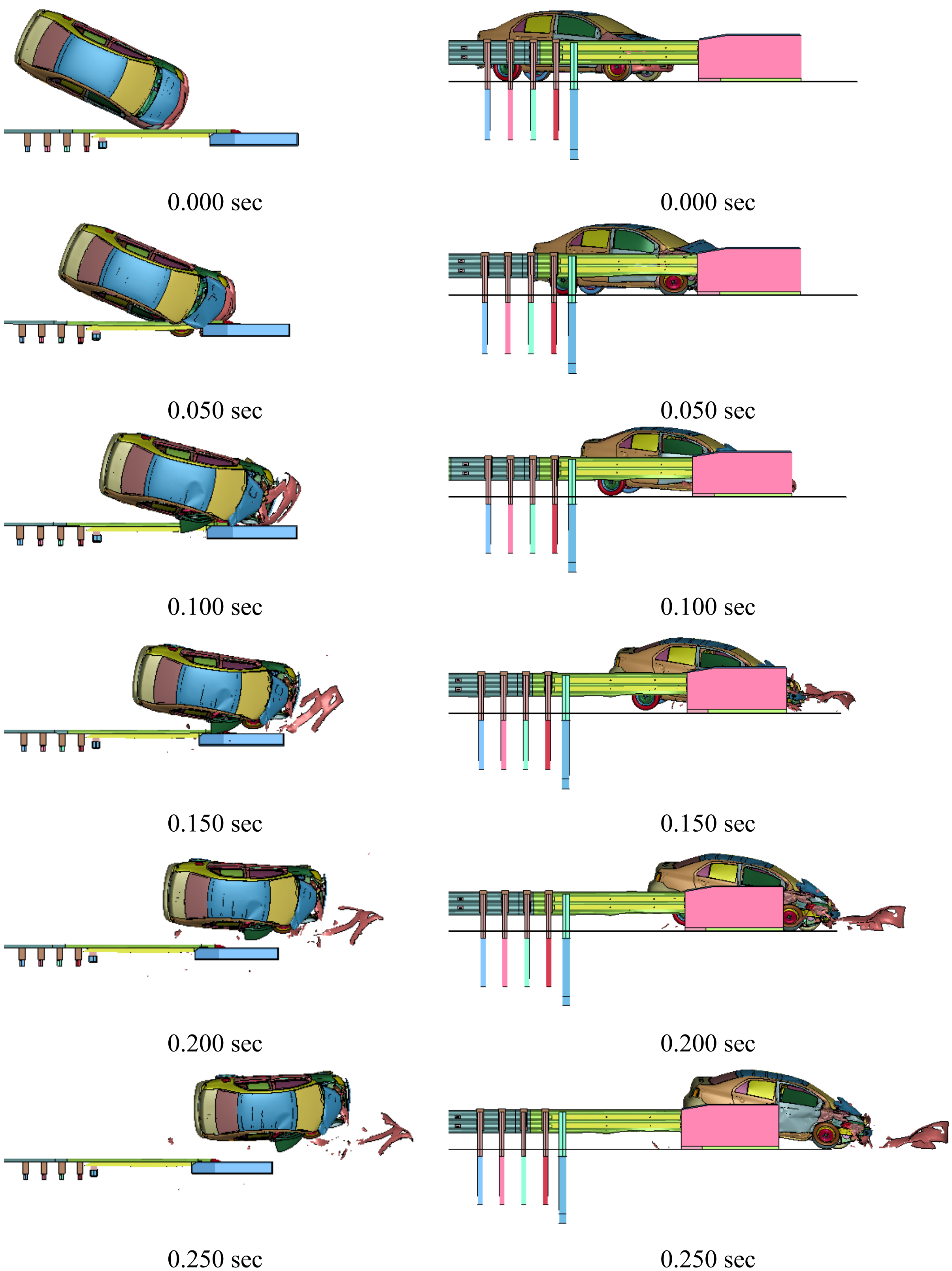


Figure 6.35 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at 53 in. US from Buttress

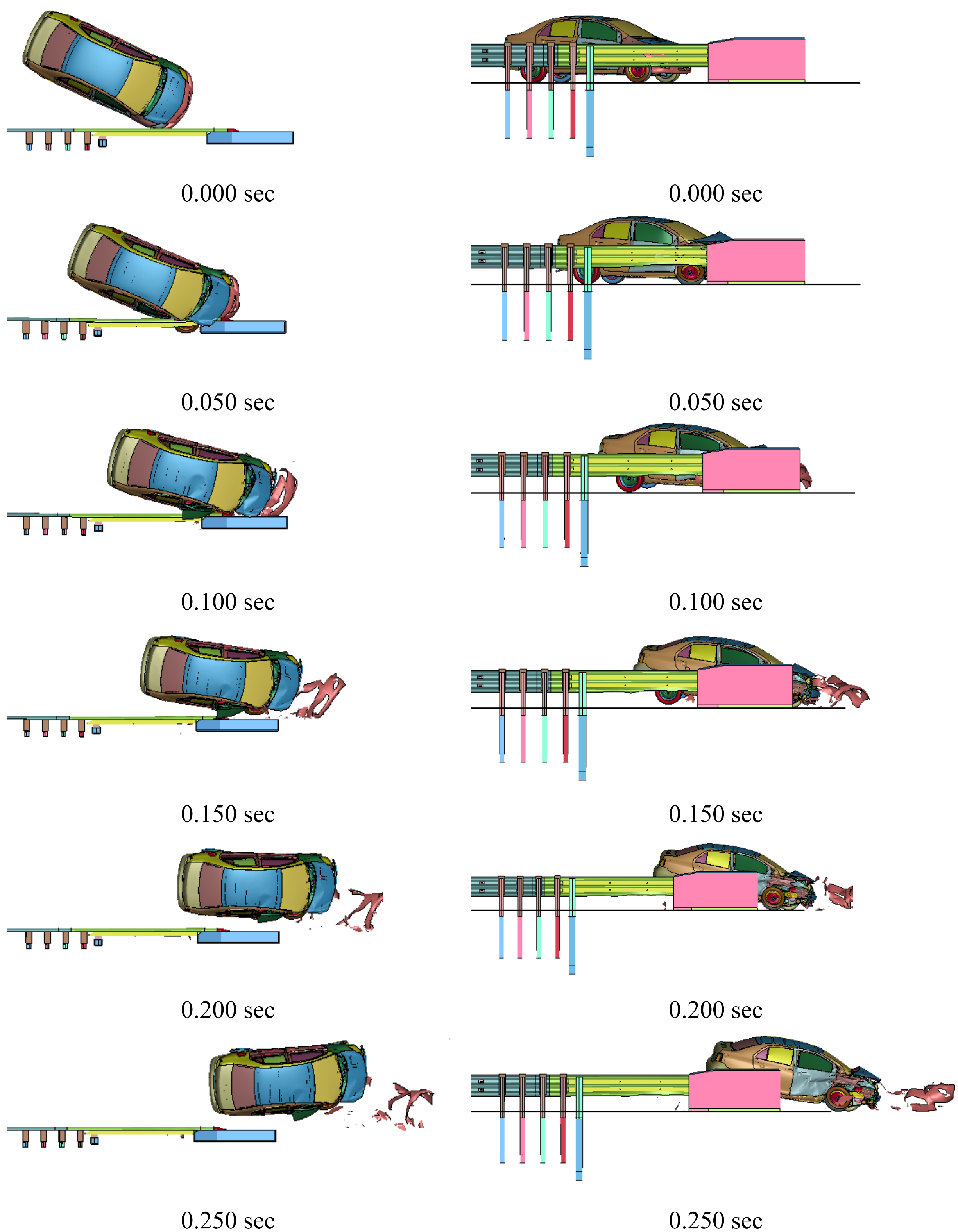


Figure 6.36 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at 47 in. US from Buttress

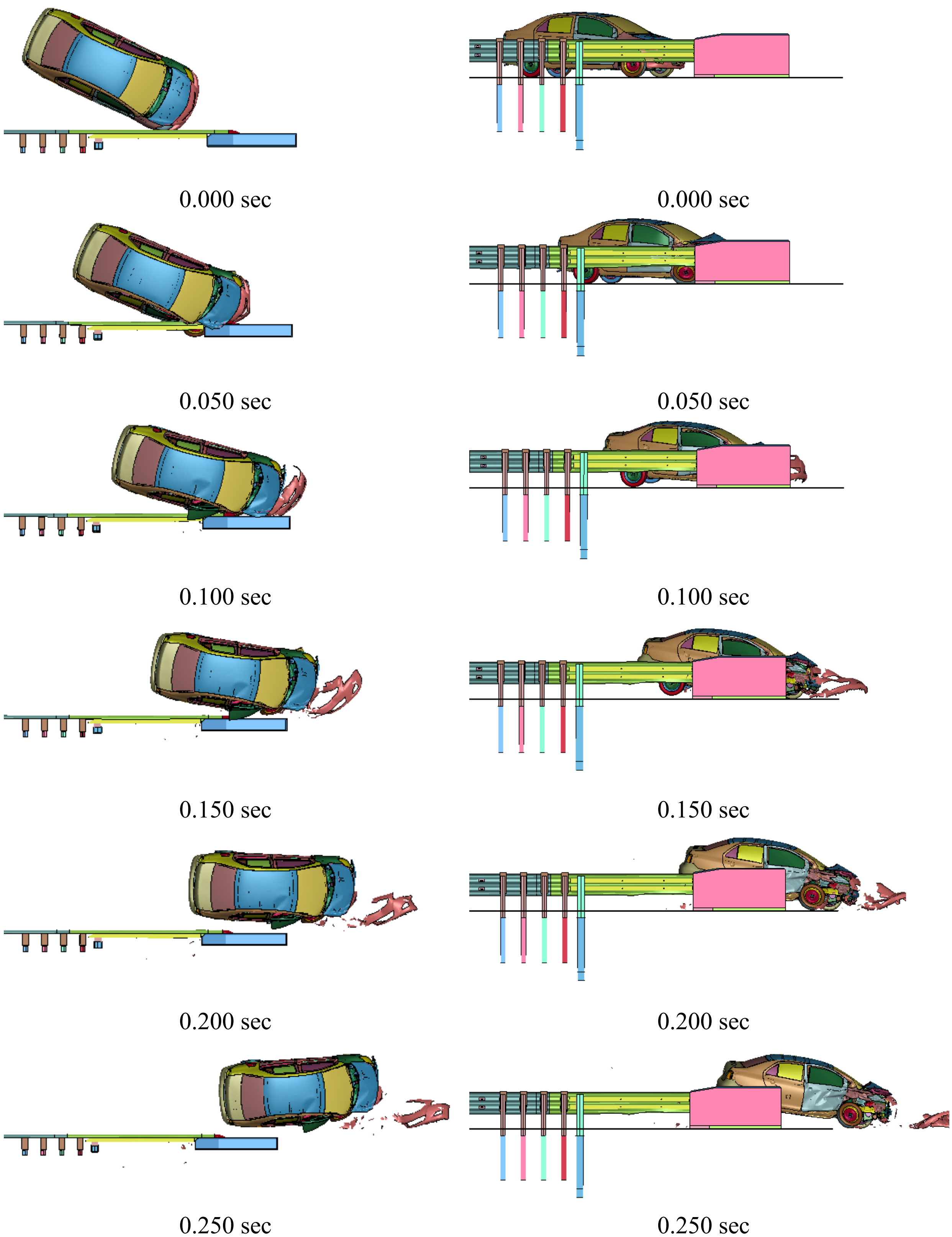


Figure 6.37 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at 41 in. US from Buttress

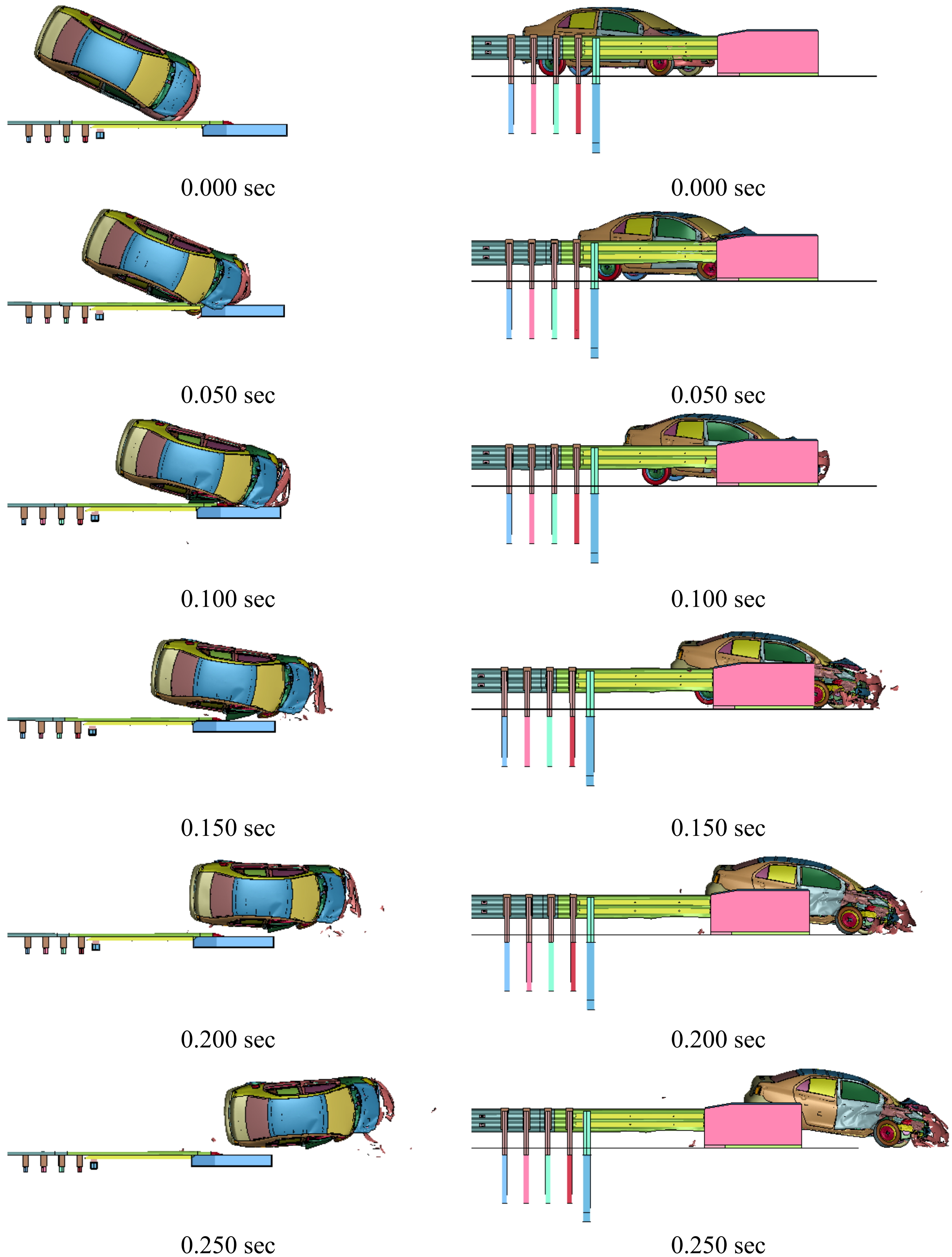


Figure 6.38 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at 35 in. US from Buttress

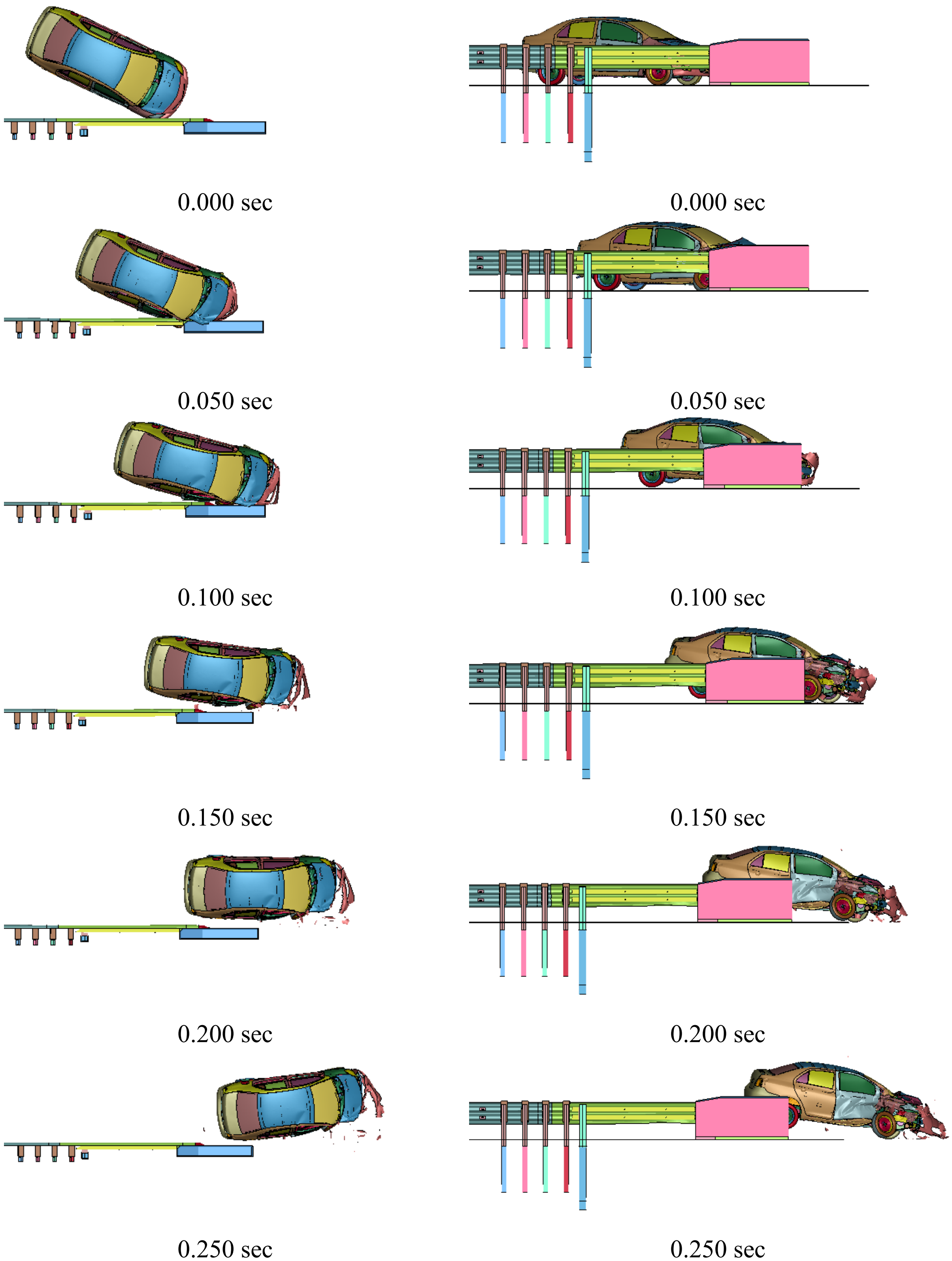


Figure 6.39 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at 29 in. US from Buttress

6.1.5 Test Designation No. 3-20, Upstream Impact

The study evaluated MASH test designation no. 3-20 cases with impacts upstream of the concrete buttress at multiple points. Impact locations were measured in inches upstream, noted as US. The simulation matrix listed each case by simulation name and impact location. Table 6.9 provides the matrix. Figure 6.40 shows how the impact points were measured relative to the buttress.

Table 6.9 Summary of Upstream Impact Simulations on Design Concept #5, Test Designation No. 3-20

Simulation Name	Impact Point
3-20_P1	Post No. 1
3-20_P2	Post No. 2
3-20_P3	Post No. 3
3-20_P4	Post No. 4
3-20_P5	Post No. 5
3-20_P6	Post No. 6
3-20_P7	Post No. 7

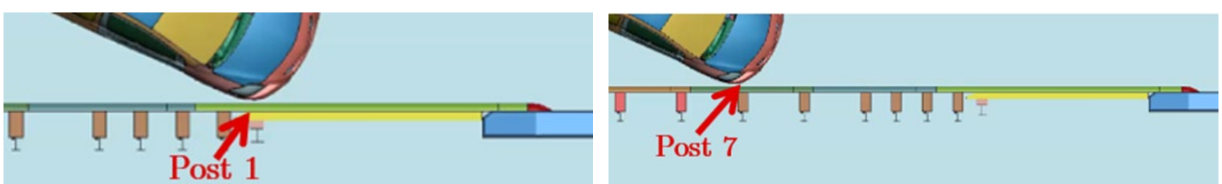


Figure 6.40 Upstream Impact Locations for MASH Test Designation No. 3-20

Occupant risk values for each simulation are shown in Table 6.10. General vehicle and system behavior for each simulation is shown in Figure 6.41 through Figure 6.47. The vehicle was smoothly redirected in all simulations. All occupant risk values were below MASH thresholds. The simulation showed no indication of significant pocketing or snag.

Table 6.10 Summary of Simulation Results, Upstream Impacts, Test Designation No. 3-20

Evaluation Criteria		Impact Point Location							MASH Limits
		Post no. 1	Post no. 2	Post no. 3	Post no. 4	Post no. 5	Post no. 6	Post no. 7	
OIV (ft/s)	Long.	26.26	25.32	25.92	28.33	28.20	28.24	25.72	±40
	Lat.	32.89	32.06	32.33	32.89	32.75	31.50	29.87	±40
ORA (g's)	Long.	7.58	6.19	5.89	6.16	14.64	12.32	12.63	±20.49
	Lat.	9.40	9.39	9.16	10.35	11.60	8.9	16.14	±20.49
Max. Angular Displacement (deg.)	Roll	6.0	4.0	3.1	2.9	3.8	2.8	3.8	±75
	Pitch	3.9	3.7	3.6	3.7	3.5	3.5	3.7	±75
	Yaw	52.8	40.7	39.8	46.6	53.1	43.9	46.3	N/A
Max. Dynamic Deflection (in.)		4.2	4.4	4.9	4.7	5.7	7.2	8.3	N/A

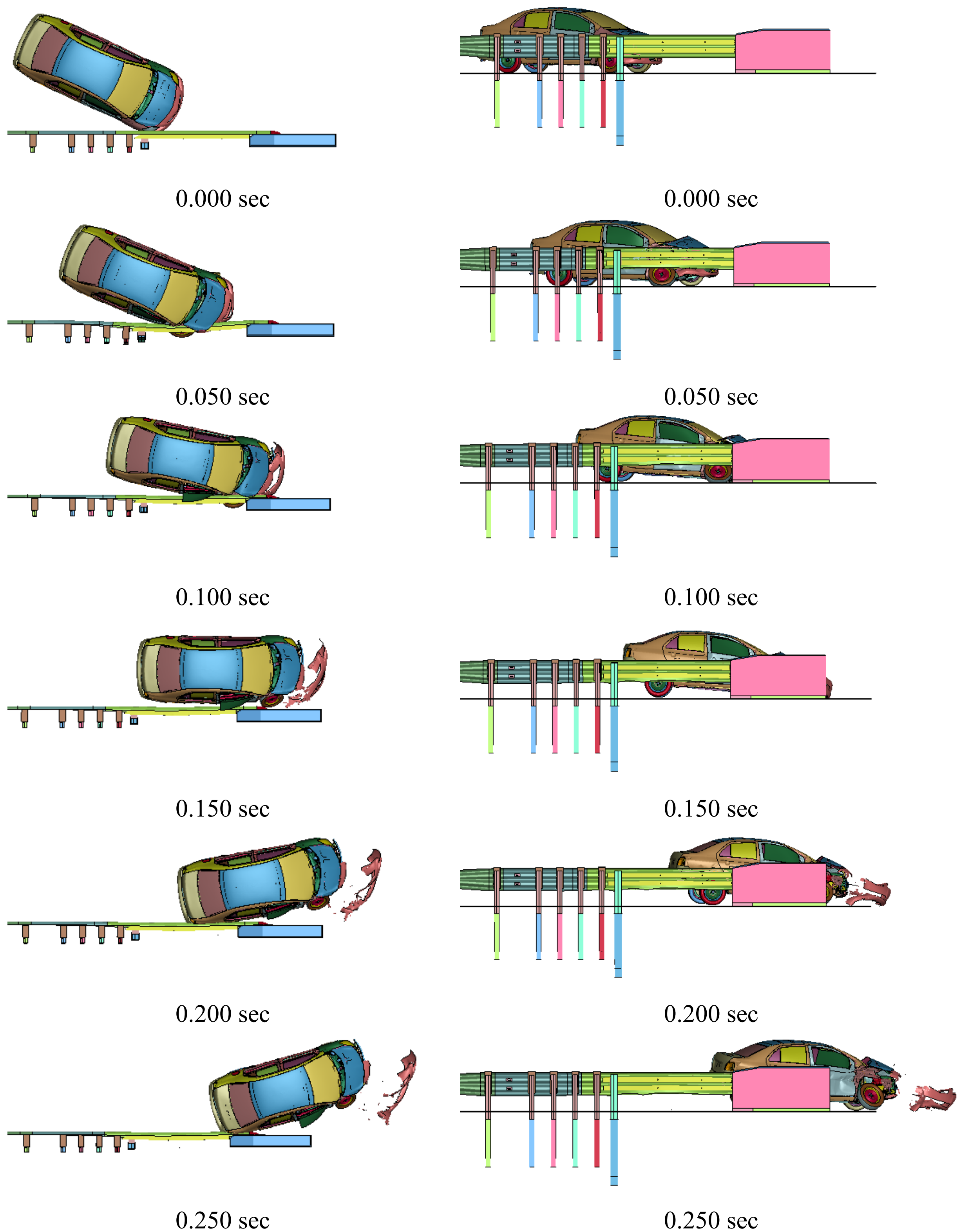


Figure 6.41 Sequential Images, 1100C Conventional Impact Direction (MASH 3-20), Impact Point at Post No. 1

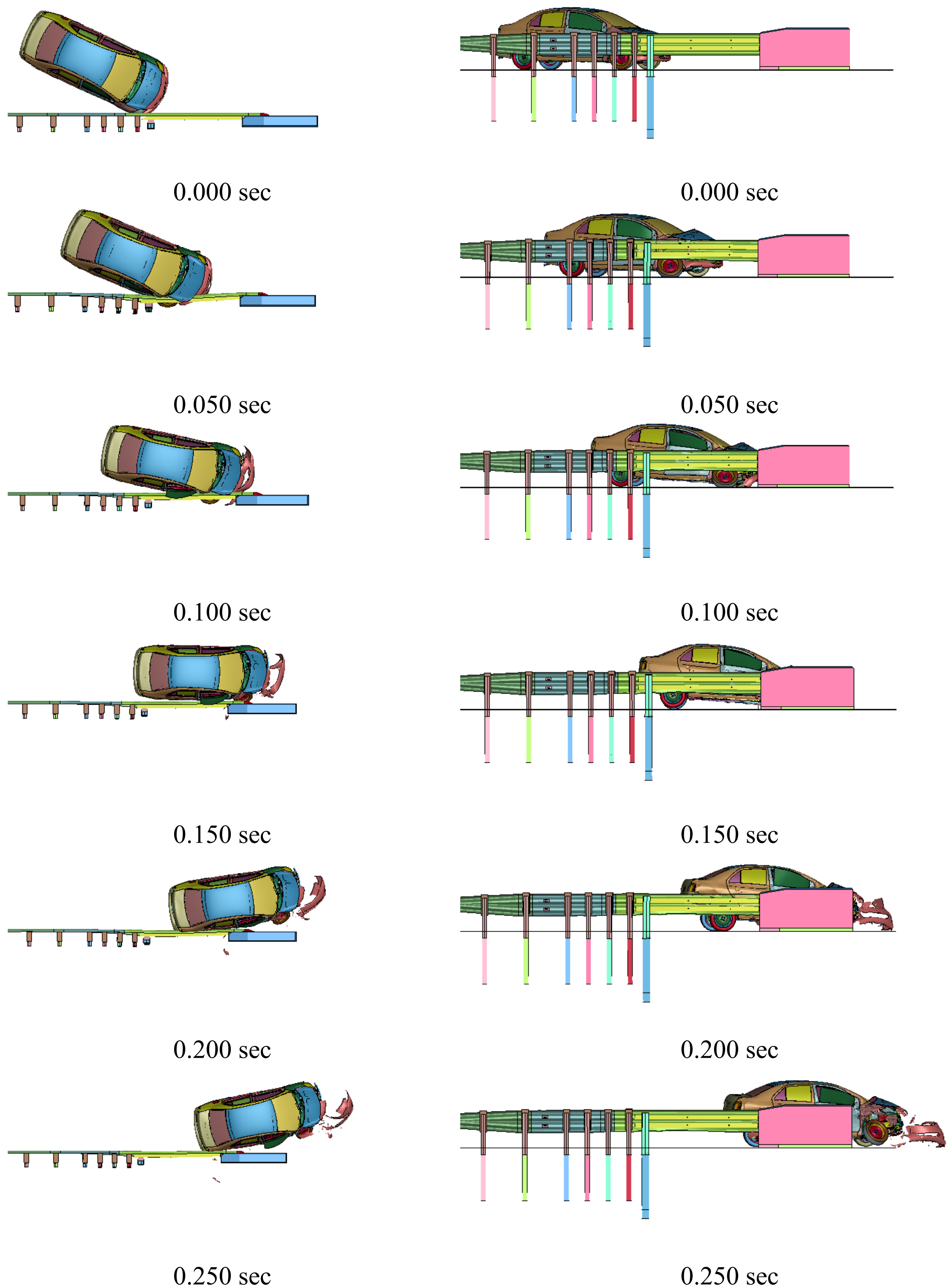


Figure 6.42 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at Post No. 2

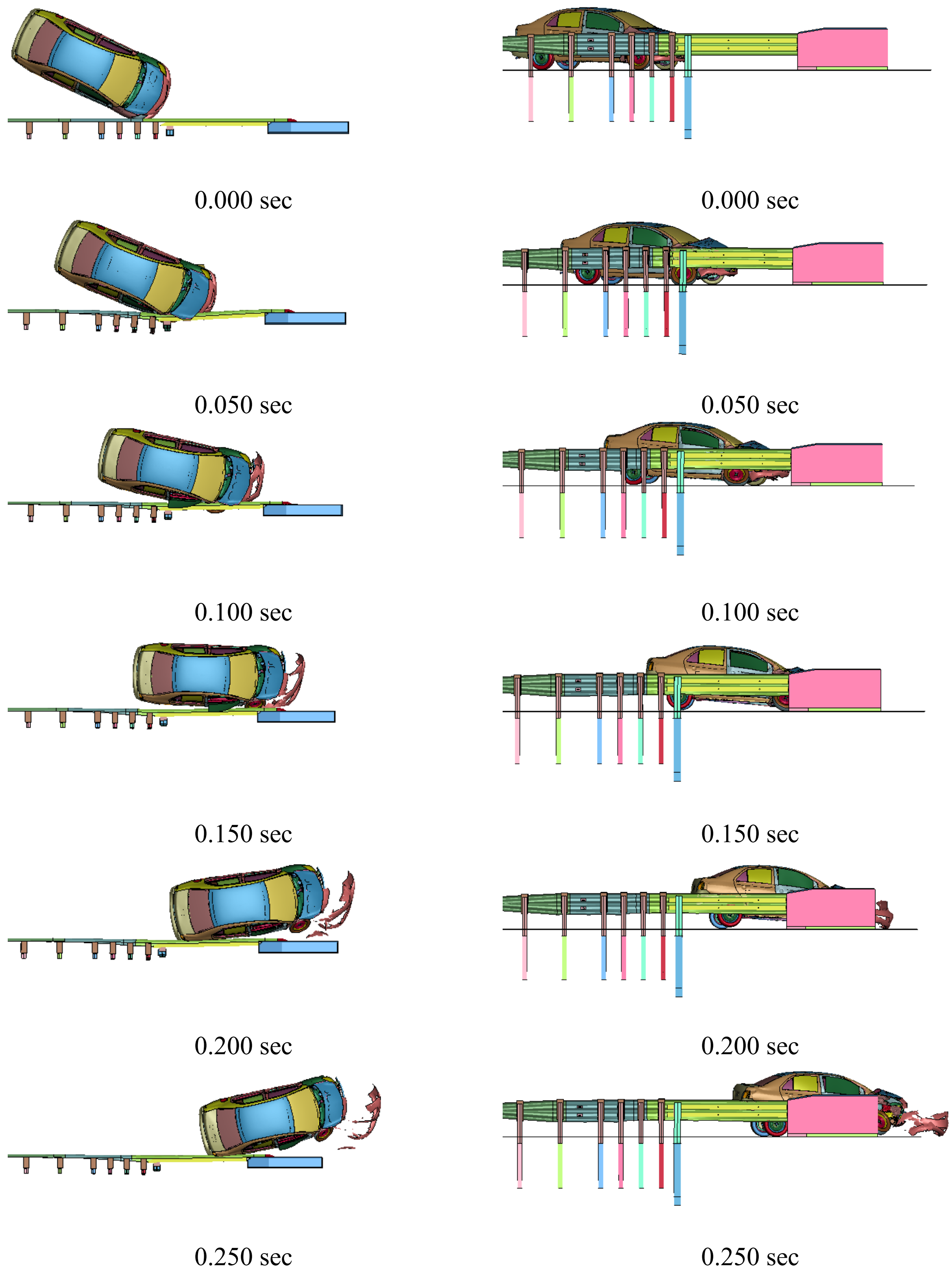


Figure 6.43 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at Post No. 3

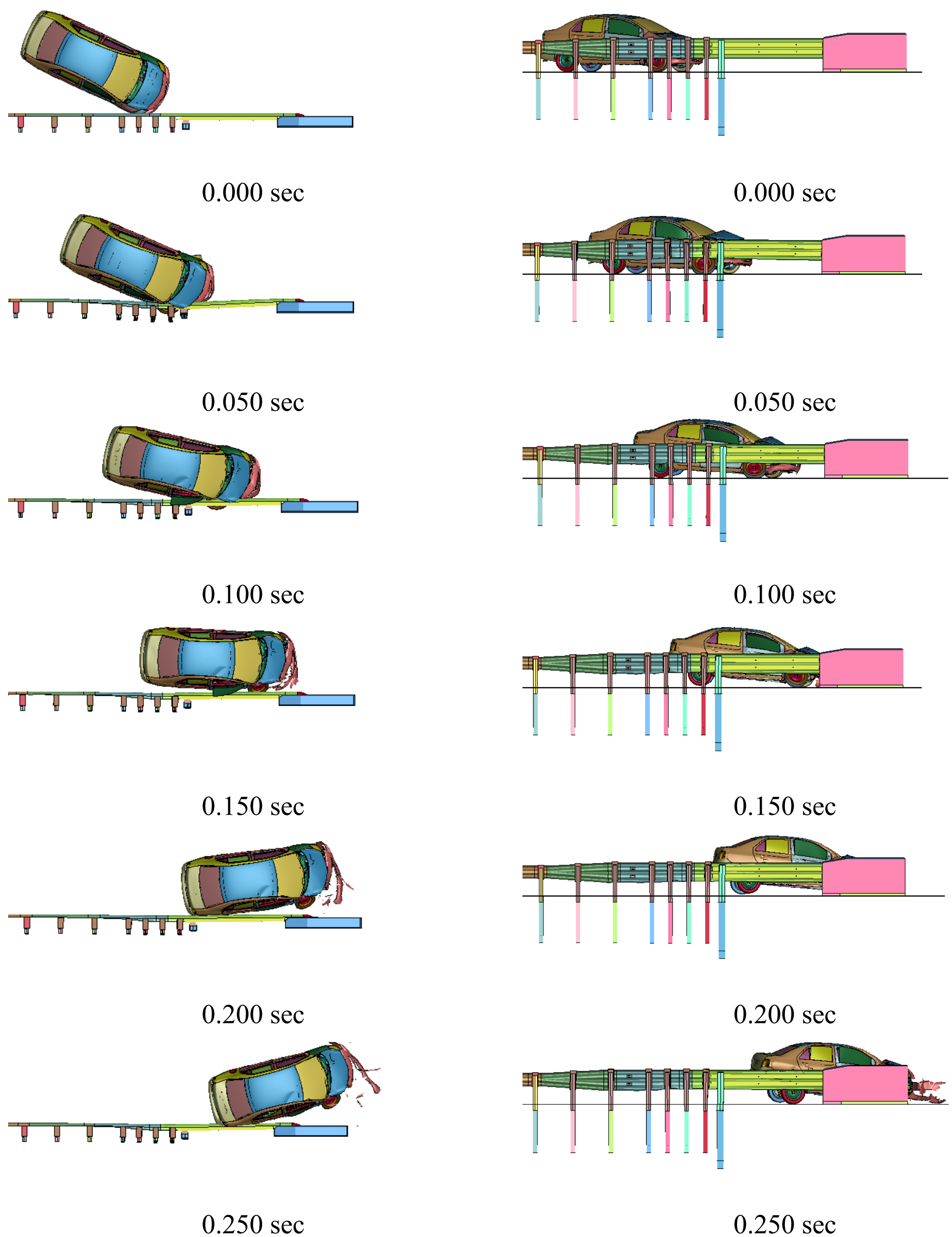


Figure 6.44 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at Post No. 4

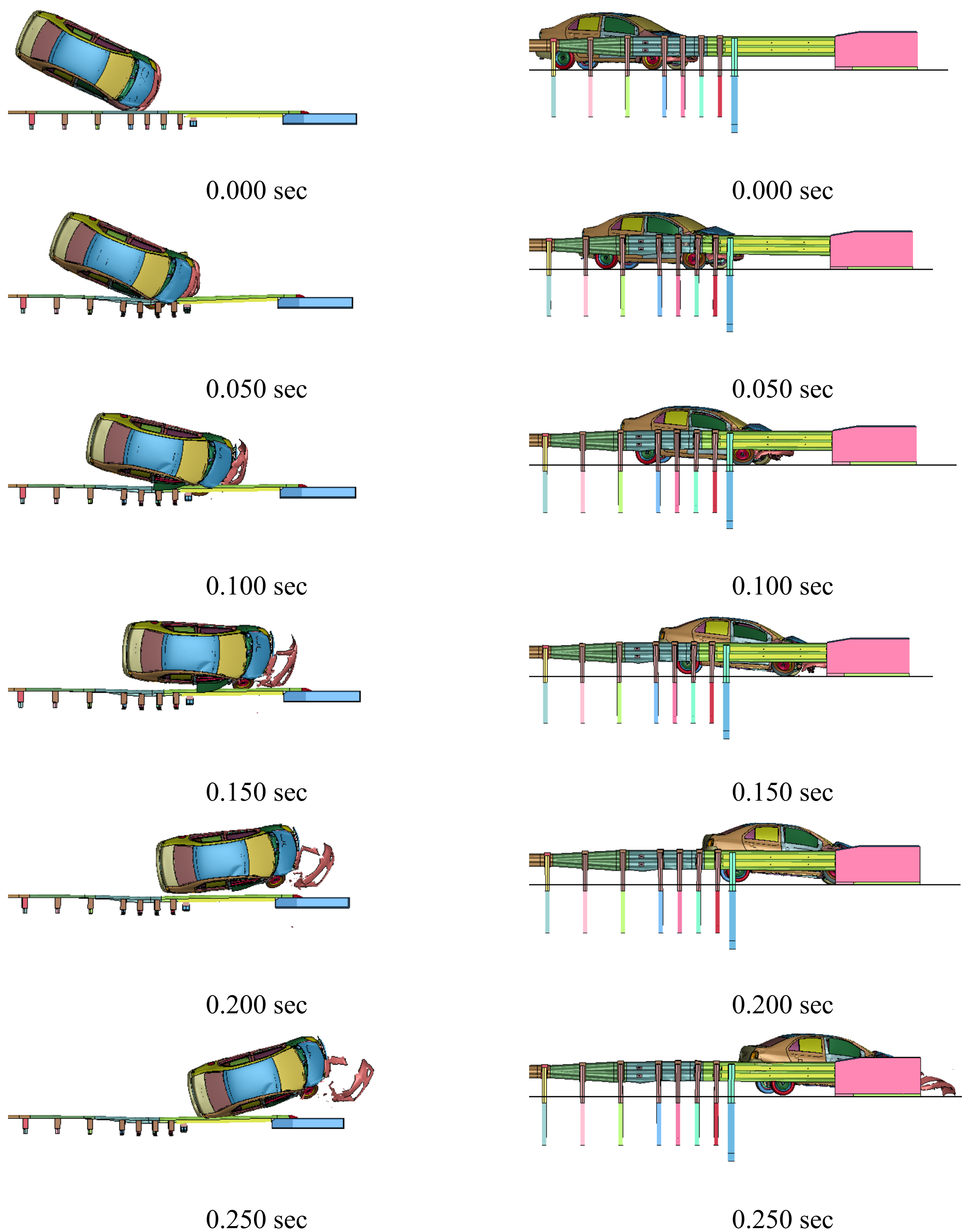


Figure 6.45 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at Post No. 5

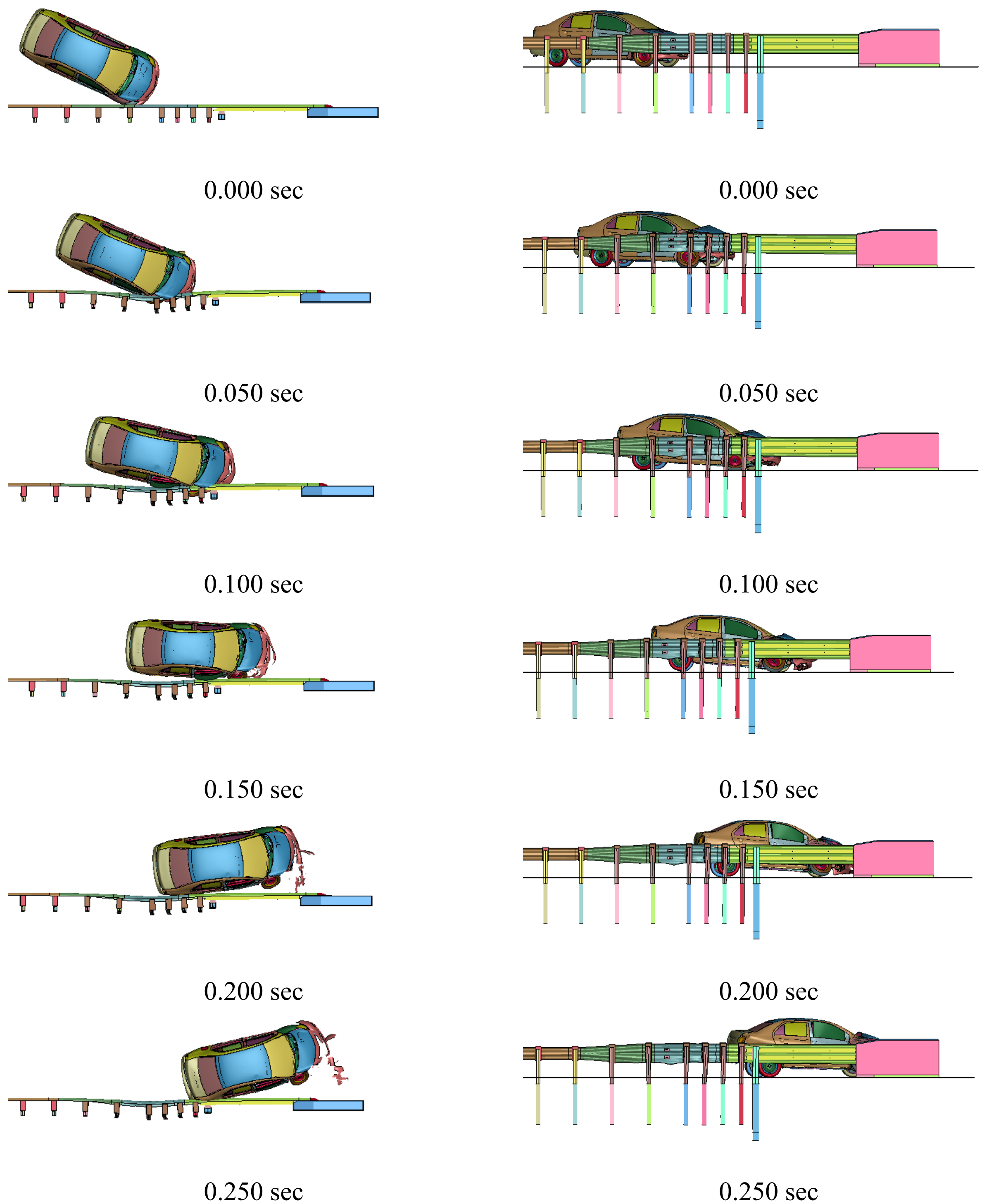


Figure 6.46 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at Post No. 6

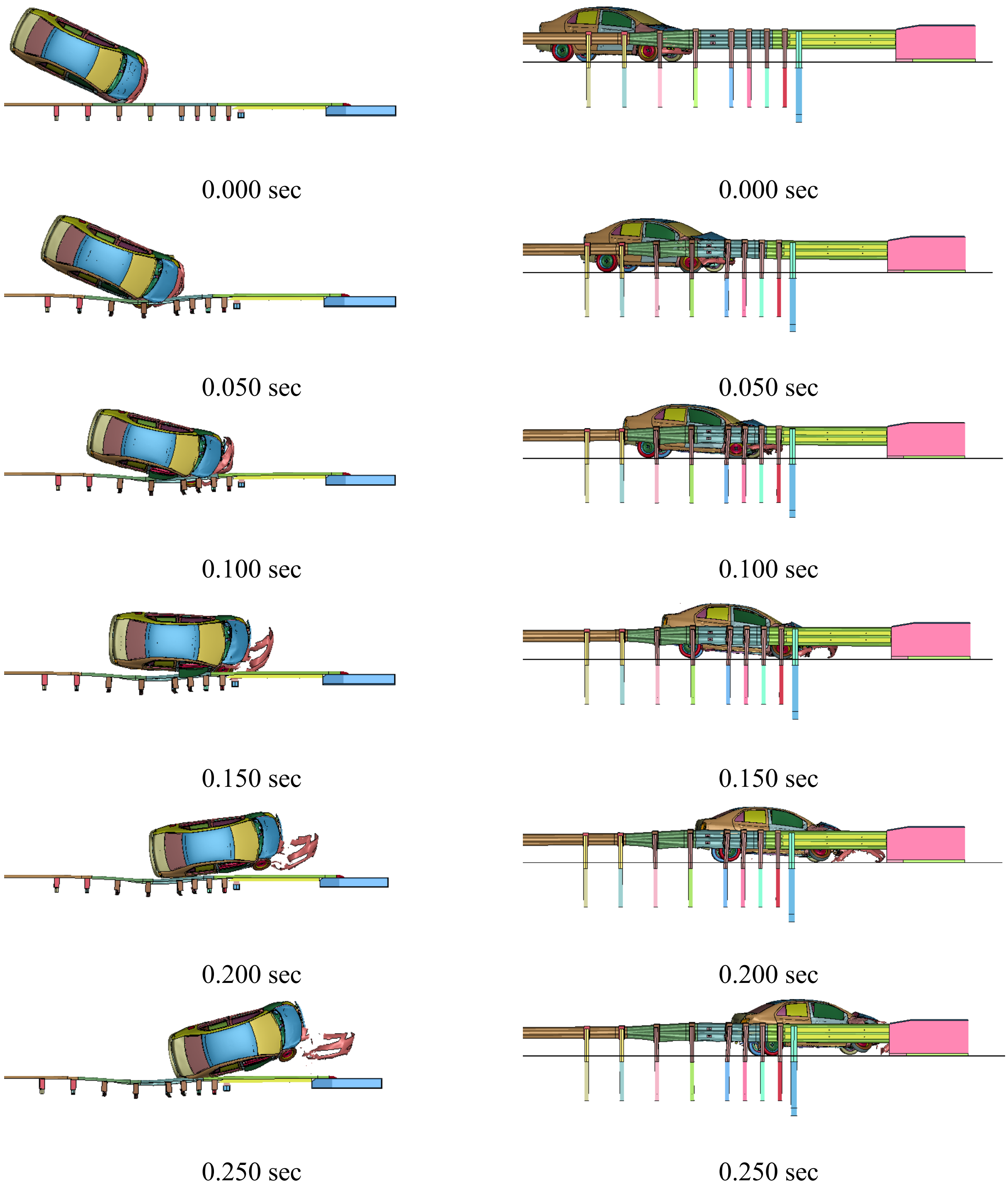


Figure 6.47 Sequential Images, 1100C Conventional Impact Direction (MASH Test Designation No. 3-20), Impact Point at Post No. 7

Chapter 7 Summary, Conclusions, and Future Research

7.1 Summary and Conclusions

The objective of this project was to develop and evaluate the standard 34-in. tall NDOT thrie-beam AGT system with increased span length between the concrete buttress end and the first transition post to accommodate a wide range of obstructions that prevent proper installation of posts, including bridge abutments and wing walls, as well as drainage and utility structures.

The research effort to develop and evaluate a MASH TL-3 compliant 34-in. NDOT thrie-beam AGT system with increased span length began with a review of previously developed and crash-tested AGT systems that have an increased span length between the concrete bridge rail end and the first transition post, as well as their associated design mechanisms. Previously developed and evaluated design retrofit concepts for existing AGTs were also reviewed. The research effort identified various critical obstructions near bridge ends through a survey of the NDOT districts. This survey information was utilized to identify the most critical obstructions and associated geometries as well as the desired maximum span length between the concrete bridge rail end and the first transition post.

Next, MwRSF researchers synthesized information regarding the design of long-span AGT configurations, retrofit design for AGTs, design and evaluation of mechanisms utilized for designing long-span structure connections, and obstructions commonly installed in Nebraska that prevent proper placement of AGT posts. The information was used to establish design criteria for the 34-in. tall NDOT AGT with an increased span length between the concrete bridge rail end and the first transition post. Multiple long-span AGT concepts were identified through an initial brainstorming effort. These AGT concepts utilized various design mechanisms to increase lateral stiffness and impact behavior and performance. Following the development of design concepts, a TAC meeting was held with NDOT to select the most promising design concept that would best accommodate the needs of NDOT. The TAC selected Design Concept #5, a double-tube system, for further development. Selection criteria were constructability, compatibility with the standard buttress, maintainability, and the likelihood of meeting MASH TL-3 performance.

An LS-DYNA model of the 34-in. tall NDOT thrie-beam AGT was previously developed by MwRSF researchers. Detailed validation of this model was performed using pickup and small car full-scale crash tests to ensure the feasibility of the AGT model to estimate the AGT system performance and behavior. Simulated impacts were consistent with MASH TL-3 impact criteria and evaluated. Within each simulation, occupant risk measures, vehicle rotations, system deflections, pocketing angles, and vehicle snag were documented and compared to full-scale crash tests conducted on the 34-in. tall NDOT AGT system (i.e., test nos. 34AGT-1 and 34AGT-2). Following identification of the preferred design concept, four tube options for Design Concept #5 were evaluated using LS-DYNA simulation under identical boundary conditions and attachments: HSS 4 in. x 4 in. x ¼ in., HSS 4 in. x 4 in. x $^3/_8$ in., HSS 4 in. x 4 in. x ½ in., and HSS 6 in. x 4 in. x $^1/_8$ in. Based on performance, handling weight, and connection demand, the research team selected the long span AGT system with the HSS 4 in. x 4 in. x 1/4 in. double tube configuration for further evaluation.

LS-DYNA computer simulations of MASH TL-3 impacts were conducted on the selected HSS 4 in. x 4 in. x ¼ in. dual-tube long-span AGT system. This system was evaluated with MASH test designation nos. 3-21 (pickup truck) and 3-20 (small car) impacts. MASH test designation no. 3-21 was simulated with conventional impacts originating from the thrie-beam to the concrete buttress, upstream impacts, and reverse-direction impacts from the concrete buttress to the thrie-beam. Several parameters were utilized to evaluate the design: (1) general vehicle behavior and snag on any system components; (2) occupant risk – longitudinal and lateral OIV and ORA; (3) stresses in dual-beam system as well as various components compared to yield and ultimate stresses; and (4) other MASH metrics.

LS-DYNA computer simulations were also used to identify critical impact points (CIPs) for both full-scale crash tests required by MASH TL-3 evaluation criteria. Multiple impacts were simulated on the long-span AGT system with both vehicles to identify the impact point that would maximize vehicle snag and thereby maximize the potential for excessive decelerations, occupant compartment crush, and/or vehicle instabilities. The CIP for MASH test designation no. 3-21 was determined to be 89 in. upstream from the concrete buttress to maximize occupant risk values and the potential for snagging on the buttress. The CIP for MASH test designation no. 3-20 was determined to be 65 in. upstream from the concrete buttress to maximize wedging of the small car tire under the concrete buttress and the potential for snagging on the buttress. LS-DYNA computer simulations of reverse-direction impacts showed no indication of significant pocketing or snag.

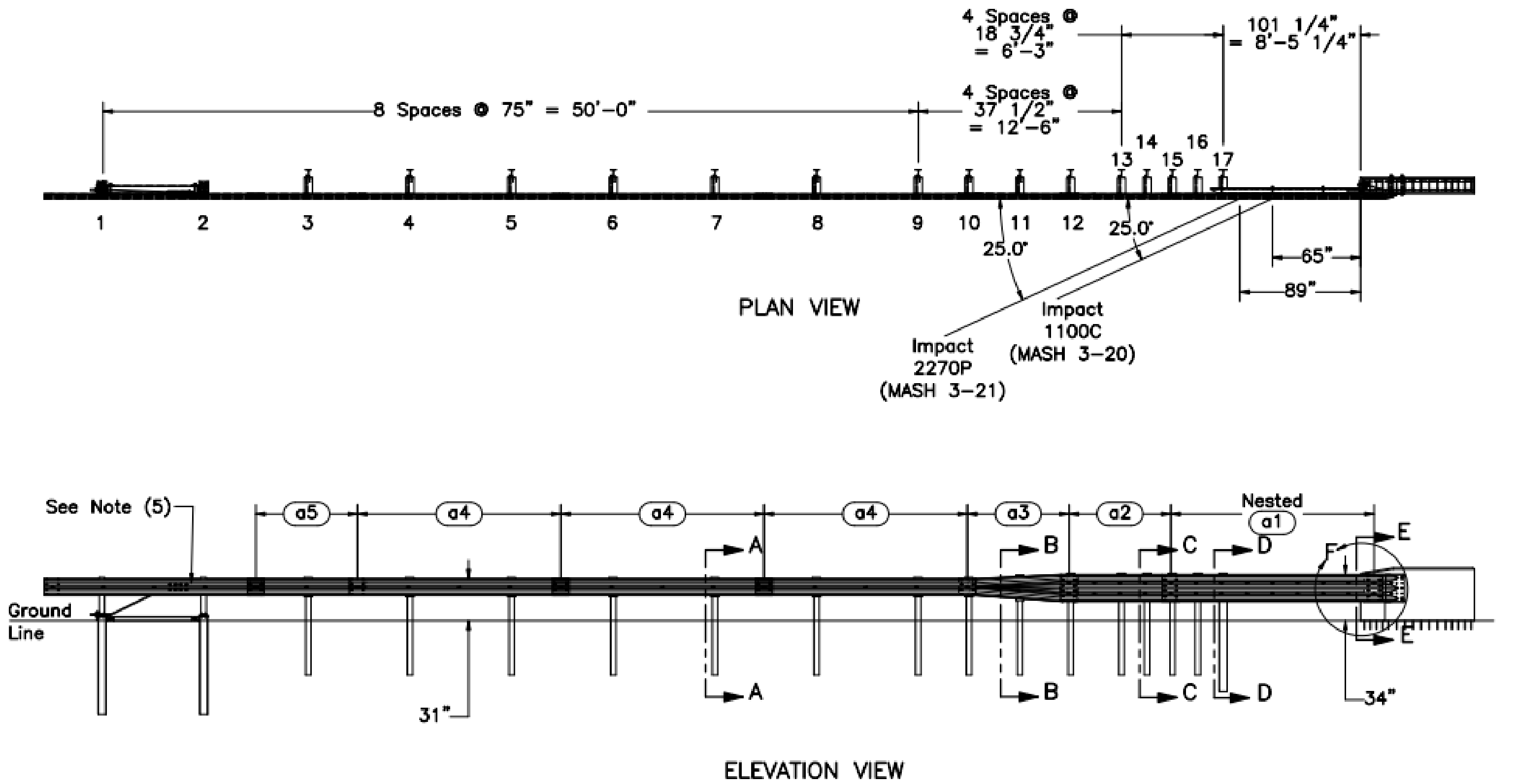
LS-DYNA computer simulations of upstream impacts did not show indication of significant pocketing at the W-to-thrie beam transition. Furthermore, crash testing of upstream transition before and after overlay was deemed non-critical during the development and evaluation of the standard NDOT 34-in. tall AGT system. Performance of the long-span AGT system was comparable to the standard NDOT 34-in. tall AGT. Therefore, crash testing of the upstream transition with both vehicles was deemed non-critical.

7.2 Future Research

This project developed and evaluated the 34-in. tall NDOT thrie-beam AGT system with increased span length between the concrete bridge end and the first transition post that would provide NDOT with crashworthy and cost-effective solutions for avoiding installation issues adjacent to the bridge end, where various obstructions (i.e., drains, foundations, utilities, etc.)

could prevent proper post placement. The new AGT system was developed to satisfy MASH TL-3 performance criteria while accommodating a wide range of obstructions by providing increased span length. Additionally, the newly developed increased span length would provide roadside designers with crashworthy solutions for non-ideal installation sites and reduce the costs associated with relocations of obstructions. Full-scale crash testing is required to fully evaluate whether the newly developed 34-in. tall NDOT AGT with an increased span between the end of the concrete bridge rail and the first transition post satisfies MASH TL-3 performance criteria. If NDOT desires a more complete evaluation of the potential designs, a Phase II research effort will be necessary. A Phase II research effort would consist of full-scale crash testing of the developed long-span AGT system according to MASH TL-3 impact safety standards.

The preliminary design details for the newly developed long-span AGT system are shown in Figure 7.1 through Figure 7.42. This report presents two connection concepts for attaching the two-steel tube system to the concrete buttress. Concept 1 uses a steel-tube socket; see Figure 7.1 through Figure 7.21, and Concept 2 uses a C-channel anchor assembly; see Figure 7.22 through Figure 7.42.



Notes: (1) Tests shall be performed according to test designation nos. 3-20 and 3-21 of MASH criteria.
(2) Test designation 3-20 impact location is 65" upstream from the buttress.
(3) Test designation 3-21 impact location is 89" upstream from the buttress.
(4) The upstream end of part a3 is rotated upward 3/4" to accommodate the 31" MGS guardrail height.
(5) See SPTA_Final-V2 for anchor system details.

MwRSF Midwest Roadside Safety Facility	NDOT AGT With Increased Span Length Increased Blockout System Layout	SHEET: 1 of 21 DATE: 9/26/2025 DRAWN BY: JRD/JCS
DWG. NAME. AGTL-C1-IB	SCALE: 1:110 UNITS: in.	REV. BY: JJO

Figure 7.1 NDOT AGT With Increased Span Length, System Layout, Concept 1

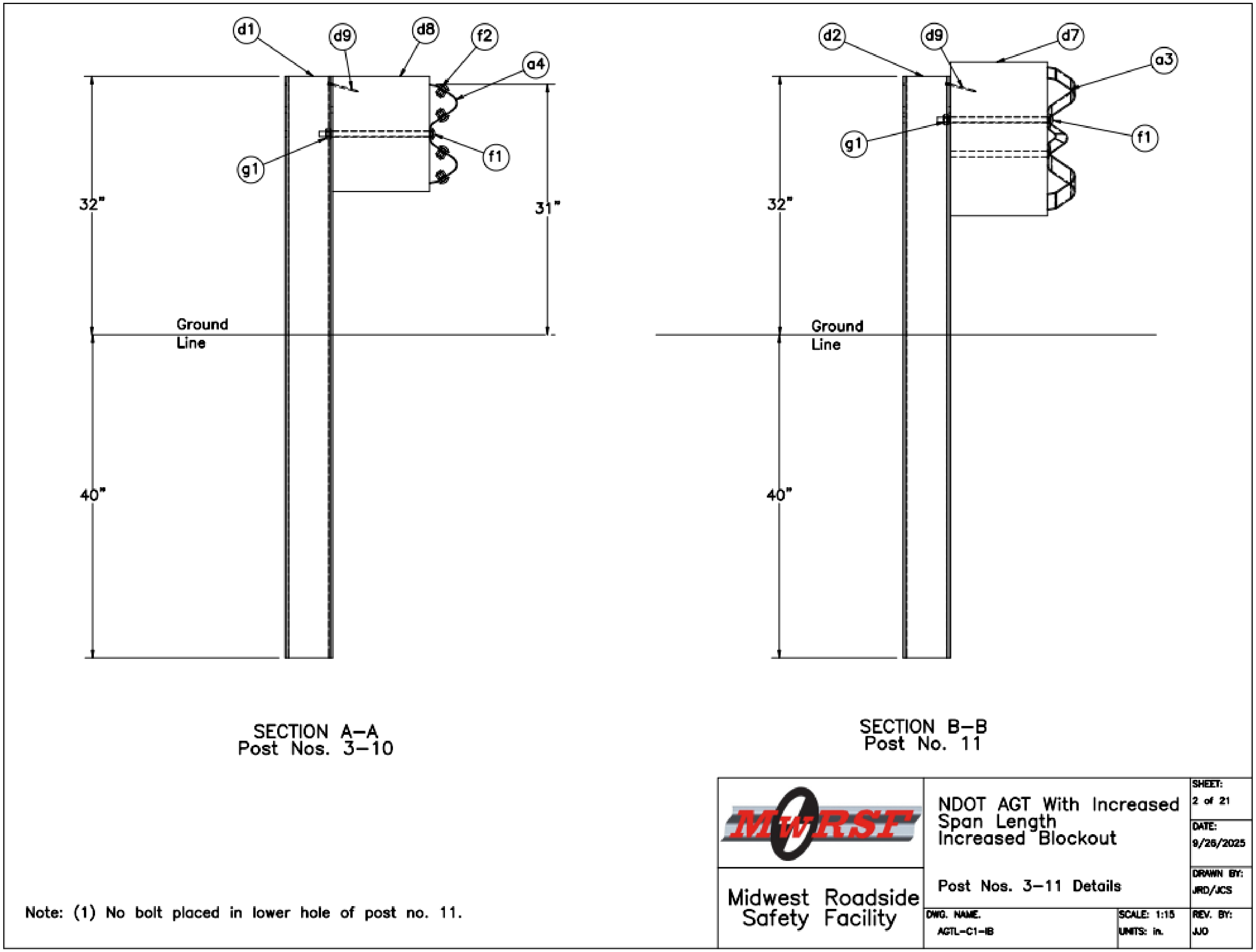


Figure 7.2 NDOT AGT With Increased Span Length, Post Nos. 3-11 Details, Concept 1

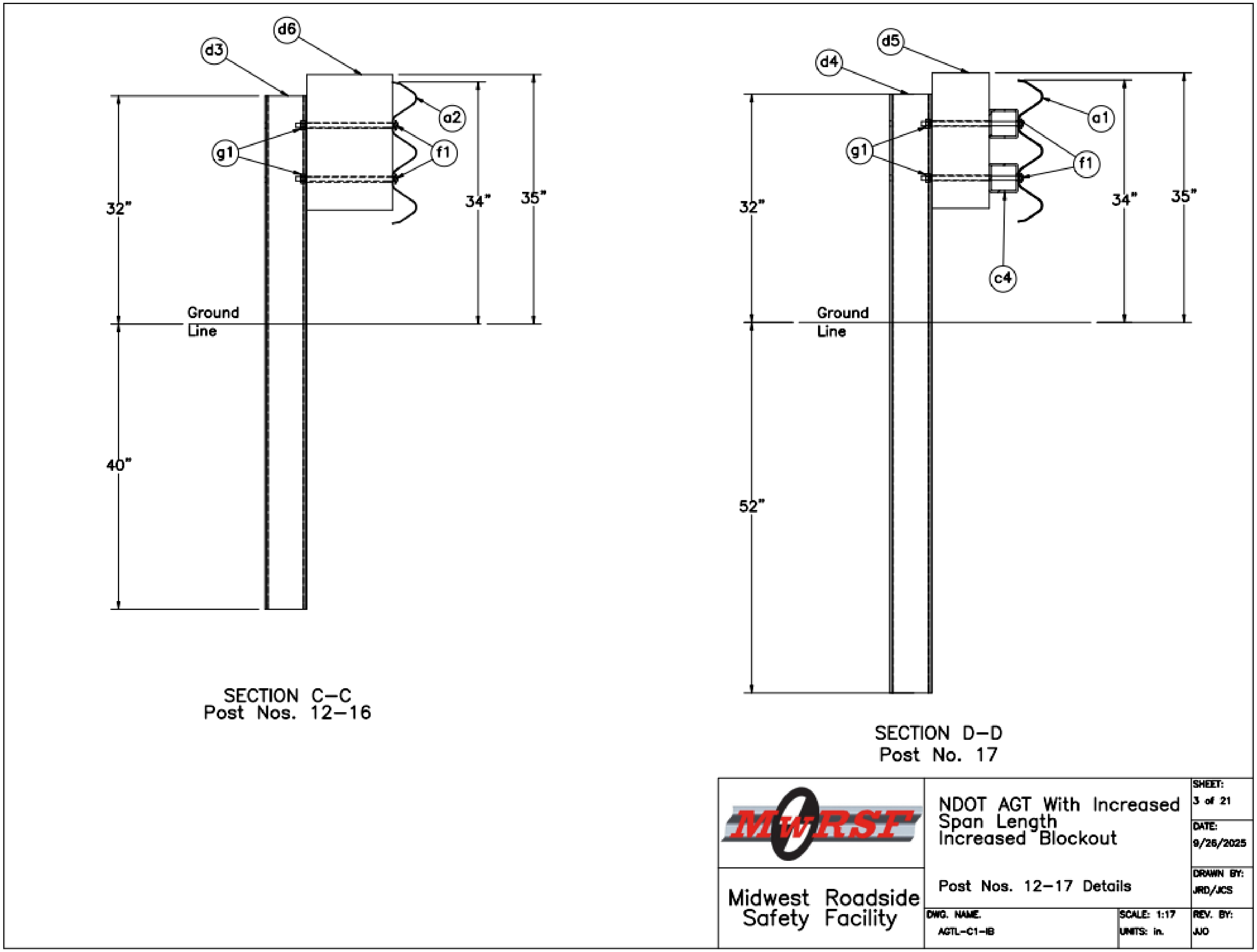


Figure 7.3 NDOT AGT With Increased Span Length, Post Nos. 12-19 Details, Concept 1

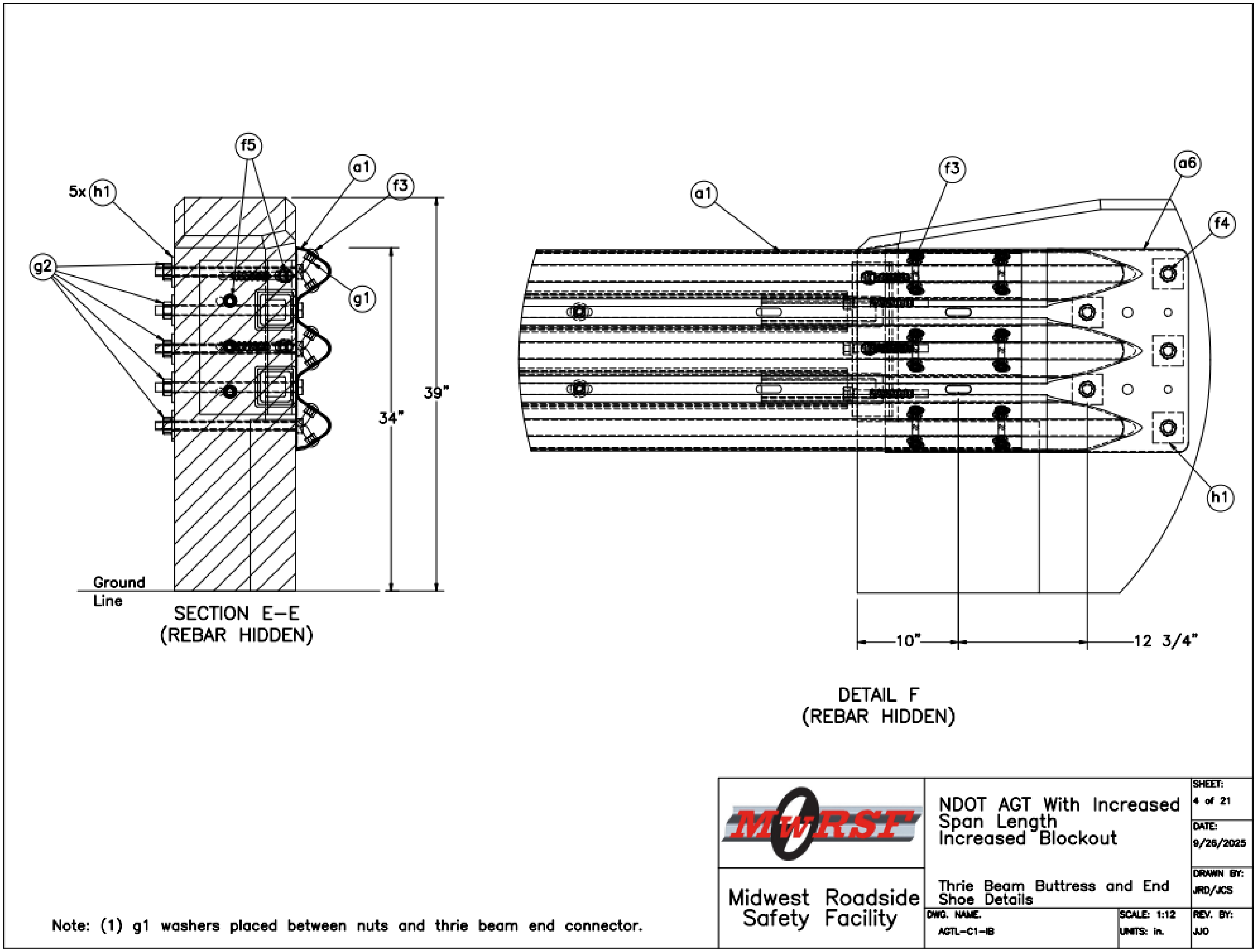


Figure 7.4 NDOT AGT With Increased Span Length, Thrie-Beam Buttress and End Shoe Details, Concept 1

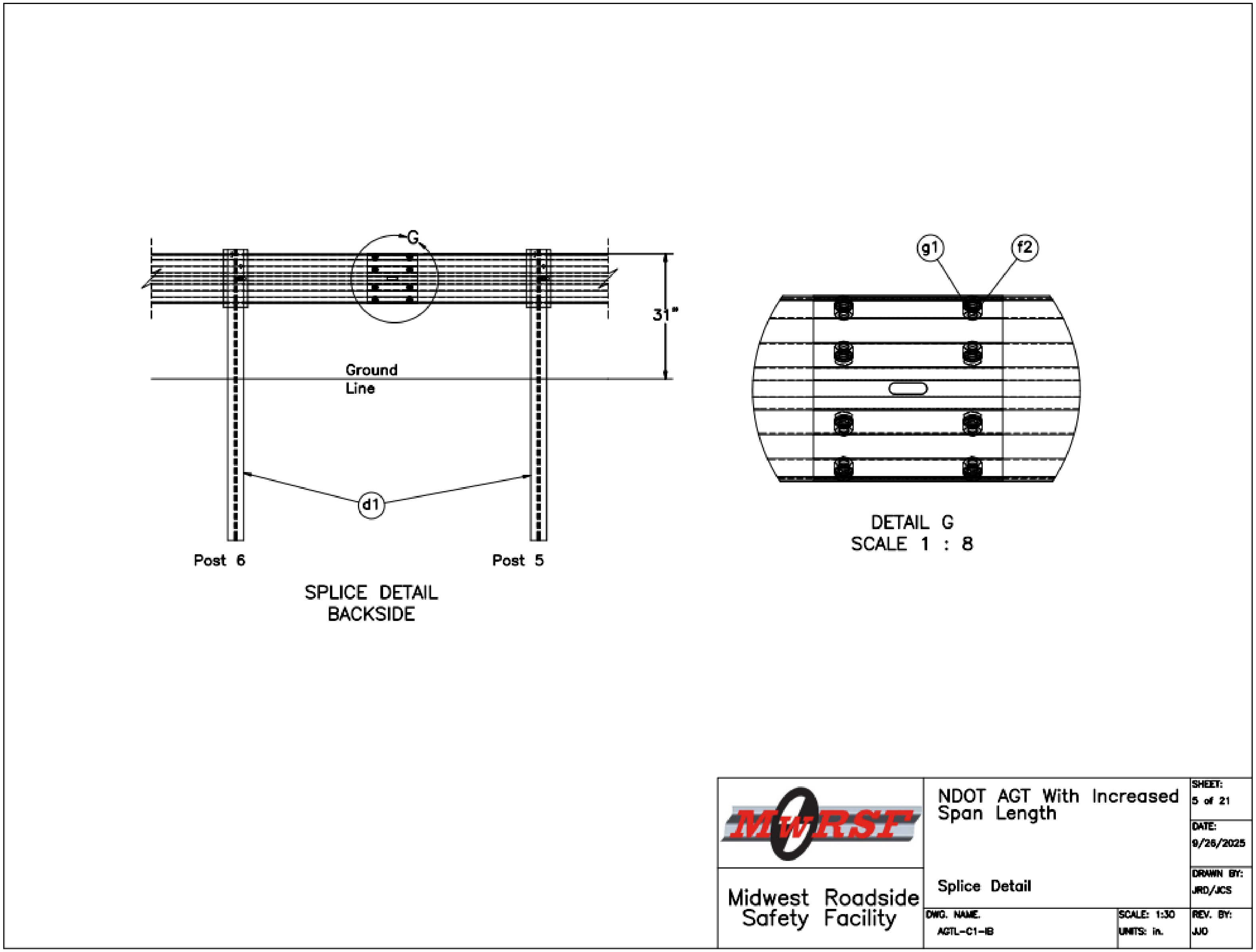


Figure 7.5 NDOT AGT With Increased Span Length, Splice Details, Concept 1

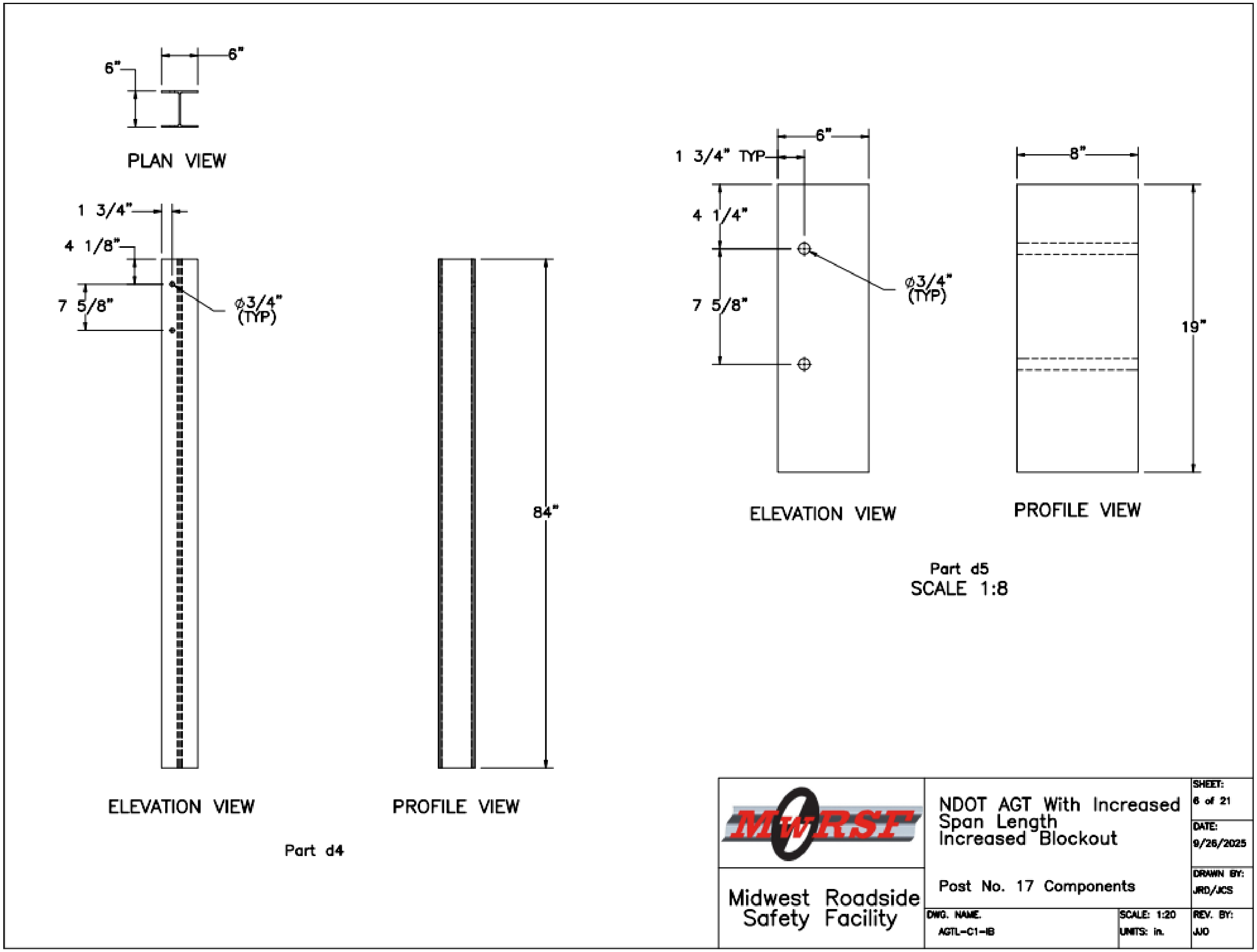


Figure 7.6 NDOT AGT With Increased Span Length, Post No. 17 Components, Concept 1

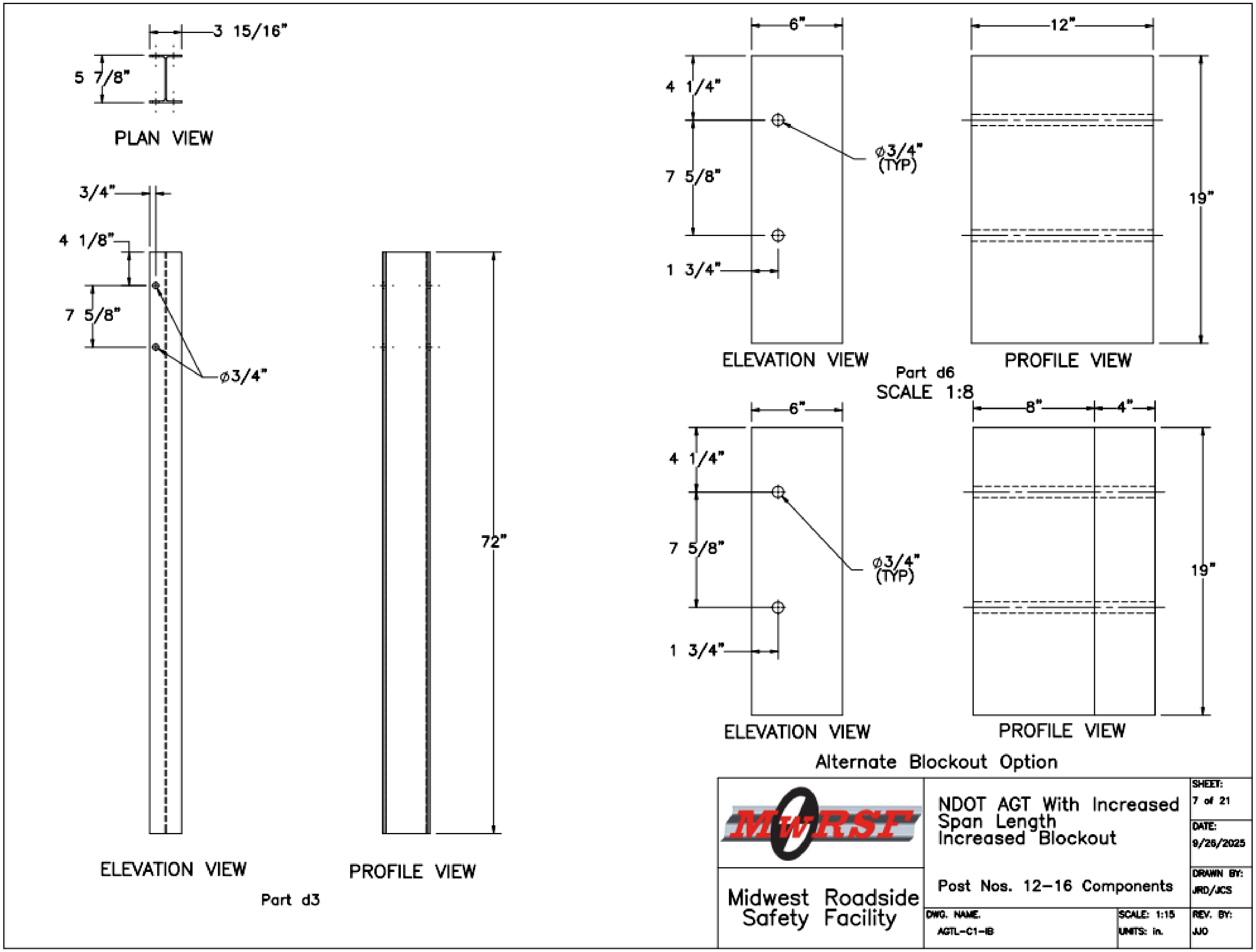


Figure 7.7 NDOT AGT With Increased Span Length, Post Nos. 12-16 Components, Concept 1

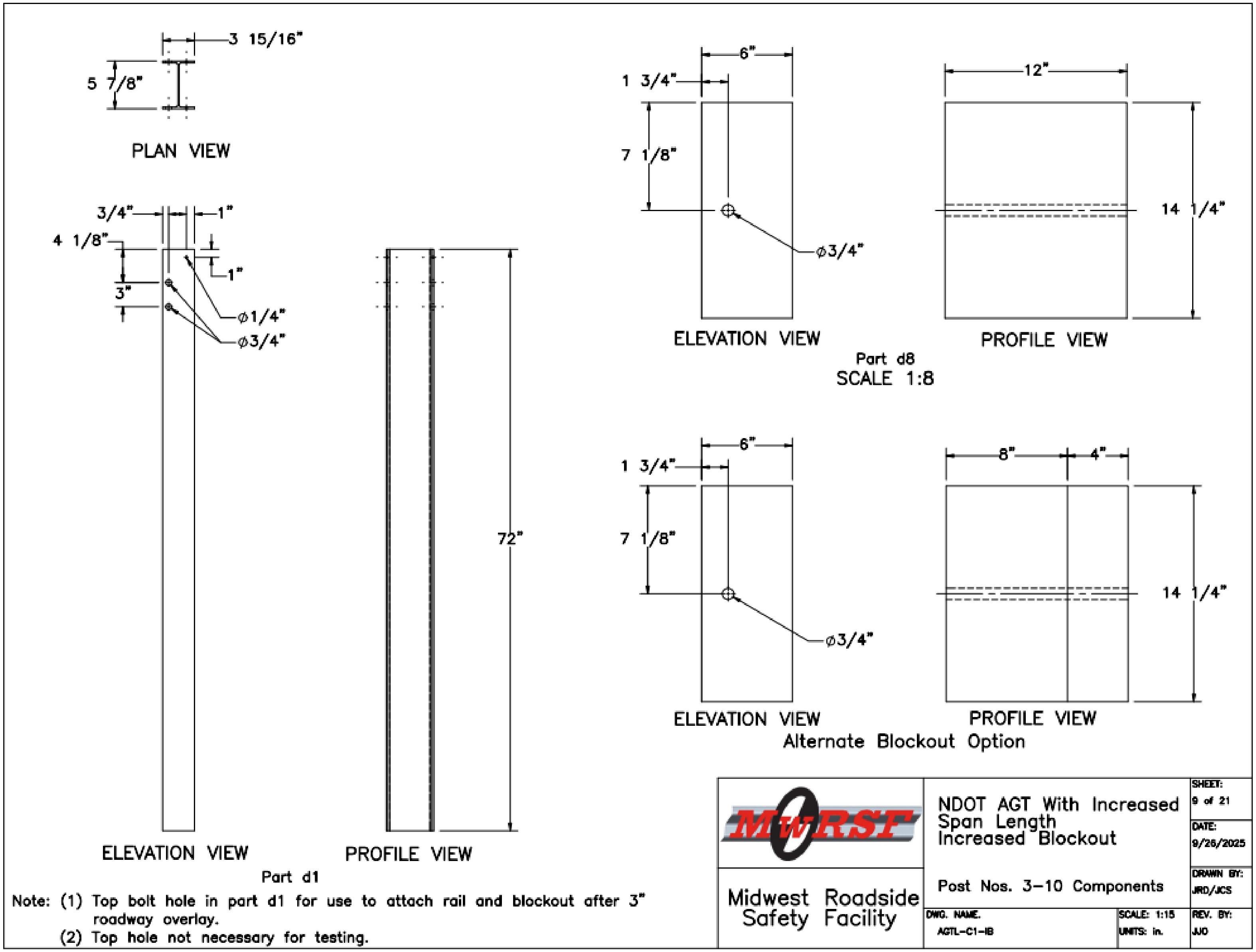


Figure 7.8 NDOT AGT With Increased Span Length, Post Nos. 3–10 Components, Concept 1

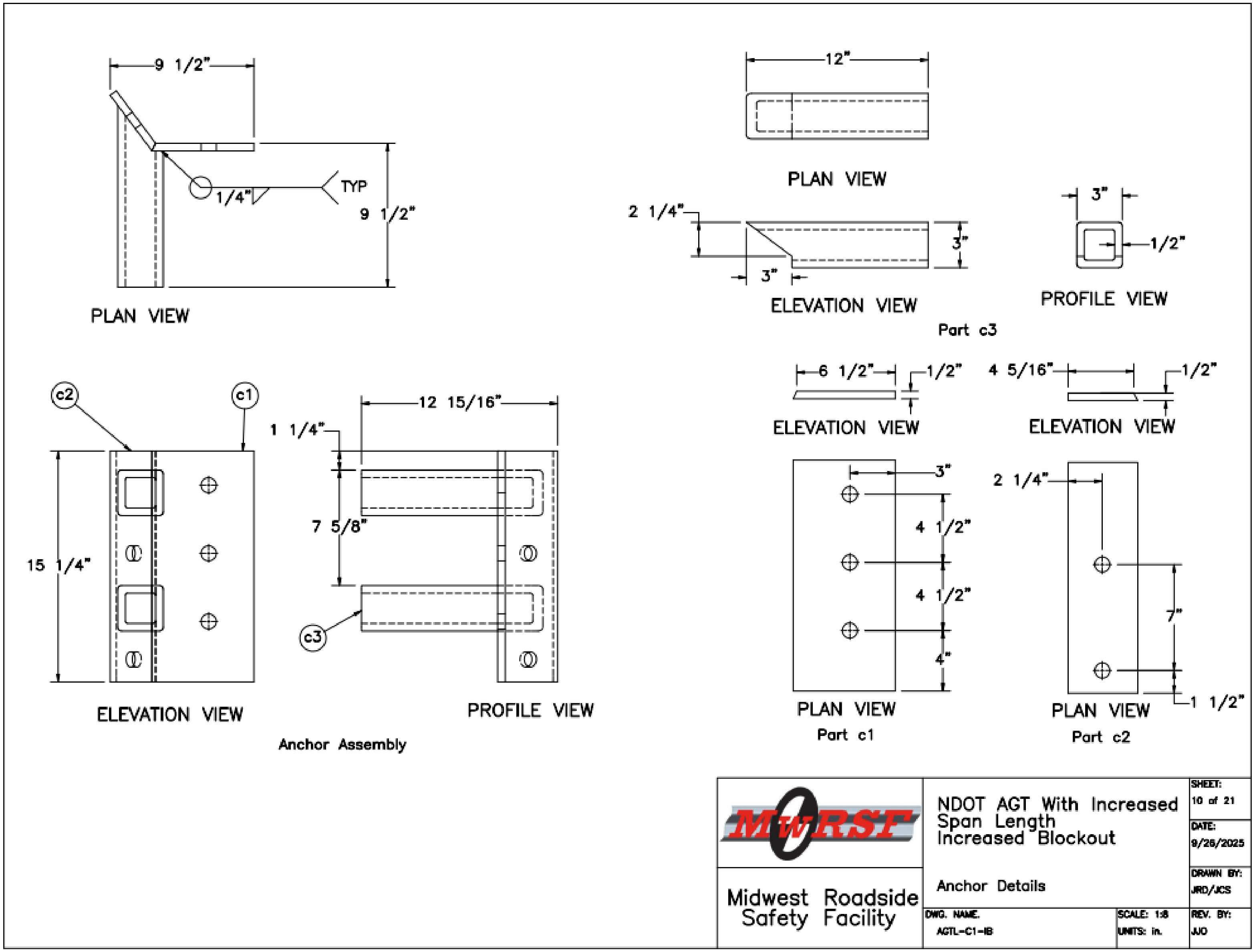


Figure 7.9 NDOT AGT With Increased Span Length, Anchor Details, Concept 1

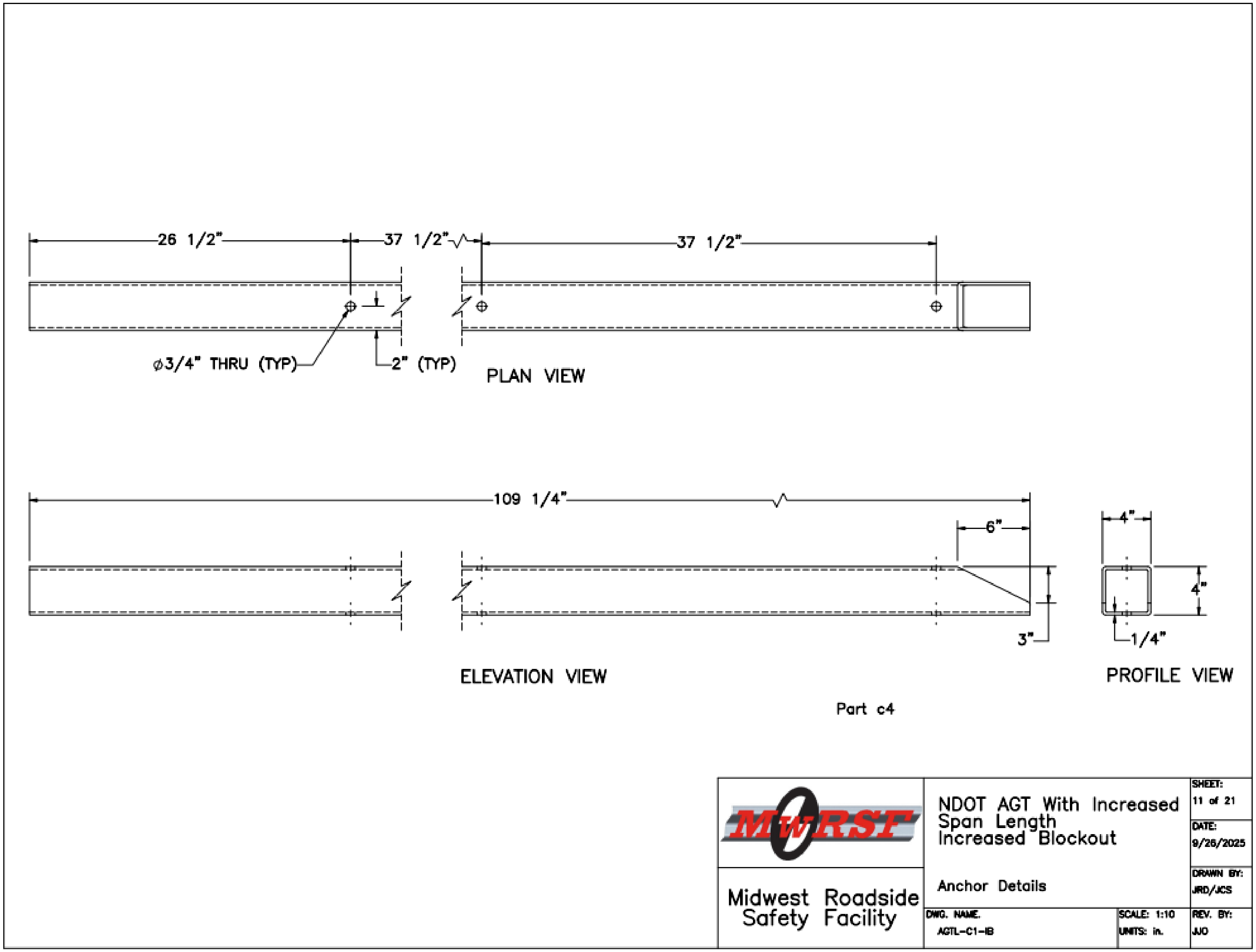


Figure 7.10 NDOT AGT With Increased Span Length, Anchor Details, Concept 1

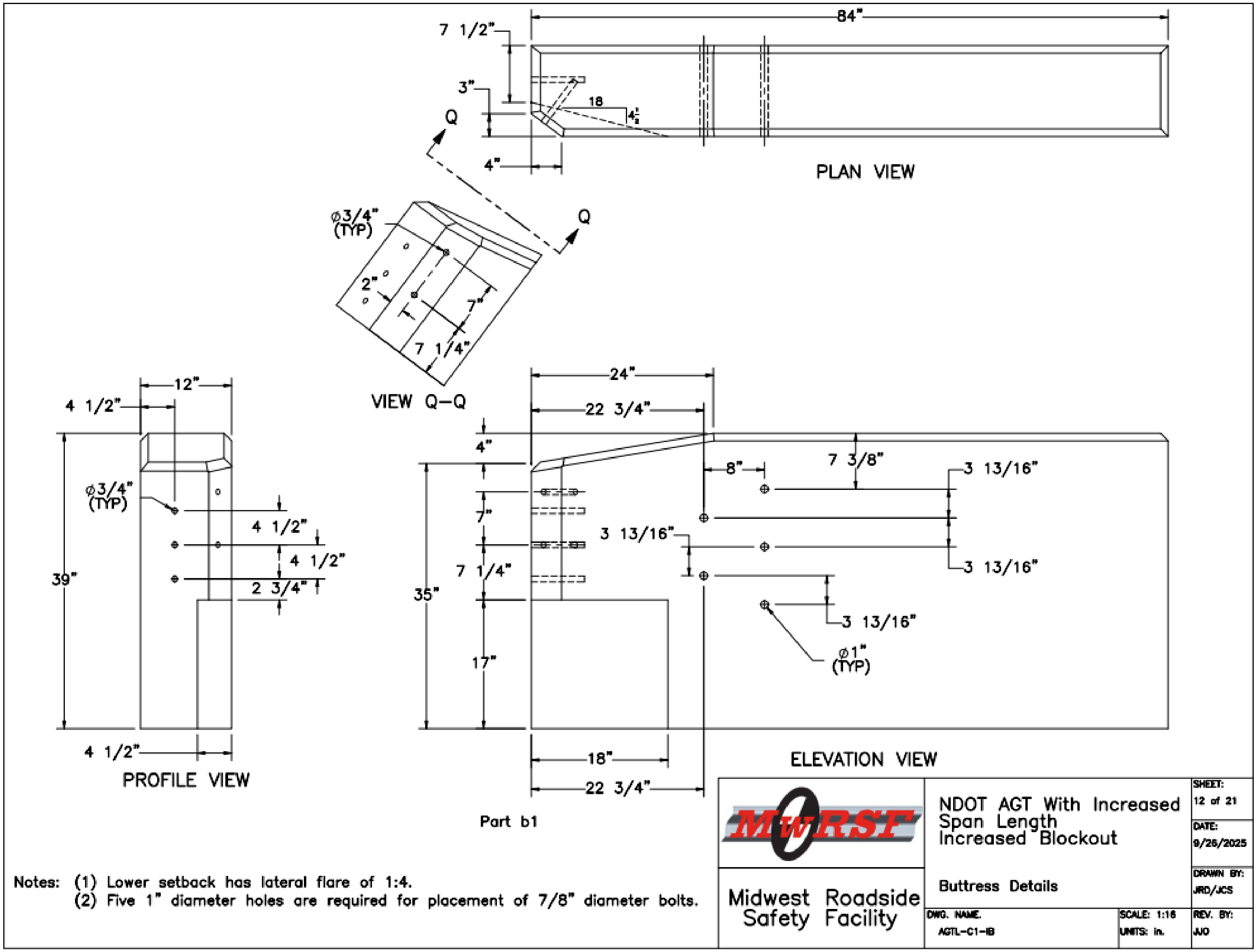


Figure 7.11 NDOT AGT With Increased Span Length, Buttress Details, Concept 1

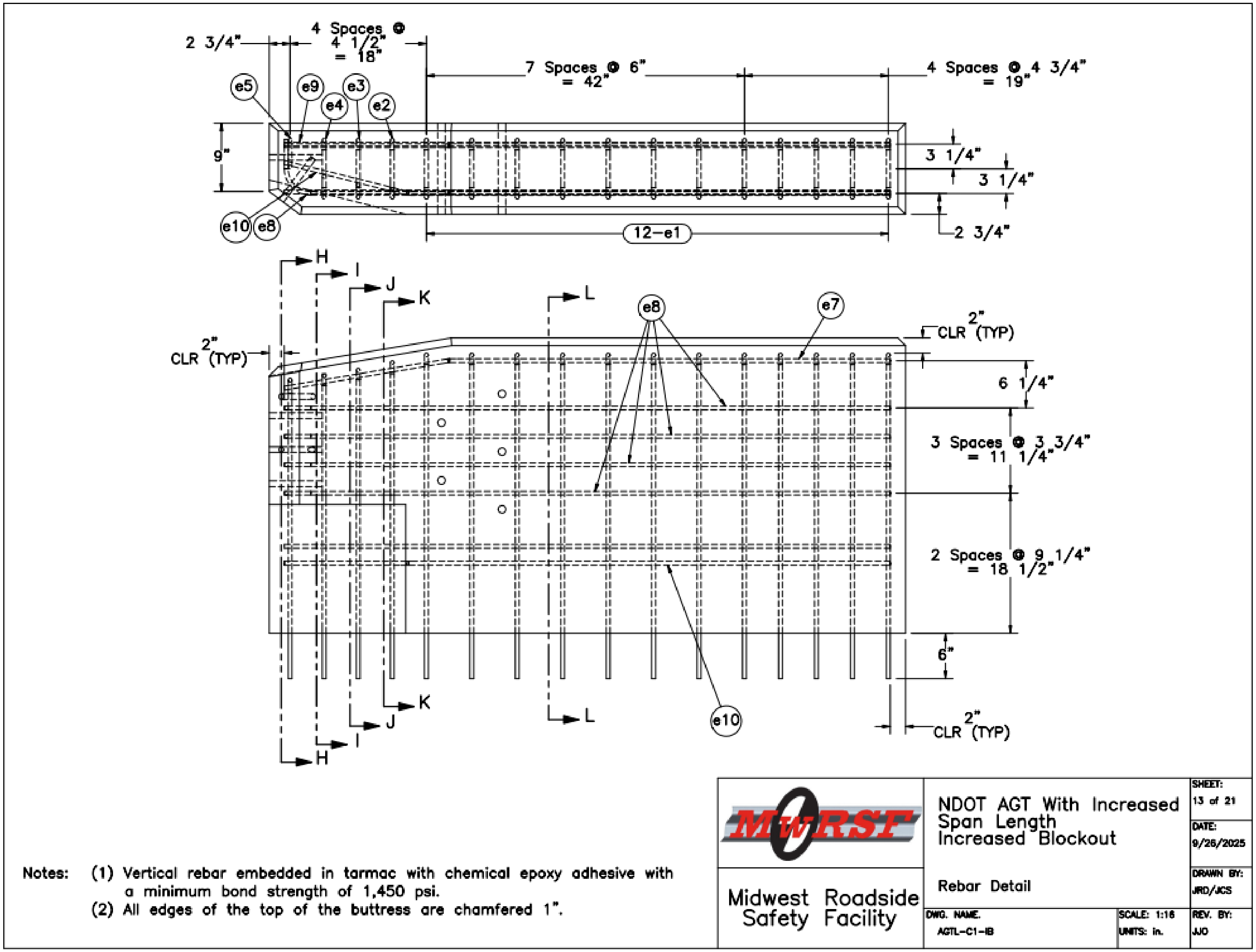
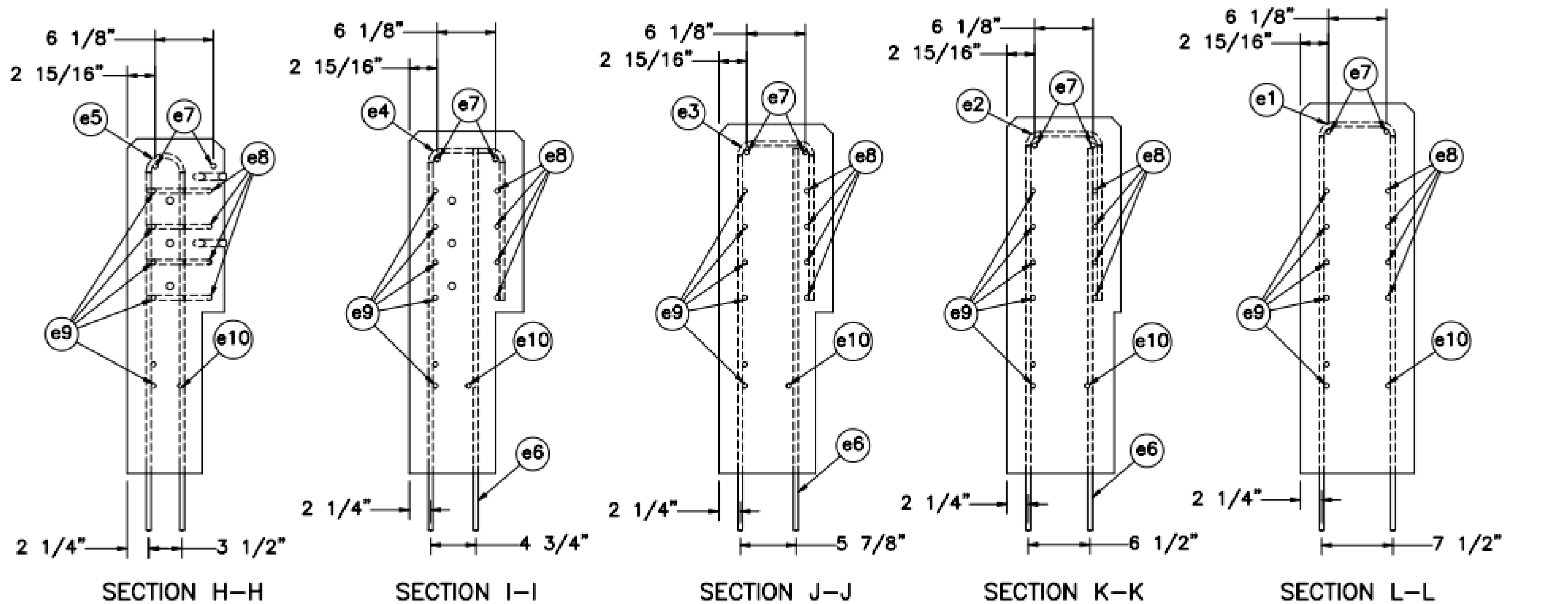


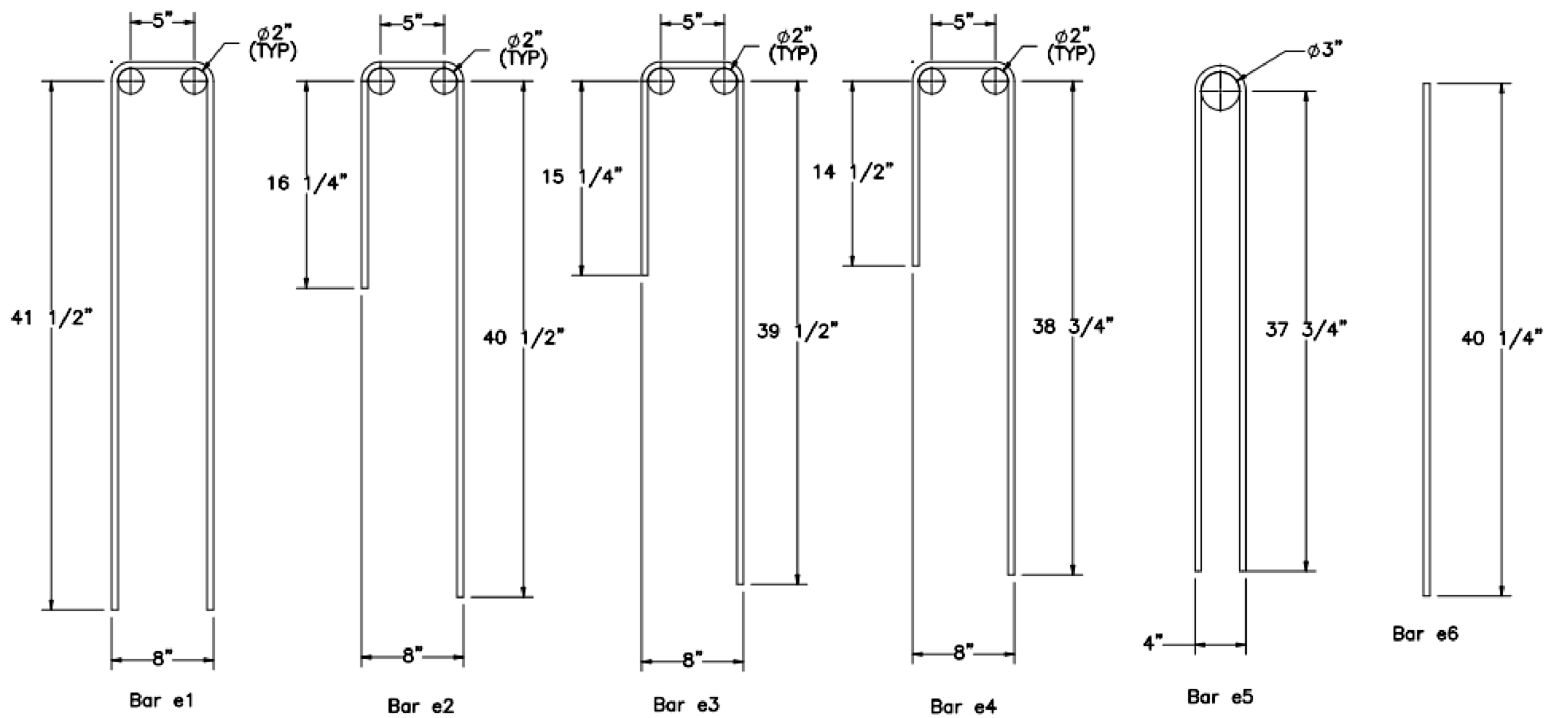
Figure 7.12 NDOT AGT With Increased Span Length, Rebar Details, Concept 1



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

Midwest Roadside Safety Facility	NDOT AGT With Increased Span Length Increased Blockout	SHEET: 14 of 21
		DATE: 9/26/2025
	Buttress Sections	DRAWN BY: JRD/JCS
DWG. NAME. AGTL-C1-IB	SCALE: 1:16 UNITS: in.	REV. BY: JJO

Figure 7.13 NDOT AGT With Increased Span Length, Buttress Sections, Concept 1



Bill of Bars					
Bar	QTY	Size	Length	Material	Treatment
e1	12	#4	92"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e2	1	#4	65 3/4"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e3	1	#4	63 1/2"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e4	1	#4	62 1/4"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e5	1	#4	80 3/4"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e6	1	#4	40 1/4"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)

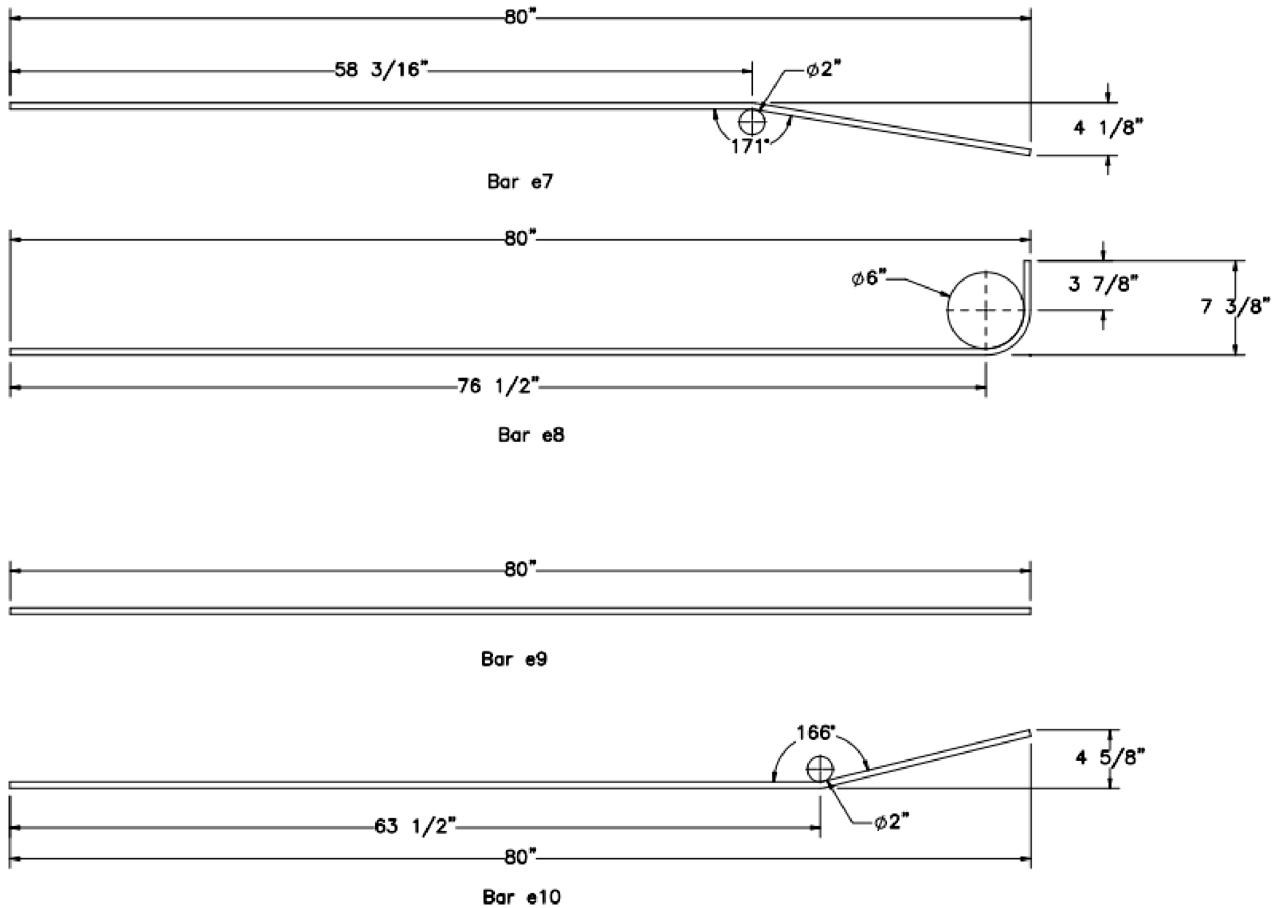
Midwest Roadside Safety Facility

NDOT AGT With Increased Span Length Increased Blockout

Vertical Rebar Details

SHEET: 15 of 21
DATE: 9/26/2025
DRAWN BY: JRD/JCS
DWG. NAME. AGTL-C1-IB
SCALE: 1:12
UNITS: in.
REV. BY: JJO

Figure 7.14 NDOT AGT With Increased Span Length, Vertical Rebar Details, Concept 1



Bill of Bars					
Bar	QTY	Size	Length	Material	Treatment
e7	2	#4	80 1/4"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e8	4	#4	85 1/2"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e9	5	#4	80"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e10	1	#4	80 1/2"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)

Midwest Roadside Safety Facility

NDOT AGT With Increased Span Length Increased Blockout

Horizontal Rebar Details

SHEET: 16 of 21
DATE: 9/26/2025
DRAWN BY: JRD/JCS
DWG. NAME. AGTL-C1-IB
SCALE: 1:12
UNITS: in.
REV. BY: JJO

Figure 7.15 NDOT AGT With Increased Span Length, Horizontal Rebar Details, Concept 1

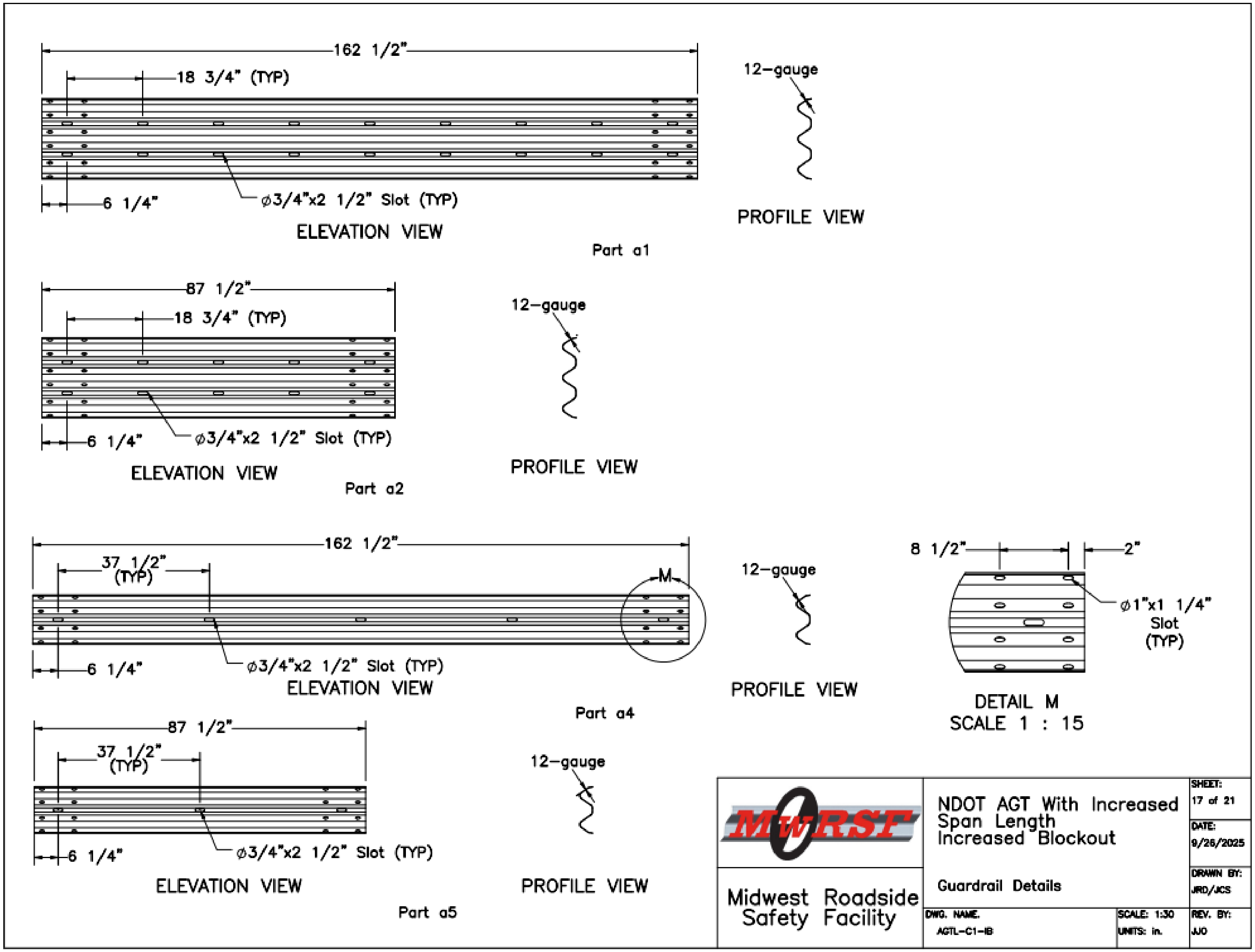


Figure 7.16 NDOT AGT With Increased Span Length, Guardrail Details, Concept 1

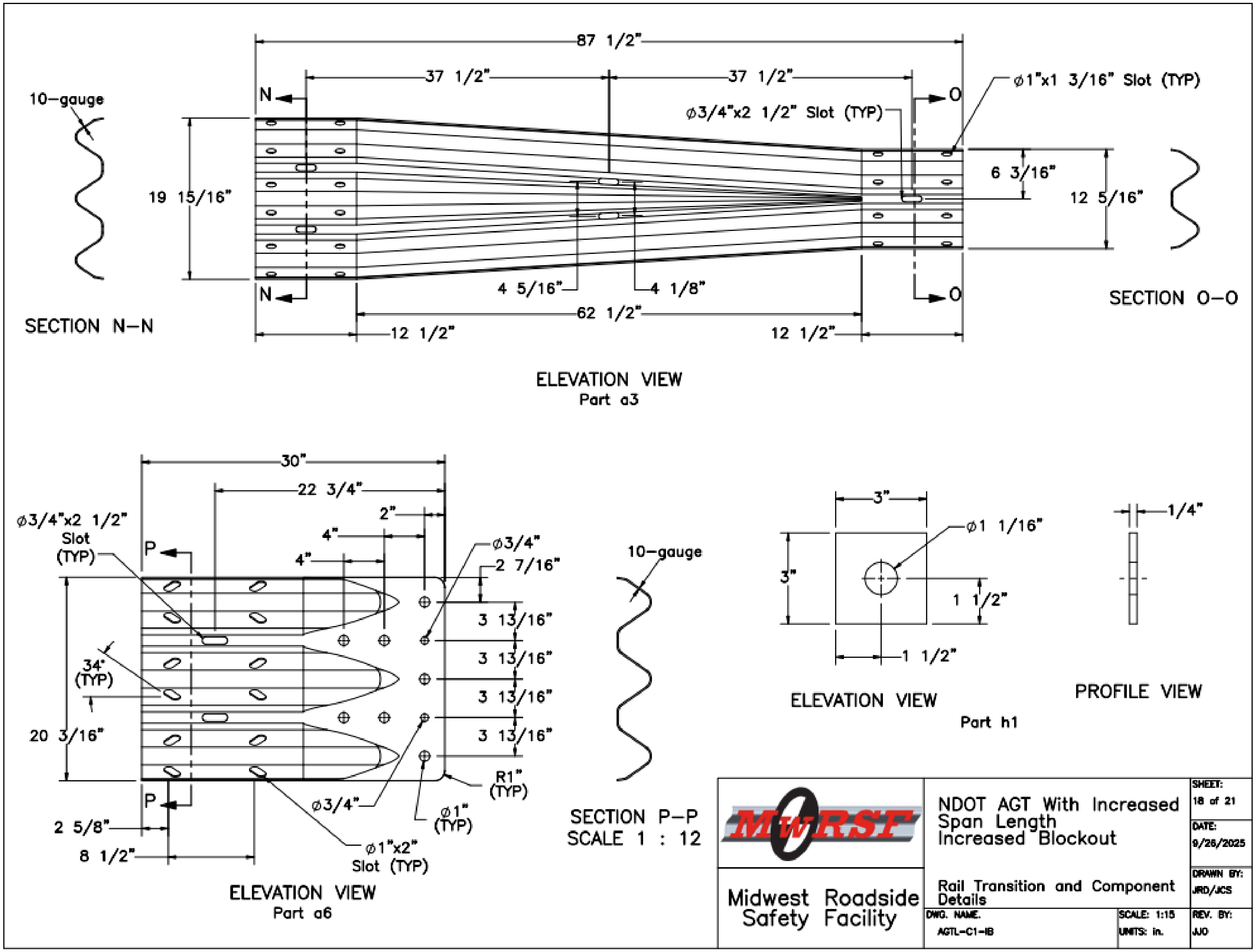


Figure 7.17 NDOT AGT With Increased Span Length, Rail Transition and Component Details, Concept 1

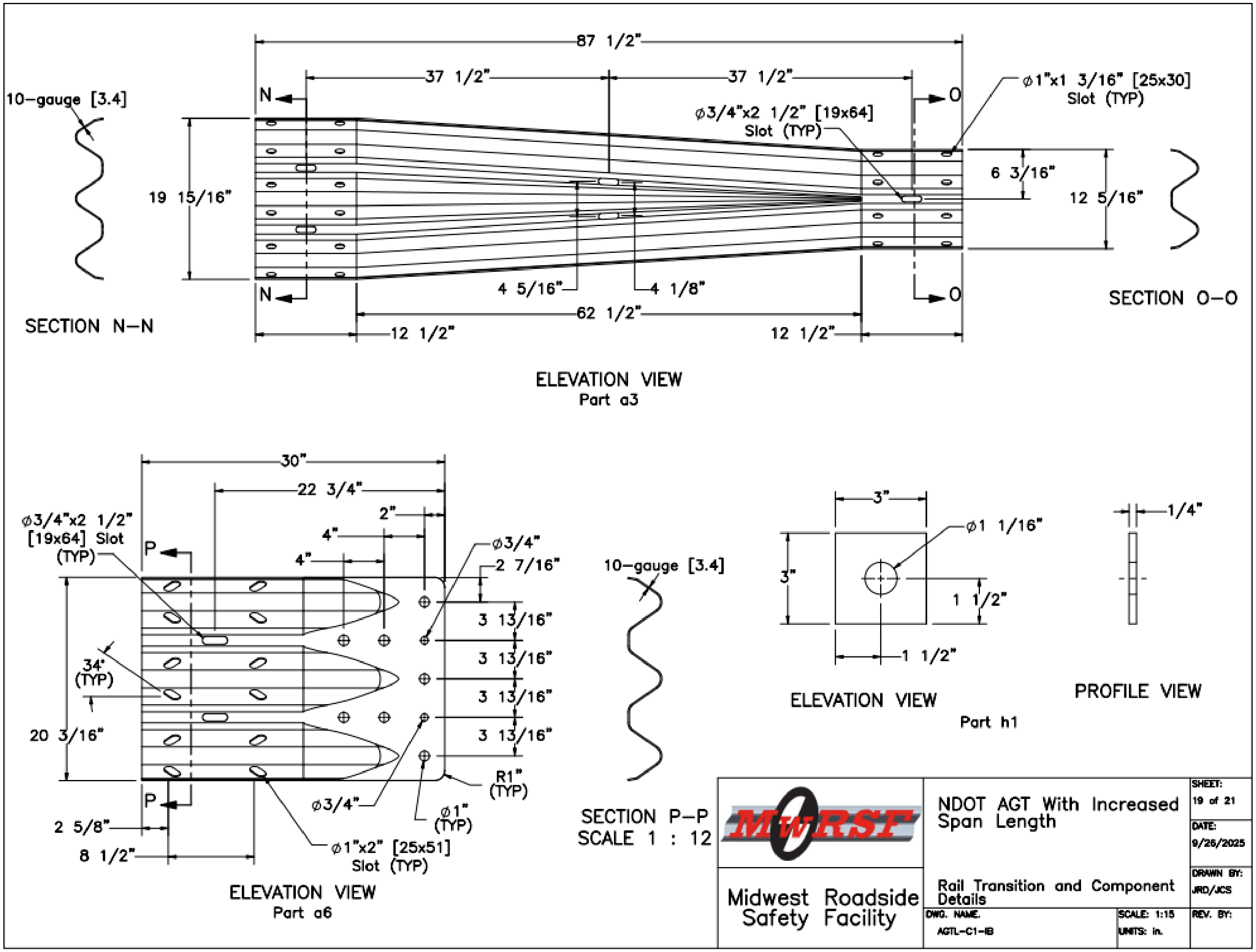


Figure 7.18 NDOT AGT With Increased Span Length, Rail Transition and Component Details, Concept 1

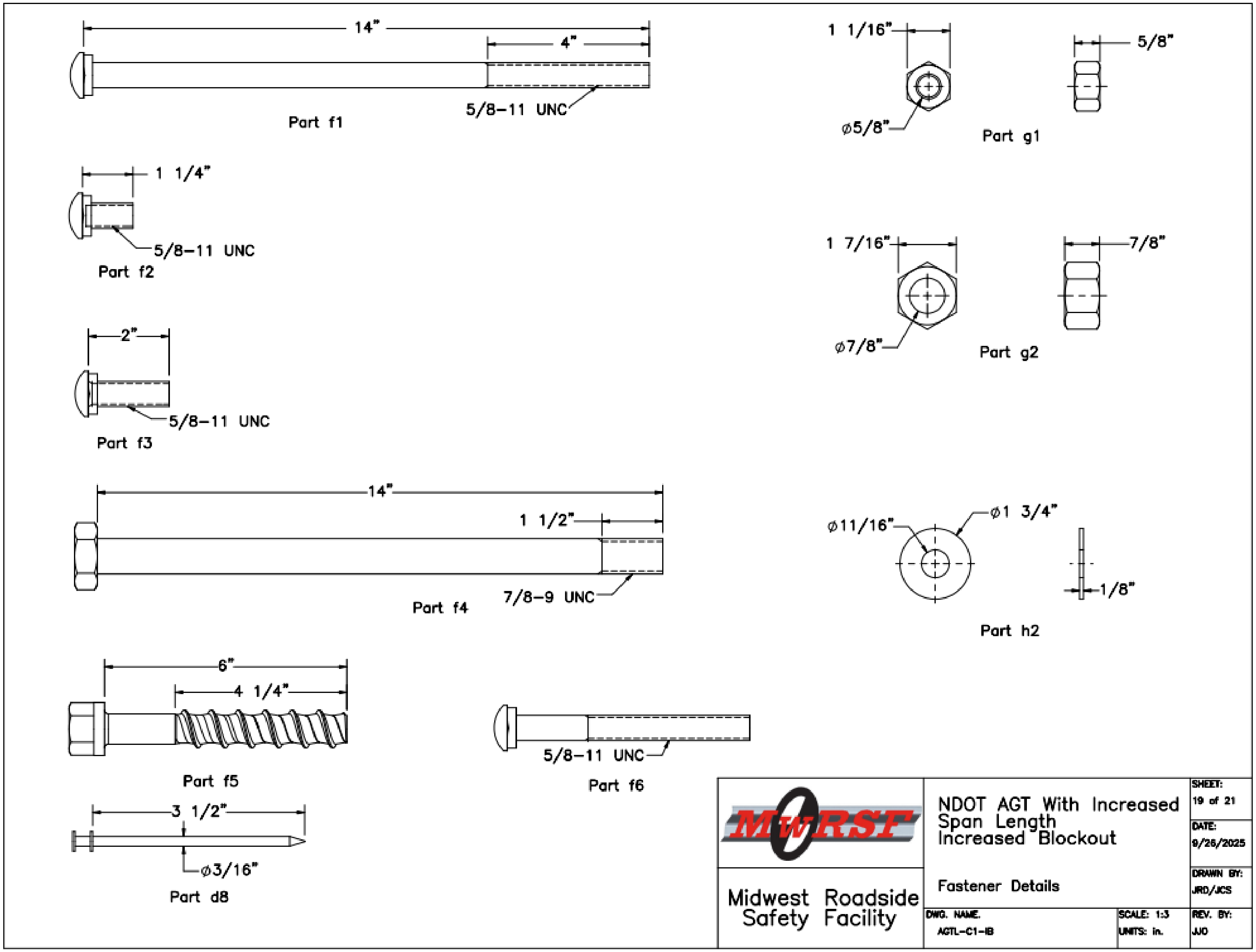


Figure 7.19 NDOT AGT With Increased Span Length, Fastener Details, Concept 1

Item No.	QTY.	Description	Material Specifications	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	6'–3" [1,905] 12–gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A653	RWM04a
a6	1	10–gauge [3.4] Thrie Beam End Shoe Section	AASHTO M180	ASTM A653	RTE01b
b1	1	Concrete – 21.9 cubic ft [0.62 cubic m]	Min. f'c = 4,000 psi [27.6 MPa]	–	–
c1	1	14.5"x8"x1/2" [368x203x13] Box Beam Anchor Plate	ASTM A36	ASTM A123	–
c2	1	14 1/4"x4 1/4"x1/2" [362x108x13] Box Beam Anchor Plate	ASTM A36	ASTM A123	–
c3	2	HSS 4"x4"x1/8" [102x102x3], 12" [304.8] Long	ASTM A36	ASTM A123	–
c4	2	HSS 4"x4"x1/4" [101.6x101.6x6], 113 1/12" [2872.32] Long	ASTM A500	ASTM A123	–
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	1	W6x15 [W152x22.3], 84" [2,134] Long Steel Post	ASTM A992	*AASHTO M111 (ASTM A123)	PWE12
d5	1	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
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	–

* 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

NDOT AGT With Increased Span Length

Bill of Materials

SHEET: 20 of 21

DATE: 9/26/2025

DRAWN BY: JRD/JCS

DWG. NAME. AGTL–C1–IB

SCALE: None

UNITS: in.

REV. BY:

Figure 7.20 NDOT AGT With Increased Span Length, Bill of Materials, Concept 1

Item No.	QTY.	Description	Material Specifications	Galvanization Specification	Hardware Guide
e5	1	1/2" Dia., 80 3/4" Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e6	3	1/2" Dia., 40 1/4" Long Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e7	2	1/2" Dia., 80 5/16" Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e8	4	1/2" Dia., 85 1/2" Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e9	6	1/2" Dia., 80" Long Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e10	1	1/2" Dia., 80 1/2" Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
f1	21	5/8" Dia. UNC, 14" Long Guardrail Bolt	ASTM A307 Gr. A	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBB06
f2	52	5/8" Dia. UNC, 1 1/4" Long Guardrail Bolt	ASTM A307 Gr. A	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBB01
f3	24	5/8" Dia. UNC, 2" Long Guardrail Bolt	ASTM A307 Gr. A	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBB02
f4	5	7/8" Dia. UNC, 14" Long Heavy Hex Bolt	ASTM A325 Type 1 or ASTM A449 or SAI J429 Gr. 5	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBX22b
f5	5	3/4" x 6" Long Concrete Wedge Bolt by Powers Fasteners	ASTM A307 Gr A	ASTM A153 or B695 Class 55 or F1941 or F2329	FBX02
f6	4	5/8" Dia. UNC, 6" Long Guardrail Bolt	ASTM A307 Gr. A	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBB03
g1	101	5/8" Dia. Guardrail Nut	Grade 5	–	–
g2	5	7/8" Dia. UNC Heavy Hex Nut	ASTM A563 DH	–	–
h1	5	3"x3"x1/4" or 3 1/2"x3 1/2"x1/4" Square Plate Washer	ASTM A572 Gr. 50	*AASHTO M111 (ASTM A123)	FWR10
h2	4	5/8" Dia. Plain USS Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC14a

* 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

NDOT AGT With Increased Span Length Increased Blockout

Bill of Materials

SHEET: 21 of 21
DATE: 9/26/2025
DRAWN BY: JRD/JCS
DWG. NAME. AGTL–C1–IB
SCALE: None
UNITS: in.
REV. BY: JJO

Figure 7.21 NDOT AGT With Increased Span Length, Bill of Materials, Concept 1, Cont.

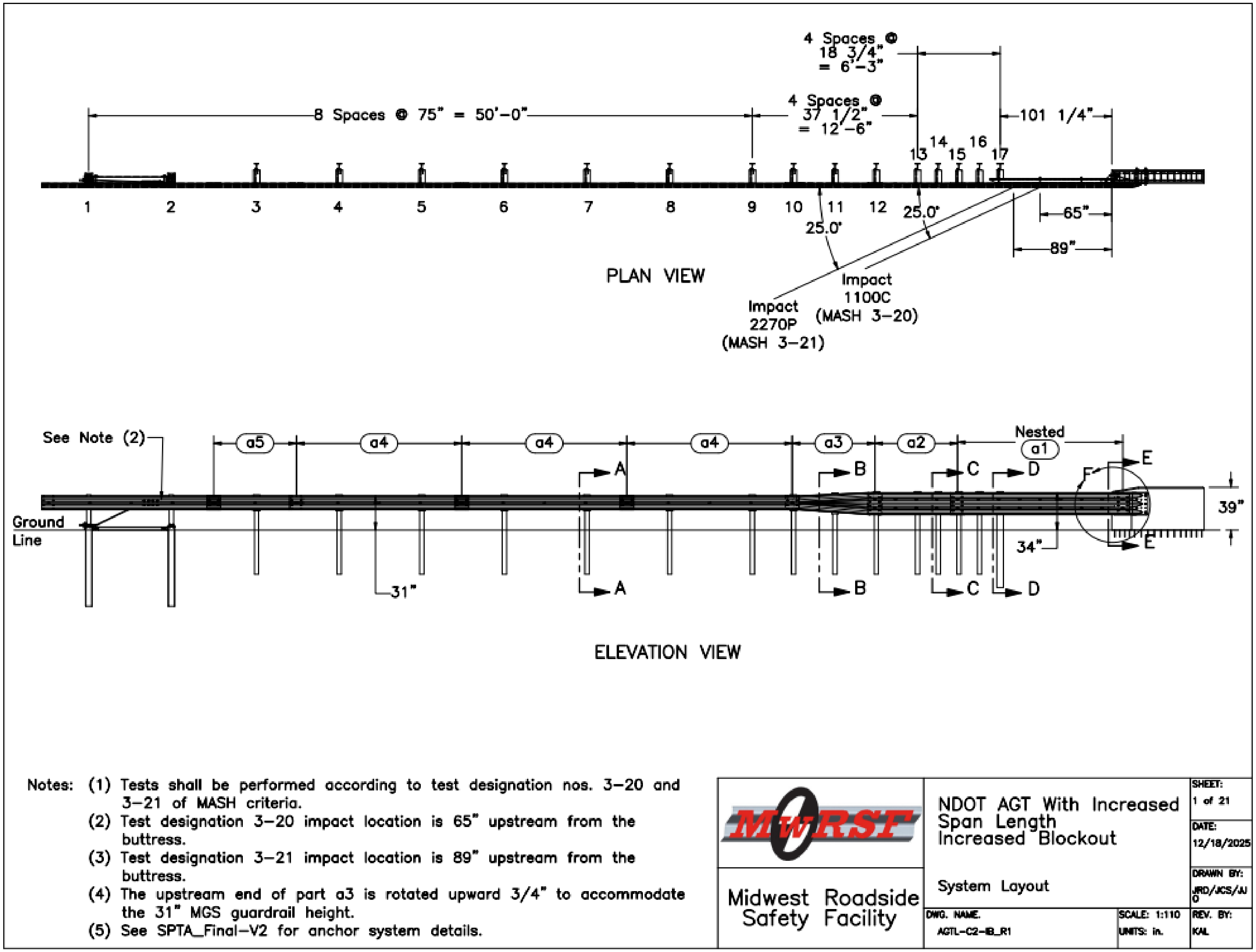


Figure 7.22 NDOT AGT With Increased Span Length, System Layout, Concept 2

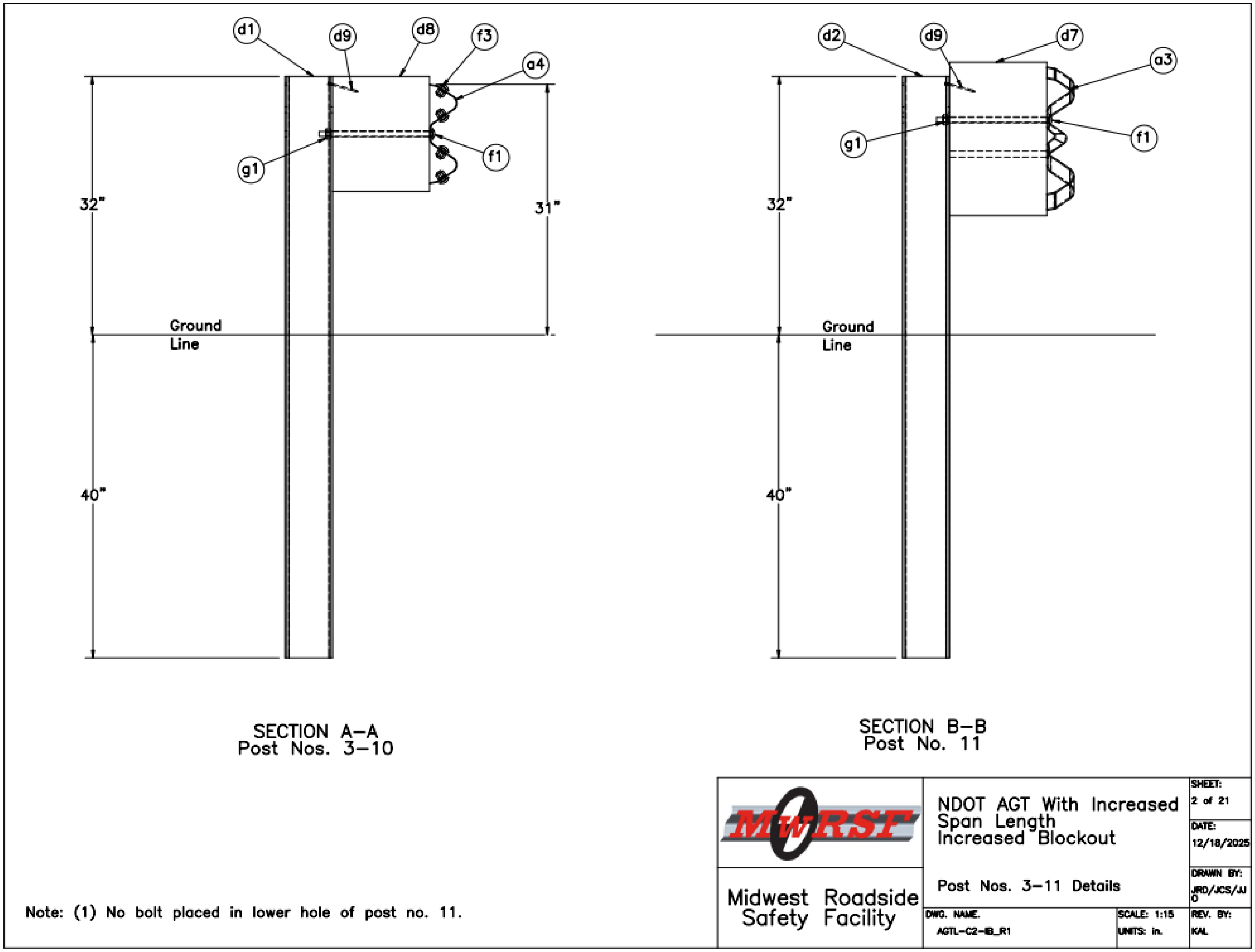


Figure 7.23 NDOT AGT With Increased Span Length, Post Nos. 3-11 Details, Concept 2

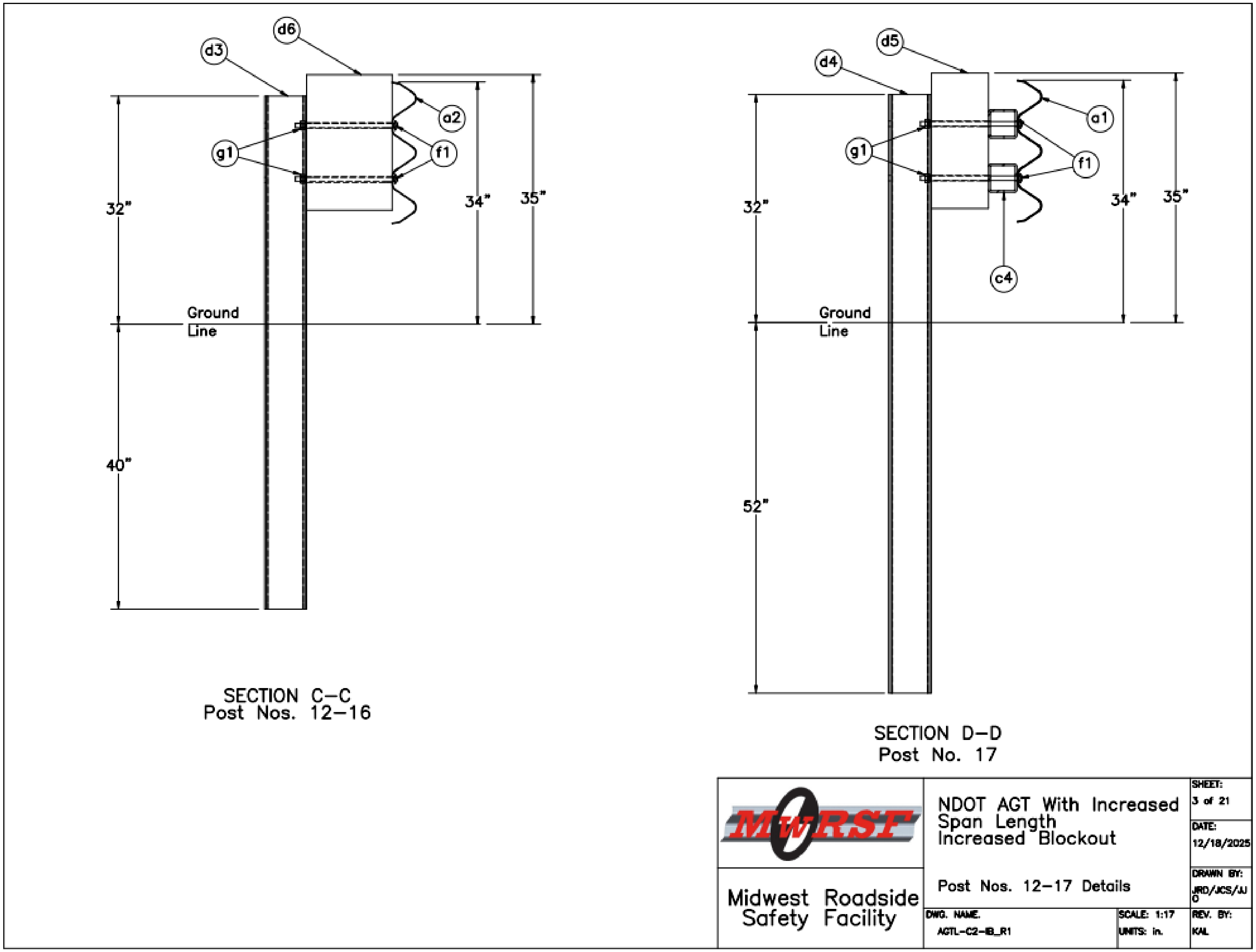


Figure 7.24 NDOT AGT With Increased Span Length, Post Nos. 12-19 Details, Concept 2

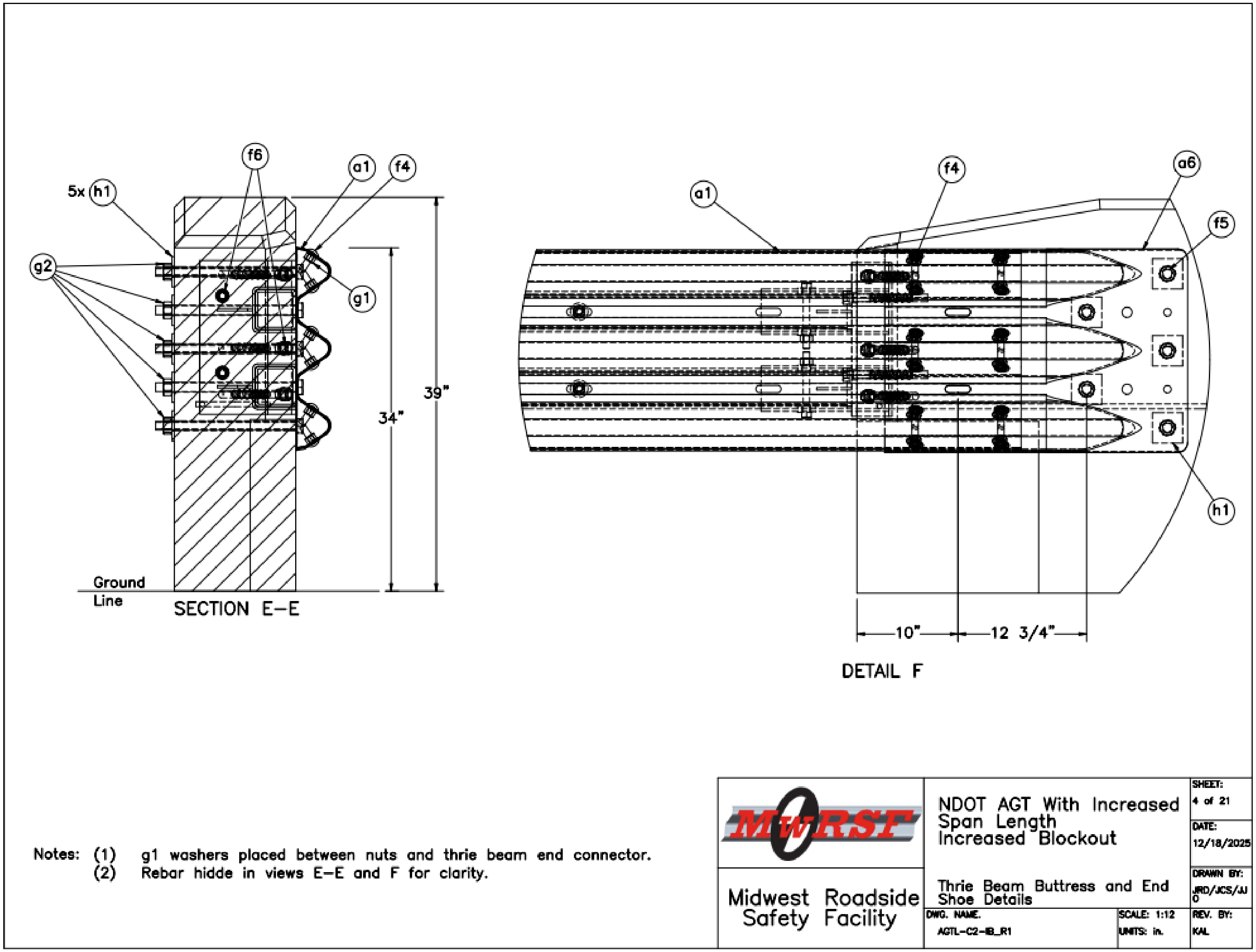


Figure 7.25 NDOT AGT With Increased Span Length, Thrie-Beam Buttress and End Shoe Details, Concept 2

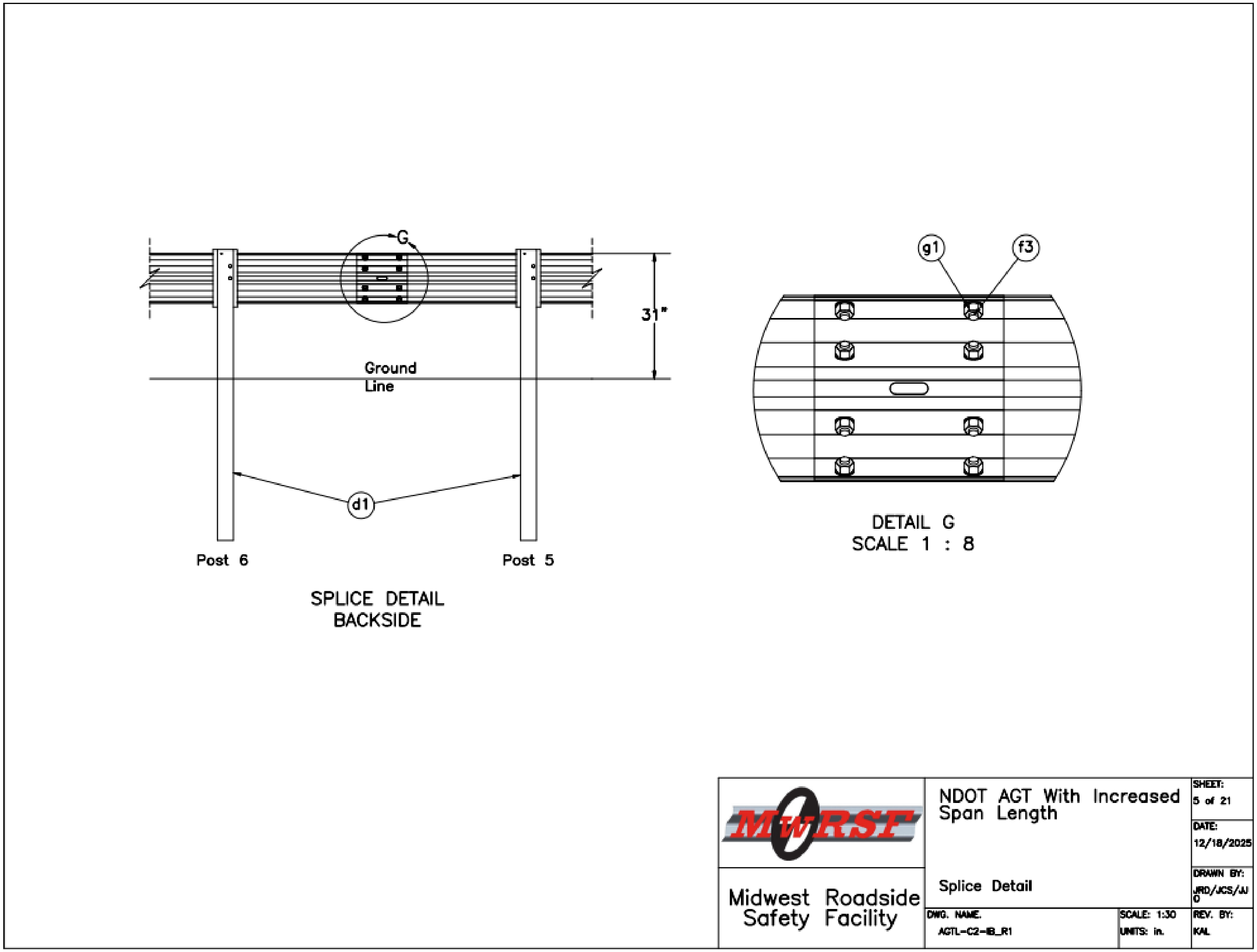


Figure 7.26 NDOT AGT With Increased Span Length, Splice Details, Concept 2

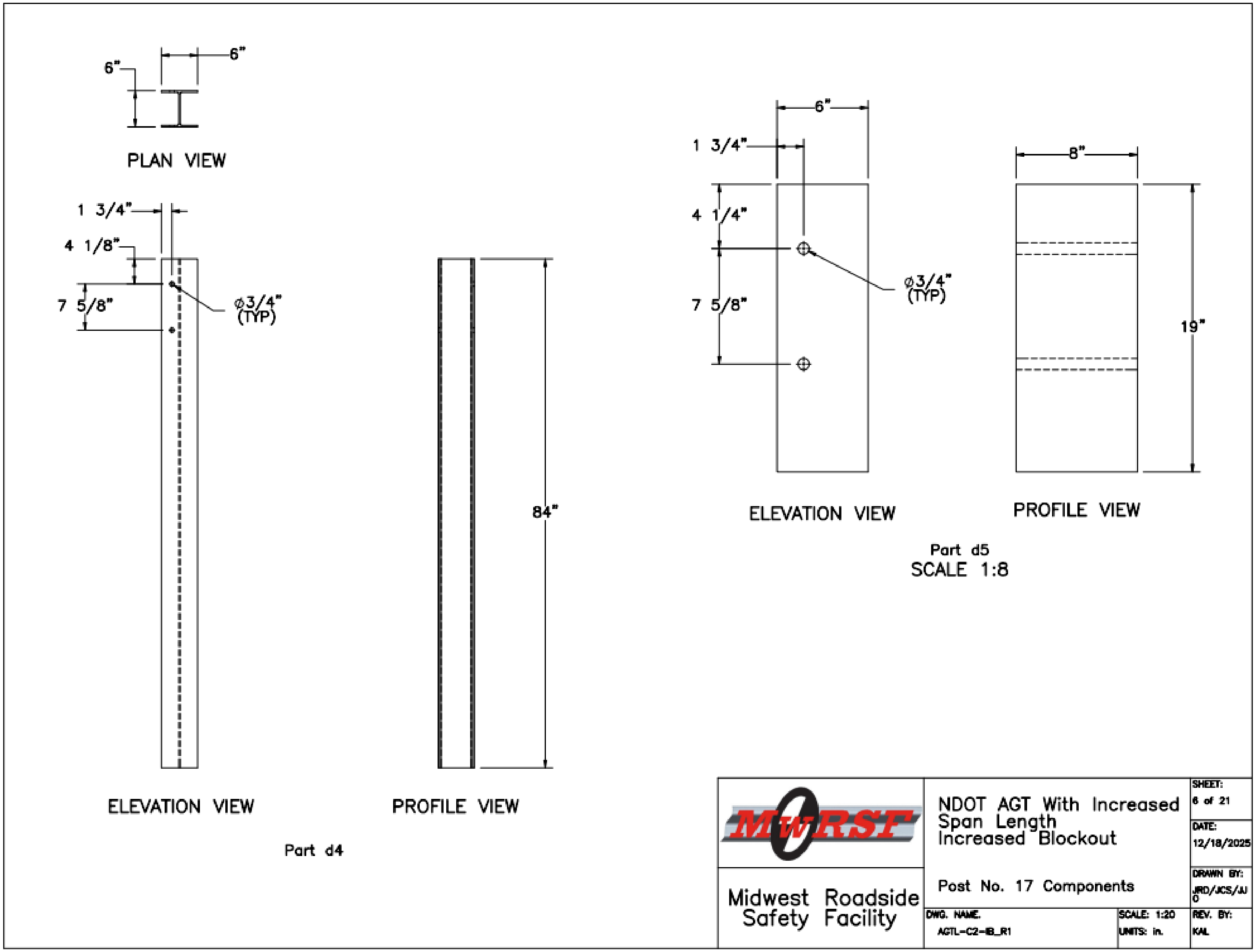


Figure 7.27 NDOT AGT With Increased Span Length, Post No. 17 Components, Concept 2

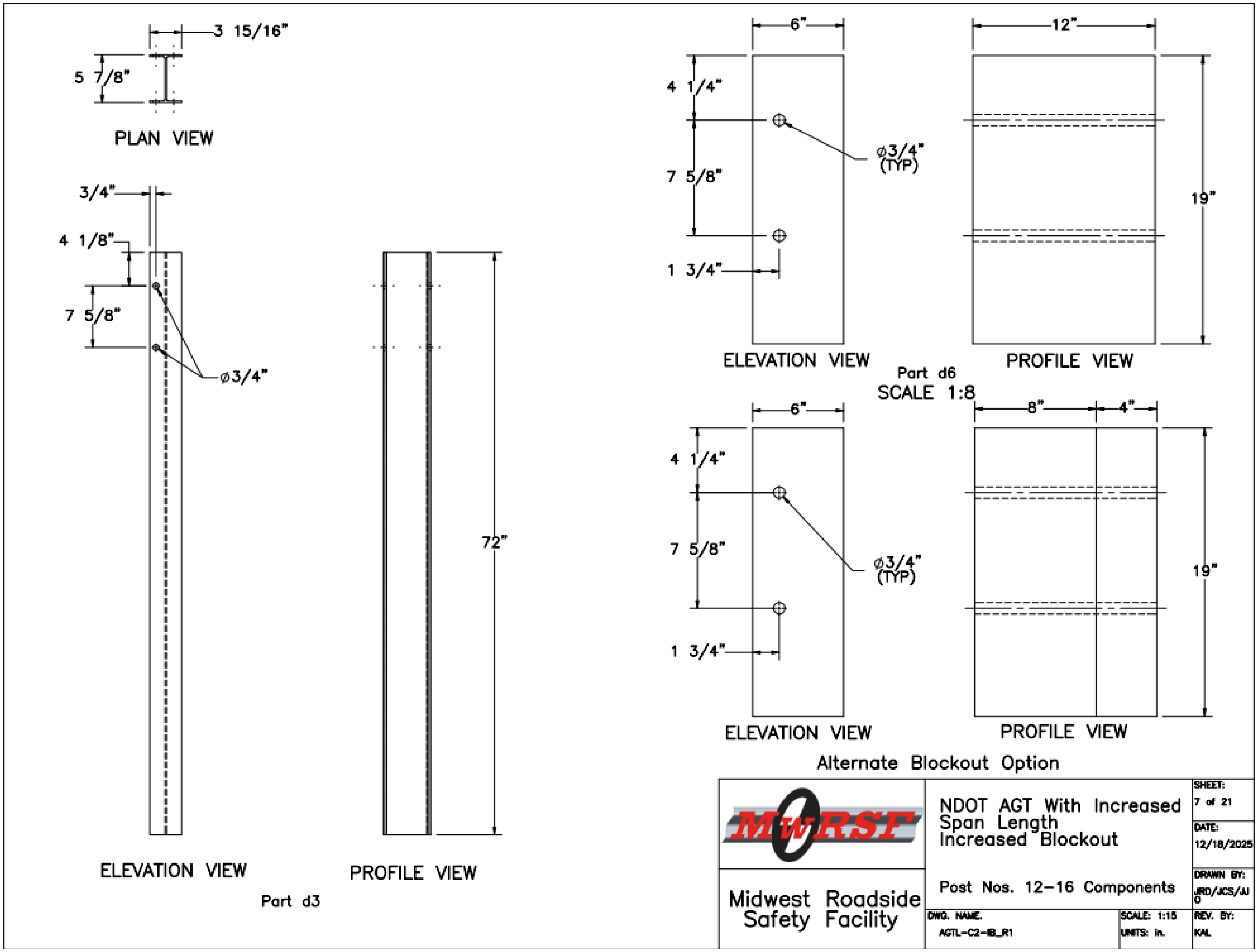


Figure 7.28 NDOT AGT With Increased Span Length, Post Nos. 12-16 Components, Concept 2

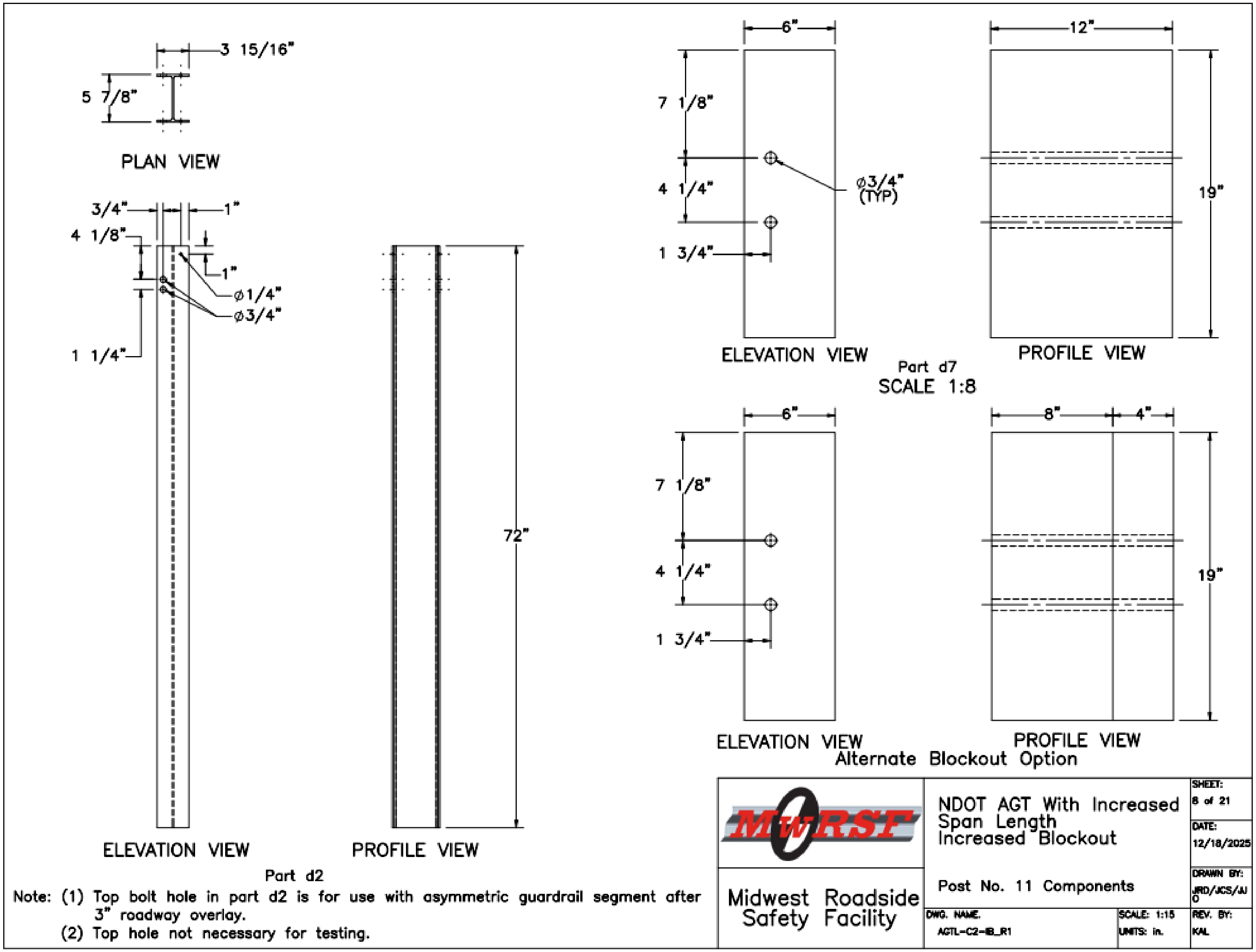


Figure 7.29 NDOT AGT With Increased Span Length, Post No. 11 Components, Concept 2

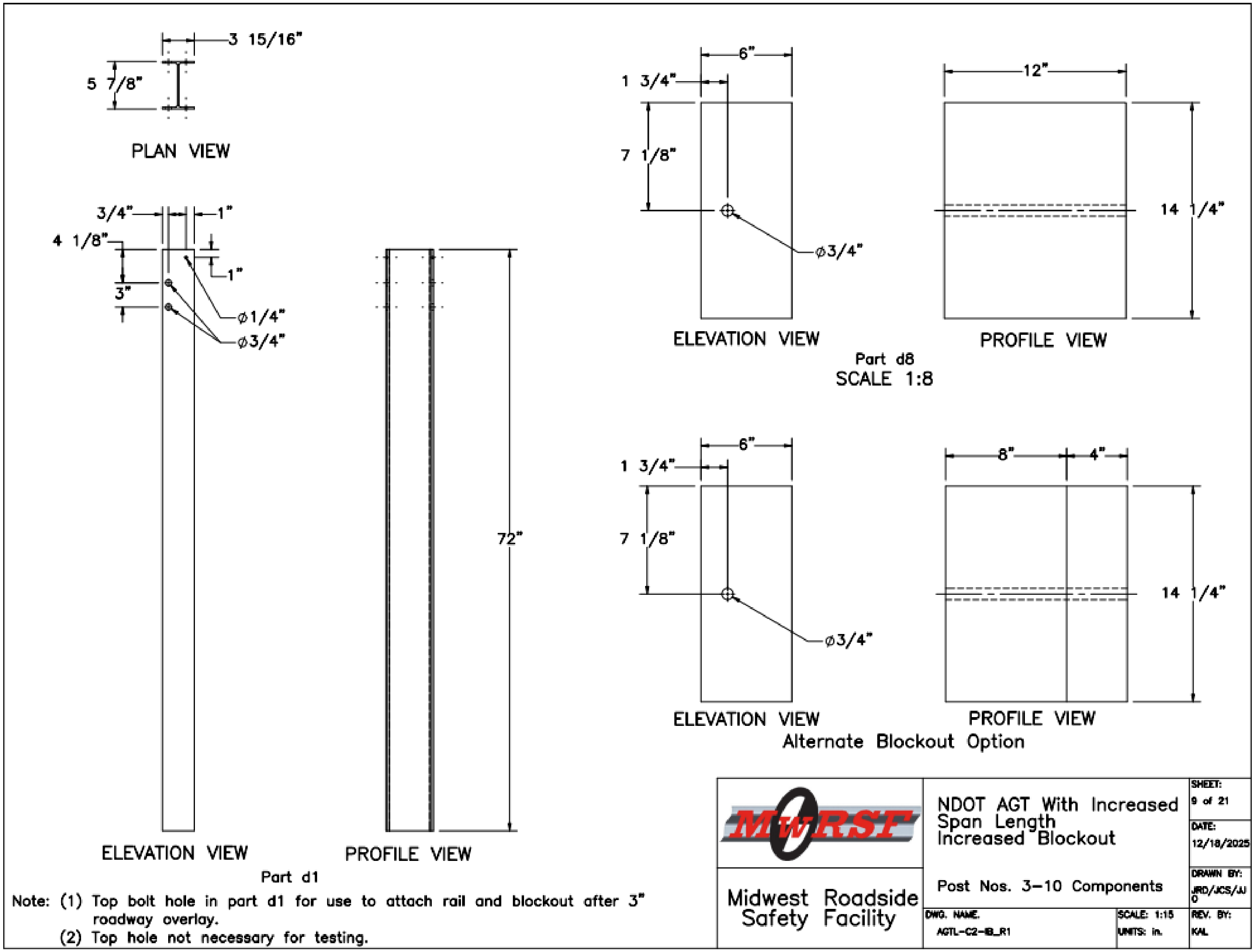
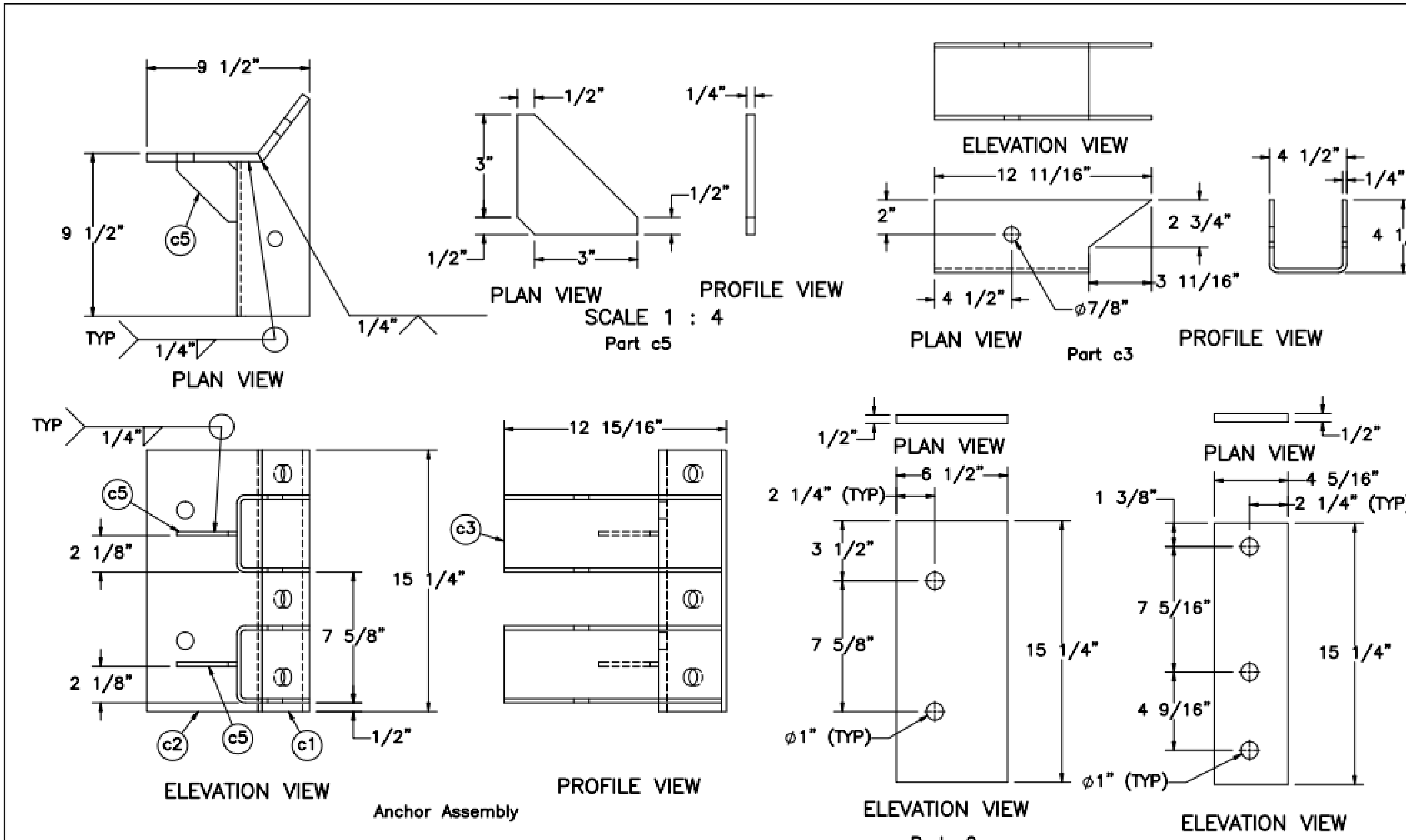


Figure 7.30 NDOT AGT With Increased Span Length, Post Nos. 3-11 Components, Concept 2



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Anchor Assembly	–	ASTM A123
c1	1	15 1/4"x4 3/16"x1/2" Box Beam Anchor Plate	ASTM A36	See Assembly
c2	1	15 1/4"x6 1/2"x1/2" Box Beam Anchor Plate	ASTM A36	See Assembly
c3	2	4"x4"x1/8", 12 11/16" Long C-Channel	ASTM A36	See Assembly
c5	2	3.5"x3.5"x0.25" Chamfered Gusset	ASTM A36	See Assembly

Midwest Roadside Safety Facility

NDOT AGT With Increased Span Length Increased Blockout

Anchor Details

SHEET: 10 of 21
DATE: 12/18/2025
DRAWN BY: JRD/JCS/JA O
DWG. NAME. AGTL-C2-IB_R1
SCALE: 1:8
UNITS: in.
REV. BY: KAL

Figure 7.31 NDOT AGT With Increased Span Length, Anchor Details, Concept 2

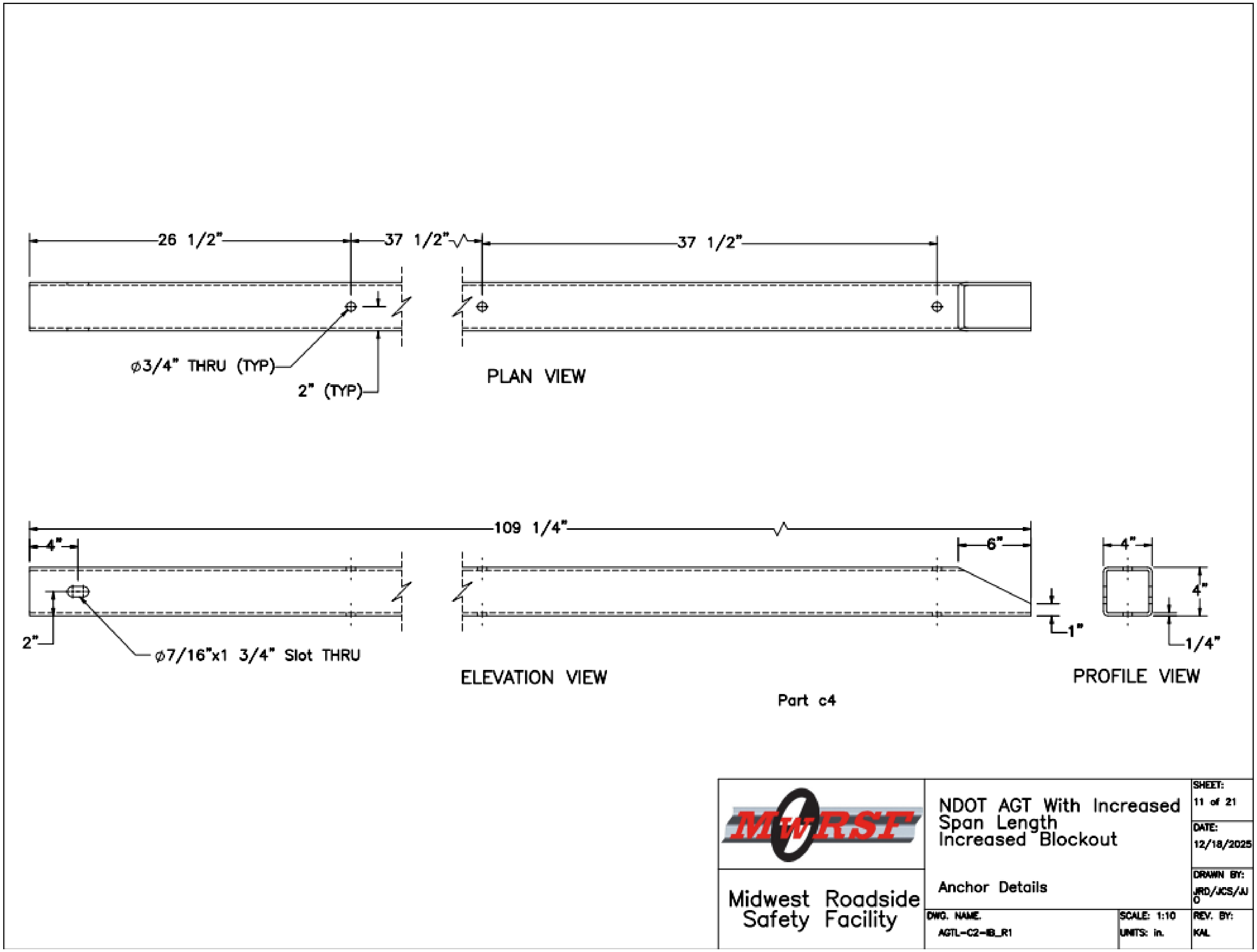


Figure 7.32 NDOT AGT With Increased Span Length, Anchor Details, Concept 2, Cont.

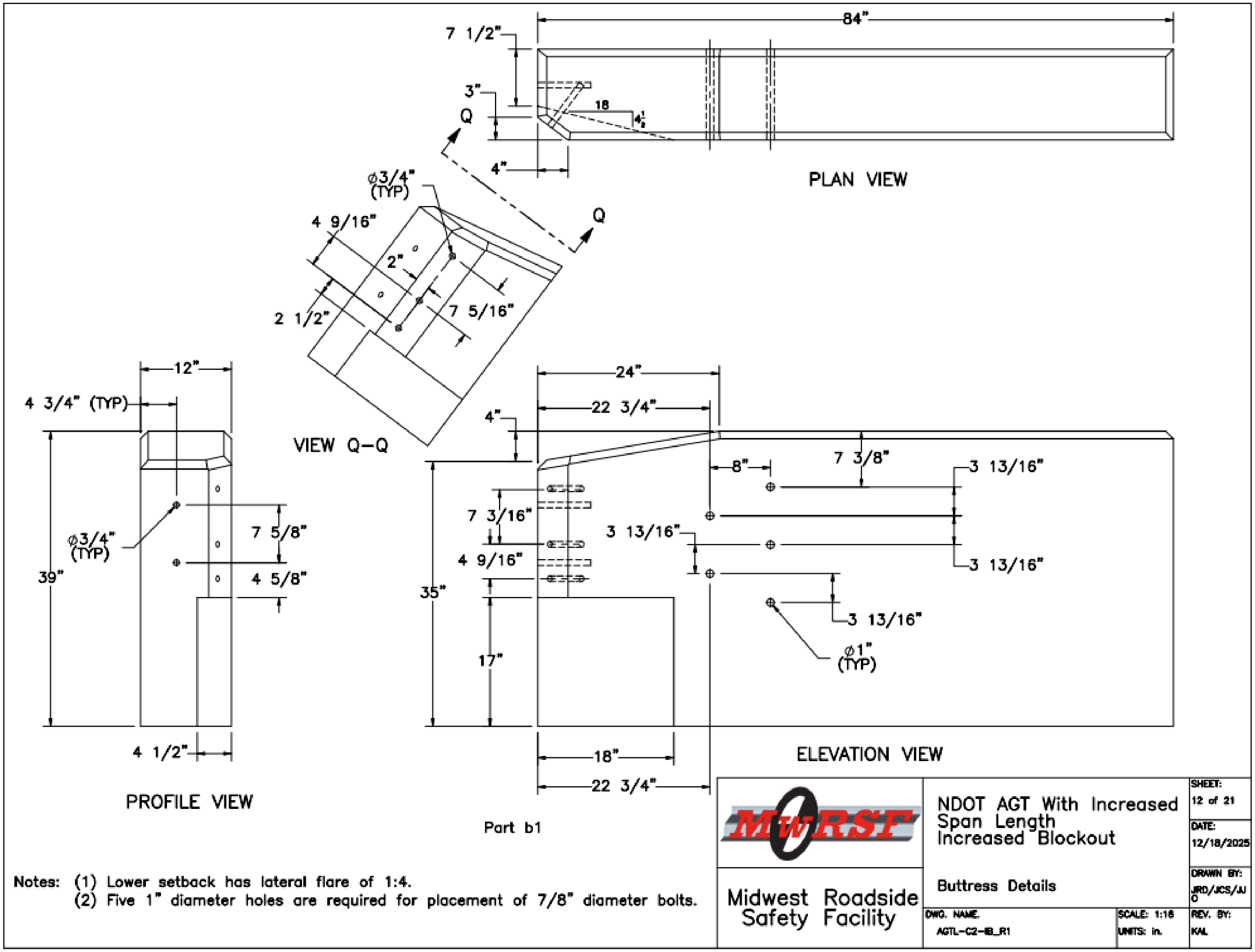
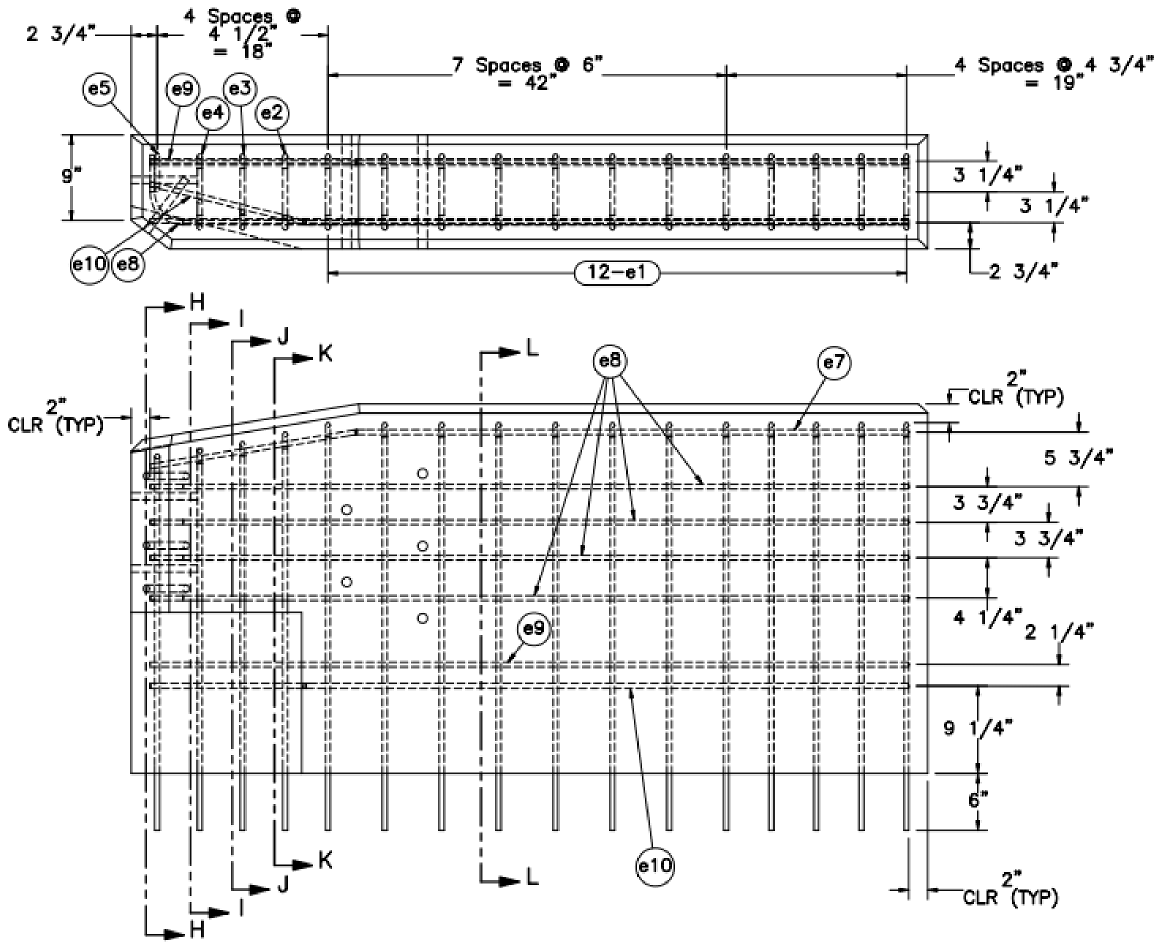


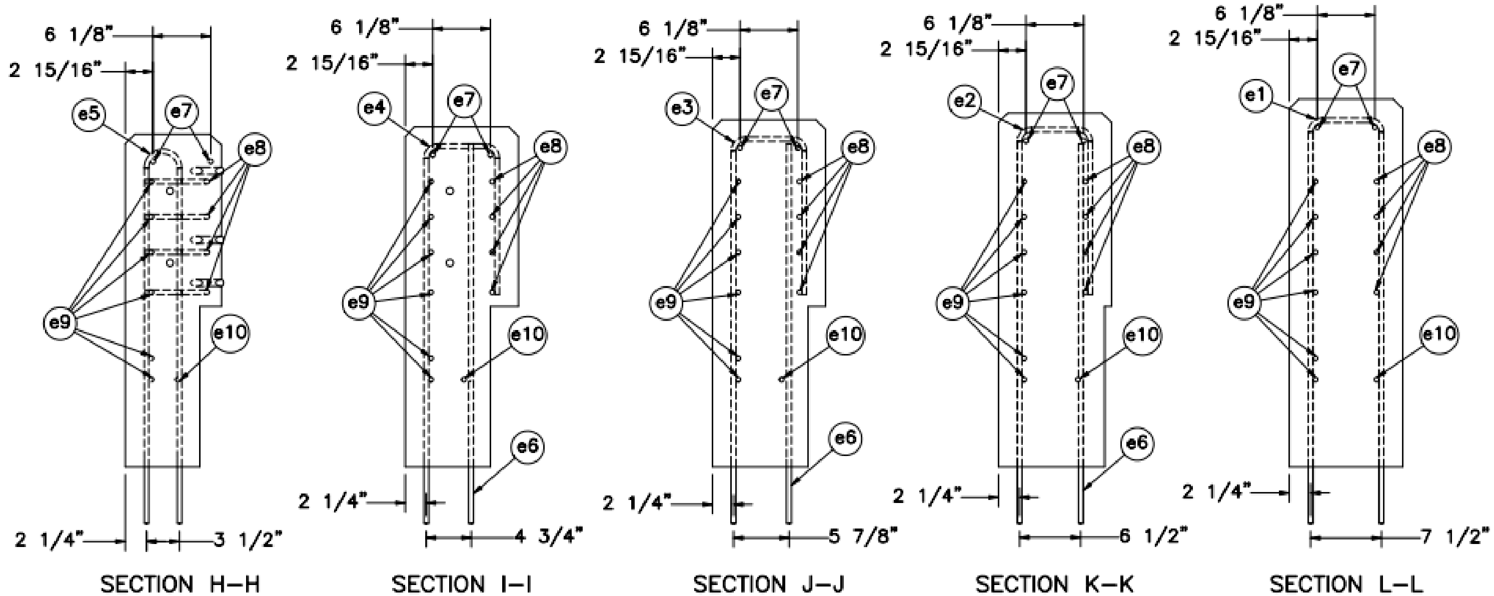
Figure 7.33 NDOT AGT With Increased Span Length, Buttress Details, Concept 2



Notes: (1) Vertical rebar embedded in tarmac with chemical epoxy adhesive with a minimum bond strength of 1,450 psi.
(2) All edges of the top of the buttress are chamfered 1".

Midwest Roadside Safety Facility	NDOT AGT With Increased Span Length Increased Blockout Rebar Detail	SHEET: 13 of 21 DATE: 12/18/2025 DRAWN BY: JRD/JCS/AJ O
	DWG. NAME. AGTL-C2-IB_R1	SCALE: 1:16 UNITS: in.
		REV. BY: KAL

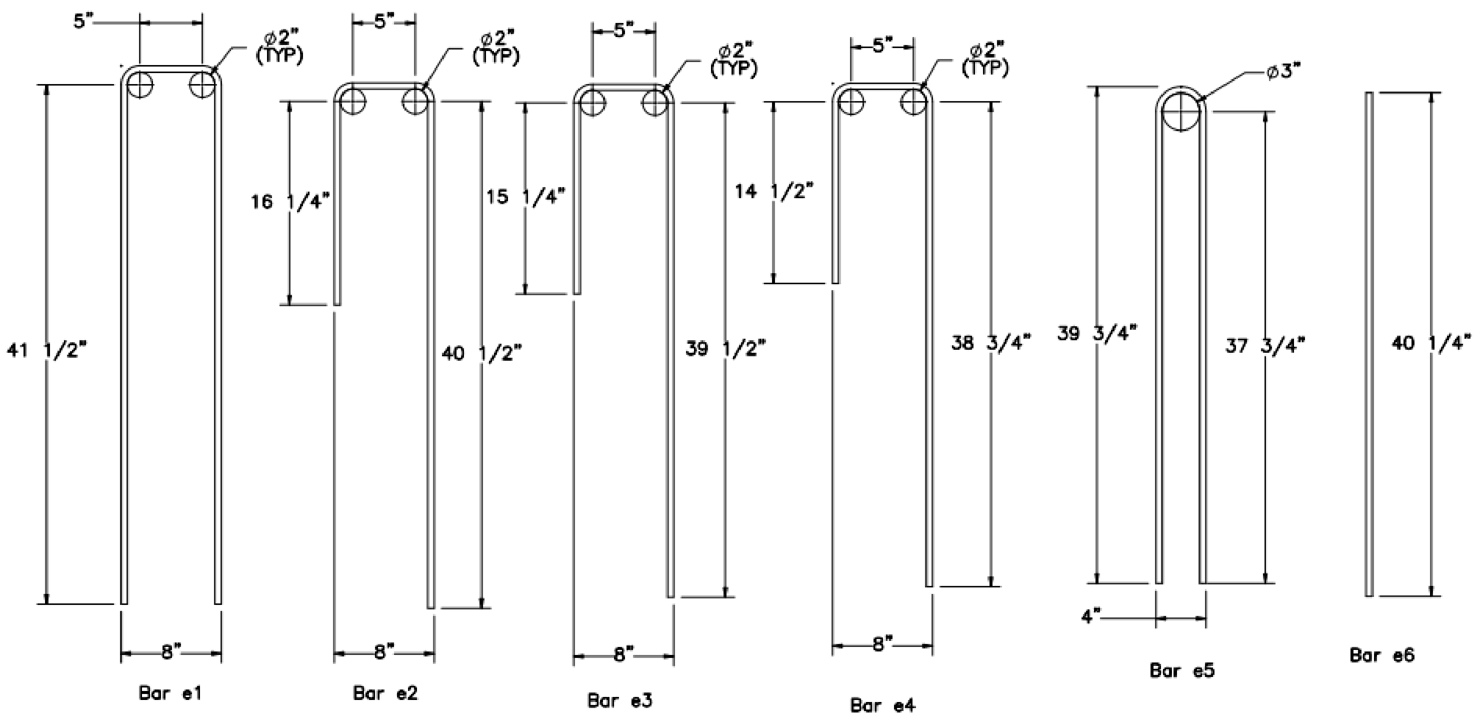
Figure 7.34 NDOT AGT With Increased Span Length, Rebar Details, Concept 2



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

Midwest Roadside Safety Facility	NDOT AGT With Increased Span Length Increased Blockout	SHEET: 14 of 21
		DATE: 12/18/2025
	Buttress Sections	DRAWN BY: JRD/JCS/AJ0
	DWG. NAME. AGTL-C2-IB_R1	SCALE: 1:16 UNITS: in.
		REV. BY: KAL

Figure 7.35 NDOT AGT With Increased Span Length, Buttress Sections, Concept 2



Bill of Bars					
Bar	QTY	Size	Length	Material	Treatment
e1	12	#4	92"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e2	1	#4	65 3/4"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e3	1	#4	63 1/2"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e4	1	#4	62 1/4"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e5	1	#4	80 3/4"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e6	1	#4	40 1/4"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)

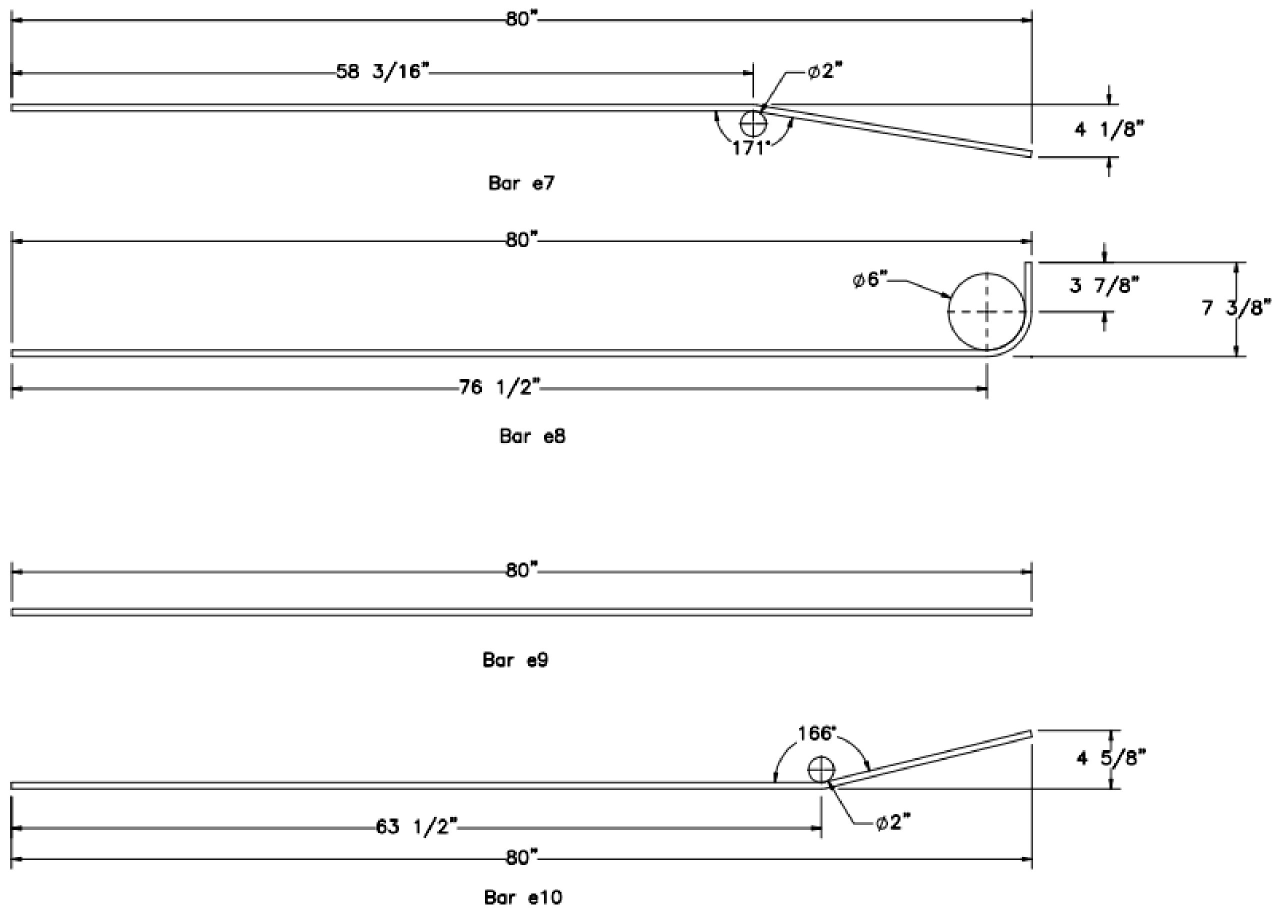
Midwest Roadside Safety Facility

NDOT AGT With Increased Span Length Increased Blockout

Vertical Rebar Details

SHEET: 15 of 21
DATE: 12/18/2025
DRAWN BY: JRD/JCS/AJO
DWG. NAME. AGTL-C2-IB_R1
SCALE: 1:12
UNITS: in.
REV. BY: KAL

Figure 7.36 NDOT AGT With Increased Span Length, Vertical Rebar Details, Concept 2



Bill of Bars					
Bar	QTY	Size	Length	Material	Treatment
e7	2	#4	80 1/4"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e8	4	#4	85 1/2"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e9	5	#4	80"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e10	1	#4	80 1/2"	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)

Midwest Roadside Safety Facility

NDOT AGT With Increased Span Length Increased Blockout

Horizontal Rebar Details

SHEET: 16 of 21
DATE: 12/18/2025
DRAWN BY: JRD/JCS/AJ0
DWG. NAME. AGTL-C2-IB_R1
SCALE: 1:12
UNITS: in.
REV. BY: KAL

Figure 7.37 NDOT AGT With Increased Span Length, Horizontal Rebar Details, Concept 2

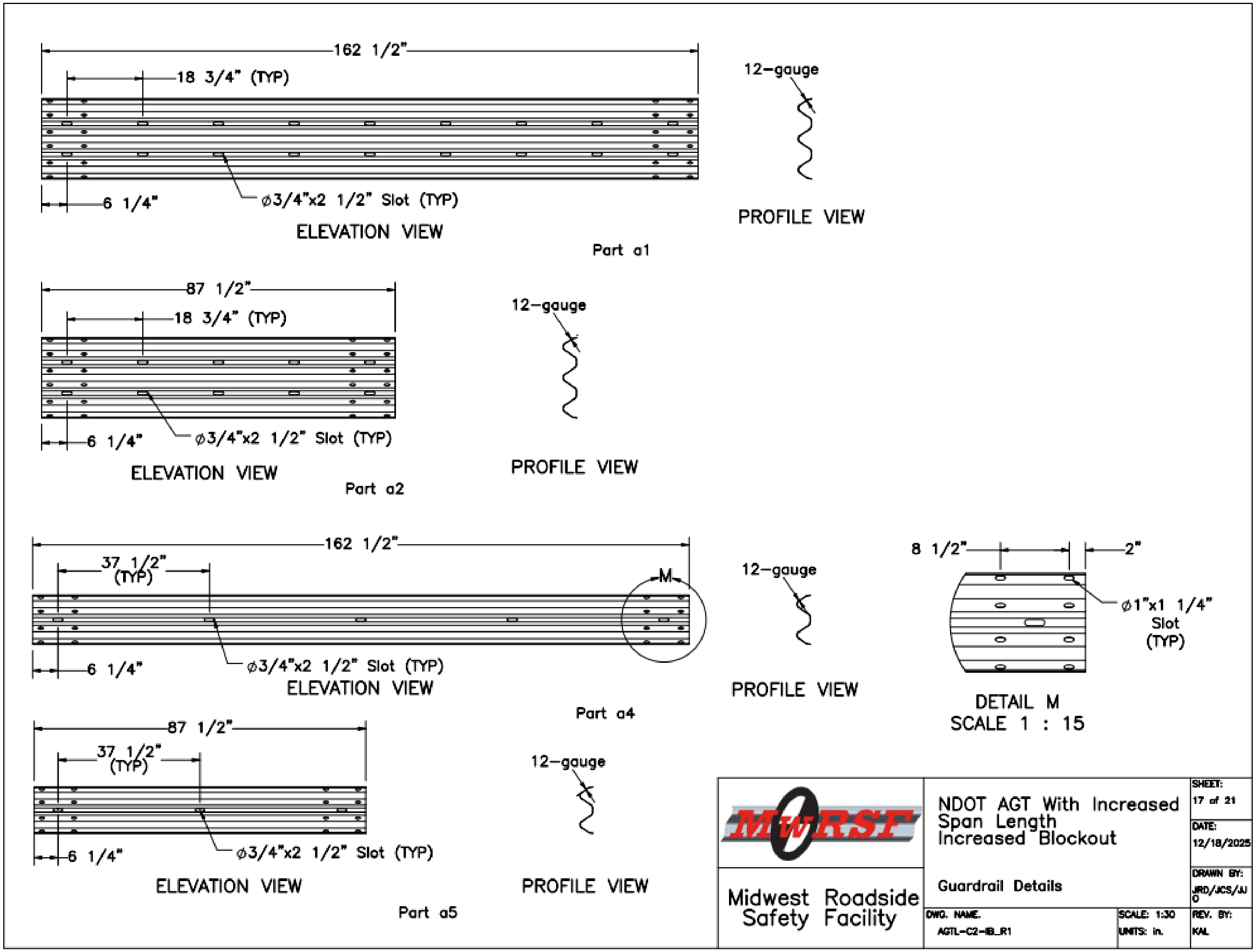


Figure 7.38 NDOT AGT With Increased Span Length, Guardrail Details, Concept 2

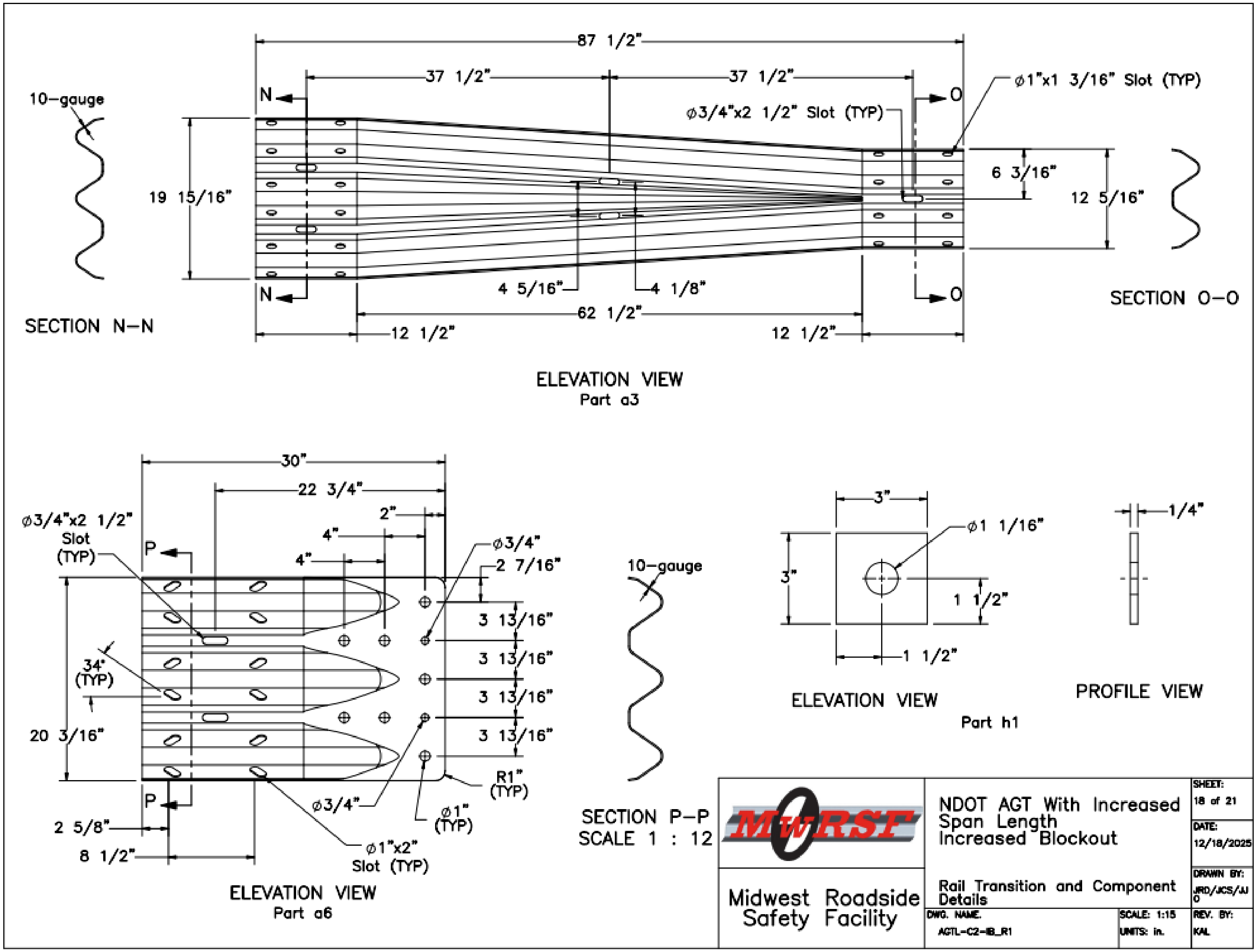


Figure 7.39 NDOT AGT With Increased Span Length, Rail Transition and Component Details, Concept 2

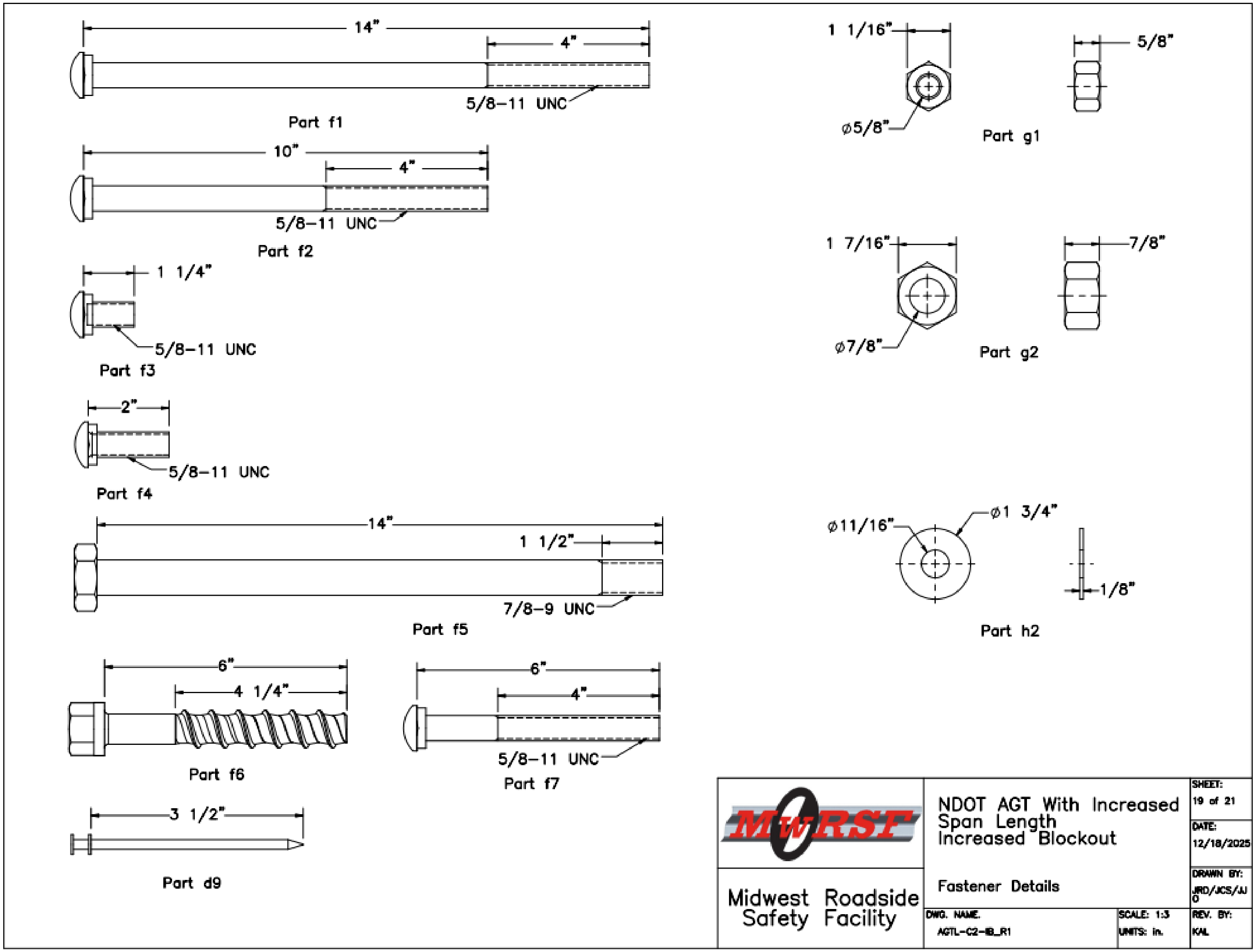


Figure 7.40 NDOT AGT With Increased Span Length, Fastener Details, Concept 2

Item No.	QTY.	Description	Material Specifications	Galvanization Specification	Hardware Guide
a1	2	12'–6" 12–gauge Thrie Beam Section	AASHTO M180	ASTM A653	RTM08a
a2	1	6'–3" 12–gauge Thrie Beam Section	AASHTO M180	ASTM A653	RTM19a
a3	1	10–gauge Symmetrical W–beam to Thrie Beam Transition	AASHTO M180	ASTM A653	RWT01b
a4	3	12'–6" 12–gauge W–Beam Section	AASHTO M180	ASTM A653	RWM04a
a5	1	6'–3" 12–gauge W–Beam MGS Section	AASHTO M180	ASTM A653	RWM04a
a6	1	10–gauge Thrie Beam End Shoe Section	AASHTO M180	ASTM A653	RTE01b
b1	1	Concrete – 21.9 cubic ft	Min. f'c = 4,000 psi	–	–
c1	1	15 1/4"x4 3/16"x1/2" Box Beam Anchor Plate	ASTM A36	See Assembly	–
c2	1	15 1/4"x6 1/2"x1/2" Box Beam Anchor Plate	ASTM A36	See Assembly	–
c3	2	4"x4"x1/8", 12 11/16" Long C–Channel	ASTM A36	See Assembly	–
c4	2	HSS 4"x4"x1/4", 109 1/4" Long	ASTM A500	ASTM A123	–
c5	2	3.5"x3.5"x0.25" Chamfered Gusset	ASTM A36	See Assembly	–
d1	8	W6x8.5 or W6x9, 72" Long Steel Post	ASTM A992	*AASHTO M111 (ASTM A123)	–
d2	1	W6x8.5 or W6x9, 72" Long Steel Post	ASTM A992	*AASHTO M111 (ASTM A123)	–
d3	5	W6x8.5 or W6x9, 72" Long Steel Post	ASTM A992	*AASHTO M111 (ASTM A123)	–
d4	1	W6x15, 84" Long Steel Post	ASTM A992	*AASHTO M111 (ASTM A123)	PWE12
d5	1	6"x8"x19" Timber Blockout	SYP Grade No.1 or better	–	PDB17
d6	5	6"x12"x19" Timber Blockout	SYP Grade No.1 or better	–	–
d7	1	6"x12"x19" Timber Blockout	SYP Grade No.1 or better	–	PDB18
d8	8	6"x12"x14 1/4" Timber Blockout	SYP Grade No.1 or better	–	PDB10a
d9	9	16D Double Head Nail	–	–	–
e1	12	1/2" Dia., 92" Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e2	1	1/2" Dia., 65 3/4" Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–
e3	1	1/2" Dia., 63 1/2" Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy–Coated	–

* 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

NDOT AGT With Increased Span Length Increased Blockout

Bill of Materials

SHEET: 20 of 21
DATE: 12/18/2025
DRAWN BY: JRD/JCS/JJ0
DWG. NAME. AGTL–C2–IB_R1
SCALE: None
UNITS: in.
REV. BY: KAL

Figure 7.41 NDOT AGT With Increased Span Length, Bill of Materials, Concept 2

Item No.	QTY.	Description	Material Specifications	Galvanization Specification	Hardware Guide
e4	1	1/2" Dia., 62 1/4" Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy-Coated	–
e5	1	1/2" Dia., 80 3/4" Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy-Coated	–
e6	3	1/2" Dia., 40 1/4" Long Rebar	ASTM A615 Gr. 60	**Epoxy-Coated	–
e7	2	1/2" Dia., 80 5/16" Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy-Coated	–
e8	4	1/2" Dia., 85 1/2" Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy-Coated	–
e9	6	1/2" Dia., 80" Long Rebar	ASTM A615 Gr. 60	**Epoxy-Coated	–
e10	1	1/2" Dia., 80 1/2" Long Bent Rebar	ASTM A615 Gr. 60	**Epoxy-Coated	–
f1	21	5/8" Dia. UNC, 14" Long Guardrail Bolt	ASTM A307 Gr. A	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBB06
f2	2	5/8" Dia. UNC, 6.5" Long Hex Head Bolt	ASTM A307 Gr. A	ASTM A153 or B695 Class 55 or F2329	FBX20a
f3	52	5/8" Dia. UNC, 1 1/4" Long Guardrail Bolt	ASTM A307 Gr. A	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBB01
f4	24	5/8" Dia. UNC, 2" Long Guardrail Bolt	ASTM A307 Gr. A	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBB02
f5	5	7/8" Dia. UNC, 14" Long Heavy Hex Bolt	ASTM A325 Type 1 or ASTM A449 or SAE J429 Gr. 5	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBX22b
f6	5	3/4" x 6" Long Concrete Wedge Bolt by Powers Fasteners	ASTM A307 Gr A	ASTM A153 or B695 Class 55 or F1941 or F2329	FBX02
f7	4	5/8" Dia. UNC, 6" Long Guardrail Bolt	ASTM A307 Gr. A	AASHTO M232 (ASTM A153) for Class C or AASHTO M298 (ASTM B695) for Class 50	FBB03
g1	103	5/8"Dia. Guardrail Nut	Grade 5	–	–
g2	5	7/8" Dia. UNC Heavy Hex Nut	ASTM A563 DH	–	–
h1	5	3"x3"x1/4" or 3 1/2"x3 1/2"x1/4" Square Plate Washer	ASTM A572 Gr. 50	*AASHTO M111 (ASTM A123)	FWR10
h2	8	5/8" Dia. Plain USS Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC14a

* 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

NDOT AGT With Increased Span Length Increased Blockout

Bill of Materials

SHEET: 21 of 21

DATE: 12/18/2025

DRAWN BY: JRD/JCS/JJO

DWG. NAME. AGTL-C2-IB_R1

SCALE: None UNITS: in.

REV. BY: KAL

Figure 7.42 NDOT AGT With Increased Span Length, Bill of Materials, Concept 2, Cont.

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Appendix A NDOT Districts Survey Questionnaire

Development and Evaluation of Crashworthy Approach Guardrail Transition with Increased Span Length Between Concrete Bridge Rail and First Transition Post – Phase I

NDOT Districts Survey

Overview

The Midwest Roadside Safety Facility (MwRSF) has begun work on the Nebraska Department of Transportation (NDOT) research project related to development and evaluation of crashworthy approach guardrail transition (AGT) with increased span length between concrete bridge rail and first transition post. The objective of this project is to develop and evaluate the standard 34-in. tall NDOT thrie beam MASH AGT system with increased span length between the concrete buttress end and the first transition post to accommodate a wide range of obstructions that prevent proper installation of posts, including bridge abutments and wing walls, as well as drainage and utility structures.

In an effort to identify the most common types of obstructions and associated geometrics, MwRSF has created a survey to solicit feedback regarding AGT installation issues near concrete bridge rail ends. With a better understanding of the obstructions preventing proper post placement, MwRSF can develop design criteria for 34-in. tall NDOT AGT with an increased span length and provide NDOT with crashworthy and cost-effective solutions for non-ideal installation sites. Thus, we are asking that the NDOT Districts fill out the survey to provide MwRSF with the background materials necessary to address the installation issues.

Questions

1. Please enter your name, email, phone no., and the name of your NDOT District.
   Name: ___________________________________
   Email: ___________________________________
   Phone No.: ___________________________________
   NDOT District: ___________________________________
   **Save & Continue Button Here!
2. Does your district experience challenges with subsurface obstructions, such as drainage structures, utility lines, wingwalls, and other concrete obstructions below grade or site constraints, including soil fill and grading, as depicted on Figure 1, that impede the installation of one or more AGT posts near concrete bridge rail ends? [Place an "X" behind all cases that apply!] Yes: _____ No: _____

Figure 1. Typical example of obstructions and site constraints near concrete bridge rail ends

**Save & Continue Button Here!

2.1. If answered "No" to Question 2, please go to Question 3. If answered "Yes" to Question 2, please provide additional details:

a. Please provide a description of the types of obstruction(s) and site constraint(s) near concrete bridge rail ends.

[INSERT TEXT HERE]

**Save & Continue Button Here!

b. Provide typical size of these obstructions and site constraints, including depth, length, surface area, and width. Please provide a description of the Slope Offset(s) and Slope Rate(s) from posts for AGT installation sites with post(s) on or near slope.
Length: _____ in.
Depth: _____ in.
Width: _____ in.
Surface Area: _____ in.^{2}

Slope Rate from posts: __ V to __ H
Slope Offset(s) from posts: _____ in.

**Save & Continue Button Here!

c. Maximum size of obstruction(s) measured in _____in.^{2} (Surface Area) or _____in.^{3} (Volume) [Place an "X" behind all cases that apply!]
**Save & Continue Button Here!

d. Typical number of posts omitted, one _____, one to two _____, three or more_____ [Place an "X" behind all cases that apply!]
**Save & Continue Button Here!

e. Maximum number of posts omitted, one_____, one to two_____, three or more_____ [Place an "X" behind all cases that apply!]
**Save & Continue Button Here!

f. Location of omitted pos location within AGT, Post No.1_____, Post No.2_____, Post No.3_____ [Place an "X" behind all cases that apply!]

**Note: Post No.1 refers to the first transition post located at the end of the concrete bridge railing. Post Nos.2 and 3 correspond to the second and the third transition posts from the concrete bridge railing's end.

**Save & Continue Button Here!

2.2. Upload photographs, plans and/or documentation for instances where AGT posts have been omitted due to these obstructions and/or site constraints, if accessible, using the link below.

**Weblink via SurveyMonkey or SurveyGizmo
**Document Upload Button Here to Upload Multiple Files!
**Save & Continue Button Here!

3. How is your district addressing challenges posed by the previously-noted site constraints and obstructions?

[INSERT TEXT HERE]

**Save & Continue Button Here!

4. Please provide information regarding the maximum span length (*L*) between the concrete bridge rail end and the first transition post in NDOT's standard 34-in. tall AGT system that will enable your district to accommodate the obstructions and site constraints previously outlined?

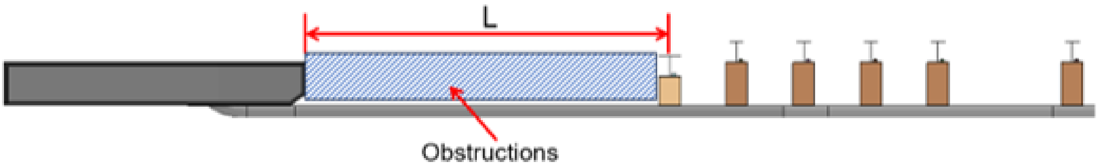

Figure 2. Schematics of NDOT's standard 34-in. tall AGT with span length "L" between concrete buttress end and first transition post

[INSERT TEXT HERE]

5. Please provide any additional comments or concerns regarding the design of NDOT's standard 34-in. tall AGT system with increased span length.

[INSERT TEXT HERE]

**Save & Continue Button Here!

6. Are you and/or a colleague willing to participate in a telephone call should additional information or clarification be required? Yes: _____ No: _____ [Place an "X" behind all cases that apply!]

   If answered "Yes" to Question 6, please provide alternative name, and contact information:

   Name: ___________________________________

   Email: ___________________________________

   Phone No.: ___________________________________

   **Save & Continue Button Here!

Thank you for taking our survey. Your response is very important to us.