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Midwest Guardrail System Without Blockouts

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ABSTRACT

The Midwest Guardrail System (MGS) has been shown to provide exceptional redirective capability in standard and many special applications. However, the roadway width required to install a guardrail system with a blockout is not always available. In response, a non-proprietary non-blocked MGS was developed and successfully crash tested according to the testing standards established in the Manual for Assessing Safety Hardware (MASH). Results from the 1100c small car and 2270p pickup truck tests are compared between the blocked and non-blocked version of the MGS, and it is concluded that the blocked MGS performs better than the non-blocked MGS. As a result, it is recommended that the non-blocked MGS only be used in places where roadway width is a limiting parameter. But, if width is not restricted, it is still recommended to use a blockout as designated in the design drawings of the standard MGS.

Keywords: Roadside Safety, Midwest Guardrail System, MGS, Non-Blocked Guardrail, MASH, Crash Testing

INTRODUCTION

The Midwest Guardrail System (MGS) is a non-proprietary, strong-post, W-beam guardrail system consisting of standard steel or wood guardrail posts with 12-in. (305-mm) deep blockouts [1-4]. The MGS has been successfully crash tested according to the Test Level 3 (TL-3) safety performance evaluation criteria for both the National Cooperative Highway Research Program (NCHRP) Report No. 350 [5] and the Manual for Assessing Safety Hardware (MASH) [6]. Unfortunately, the roadway space required to install the blocked guardrail system is not always available. Therefore, a non-blocked version of the MGS would be useful in many situations.

Currently, in areas where space is limited, states are forced to utilize a proprietary system due to the lack of a non-proprietary alternative. Three propriety, strong-post, non-blocked W-beam guardrail systems have been recently developed and successfully crash tested. One was developed by Trinity Industries and is called the T-31 Guardrail [7]. The second is offered by Gregory Industries and is called the Gregory Mini Spacer (GMS) Guardrail [8]. The third was developed by Nucor Steel Marion Inc. and is called Nucor Strong Post W-Beam Guardrail System (NU-GUARD) [9]. These proprietary non-blocked W-beam guardrail systems use unique components such as post-rail attachment hardware or variations to the standard guardrail post.

The MGS has demonstrated improved vehicle containment, safety performance, and redirective capacity over that provided by conventional, strong-post, W-beam guardrail systems [1-4, 10-13]. The MGS has also been shown to provide satisfactory safety performance when used in combination with curbs, culverts, slopes, high flare rates and other roadside anomalies. More recently, a version of a non-blocked MGS was successfully developed for use in shielding the hazardous vertical drop-offs created by wire-faced MSE walls [14]. The MSE wall application placed the non-blocked MGS at the slope break point of a 6-ft (1.9-m) wide, 3H:1V fill slope located on the wall.

Thus, based on the historical performance of the standard MGS and its specialized applications, the Midwest States Pooled Fund Roadside Safety Program sponsored the project reported herein to develop and test a standard non-proprietary MGS without blockouts. A detailed comparison between the blocked and non-blocked MGS test results is also included.

DESIGN DETAILS

The standard MGS formed the basis for the barrier system. However, the MGS was modified by removing the 12-in. (305-mm) deep wood spacer blocks and incorporating W-beam backup plates. The test installation consisted of 181 ft-3 in. (55.25 m) of standard 12-gauge (2.66-mm thick) W-beam supported by steel posts. Complete design details as well as the results of the testing are provided in MwRSF report TRP-03-262-12 [15]. System layouts of the tested systems are shown in Figure 1.

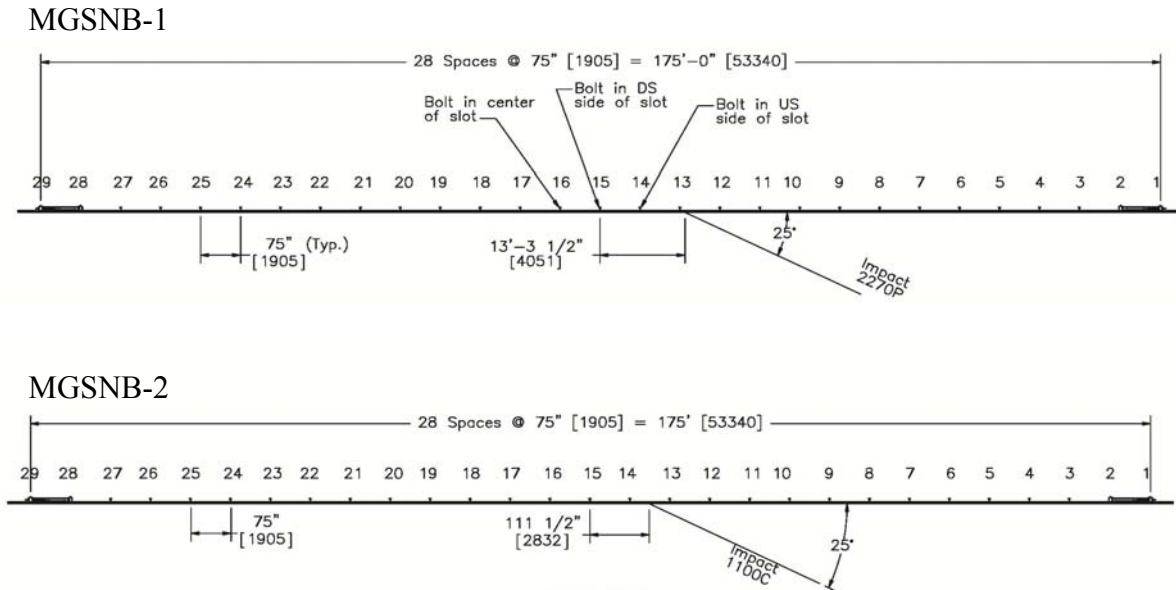


FIGURE 1 System Layout

The system was constructed with twenty-nine guardrail posts spaced 75 in. (1,905 mm) on center. Post nos. 3 through 27 were galvanized ASTM A992 steel W6x8.5 (W152x12.6) sections measuring 6 ft (1.8 m) long with a soil embedment depth of 40 in. (1,016 mm). Post nos. 1, 2, 28, and 29 were breakaway cable terminal (BCT) timber posts measuring 5½ in. wide x 7½ in. deep x 46 in. long (140 mm x 191 mm x 1,168 mm) and were placed in 6-ft (1.8-m) long foundation tubes. All posts were placed in a compacted coarse, crushed limestone material as recommended in MASH.

Rail splices were placed at the midspan locations between guardrail posts. All lap splice connections between the rail sections were configured with the upstream segment in front to reduce vehicle snag at the splice during the crash test. For post nos. 3 through 27, 12-in. (305-mm) long, 12-gauge (2.66-mm thick) W-beam backup plates were located between the rail and the front face of the steel posts. Anchorage systems similar to those used on tangent guardrail terminals were utilized on both the upstream and downstream ends of the guardrail system.

The mounting height of the W-beam was test dependent. For the pickup test, MGSNB-1, the top mounting height was 31 in. (787 mm) above ground with a 24⅞ in. (632-mm) center mounting height. While for the small car test, MGSNB-2, the rail was raised 1 in. (25 mm) such that the height to the top of the guardrail was 32 in. (813 mm). The rail was attached to the posts using ASTM A307 5/8" x 1½" [M16x38] long guardrail bolts and nuts.

TEST REQUIREMENTS AND EVALUATION CRITERIA

Longitudinal barriers, such as W-beam guardrails, have been required to satisfy the impact safety standards provided in MASH to be eligible according to the FHWA for use on National Highway System (NHS) construction projects or as a replacement for existing designs not meeting current safety standards. According to TL-3 criteria found in MASH, longitudinal barriers must be subjected to two full-scale vehicle crash tests: (1) a 2,425-lb (1,100-kg) passenger car impacting at a speed of 62 mph (100 km/h) and at an angle of 25 degrees and (2) a 5,000-lb (2,268-kg) pickup truck impacting at a speed of 62 mph (100 km/h) and at an angle of 25 degrees.

The evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the guardrail to contain and redirect the vehicle. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Vehicle trajectory after collision is a measure of the potential for the post-impact trajectory of the vehicle to result in multi-vehicle accidents. This criterion also indicates the potential for safety hazard for the occupants of other vehicles or occupants of the crash vehicle when subjected to secondary collisions with other fixed objects. These three evaluation criteria are described in greater detail in MASH.

FULL-SCALE CRASH TESTING

Test No. MGSNB-1 – Pickup Truck Test

For test no. MGSNB-1, a 5,181-lb (2,350-kg) pickup truck impacted the non-blocked MGS at a speed of 62.7 mph (100.9 km/h) and at an angle of 24.7 degrees. A summary of the test results are shown in Figure 2. Initial impact occurred at 9½ in. (0.2 m) upstream from the centerline of post no. 13. At 0.248 sec after impact, the vehicle became parallel to the guardrail with a speed of 47.9 mph (77.1 km/h). At 0.504 sec, the vehicle exited the guardrail at an angle of 14.4 degrees and at a speed of 47.4 mph (76.3 km/h). The vehicle was smoothly redirected even though the right-front tire snagged on post no. 15 and was disengaged from the vehicle.

Exterior vehicle damage was moderate, and the interior occupant compartment deformations were minimal, with a maximum of 1¼ in. (32 mm), consequently not violating the limits established in MASH. Damage to the barrier was also moderate, consisting mostly of deformed W-beam and guardrail posts as well as contact marks on guardrail and posts. The maximum lateral dynamic rail deflection was 34.1 in. (867 mm) at the mid-span between post nos. 14 and 15. The working width of the system was 43.2 in. (1,097 mm). All occupant risk measures were well below recommended values, and the test vehicle showed no tendency to roll over. Therefore, test no. MGSNB-1 was determined to be acceptable according to the TL-3 safety performance criteria found in MASH.

Test No. MGSNB-2 – Small Car Test

For test no. MGSNB-2, a 2,578-lb (1,169-kg) small car impacted the non-blocked MGS at a speed of 63.0 mph (101.4 km/h) and at an angle of 25.5 degrees. A summary of the test results are shown in Figure 3. Initial impact occurred at 32¼ in. (0.8 m) upstream from the centerline of post no. 14. After impact, the vehicle began to redirect, including a counter-clockwise yaw rotation (i.e., backend towards the rail). At 0.036 sec after impact, the vehicle snagged on post no. 14 causing the vehicle to essentially stop yawing. At 0.404 sec, the vehicle exited the guardrail at a trajectory angle of 19.1 degrees and at a speed of 25.7 mph (41.4 km/h).

Exterior vehicle damage was moderate, and the interior occupant compartment deformations were minimal, with a maximum deformation of 1¼ in. (32 mm), consequently not violating the limits established in MASH. Damage to the barrier was moderate, consisting mostly of deformed W-beam rail and steel guardrail posts as well as contact marks on guardrail and posts. The maximum lateral dynamic rail deflection was 29.1 in. (740 mm) at the mid-span between post nos. 14 and 15. The working width of the system was 34.5 in. (877 mm). All occupant risk measures were well below recommended values, and the test vehicle showed no tendency to roll over. Therefore, test no. MGSNB-2 was determined to be acceptable according to the TL-3 safety performance criteria found in MASH.

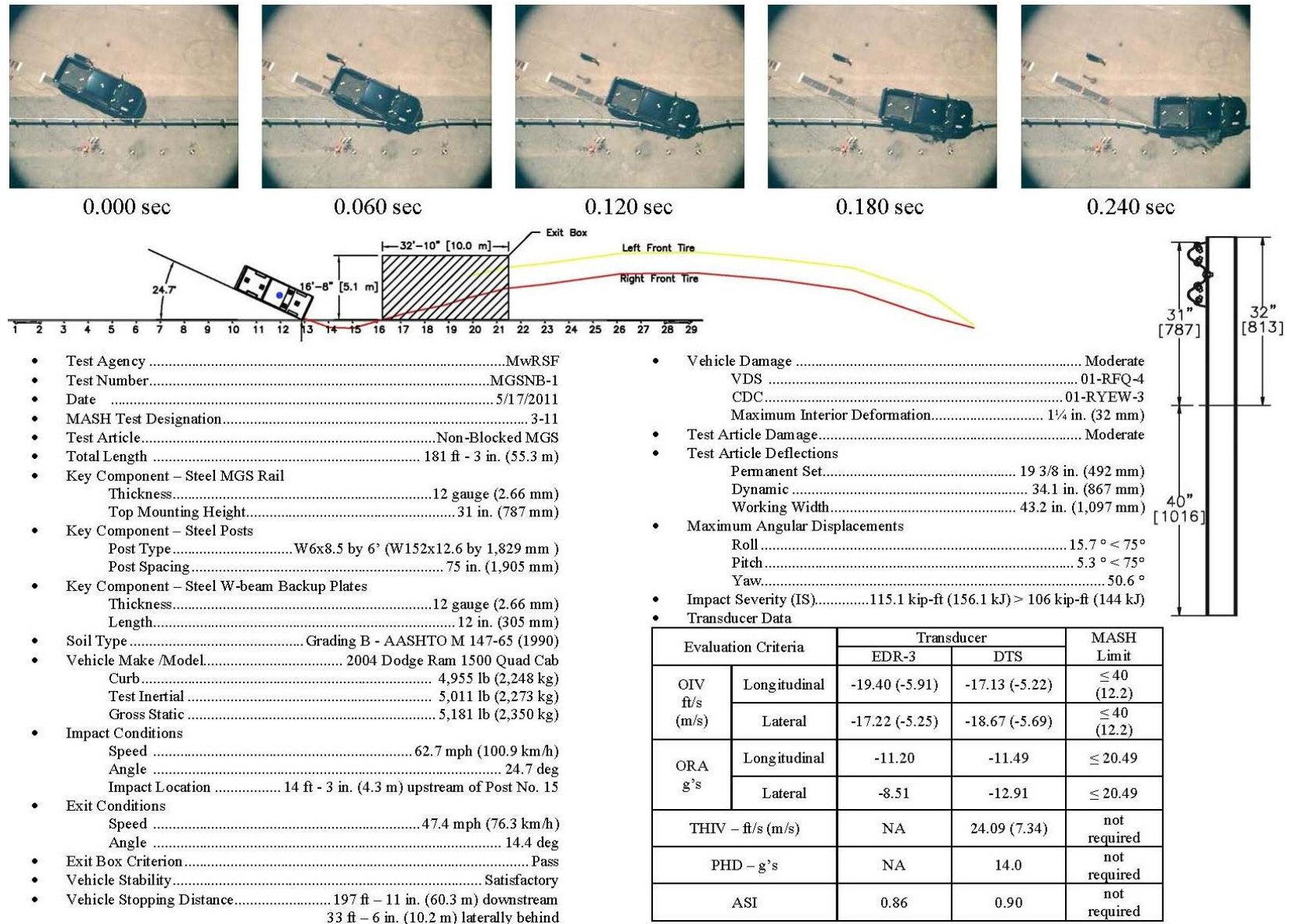
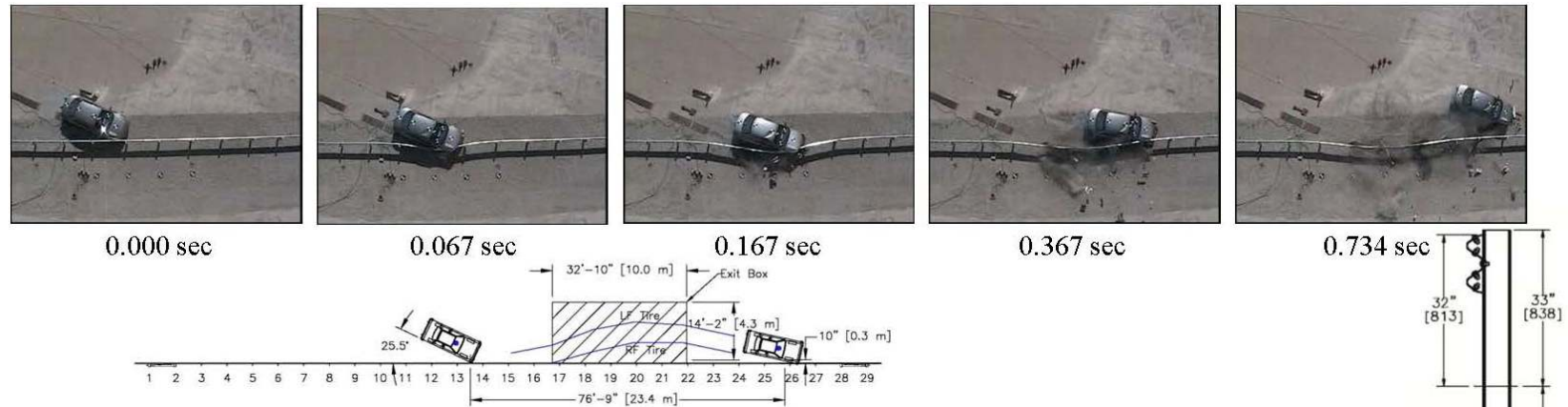


FIGURE 2 Test MGSNB-1 Results



- Test AgencyMwRSF
- Test Number.....MGSNB-2
- Date6/15/2011
- MASH Test Designation.....3-10
- Test Article.....Non-Blocked MGS
- Total Length181 ft - 3 in. (55.3 m)
- Key Component – Steel MGS
 - Thickness.....12 gauge (2.66 mm)
 - Top Mounting Height.....32 in. (813 mm)
- Key Component – Steel Posts
 - Post Type.....W6x8.5 by 6' (W152x12.6 by 1,829 mm)
 - Post Spacing.....75 in. (1,905 mm)
- Key Component – Steel W-beam Backup Plates
 - Thickness.....12 gauge (2.66 mm)
 - Length.....12 in. (305 mm)
- Soil Type.....Grading B - AASHTO M 147-65 (1990)
- Vehicle Make /Model.....2005 Kia Rio
 - Curb.....2,375 lb (1,077 kg)
 - Test Inertial2,408 lb (1,092 kg)
 - Gross Static2,578 lb (1,169 kg)
- Impact Conditions
 - Speed63.0 mph (101.4 km/h)
 - Angle25.5 deg
 - Impact Location8 ft - 11¼ in. (2.7 m) upstream of Post No. 15
- Exit Conditions
 - Speed25.7 mph (41.4 km/h)
 - Angle19.1 deg
- Exit Box Criterion.....Pass
- Vehicle Stability.....Satisfactory
- Vehicle Stopping Distance.....76 ft-9 in. (23.4 m) downstream
10 in. (0.3 M) laterally in front

- Vehicle Damage
 - VDS.....01-RFQ-5
 - CDC01-RYEW-4
 - Maximum Interior Deformation1¼ in. (32 mm)
- Test Article Damage.....Moderate
- Test Article Deflections
 - Permanent Set.....13 7/8 in. (352 mm)
 - Dynamic29.1 in. (740 mm)
 - Working Width.....34.5 in. (877 mm)
- Maximum Angular Displacements
 - Roll.....8.27 ° < 75°
 - Pitch.....3.98 ° < 75°
 - Yaw.....14.24 °
- Impact Severity (IS).....59.3 kip-ft (80.4 kJ) > 51 kip-ft (69.7 kJ)
- Transducer Data

Evaluation Criteria		Transducer		MASH Limit
		EDR-3	DTS	
OIV ft/s (m/s)	Longitudinal	-31.17 (-9.81)	-31.26 (-9.53)	≤ 40 (12.2)
	Lateral	-15.46 (-4.71)	-15.83 (-4.82)	≤ 40 (12.2)
ORA g's	Longitudinal	-10.47	-10.20	≤ 20.49
	Lateral	-6.03	-6.30	≤ 20.49
THIV – ft/s (m/s)		NA	34.65 (10.56)	not required
PHD – g's		NA	10.21	not required
ASI		0.97	1.04	not required

FIGURE 3 Test MGSNB-2 Results

COMPARISON BETWEEN BLOCKOUT AND NON-BLOCKOUT MGS TESTING

A comparison between the blocked and non-blocked MGS for both the 2270p truck and 1100c small car is presented in Table 1. Rear view sequentials for the 2270p and 1100c tests are shown in Figures 4 and 5, respectively. Barrier damage and vehicle damage are shown in Figures 6 and 7, respectively. Longitudinal and lateral change in velocity plots are shown in Figure 8.

TABLE 1 Test Comparisons

Comparison of Results		MASH Test 3-11		MASH Test 3-10	
		Standard MGS	Non-Blocked MGS	Standard MGS	Non-Blocked MGS
Test Number		2214MG-2	MGSNB-1	2214MG-3	MGSNB-2
Reference Number		[2]	[14]	[3]	[14]
Vehicle	Designation	2270p	2270p	1100c	1100c
	Test Inertial, lb (kg)	5,000 (2,268)	5,011 (2,273)	2,423 (1,099)	2,407 (1,092)
Impact Conditions	Speed, mph (km/h)	62.8 (101.1)	62.7 (100.9)	60.8 (97.8)	63.0 (101.4)
	Angle, deg	25.5	24.7	25.4	25.5
Exit Conditions	Speed, mph (km/h)	39.6 (63.7)	47.4 (76.3)	30.1 (48.4)	25.7 (41.4)
	Trajectory Angle, deg	13.5	14.4	14.1	19.1
ORD, g's	Longitudinal	8.2	11.5	16.1	10.2
	Lateral	6.9	12.9	8.4	6.3
OIV, ft/s (m/s)	Longitudinal	15.3 (4.7)	17.1 (5.2)	14.8 (4.5)	31.3 (9.5)
	Lateral	15.6 (4.8)	18.7 (5.7)	17.1 (5.2)	15.8 (4.8)
Test Article Deflections, ft (m)	Dynamic	3.6 (1.1)	2.8 (0.9)	3.0 (0.9)	2.4 (0.7)
	Permanent	2.6 (0.8)	1.6 (0.5)	1.7 (0.5)	1.2 (0.4)
	Working Width	4.1 (1.2)	3.6 (1.1)	4.0 (1.2)	2.9 (0.9)
Impact Severity, kip-ft (kN-m)		122 (166)	115 (156)	55 (75)	59 (80)
Max. Occupant Compart. Deformation, in. (mm)		0.8 (19)	1.3 (32)	0.2 (6)	1.3 (32)
Max. Yaw Angle, deg.		-46	51	-29	-14
Max. Roll Angle, deg.		-5	16	-13	8
Max. Pitch Angle, deg.		-2	-5	-6	4
Impact Point		18" upstream post 12	10" upstream post 13	46" upstream post 14	32" upstream post 14
Posts detached from rail during impact		posts 13-16	posts 14-15	posts 15-17	posts 14-17
Posts hit by leading tire (wheel snag)		posts 13-15	posts 14-15	posts 15-16	posts 14-17
Posts pulled out of ground		none	none	none	posts 14 and 16
Leading tire/wheel disengaged		mostly	yes	tire debeaded	yes

Each test successfully passed all criteria set forth by MASH. In fact, all data, photos, and videos showed that none of the tests conducted were in any danger of failing any of the criteria. However, there were some noteworthy differences between the blocked and non-blocked results for the respective vehicles.

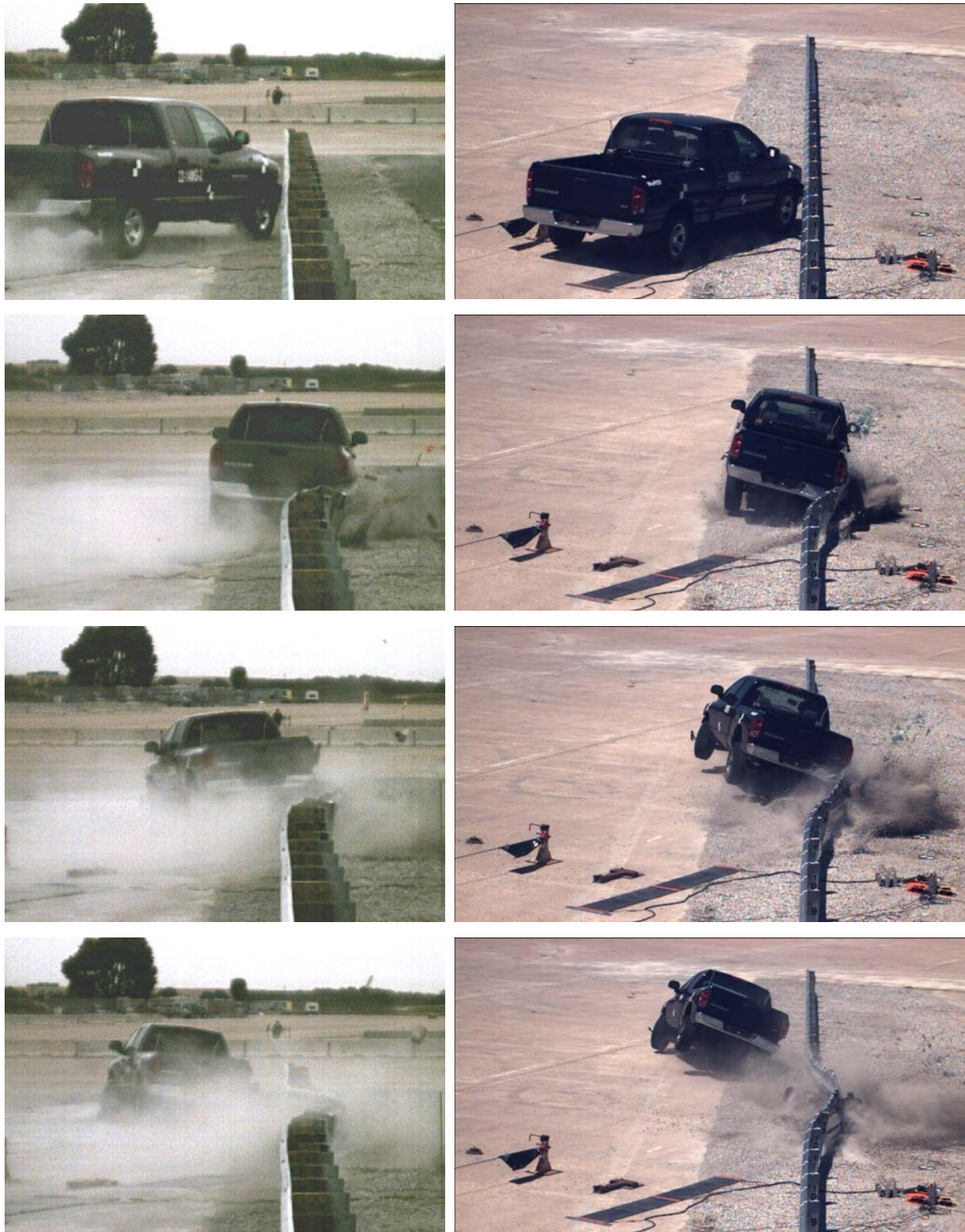


FIGURE 4 Rear View of 2270p Truck Tests – 2214MG-2 (left) and MGSNB-1 (right)

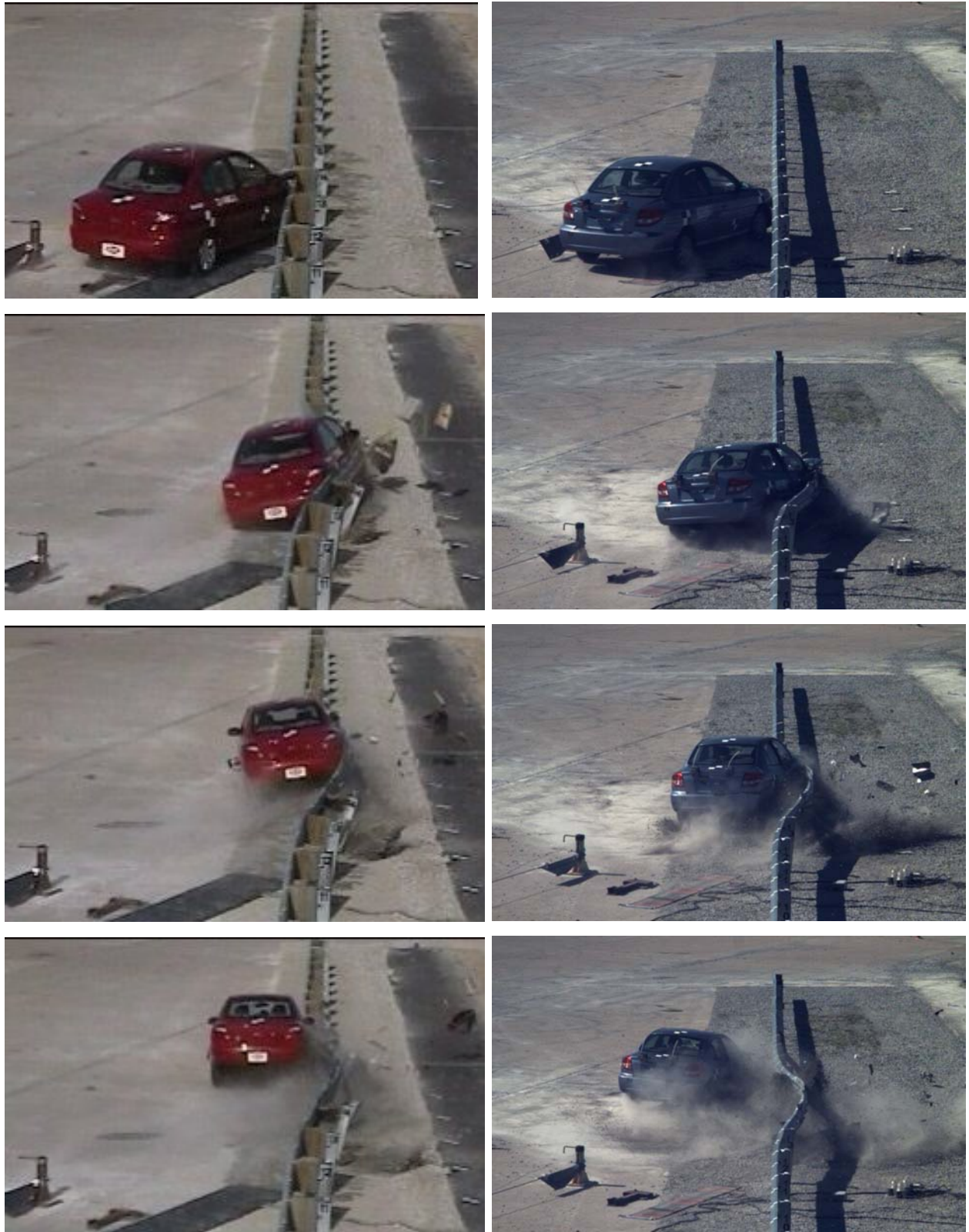


FIGURE 5 Rear View of 1100c Car Tests – 2214MG-3 (left) and MGSNB-2 (right)

2214MG-2



MGSNB-1



2214MG-3



MGSNB-2

FIGURE 6 Barrier Damage



FIGURE 7 Vehicle Damage (left – blocked tests, right – non-blocked tests)

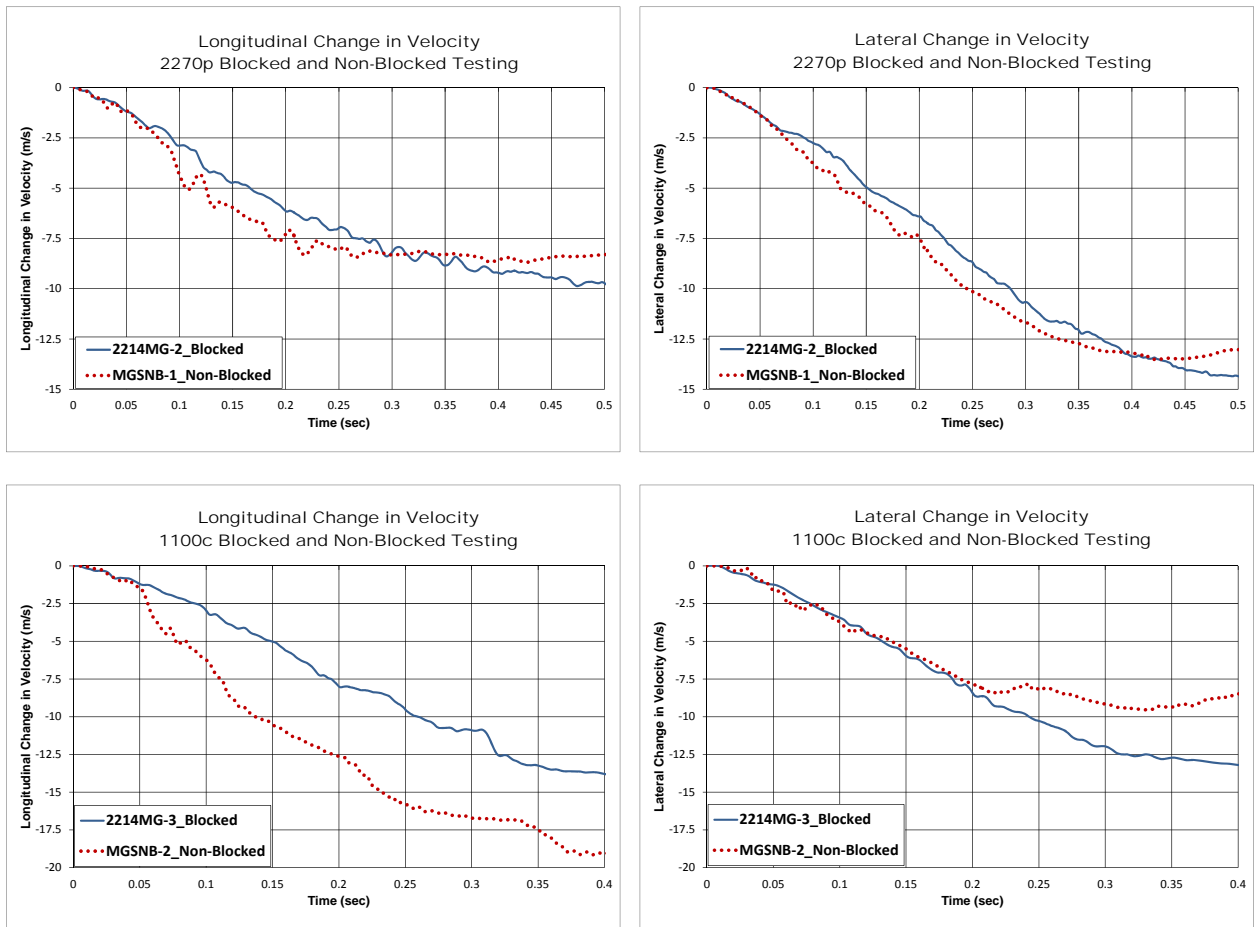


FIGURE 8 Longitudinal and Lateral Change In Velocity

For the 2270p vehicle, the non-blocked test when compared to the blocked test had significantly reduced rail deflections, a roll into the barrier as opposed to away from the barrier, fewer posts detached from the rail, and fewer posts snagged by the tire. The occupant ridedown decelerations (ORD) and occupant impact velocity's (OIV) were, percentage wise, much higher for the non-blocked system; these differences are also somewhat evident by examining the change in velocity plots. However, the occupant risk measures for both systems were small enough to not cause undue concern. In general, the blocked MGS had higher rail deflections and lower occupant risk numbers.

For the 1100c vehicle, the non-blocked test compared to the blocked test had significantly reduced rail deflections, a yaw that was essentially stopped due to wheel snag, more posts detached from the rail, and more posts snagged by the tire. The occupant ridedown decelerations were much lower for the non-blocked system. But the longitudinal occupant impact velocity was significantly higher for the non-blocked system due to a large wheel snag early in the non-blocked test. Again, these occupant differences are evident by examining the change in velocity plots. In general, the blocked MGS had higher rail deflections and prevented an early wheel snag that essentially controlled the occupant risk measures for the non-blocked system.

Much of the rail deflection differences can probably be attributed to the soil conditions. The more recent non-blocked MGS testing was performed in soil that used a relatively new compaction method, which has been determined to provide a somewhat stiffer soil condition. Thus, most likely, reducing dynamic deflections. Soil conditions for all tests were well within MASH recommendations.

Discussion

Based on the full-scale testing results, the main advantages of using a blockout for the MGS are threefold: (1) there is improved stability for both vehicles, lower roll and pitch for the pickup truck partially due to an effective rail height increase during post rotation, and smoother redirection for the small car as seen by the consistent/smooth yaw motion; (2) reduced snag on posts which provides for lower longitudinal velocity change for the small car, smoother yaw motion of the small car, and lower longitudinal decelerations for both vehicles, and (3) reduced occupant risk measures, all are better for the truck, while the small car's longitudinal OIV is much better. Additionally for the small car, the non-blocked test did have lower lateral ORD but that was due to lack of yaw caused by wheel snag, and its' lower longitudinal ORD was due to high initial longitudinal decelerations, as seen in the early steep drop of longitudinal change in velocity (see Figure 8). Overall, it was concluded that the blocked system performed better than the non-blocked system.

RAIL-POST ATTACHMENT

During MGSNB-1 and MGSNB-2, the locations of the post bolts were varied within the rail slots in order to investigate rail release away from the posts, as indicated in Figure 1 and shown in Figure 9. Post 15 was determined to be the most likely worst case scenario if the rail did not release from the post during impact. As a result, the post bolt was located at the downstream end of the rail slot. For both the pickup and small car tests, the guardrail detached from post 15 as the bolt head was pulled through the rail. Slight tearing of the rail was evident around the rail bolt hole, but not of significance to cause concern for rail rupture. Video analysis also showed that the release of the rail occurred considerably before the post could pull the rail down as the posts rotated in the soil.

Further, for both tests, the post bolt at post 16 was initially in the center of the slot. For the truck test, MGSNB-1, post 16 rotated in the soil, the rail did not release from the post, and the tire did not snag on the post. Although in the impact zone, release of the rail for this post was not required for good redirection performance. For the small car test, MGSNB-2, the rail slipped along the bolt, causing the bolt to butt up against the end of the slot. The bolt head was then pulled through the rail in a timely manner, this time without any tearing of the rail around the bolt hole.

Similar behavior for rail release under worst case scenarios occurred during testing of the non-blocked MGS for MSE walls. That performance was documented in [14].

In order to prevent the rail from being pulled down as a post rotates in the soil, as well as a possible vehicle override of the barrier during an impact event, the rail may need to detach away from the post. Fortunately, it has been shown that the bolt attachment mechanism used for the MGS, the same one used for standard W-beam guardrail systems for several decades, provides for satisfactory rail detachment.



(a) MGSNB-1 (2270p, non-blocked)



(b) MGSNB-2 (1100c, non-blocked)

FIGURE 9 Bolt Located in Worst Case Location – Pull-Through Behavior Still Occurred

IMPORTANCE OF THE BLOCKOUT

The 31-in. mounting height is only one component which contributes to the enhanced performance of the MGS. It is well acknowledged that blockouts serve two primary purposes in the strong-post system. The first, and most important, is causing the rail to rise during an impact. As illustrated in Figure 10, during an impact, the rotation of the posts in conjunction with the blockout causes the rail to rise in the MGS (as well as in Standard W-Beam Guardrail Systems). This is not the case for the 31-in. W-Beam Guardrail System without blockouts; where the rail immediately begins to drop as the post rotates in the soil. The deeper blockout on the MGS has significantly improved performance in concert with the increased mounting height.

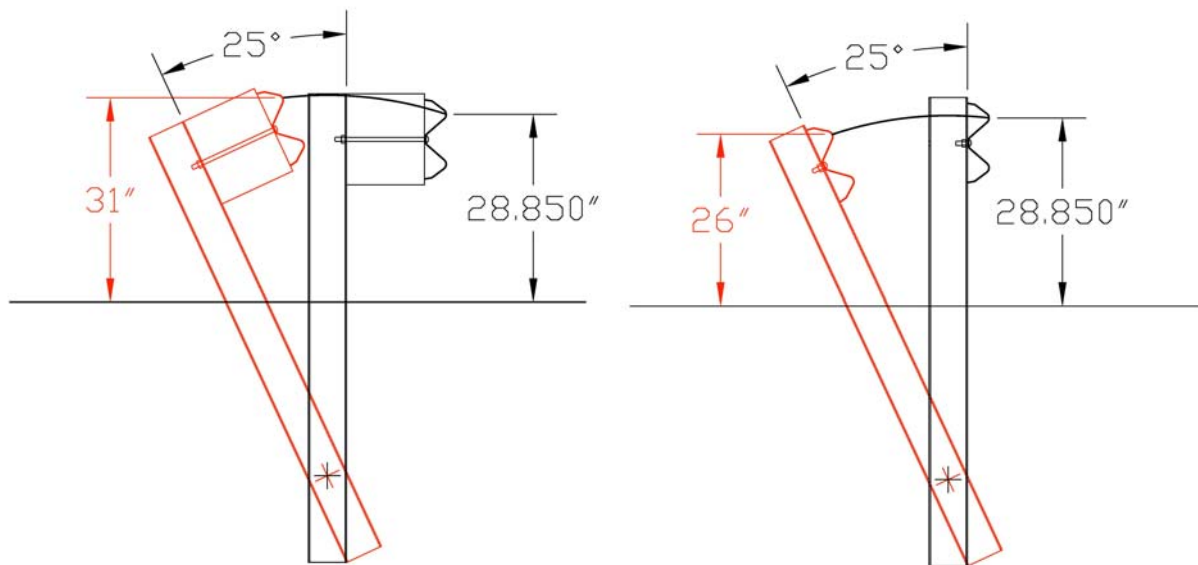


FIGURE 10 Post/Rail Rotation During Impact - Blockout Holds Rail Up

As indicated by the successful crash testing, this does not mean that the non-blocked MGS system is unsafe. Even though the rail is dropping upon post rotation in the non-blocked system, it is not dropping below a critical height during the initial 25 degrees of rotation. In fact, the rail of the 31-in. height MGS with no blockout after 25 degrees of rotation is approximately at the initial height of standard metric W-beam guardrail system. Post-in-soil rotation of 25 degrees is considered a reasonable amount for absorbing a significant amount of energy of the impacting vehicle. However, the larger blockout depth clearly increases the effective guardrail height.

The second function of the blockout is to keep vehicles away from the posts, thus reducing both the potential for wheel snag and the amount of wheel snag if it were to occur. Although in all of the testing of the MGS and its' variations over the past decade, wheel snag has never proven to be a problem. However, it is prudent to avoid unnecessary impacts of major components. While our surrogate test vehicles may function without blockouts, many other vehicles on the road may suffer degraded performance when interacting with a no-blockout system.

A significant wheel snag occurred at post 14 during test MGSNB-2 which did not occur during test 2214MG-3, as shown in Figure 11. Initial impact for both tests was just upstream of post 13, and each vehicle easily cleared post 13 without tire-post overlap. The wheel snag at post 14 during MGSNB-1 was the cause for the relatively abrupt change in longitudinal velocity (see Figure 8), as well as the relatively high OIV compared to the blocked test, 2214MG-3 (31.3 ft/s versus 14.8 ft/s). It also helped pull post 14 out-of-the-ground as well as helped disengage the tire/wheel during the test.



2214MG-3 – Blocked



MGSNB-2 – Non-Blocked

FIGURE 11 1100c Crash Tests at Post 14 – Blockout Reduces Wheel Snag

CONCLUSIONS AND RECOMMENDATIONS

The non-proprietary, non-blocked MGS was successfully crash tested using both the 1100c small car and 2270p pickup truck vehicles according to TL-3 safety performance guidelines provided in MASH. Based on this research, the non-blocked MGS has demonstrated to be a safe and viable option for use in areas where the roadway space is limited. The non-blocked MGS provides an economical design variation of the MGS for such applications.

Previously, it has been demonstrated that wood blockouts used in combination with the MGS greatly increases barrier capacity, often reduces occupant risk, and improves the vehicle post-impact trajectory compared to standard W-beam guardrail systems. Now, based on comparing the blocked to the non-blocked MGS test results, it is concluded that the blocked MGS performs better than the non-blocked MGS. Thus, it is recommended that 12-in. (305-mm) deep wood spacer blocks, or acceptable alternatives, be used with the MGS whenever the roadside geometry can accommodate a guardrail system with increased width.

Several variations of the MGS system have been developed for special applications, which may be more sensitive to the elimination of the blockouts. These special applications would include the MGS long span system, MGS adjacent to 2:1 fill slopes, MGS on 8:1 approach slopes, MGS adjacent to curb, MGS stiffness transition to approach guardrail transitions, MGS

with reduced post spacing, and MGS with various wood posts. Since several MGS variations are available, recommendations regarding the use of a blockout will likely vary depending on the nature and behavior of the special applications listed above. Implementation guidance and/or recommendations regarding the use or omission of blockouts in these special applications are discussed in detail in the report documenting this project [15].

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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