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A Synthesis of MASH Tested 31-in. Tall, Non-Proprietary, W-Beam Guardrail Systems

by

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ABSTRACT

Since its initial development in the early 2000's, 31-in. tall W-beam guardrail has proven to be one of the most robust roadside barrier systems available today. Full-scale crash testing has been successfully conducted on numerous configurations of 31-in. W-beam guardrail installations including median and roadside systems, steel and timber post systems, 12-in. and 8-in. deep blockout systems, non-blocked systems, and systems placed on or adjacent to roadside slopes. Additionally, 31-in. W-beam systems have been developed for use in special applications such as bridge rails, long-span systems, and as culvert mounted installations.

This paper contains details and drawings encompassing a wide range of 31-in. tall W-beam guardrail configurations that have been developed and evaluated to MASH safety standards. The various configurations are discussed in terms of key components and performance characteristics, such as test level and working width. Finally, implementation guidance is provided for the proper selection, layout, and installation of the various 31-in. W-beam guardrail configurations.

Keywords: Vehicle Barriers, W-beam, Guardrail, MASH, TL-2, TL-3, 31-in. Tall Guardrail, MGS, Slopes, Bridge Rail, Median Barrier, Long-Span, Culverts, and Terminal

INTRODUCTION

W-beam guardrail systems are some of the most popular and frequently used vehicle barrier systems. For over 50 years, these barrier systems have been redirecting errant vehicles and preventing impacts into roadside hazards. However, by the 1990's the increased size of the vehicle fleet was beginning to push the containment limits of the existing W-beam guardrail configurations. Full-scale vehicle crash testing with heavy, high center-of-gravity passenger vehicles, such as pickup trucks and vans, often resulted in rail ruptures and vehicle rollovers. Thus, W-beam guardrails needed to be reconfigured to handle the larger vehicle fleet.

In the early 2000's, the Midwest Guardrail System (MGS) was developed through modifications to the existing G4(1S) W-beam guardrail system. These modifications included raising the height to the top of the rail to 31 in., a reduction in the post embedment depth to 40 in., and moving the rail splices from post locations to mid-spans (*1-2*). Additionally, the depth of the blockouts was increased to 12 in. to aid in the containment of taller vehicles and to reduce vehicle snag on the system posts. Details for the MGS are shown in Figure 1.

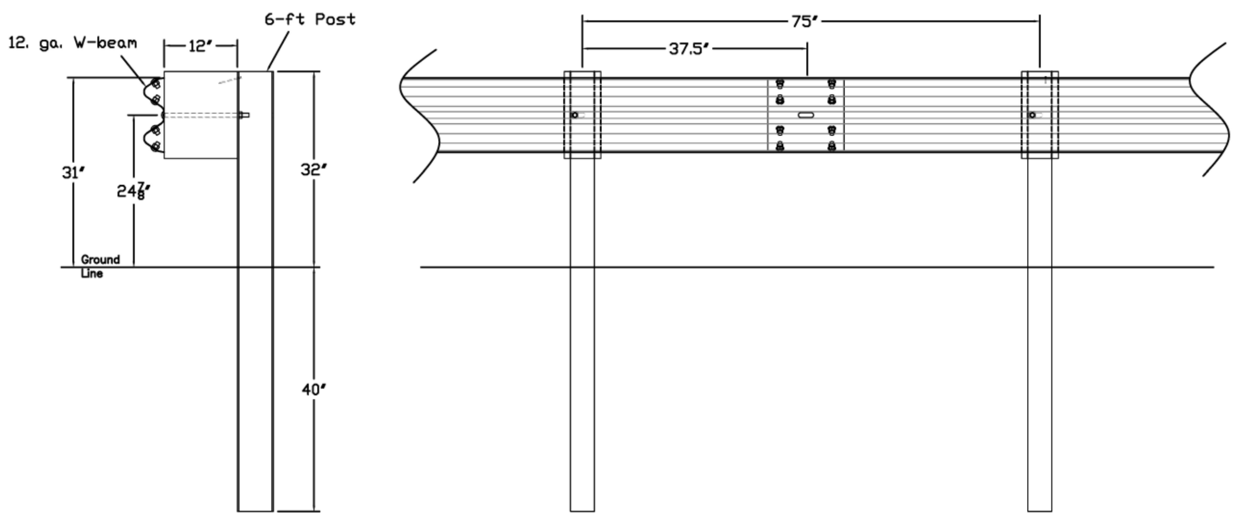


FIGURE 1 Characteristics of standard strong-post MGS, 31-in. tall W-beam guardrail.

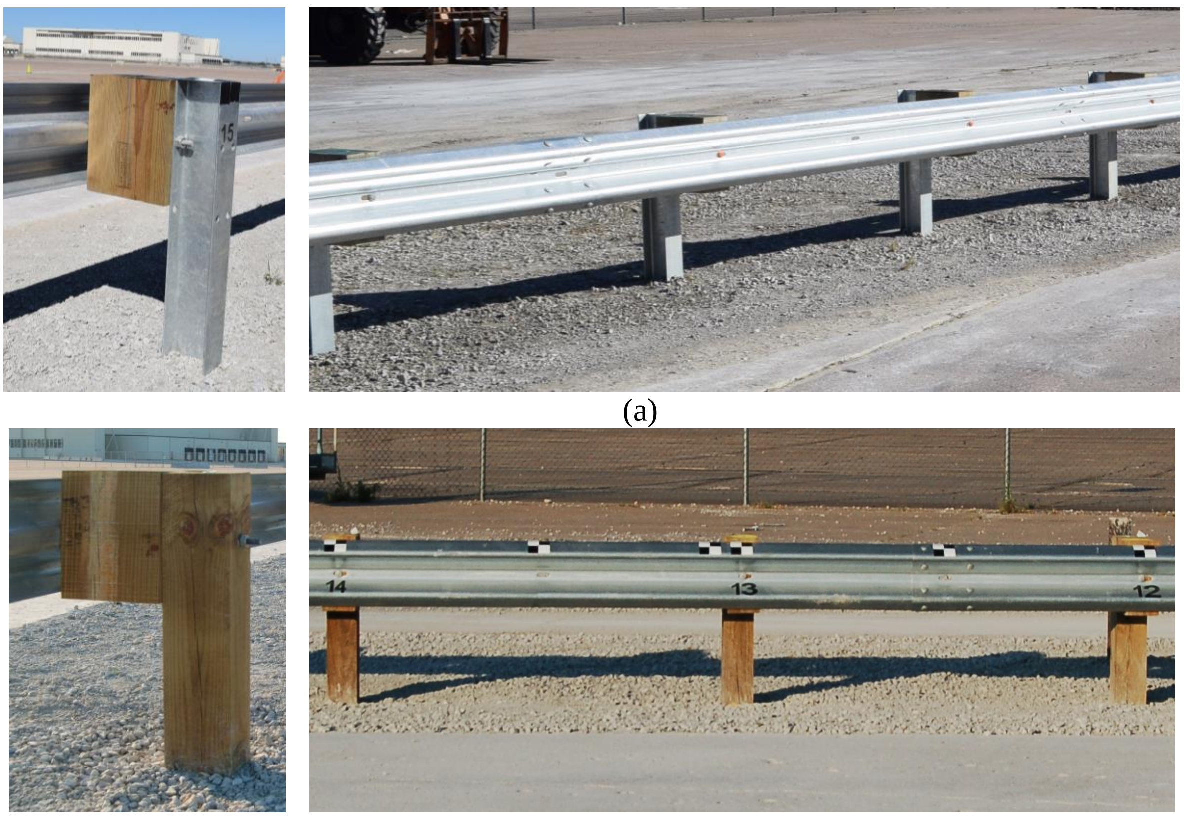
The MGS was originally developed and successfully crash tested to the Test Level 3 (TL-3) safety performance standards of NCHRP Report No. 350 (*3*). Since its inception, the MGS has proven to be a very robust barrier system as multiple variations and special applications of the MGS have been developed and successfully crash tested. Even with the adoption of a new crash testing standard, the *Manual for Assessing Safety Hardware (MASH)* (*4*), which utilizes larger vehicles and higher impact severities than NCHRP Report No. 350, the MGS and its variations have continued to provide crashworthy results.

This purpose of this paper is to provide a single resource documenting the numerous non-proprietary, 31-in. tall W-beam guardrail configurations and special applications. Details required for the proper installation of each system configuration are provided herein, including drawing sets, component details, performance levels, working widths, and installation guidance. Since AASHTO and FWHA established December 31, 2017 as the implementation date for W-beam guardrail installations to satisfy MASH safety standards (*5*), this paper is focused on only the MASH crash tested systems.

STRONG-POST SYSTEMS

Strong-post W-beam guardrail systems, which include both steel and timber posts, have been the most widely used guardrail systems for decades. Accordingly, both steel- and wood-post MGS systems have been successfully tested and evaluated to MASH TL-3 [*6-10*]. The steel post version of the MGS utilizes 6-ft long W6x9 or W6x8.5 posts, which have nearly identical flange widths and section depths and provide similar bending strengths. Thus, both post sections provide similar performance when used as a guardrail post. Timber post versions typically utilize 6-ft long rectangular posts measuring 6 in. wide and 8 in. deep.

Both steel- and timber-post versions of the MGS utilize the same general system layout with 12-in. blockouts, a 75-in. post spacing, and rail splices located at mid-span, as shown in Figure 1. Aside from the posts, the only difference between the steel- and timber-post systems is the length of the 5/8-in. diameter guardrail bolt. Photos of both systems are shown in Figure 2.



(a)

(b)

FIGURE 2 Strong-post MGS installations with (a) Steel and (b) rectangular timber posts.

During full-scale crash testing, both the steel- and timber-post versions of the MGS performed similarly in terms of vehicle behavior, occupant ridedown accelerations (ORA), and occupant impact velocities (OIV), which were all well within the MASH limits. However, there are a few notable differences between the systems. Wood posts tend to fracture under extreme loading conditions while steel posts plastically deform and continue to apply a resistance force to the vehicle. Consequently, the working width for timber-post systems is slightly higher than that of the steel-post system, as shown in Table 1. Thus, the required clear distance behind the barrier, which should be free of all hazards, depends on the post type.

The timber species utilized for the posts also factor into the system performance. The MGS has been evaluated to MASH utilizing both Southern Yellow Pine (SYP) and White Pine (WP) rectangular timber posts. WP posts have roughly 37 percent less strength than SYP posts. This reduction in strength resulted in increases in the number of fractured posts, the deformed length of the guardrail system, and the system working width, as shown in Table 1. Therefore, it is recommended that rectangular timber posts only be made from timbers with strength greater than or equal to that of Select Structural WP unless further evaluation is performed.

TABLE 1 Comparison of Steel- and Timber-Post MGS

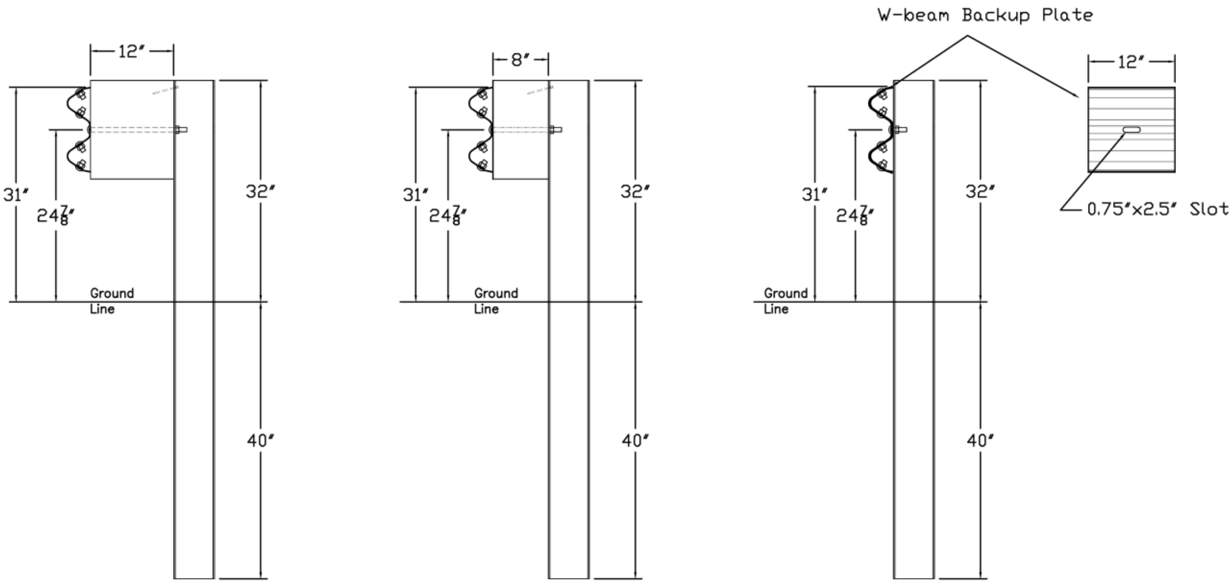
System	Steel-Post MGS	Timber-Post MGS	Timber-Post MGS
Posts	W6x8.5	6-in. x 8-in. SYP	6-in. x 8-in. WP
Reference	(*6*)	(*8*)	(*10*)
Performance Level	MASH TL-3	MASH TL-3	MASH TL-3
MASH 3-11 Results			
Working Width	48.6 in.	53.8 in.	58.4 in.
Contact Length	33.8 ft	34.3 ft	36.5 ft
No. Deflected Posts	6	6	7
No. Fractured Posts	-	4	5

BLOCKOUT VARIATIONS

The MGS was originally designed with 12-in. deep timber blockouts for two reasons: 1) to reduce the likelihood and severity of vehicle snag on guardrail posts and 2) to maintain rail height as the post deflects backward, making the system more likely to capture large vehicles. However, 31-in. tall W-beam guardrail has been successfully crash tested to MASH TL-3 standards while utilizing 8-in blockouts and in non-blocked configurations. All three blockout variations are shown in Figure 3.

The 31-in. W-beam guardrail system with 8-in blockouts differs from the standard MGS only in the depth of the blockout and length of the attachment bolt. This configuration was crash tested to MASH test designation 3-10 to evaluate any potential for the 1100C small car to snag on the guardrail posts. The test passed and resulted in vehicle and system behavior similar to that of the MGS with 12-in. blockouts (*11*). Thus, 8-in. blockouts can be utilized with either steel- or timber-post versions of the MGS.

The non-blocked MGS eliminated the timber blockout, but a 12-in. long segment of W-beam was placed between the rail and the post to prevent contact between the post flanges and the rail, which could initiate tearing of the rail. The non-blocked system was evaluated to MASH TL-3 and satisfied all safety criteria for both full-scale crash tests (*12-13*). The working width for the non-blocked system was measured to be 43.2 in.



(a) (b) (c)

FIGURE 3 MGS details for (a) 12-in. blockouts, (b) 8-in. blockouts, and (c) non-blocked configurations.

During evaluation of the non-blocked system, the small car contacted the posts earlier in the impact event and caused the vehicle to be non-tracking, or side skidding, as it exited the system. Additionally, snag on the posts resulted in a longitudinal OIV value of 31.3 ft/s, which was more than double that of the MGS with 12-in. blockouts but still within the MASH limit of 40 ft/s. These differences illustrate the benefits of utilizing blockouts within a guardrail system. As such, the use of blockouts is recommended for guardrail installations whenever the roadside can accommodate the increased width. Additionally, the non-blocked system has not been evaluated with timber posts, which may further increase vehicle snag, vehicle decelerations, and the risk for vehicle instabilities. Therefore, it is not recommended to utilize a non-blocked system with timber posts until further analysis is performed.

MEDIAN BARRIER

A 31-in. W-beam median barrier was developed and successfully crash tested to MASH TL-3 safety criteria. The median system utilized 12-ga. W-beam guardrail, spices at mid-span locations, and 8-in. deep blockouts mounted on both sides of standard steel guardrail posts, as shown in Figure 4. Although the system deflections were similar to those of the standard roadside systems, the increased width of the median system resulted in a 55-in. working width (*14)*.

Testing and evaluation of the median system was conducted with 8-in. blockouts, but 12-in. blockouts should provide similar system performance. During the small car test on the median system, a tear extended through two-thirds of the rail. Eliminating the blockouts could result in small increases to the rail loads and cause complete rupture of the rail. Additionally, vehicle snag on posts directly attached to two rail elements may result in excessive decelerations to the small car. Therefore, it is not recommended to install the median system in a non-blocked configuration without further analysis.

The median barrier system was evaluated on level terrain, and its performance on sloped terrain remains unknown. Thus, the median barrier system should only be install in median with a slope of 10:1 or flatter until further evaluation is performed. Finally, the ends of the system need to be properly treated with a crashworthy median guardrail terminal capable of anchoring a dual-sided, W-beam system.

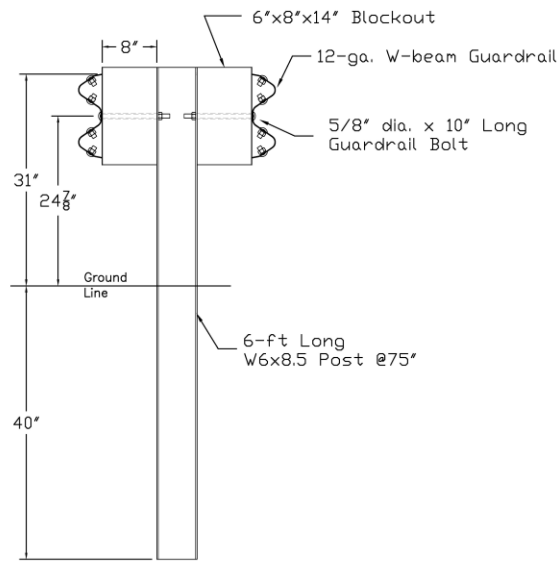


FIGURE 4 Details for 31-in. W-beam median barrier.

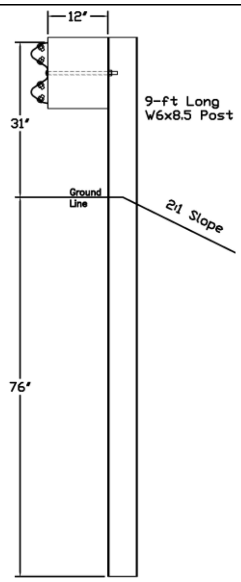
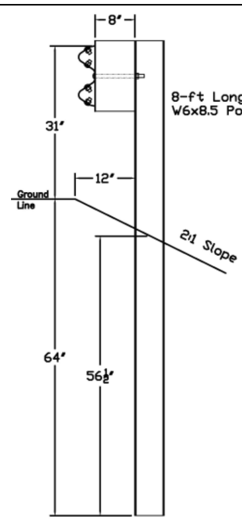
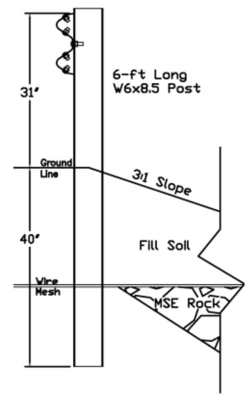
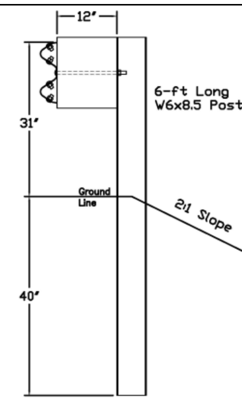
SYSTEMS INSTALLED NEAR SLOPES

The strength and stiffness of w-beam guardrail is heavily dependent on post-soil resistance forces. Placing the system on or adjacent to a slope reduces the amount of soil behind the post, lowers the post-soil resistance, and can negatively affect the performance of the system. Thus, it is recommended for guardrail posts to be installed with at least 2 ft of level terrain behind the system to ensure the system performs as initially developed and evaluated. However, there are instances where placing guardrail adjacent to slopes is necessary due to limited roadside widths.

To date, there have been four different W-beam guardrail configurations that have been successfully developed and crash tested to MASH TL-3 (*15-20*). Although all four systems utilized 31-in. tall w-beam rail, they had varying post lengths, blockouts, allowable slopes, and placements relative to the slope break point, as shown and detailed in Table 2. The system denoted as System C in Table 2 was developed specifically for use on top of Mechanically Stabilized Earth (MSE) walls. The posts were extended through the wire mesh utilized to anchor the MSE wall, effectively stiffening the system (*18*). Thus, System C requires installation within these MSE wall components in order to maintain the listed system performance, specifically the reduced working width. Placement on a standard fill slope would likely result in system deflections and working widths similar to System D.

System A was the first guardrail system developed for use adjacent to slopes and tested to MASH TL-3. It utilized 12-in. blockouts and 9-ft long posts centered on the slope break point (SBP) of a 2:1 slope. Dynamic testing of various posts located at the SBP of a 2:1 slope illustrated that 7.5-ft long 6-in. x 8-in. rectangular SYP timber posts would provide similar strength to the full-scale crash tested system (*15*). Full-scale testing of System B and additional dynamic post testing on slopes has since justified the use of 8-ft steel posts as well. Thus, both are listed as alternative post options for System A. Additionally, System C illustrated the crashworthiness of a non-blocked guardrail system on slopes, so both 8-in blockouts and non-blocked configurations of System A are listed as alternative options.

TABLE 2 Details for 31-in. W-Beam Guardrail on Slopes

System	A	B	C	D
Layout				
Reference	(*15*)	(*17*)	(*18*)	(*20*)
Performance Level	MASH TL-3	MASH TL-3	MASH TL-3	MASH TL-3
Full-Scale Tests	MASH 3-11	MASH 3-10 MASH 3-11	MASH 3-10 MASH 3-11	MASH 3-11
Post	9-ft W6x8.5	8-ft W6x8.5	6-ft W6x8.5	6-ft W6x8.5
Blockout	12-in. Blockout	8-in. Blockout	Non-Blocked	12-in. Blockout
Slope	2:1	2:1	3:1	2:1
Post Locations	Centered on SBP	Centered 15 in. Down Slope	Centered on SBP	Centered on SBP
Working Width	62.4 in.	55.2 in.	45.2 in.	77.4 in.
Alternative Posts	8-ft W6x8.5 or 7.5-ft 6"x8" Timber*	-	-	6-ft 6"x8" Timber*
Alternative Blockouts	Non-Blocked or 8" Blockout	12-in. Blockout	-	Non-Blocked or 8" Blockout
Allowable Slopes	2:1 or Flatter	2:1 or Flatter	-	2:1 or Flatter

* Timber Posts should have strength equal to or greater than SYP grade 1

System B is the only system to be developed and crash tested with the posts installed beyond the SBP. It utilized 8-in. blockouts and 8-ft long W6x8.5 posts centered 15 in. down a 2:1 slope (*17*). Thus, the face of the rail was located directly above the SBP. Due to a lack of dynamic testing on timber posts positioned beyond the SBP, which effectively increases the moment arm in the post from the center of the rail to the soil support and increases the possibility of post fracture, there have not been any timber posts identified as alternative posts for use with System

B. Non-blocked guardrail located beyond the SBP has not yet been evaluated, but may affect the relative height of the W-beam rail as system deflects during impacts. Specifically, the rail may be pulled downward as the posts deflect backward, which increases the possibility of vehicle override. As such, System B is not recommended to be installed as a non-blocked installation without further analysis.

System D represents a standard strong post MGS installed at the SBP of a 2:1 slope (*20*). The system was tested with steel guardrail posts, but standard rectangular timber posts installed at the SBP should provide similar performance. Thus, the 6-ft long 6-in. x 8-in. SYP timber post is listed as an alternative post for System D. Additionally, based on the performance of System C, both 8-in blockouts and non-blocked were listed as alternative blockout options for System D.

Due to the shorter post length of System D, a significant increase in working width was observed. It is important to note that MASH requires guardrail systems to be tested within strong soils to evaluate critical loading to barrier components. If the system is installed in a weaker soil, the deflections and working width would increase even further and may eventually become excessive and lead to vehicle instability, loss of vehicle containment, or rail rupture. Thus, System D is only recommended to be utilized in strong soil conditions similar to the soil specified by MASH. Installations sites with weaker or sandy soils are encouraged to utilize Systems A or B.

During the full-scale testing of System A, a MASH 3-11 test was conducted on a system with a 27¾ in. top mounting height. The 2270P pickup overrode this lower-height guardrail, thus failing the test. Subsequently, it is recommended for all W-beam guardrails adjacent to slopes to be installed with a minimum rail height of 31-in. without further analysis. Additionally, guardrail systems have only been evaluated on slopes as steep as 2:1. Thus, these guardrail systems should be limited to slopes of 2:1 or flatter until further evaluation is performed.

Finally, the recommendations listed herein for W-beam guardrail placed on or adjacent to steep slopes are applicable only to guardrail length of need installations. Special guardrail applications such as long-span installations, omitted posts, roadway curbs, and guardrail stiffness transitions have not yet been designed or evaluated for use on slopes. As such, it is not recommended to install these specialized guardrail applications on or adjacent to steep slopes without further analysis. Similarly, guardrail end terminals require specific grading to function properly. It is recommended that guidance from the individual end terminal manufacturer be sought after and followed concerning placement on slopes.

GUARDRAIL WITH OMITTED POSTS

Occasionally within a guardrail installation, obstructions within the ground prevent the proper installation of a post. At these locations, it is often desired to omit the guardrail post leaving a 12.5-ft span between the posts adjacent to the obstruction. Subsequently, a steel post MGS installation with a single missing post was subjected to MASH test 3-11 to evaluate critical rail loadings and possible vehicle instabilities. The system contained and redirected the vehicle with a working width of 50.1 in., and the system was determined to satisfy MASH TL-3 safety criteria (*21*).

The omission of a post effectively weakens the guardrail system and results in increased system deflections, rail loads, and vehicle pocketing. The omission of multiple posts within the contacted region of a guardrail installation system may lead to excessive displacements, loads, and/or pocketing that may ultimately lead to system failure. Therefore, until further evaluation is completed on multiple missing posts within a system, it is recommended that at least eight posts be installed between omitted posts to ensure proper system performance.

Since the performance of timber and steel posts are so similar, the same guidelines should be utilized for the omission of a post within a guardrail system for either post type. Additionally, utilization of either 8-in. or 12-in. blockouts are acceptable adjacent to the omitted post location. However, the increased deflections associated with an omitted post may be problematic for a non-blocked system due to the increased risk for rail rupture and exposure of the vehicle floor pan to contact with posts. Thus, it is not recommended to omit posts within a non-blocked system until further evaluation is conducted.

Finally, these guidelines on omitted post are only intended for standard, length-of-need installations. Specialized W-beam applications such as guardrail adjacent to slopes, guardrail stiffness transitions, guardrail in combination with roadway curbs, or guardrail end terminals are sensitive systems that may be negatively affected by a post omission. Thus, it is not recommended to omit posts within these specialized guardrail regions without further analysis.

MGS LONG SPAN GUARDRAIL

The MGS Long-Span guardrail system was developed to treat sites where an obstruction prevents multiple adjacent guardrail posts from being installed, such as a low-fill culvert or short bridge. The MGS Long Span system consists of a 25-ft unsupported span (equivalent of three omitted posts) with three timber Controlled Release Terminal (CRT) posts on each side (*22-23*), as shown in Figure 5. Because CRT posts were designed to breakaway when impacted, they help prevent excessive rail loads, pocketing, and vehicle snag during impacts to the unsupported span. Each CRT post utilizes a 12-in blockout, and standard strong-post MGS should be used adjacent to each end of the MGS Long Span. This system was successfully tested to the TL-3 safety criteria of MASH and the working width was determined to be 93.4 in.

The MGS Long Span was tested with the back of the CRT posts 9-in. in front of the outside face of a simulated culvert headwall, which resulted in the face of the guardrail being 32 in. from the edge of the culvert. These distances represent the recommended minimum lateral offsets required between the system and the outside edge of a culvert headwall or bridge deck without further analysis. Additionally, it is recommended it install the CRT posts with a minimum of 2 ft of level terrain behind the posts to ensure proper performance until further analysis is conducted.

Culvert headwalls may extend above the ground line and act a vertical roadway curb beneath barrier. Curbs of any type may create vehicle instabilities if placed in combination with the MGS Long Span. Thus, it is recommended that culvert headwalls extend no higher than 2 in. above the ground line.

As discussed previously, the increased rail height and blockout depth of the MGS over previous W-beam guardrail systems has led to a more robust barrier. With a working width of 93.4 in., these characteristics may be vital to the performance of the system. As such, it is recommended that the MGS Long Span be installed with a top rail height of 31 in. and a 12-in blockout until further analysis is performed. Additionally, it is not recommended to extend the unsupported length of the guardrail beyond 25 ft without further analysis as testing with a 31.25-ft unsupported span length has proven unsuccessful (*24*).

To ensure proper load distribution away from the MGS Long Span, it is recommended that at least 62.5 ft of guardrail, including the end anchorage, be installed both upstream and downstream from the CRT posts. The MGS adjacent to the three CRT posts may consist of any of the MASH TL-3 roadside configuration contained herein, unless otherwise noted.

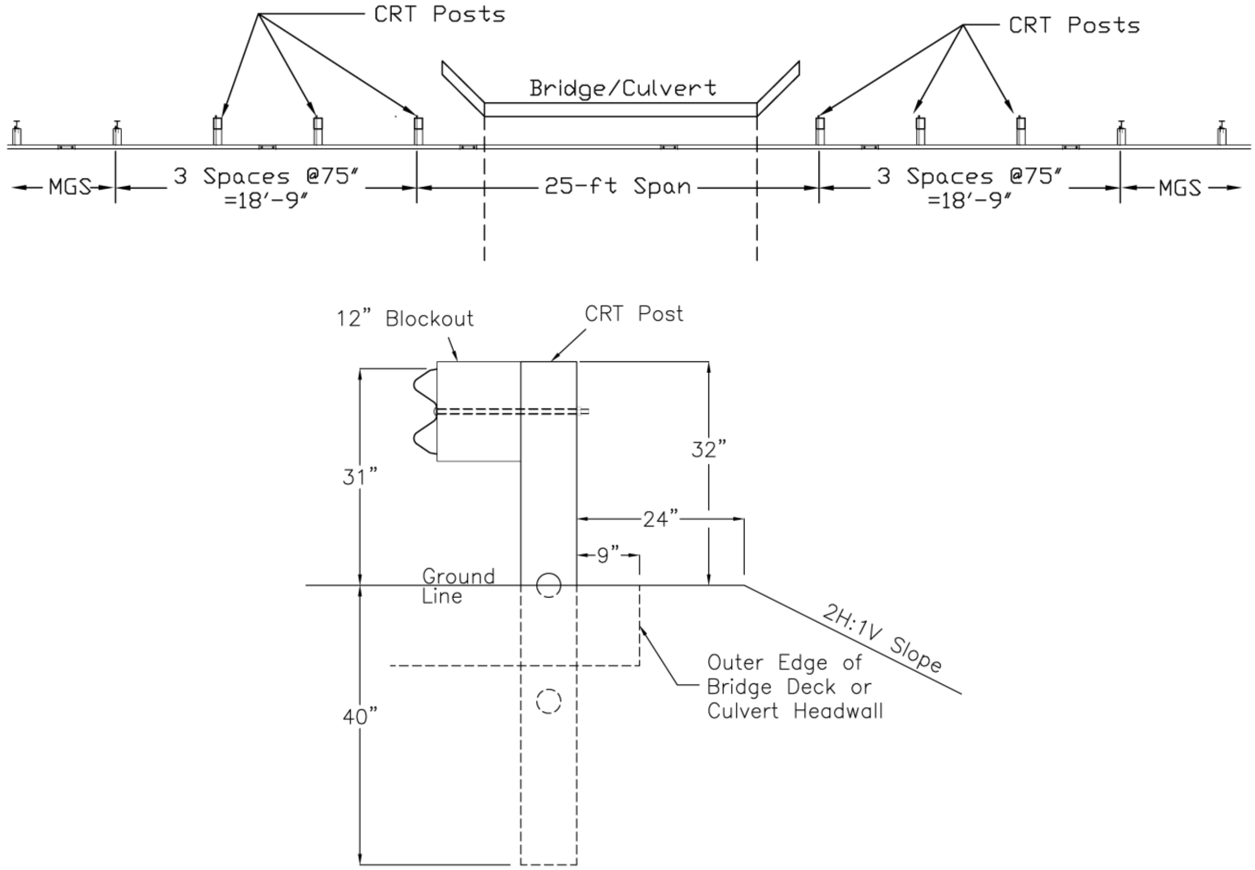


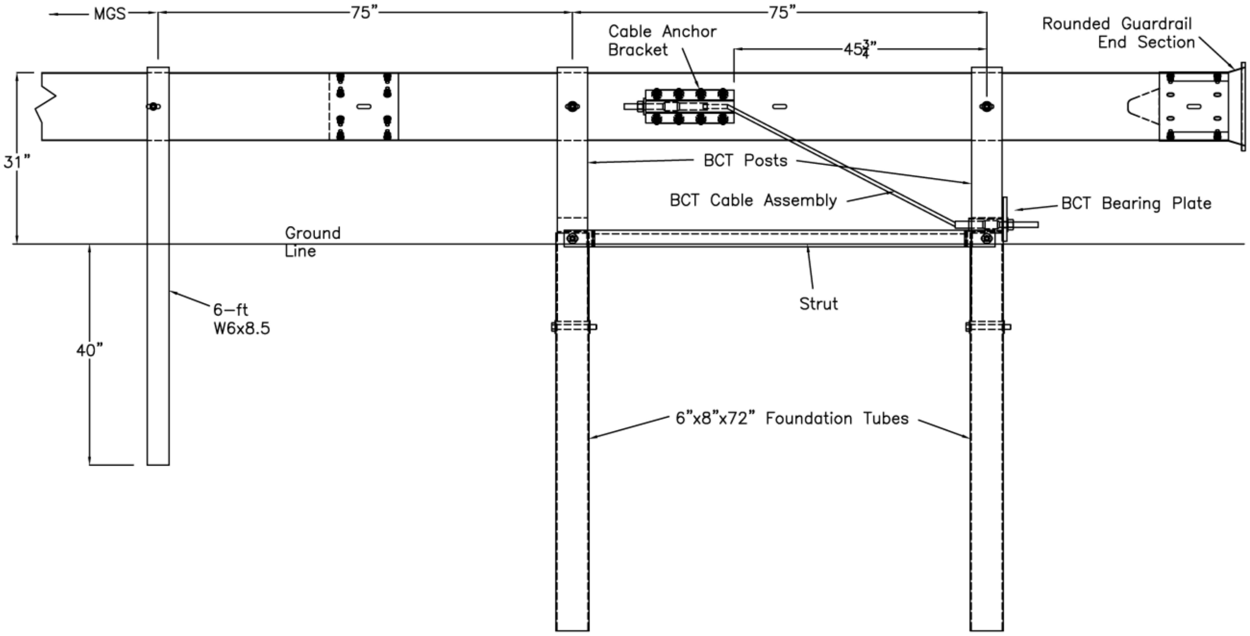
FIGURE 5 Details of the MGS long-span guardrail system.

END TERMINALS

Multiple 31-in. guardrail end terminals have been developed and successfully evaluated to MASH safety criteria. The majority of these terminals are proprietary, and, thus, are not discussed herein. However, two non-proprietary, trailing-end terminals have been developed for 31-in. tall W-beam guardrail. Both terminals were two post systems that utilize Breakaway Cable Terminal (BCT) cable assemblies, bearing plates, and 6-in. x 8-in. x 72-in. long foundation tubes to anchor the W-beam. The two main differences between the two terminals were 1) the struts between the foundation tubes and 2) the size of the breakaway timber posts placed in the foundation tubes, as shown in Figure 6. One terminal utilized an 8½-in. x 5½-in. x 10 gauge channel strut and standard 5½-in. x 7½-in. BCT posts (*25-26*). The other terminal utilized dual C3x5 channels as the struts between foundation tubes and modified BCT posts measuring 5¼-in. x 7¼-in. (*27*).

Both terminals were successfully crash tested to MASH TL-3 safety criteria as trailing end terminals, meaning they should only be utilized on the downstream end of guardrail installations that are out of the clear zone of opposing lanes of traffic. The terminal utilizing standard BCT post was evaluated with a 2270P pickup, and the end of length-of-need point was determined to be the sixth post from the end of the installation. Due to the similarity of the terminal systems, this point could be the end of length-of-need for the modified BCT post terminal as well.

Both terminals were crash tested in combination with a blocked, steel post 31-in. guardrail system. However, these trailing end terminals should be compatible with both steel or timber post systems, and blocked or non-blocked systems. As with most terminals, adequate grading (10:1 or flatter) is recommended around these terminals to ensure proper anchorage and vehicle stability while in contact with the system. Finally, the area behind the terminal should be clear of roadside hazards as these terminals are gating systems. Guidance on the recommended clear area behind the terminal was provided within one of the terminal testing reports (*25*).



(a) (b)

FIGURE 6 Details for the non-proprietary, trailing-end terminals with (a) BCT posts and a 10-gauge, bent-plate strut and (b) modified BCT posts and dual C3x5 struts.

WEAK POST BRIDGE RAILS

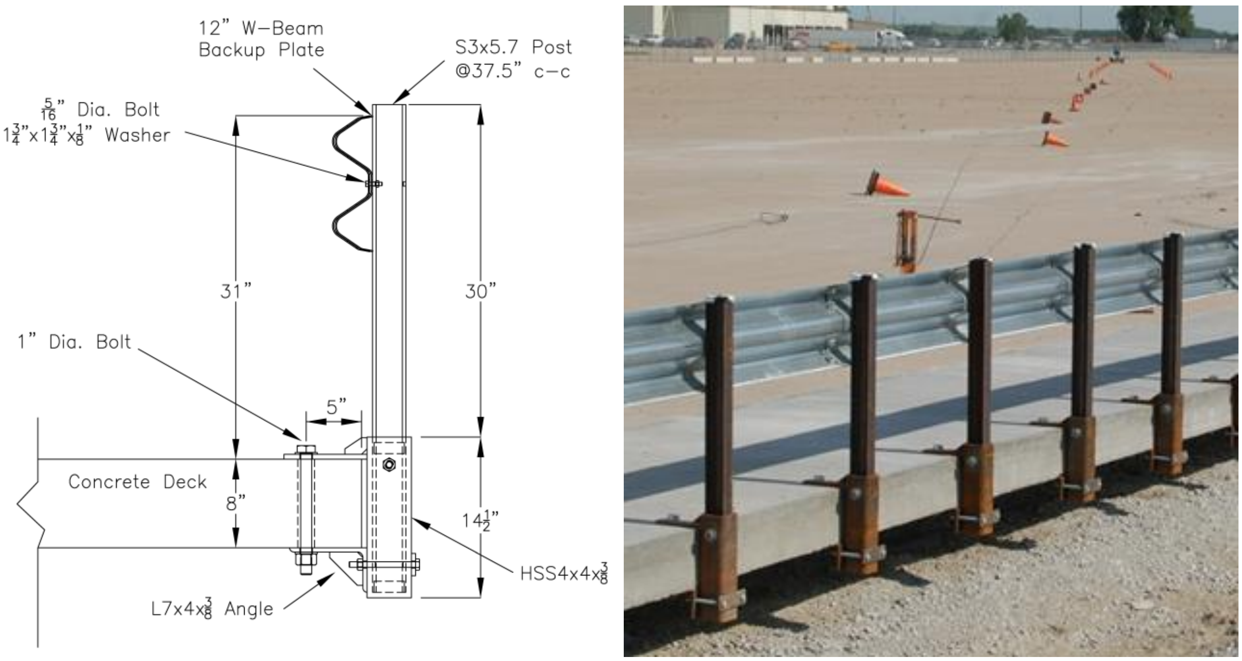
Two 31-in. W-beam bridge rails have been developed to MASH standards. Both bridge rails were comprised of non-blocked configurations supported by S3x5.7 weak-posts (*28-32*), as shown in Figure 7. Non-blocked guardrail maximizes the traversable width of the bridge, while the weak posts limit impact loads and the potential for deck damage. Both systems also utilized $^{5}/_{16}$-in. diameter bolts and 1¾-in. square washers to attach the rail to the posts.

The weak-post MGS bridge rail utilized steel tube sockets mounted to the side of the bridge deck to support the S3x5.7 posts (*28-29*). The posts were spaced at 37.5 in. on center and had two ¼-in. thick shim plates welded on the upstream and downstream sides of the post so that the post fit snuggly in the socket. A $^{7}/_{16}$-in. thick top mounting plate was welded to the front of the

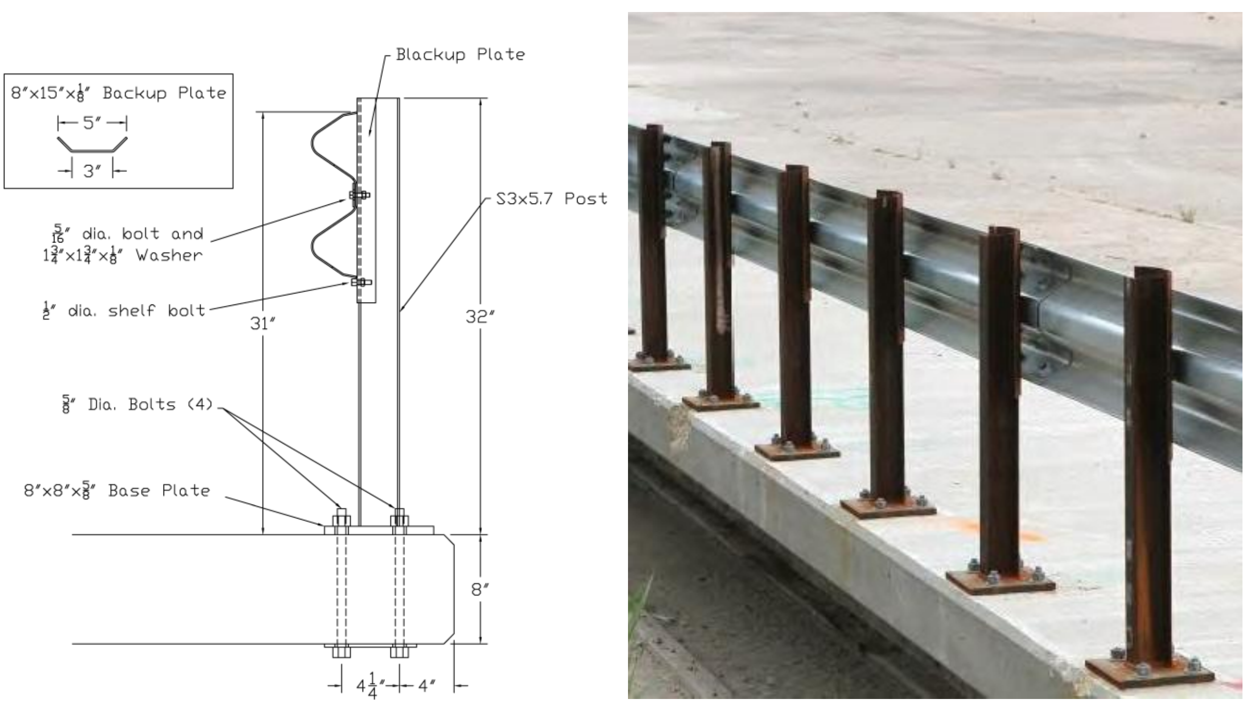
HSS4x4x⅜ sockets, and the assembly was attached to the deck with a 1-in. diameter bolt. The bottom of the socket was bolted to an L7x4x⅜ angle to provide support for reverse bending and longitudinal loads. This bridge rail utilized 12-in. long W-beam backup plates similar to the non-blocked version of the MGS. This system was successfully crash tested to MASH TL-3 and has a 53.2-in. working width.

The T631 bridge rail utilized a ⅝-in. thick baseplate, a ¼-in. thick washer plate, and four ⅝-in. diameter bolts to mount the S3x5.7 posts to the top of the bridge deck (*30*-*32*). A ½-in. diameter shelf bolt was used to support the rail vertically. The T631 bridge rail can be configured with two different post spacings. A 75-in. post spacing was successfully tested and evaluated to MASH TL-2 with a 30.0-in. working width. A MASH 3-11 test was conducted on the 75-in. spacing, but the rail ruptured and the test failed. Reducing the post spacing to 37.5-in. resulted in the T631 being successfully tested and evaluated to MASH TL-3 with a 57.7-in working width.

Because the working widths of these bridge rails are so similar to those of standard roadside MGS configurations, these bridge rails do not require guardrail stiffness transitions. The ends of the bridge rails attach directly to an adjacent MGS system utilizing a 75-in. spacing between the outermost bridge post and the adjacent MGS strong post. Additionally, the adjacent MGS may utilize any approved post and/or blockout combination. Guardrail installations utilizing 6-ft posts and placed adjacent to sloped terrain have working widths significantly higher than these weak-post bridge rails. Therefore, it is recommended to utilize either 8-ft or 9-ft posts in the adjacent guardrail installations when steep slopes are present.



(a)



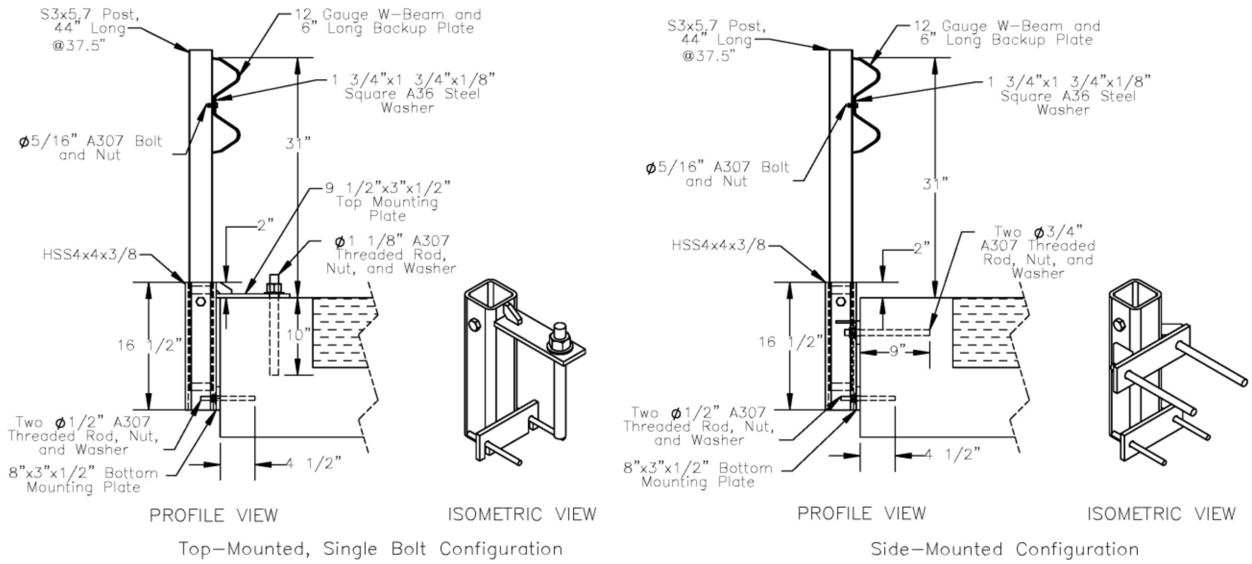
(b)

FIGURE 7 Details and photos of (a) the weak-post MGS Bridge Rail and (b) the T631 Bridge Rail

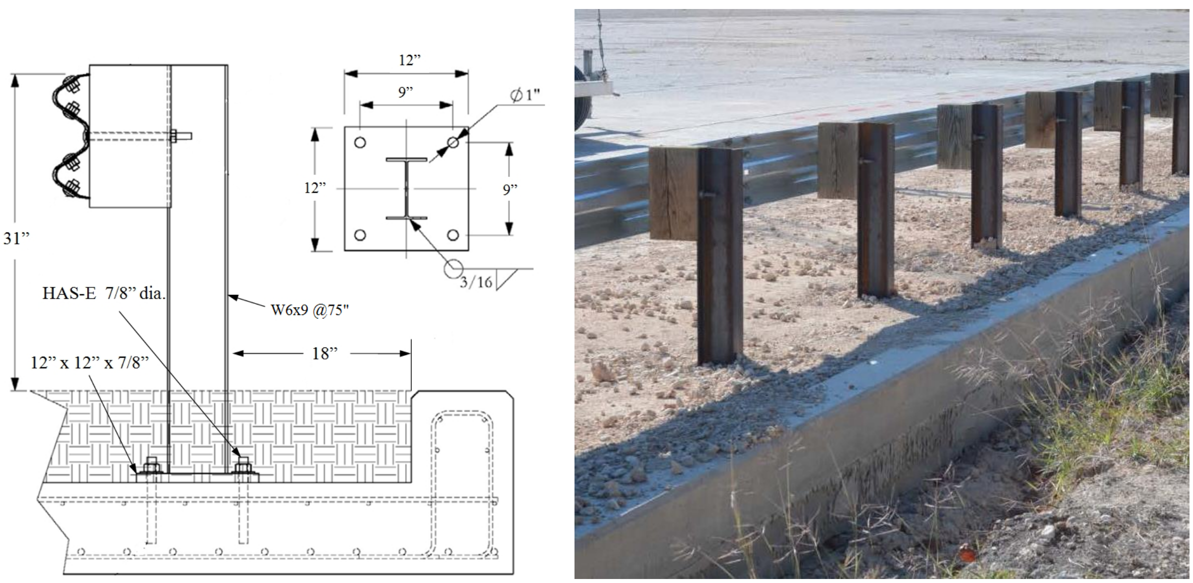
GUARDRAIL ATTACHMENTS TO CULVERTS

Two 31-in. W-beam guardrail systems have been developed for attachment to low-fill culverts. The first system utilized the same posts, post spacing, guardrail bolts, backup plates, and sockets as the MGS bridge rail. However, the socket attachment hardware was modified to mount the socket to the outside face of culvert headwalls (*33-34*). Multiple attachment configurations were developed including a top mounted single bolt configuration, which was similar to the bridge rail, and a side mounted configuration, as shown in Figure 8. Both configurations utilized epoxy anchors so that the guardrail system could be attached to both new and existing culvert structures. Because the post and rail were identical to the weak-post MGS bridge rail, these culvert attachment configurations are crashworthy to MASH TL-3 and have the same installation guidance as the weak-post MGS bridge rail.

The second system was a strong-post, top-mounted system, as shown in Figure 8. The W6x9 posts were spaced at 75 in. on center and were positioned 18 in. from the inside face of the headwall (*35*). The posts were welded to baseplates and mounted to the culvert slab with four epoxy anchors. The system was successfully crash tested to MASH TL-3 and has a 49.2-in. working width. The system can be installed with either 8-in. or 12-in. blockouts, but it is not recommended to be installed non-blocked without further analysis. Finally, this system can be directly connected to the other 31-in. W-beam systems shown herein as long as adequate soil grading is provided behind the adjacent systems posts.



(a)



(b)

FIGURE 8 Details and photos of (a) side-mounted and (b) top-mounted guardrail systems attached to culverts.

TL-2 SYSTEM

A TL-2 version of standard strong-post guardrail has been developed by doubling the post spacing to 12.5-ft. The system was comprised of 31-in. tall W-beam, standard 6-ft W6x8.5 posts, and 8-in. deep blockouts. The system was successfully tested and evaluated to MASH TL-2 and has a 44.3-in. working width (*36*). Either steel or timber strong-post are compatible with the TL-2 system. However, it is not recommended to install the TL-2 system on slopes, with omitted posts, or in a non-blocked configuration without further analysis.

FUTURE DEVELOPMENTS

Other MASH crashworthy, W-beam guardrail systems exist beyond the systems presented herein. Some are proprietary, some utilize different guardrail heights, and some were left out simply due to a lack of word space (e.g., guardrail in mow strips and guardrail stiffness transitions). In addition, there are numerous 31-in. W-beam systems that were initially developed and evaluated under prior safety standards that have yet to be evaluated to MASH including:

- MGS with reduced post spacing
- MGS with curb
- MGS on approach slopes
- MGS with alternative timber species and round posts

The details and installation guidance provided for the various guardrail configurations herein incorporate all of the knowledge currently available on the testing and evaluation of 31-in. guardrail systems. However, it is recognized that the future will bring new developments, new systems, and new testing and evaluations on performance of W-beam guardrail. The guidance provided herein should be used in combination with any future knowledge to optimize the performance of W-beam guardrail systems.

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