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Evaluation of the Midwest Guardrail System Stiffness Transition with Curb

by

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ABSTRACT

A W-beam to thrie beam stiffness transition with a 4-in. tall concrete curb was developed to connect 31-in. tall w-beam guardrail, commonly known as the Midwest Guardrail System (MGS), to a previously-developed thrie beam approach guardrail transition system. This upstream stiffness transition was configured with standard steel posts that are commonly used by several State Departments of Transportation. The toe of a 4-in. tall sloped concrete curb was placed flush with the backside face of the guardrail and extended the length of the transition region. Three full-scale crash tests were conducted according to the Test Level 3 (TL-3) safety standards provided in AASHTO's *Manual for Assessing Safety Hardware* (MASH). During the first test, MASH test no. 3-20, the 1100C small car extended and wedged under the rail and contacted posts while traversing the curb. Subsequently, the W-beam rail ruptured at a splice location, and the test was deemed a failure. To prevent guardrail rupture, the stiffness transition was modified to include a 12-ft 6-in. long, nested W-beam rail segment upstream from the W-beam to thrie beam transition element. A repeat of MASH test no. 3-20 was performed on the modified system, and the 1100C small car was successfully contained and redirected. During a third full-scale test, MASH test no. 3-21, a 2270P pickup truck was successfully contained and redirected. Following the crash testing program, the system was deemed acceptable according to the TL-3 safety performance criteria specified in MASH.

Keywords: Highway Safety, Crash Test, Roadside Appurtenances, MASH, TL-3, Curb, Asymmetric W-Beam to Thrie Beam Transition, Guardrail Stiffness Transition, Steel Post, Midwest Guardrail System, MGS

INTRODUCTION

In 2010, the Midwest Roadside Safety Facility (MwRSF) successfully developed and crash tested a simplified, upstream stiffness transition for connecting 31-in. tall w-beam guardrail, known as the Midwest Guardrail System (MGS), to thrie beam approach guardrail transition systems (*1-2*). The upstream stiffness transition consisted of standard 12-gauge W-beam guardrail, an asymmetrical 10-gauge W-to-thrie transition segment, and standard 12-gauge thrie beam guardrail. This upstream end stiffness transition was supported using only standard 6-ft long W6x8.5 steel guardrail posts at various spacings. For testing purposes, a stiff, thrie beam approach transition system was selected as the downstream end of the full transition (defined as the entire transition from w-beam guardrail to rigid parapet or bridge rail). The downstream end of the transition consisted of nested 12-gauge thrie beam guardrail supported by 7-ft long W6x15 steel posts spaced at 37.5-in. on center. Crash testing was successfully performed in accordance with the Test Level 3 (TL-3) impact safety standards published in the AASHTO *Manual for Assessing Safety Hardware* (MASH) (*3*).

Though the system was designed and tested without a curb, several State Departments of Transportation expressed the desire to use a curb in conjunction with the upstream stiffness transition for drainage control. However, the addition of a curb may negatively affect the performance of the system in a number of ways. For example, small car front ends may become wedged between the curb and the bottom of the W-to-thrie transition segment which can lead to excessive snagging and rail loads. Additionally, a curb may cause vehicle instabilities and/or rollovers during redirections in this stiffness-sensitive region.

Previous testing has shown that curbs can significantly affect the behavior of approach guardrail transitions. Several full-scale crash tests conducted with pickup trucks according to NCHRP Report 350 (*4*) and MASH TL-3 conditions haven shown that similar transition systems can perform significantly different based on the addition or removal of a curb below the guardrail (*5-10*). Typically, the addition of a curb helped mitigate snag near the downstream end of a transition system. However, the vast majority of transition testing under NCHRP Report 350 and MASH has been conducted with pickups impacting near the downstream end of the transition. The effect of curbs on the upstream end of the transition is largely unknown, especially for small car impacts where the vehicle may get underneath the w-to-thrie transition segment.

RESEARCH OBJECTIVE

The objective of the research project was to evaluate the safety performance of the MGS to thrie beam stiffness transition configured with a lower concrete curb. The safety performance evaluation was conducted according to MASH TL-3 standards. Thus, the transition with curb system was evaluated through full-scale crash testing with both the small car and the pickup vehicles, as detailed below.

1. MASH Test No. 3-20: a 2,425-lb passenger car (denoted as an 1100C vehicle) impacting the system at a nominal speed and angle of 62 mph and 25 degrees, respectively.

2. MASH Test No. 3-21: a 5,000-lb pickup truck (denoted as a 2270P vehicle) impacting the system at a nominal speed and angle of 62 mph and 25 degrees, respectively.

PRELIMINARY DESIGN

The full-scale crash test installation utilized the same guardrail transition installation (including upstream stiffness transition, downstream transition, and bridge rail) that was previously evaluated according to MASH. Only this time, a 4-in. tall curb was placed below the guardrail. The test installation was 87.5 ft long, as shown in Figure 1, which consisted of five major structural components: 1) a 12-ft 6-in. long thrie beam and channel bridge railing system; 2) 12 ft – 6 in. of nested 12-gauge thrie beam guardrail; 3) 6 ft – 3 in. of standard 12-gauge thrie beam guardrail; 4) a 6-ft 3-in. long, asymmetrical 10-gauge W- to-thrie transition segment; and 5) 50 ft of standard 12-gauge W-beam rail attached to a simulated anchorage device. All rails had a top height of 31 in., and the lap-splice connections between adjacent rail sections were configured to reduce vehicle snag at the splices.

The guardrail components were supported by two BCT timber posts, 16 steel guardrail posts, and three steel bridge posts. Post nos. 1 and 2 were BCT posts placed in 6-ft long steel foundation tubes to anchor the system. Post nos. 3 through 15 were standard 6-ft long W6x8.5 guardrail posts with 12-in. deep wood blockouts. Post nos. 16 through 18 were 7-ft long W6x15 posts with 8-in. deep wood blockouts. The steel posts were placed at various spacings, as shown in Figure 1. The transition was installed within a compacted crushed limestone soil that met AASHTO Grade B gradation specifications and the soil strength requirements of MASH.

The transition system's downstream end was connected to a thrie beam and channel bridge railing. Bridge post nos. 19 through 21 were W6x20 steel sections measuring 29⅝ in. long. The bridge posts were rigidly attached to the concrete tarmac located at the MwRSF's outdoor proving grounds.

A 4-in. tall triangular shaped curb was selected for use with this system since it is one of the more common curbs used in transition systems. The system was installed with the toe of the curb flush with the back face of the guardrail, as shown in Figure 1. The curb extended from 37½ in. upstream from post no. 5 until 18¾ in. downstream from post no. 18. No soil backfill was installed behind the curb. This was considered a worst case scenario for inducing wheel snag on the curb and vehicle instabilities. Further design details of the system are shown in the test report by Winkelbauer et al. (*11*).

FULL-SCALE CRASH TEST NO. MWTC-1

The 1100C vehicle impacted the MGS to thrie beam stiffness transition with curb at a speed of 62.9 mph and at an angle of 25.0 degrees. Initial vehicle impact was targeted for 93¾ in. upstream of the W-to-thrie transition segment, which was selected to maximize the potential for the small car to wedge underneath the transition segment. The same impact point was utilized in previous testing (*1-2*). The actual point of impact was 4 in. upstream of the target impact location. A summary of the test results and sequential photographs are shown in Figures 2 and 3.

The car's front bumper began to underride the guardrail upon impact, and the left-front tire overrode the curb. At 0.068 sec after impact, the car began to pitch downward, and at 0.075 sec, the front bumper impacted post no. 9. At 0.118 sec, the W-beam guardrail ruptured at the splice between the W-beam and W-to-thrie transition segment, located at post no. 9. Subsequently, the vehicle stopped redirecting and began impacting the guardrail posts head-on. The vehicle stopped moving downstream by 0.188 sec after impact, but pitched downward over 35 degrees bringing the rear tires above the top of the guardrail. The vehicle eventually came to rest in front of post no. 11 (15.8 ft downstream of impact) and was facing the barrier. The vehicle trajectory and final position are shown in Figure 2.

Damage to the barrier was severe, as shown in Figure 3. The rail was kinked and flattened throughout the impact region, while post nos. 8 through 12 were bent and twisted. The 12-gauge W-beam rail ruptured at the splice at post no. 9 with all bolts remaining on the downstream end of the ruptured rail, or on the 10 gauge W-to-thrie transition element. The guardrail tore from the top, downstream corner of the splice diagonally to the bottom, upstream corner. The downstream edge of the W-beam remained attached to the W-to-thrie transition segment. The downstream end of rail folded back and behind the system at post no. 12. Additionally, a 1½-in. vertical tear occurred in the thrie beam at the bottom post bolt of post no. 12. Finally, the top of the curb was gouged in several places from contact with the vehicle bumper and undercarriage.

The damage to the vehicle was moderate with most of the damage occurring on the left side of the vehicle. The left fender, radiator, and headlight were all crushed inward, and the left-front tire was torn. The front bumper and bumper cover were dented and disengaged, the left-front corner of the hood folded under, and the engine cover split. Also, minor spider web cracking occurred in the lower-left corner of the windshield.

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Figure 1. Note that the OIVs were within the suggested limits provided in MASH, but the longitudinal ORA values exceeded the MASH limits. The measured occupant compartment deformations were all within MASH limits.

Due to the w-beam rail rupturing, the loss of vehicle containment, and the excessive ORA values recorded by the accelerometers, test no. MWTC-1 on the MGS to thrie beam stiffness transition with curb was determined to be unacceptable according to the MASH safety performance criteria for test designation no. 3-20. More comprehensive test results are detailed in the test report by Winkelbauer et al. (*11*).

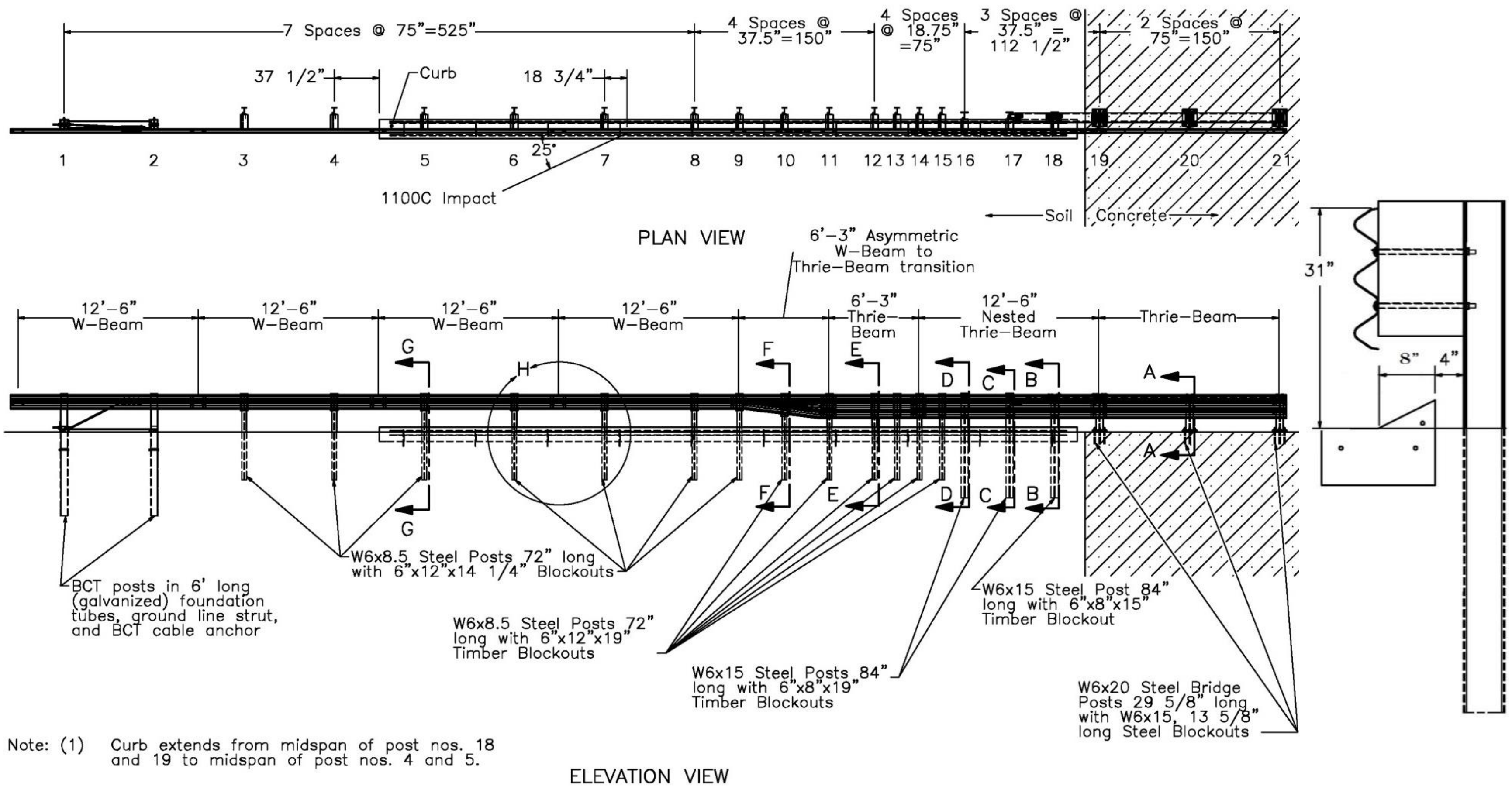
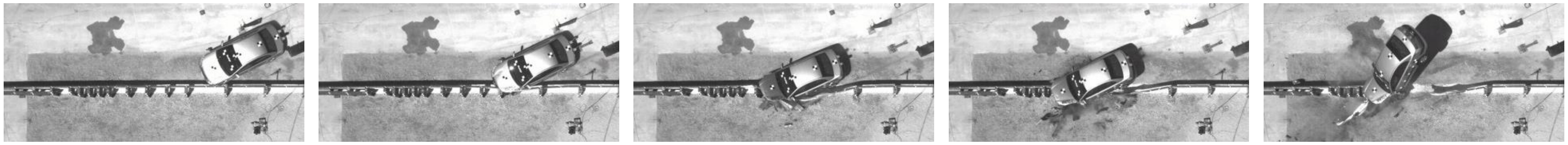


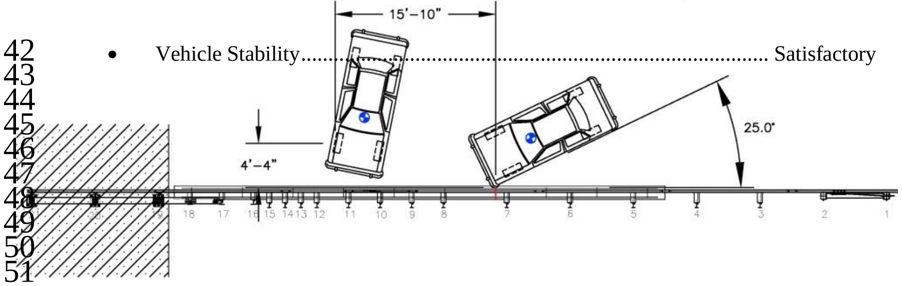
FIGURE 1 System details, test no. MWTC-1.



0.000 sec 0.044 sec 0.152 sec 0.248 sec 0.710 sec

- Test Agency....................MwRSF
- Test Number....................MWTC-1
- Date....................8/10/12
- MASH Test Designation....................3-20
- Test Article....................MGS Stiffness Transition with Curb
- Total Length....................87.5 ft
- Height to Top of Rail....................31 in.
- Steel 12 gauge W-Beam Guardrail
  - Segment Location - Single....................Post nos. 1 to 9
- Steel 10 gauge W-Beam to Thrie Beam Transition
  - Segment Location....................Post nos. 9 to 11
- Steel 12 gauge Thrie Beam Guardrail
  - Segment Location - Single.................... Post nos. 11 to 14 and 19 to 21
  - Segment Location - Nested....................Post nos. 14 to 19
- Guardrail Posts
  - Post Nos. 1-2....................46 in. long, BCT timber posts
  - Post Nos. 3-15.................... 72 in. long, W6x8.5
  - Post Nos. 16-18.................... 84 in. long, W6x15
  - Post Nos. 19-21.................... 29⅝ in. long, W6x20
- Post Spacing
  - Post Nos. 1-8, 19-21....................75 in.
  - Post Nos. 8-12, 16-19....................37½ in.
  - Post Nos. 12-16....................18¾ in.
- Soil Type....................AASHTO Grade B
- Vehicle
  - Make and Model....................2007 Kia Rio
  - Test Inertial....................2,457 lb
  - Gross Static....................2,623 lb
  - Curb....................2,468 lb
- Impact Conditions
  - Speed....................62.9 mph
  - Angle....................25.0 deg
  - Impact Severity (IS)....................58.0 kip-ft > 51.0 kip-ft
  - Impact Location.................... 14¾ in. downstream of post no. 7
- Exit Conditions
  - Speed....................NA
  - Angle....................NA
- Exit Box Criterion....................NA

- Vehicle Stability....................Satisfactory



- Vehicle Stopping Distance....................15.8 ft downstream of impact
  4.3 ft laterally in front of system
- Vehicle Damage....................Moderate
  - VDS (*12*)....................11-LFQ-5
  - CDC (*13*)....................11-LFEW2
  - Maximum Interior Deformation....................¾ in.
- Test Article Damage....................Severe (rail ruptured)
- Maximum Test Article Deflections
  - Permanent Set....................NA (rail ruptured)
  - Dynamic....................NA (rail ruptured)
  - Working Width....................NA (rail ruptured)
- Maximum Angular Displacements
  - Roll....................13.7° < 75°
  - Pitch....................-36.3° < 75°
  - Yaw....................-54.1°
- Transducer Data

Evaluation Criteria		Transducer			MASH Limit
		DTS	DTS SLICE	EDR-3	
OIV ft/s	Longitudinal	-35.86	-32.56	-37.52	≤ 40
	Lateral	16.45	17.59	16.01	≤ 40
ORA g's	Longitudinal	-21.76	-22.25	-21.23	≤ 20.49
	Lateral	-8.70	-8.51	-8.42	≤ 20.49
THIV – ft/s		38.78	36.88	NA	Not required
PHD – g's		23.29	23.79	NA	Not required
ASI		1.23	1.26	1.26	Not required

FIGURE 2 Summary of test results, test no. MWTC-1.

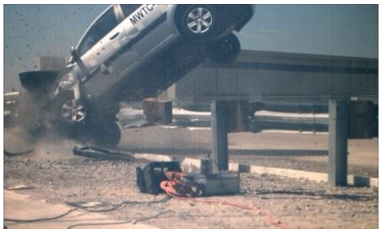
0.000 sec

0.036 sec

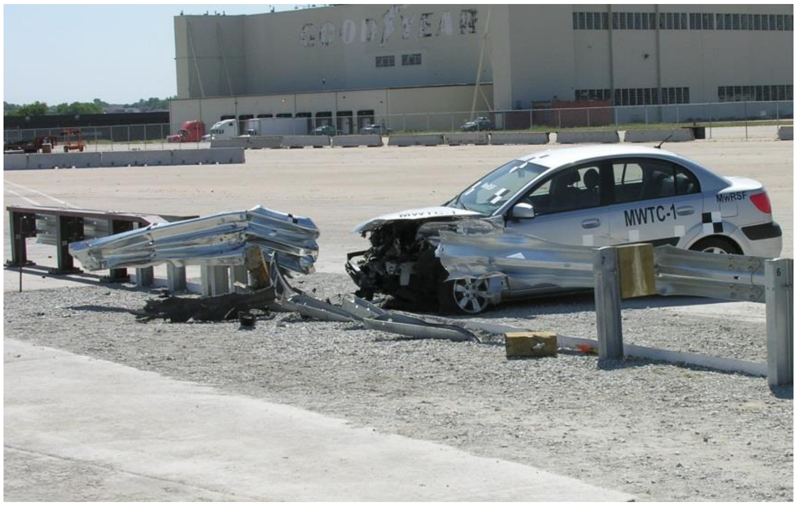
0.068 sec

0.110 sec

0.314 sec



0.710 sec



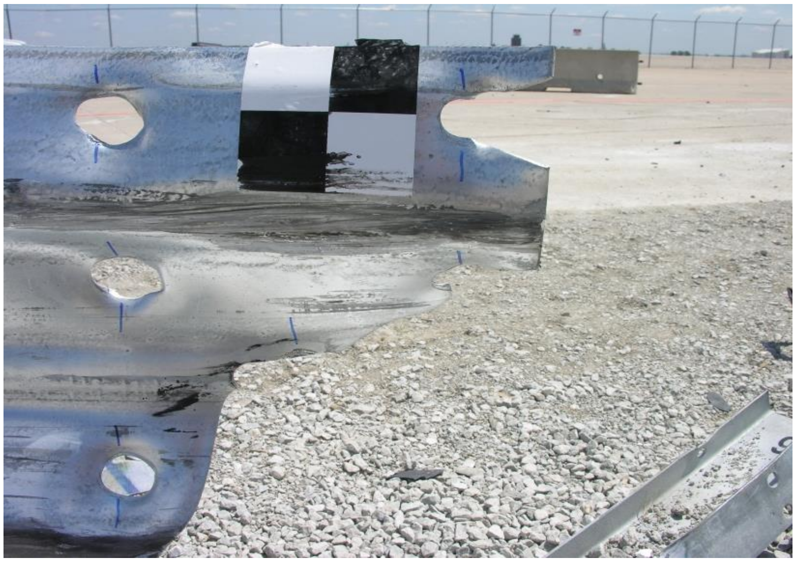


FIGURE 3 Sequential photos and system damage, test no. MWTC-1.

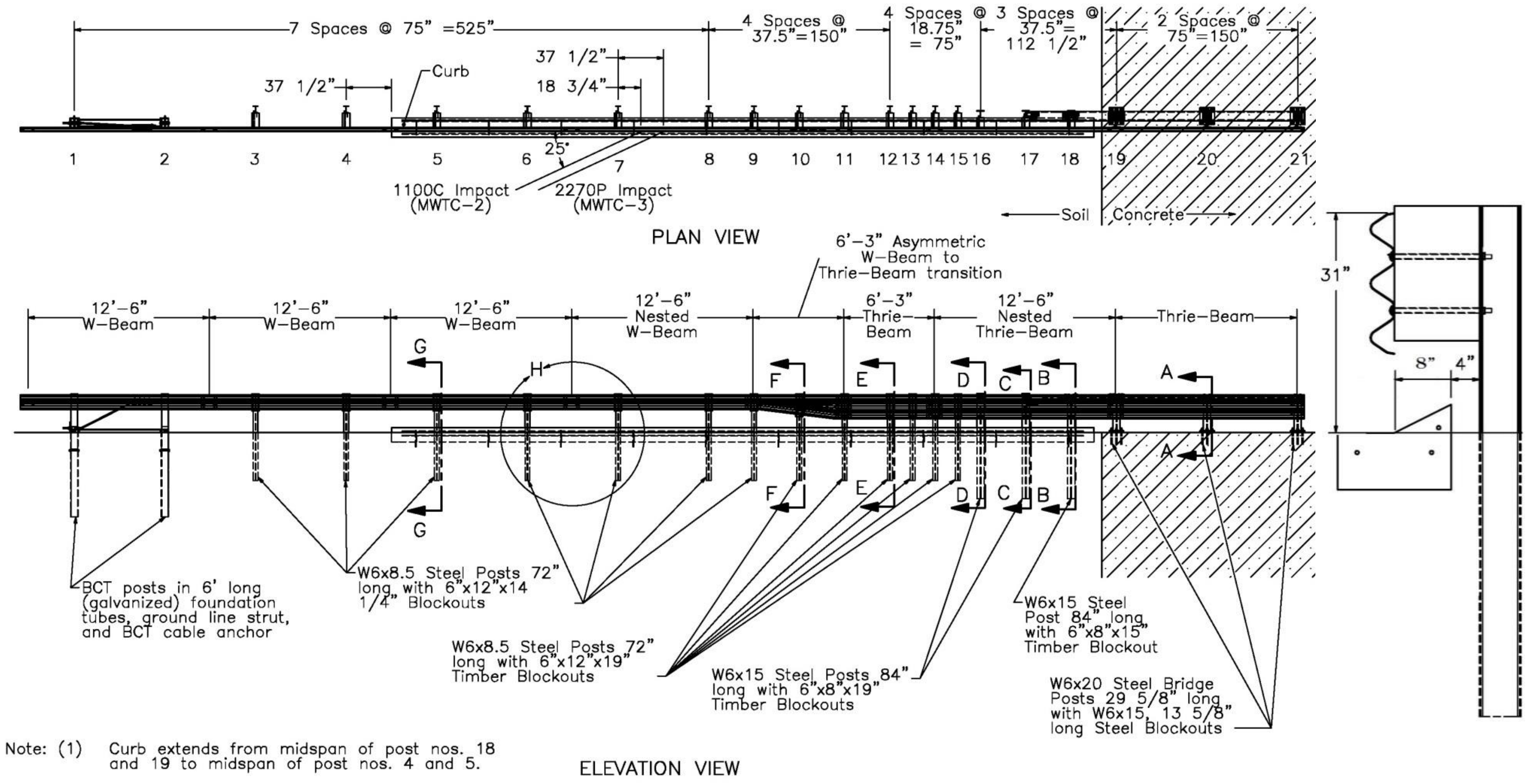
MODIFICATIONS AND DESIGN DETAILS

During test no. MWTC-1, components of the small car penetrated under the W-beam rail, while the wheel climbed up and overrode the curb, compressing the suspension. These events led to heavy upward and lateral vehicle loading to the guardrail near the splice between the W-beam and W-to-thrie transition segment. The vehicle bumper impacting posts as it traveled through this region of the transition further increased the loads applied to the guardrail elements of this splice. Eventually, the W-beam rail ruptured at the splice location, gave way, and allowed the vehicle to snag on a stiff rail element in combination with several exposed transition posts.

The presence of a curb under the MGS to thrie beam stiffness transition likely changed the load direction and magnitude applied to the guardrail in advance of the splice location. In addition, the presence of a curb may also have provided increased soil confinement and/or resistance to post-soil rotation within the guardrail region in advance of the splice location. The wheel interaction with the top and back side edge of the curb may have contributed to an-altered vehicle trajectory from that observed in the successful 1100C test on the system without a curb. One or more of these factors, likely led to the W-beam rupture at the splice to the W-to-thrie transition element.

Since the presence of a curb within the transition caused increased loading to the guardrail segments and lead to rail rupture, design modifications were required to strengthen the rail upstream of the W-to-thrie transition element. Thus, an additional 12-gauge W-beam segment was incorporated into the system such that 12.5 ft of nested W-beam guardrail preceded the 10-gauge W-to-thrie transition segment. This minor modification was believed to be sufficient to prevent rail rupture observed during a small car impact just upstream from the asymmetrical element and in combination with a concrete curb.

Design details for test nos. MWTC-2 and MWTC-3 are shown in Figure 4. The system layouts for these two tests are nearly identical to that of test no. MWTC-1 with only the addition of the 12.5 ft nested W-beam section prior to the W-to-thrie transition segment.



Note: (1) Curb extends from midspan of post nos. 18 and 19 to midspan of post nos. 4 and 5.

FIGURE 4 System layout, test nos. MWTC-2 and MWTC-3.

FULL-SCALE CRASH TEST NO. MWTC-2

The 1100C vehicle impacted the MGS to thrie beam stiffness transition with curb at a speed of 61.3 mph and at an angle of 25.6 degrees. Initial vehicle impact was targeted for 93¾ in. upstream of the W-to-thrie transition segment, same as the previous test. The actual point of impact was 7 in. of the targeted location. A summary of the test results and sequential photographs are shown in Figures 5 and 6.

Upon impact, the left-front corner of the vehicle underrode the rail, and the vehicle pitched down. The left-front tire proceeded to override the curb, and contact post nos. 8 and 9. This time, the rail and splices held together and contained the vehicle as it continued to contact posts within the system. The vehicle was eventually redirected and exited the system 0.312 sec after impact at an angle of 11 degrees. The vehicle came to rest 43.0 ft downstream of impact and 3.8 ft laterally in front of the system. The vehicle trajectory and final position are shown in Figure 5.

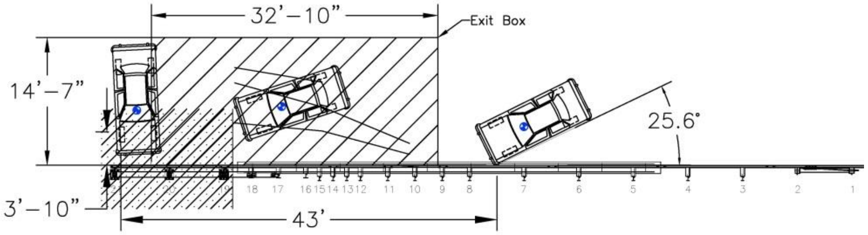
Damage to the barrier was moderate, as shown in Figure 6. The guardrail was kinked and flattened throughout the impact region, and the rail disengaged from post nos. 8 through 10. Post nos. 8 through 11 were bent back and downstream. The top of the curb had spalling between post nos. 7 and 9. The maximum lateral dynamic post and barrier deflections were 14.4 in. at post no. 9 and 16.4 in. at post no. 8, respectively. The working width of the system was found to be 32.5 in.

The majority of the vehicle damage was concentrated on the left-front corner and left side of the vehicle where the impact occurred. The left-front tire was deflated, disengaged, and came to rest adjacent to post no. 12. The left-front fender was crushed inward and pushed under the hood. Gouging was found on the fender, the left-front door, and the hood. Finally, the front bumper disengaged from the left side of the vehicle.

The calculated OIVs and ORAs in both the longitudinal and lateral directions were within the suggested limits provided in MASH, as shown in Figure 5. Also, deformations to the occupant compartment were minor. Therefore, test no. MWTC-2, conducted on the MGS to thrie beam stiffness transition with curb, was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-20. More comprehensive test results are detailed in the test report by Winkelbauer et al. (*11*).

0.000 sec 0.162 sec 0.412 sec 0.558 sec 0.772 sec

- Test Agency: MwRSF
- Test Number: MWTC-2
- Date: 11/30/12
- MASH Test Designation: 3-20
- Test Article: MGS Stiffness Transition with Curb
- Total Length: 87.5 ft
- Height to Top of Rail: 31 in.
- Steel 12 gauge W-Beam Guardrail
    - Segment Location - Single: Post no. 1 to Splice 6/7
    - Segment Location - Nested: Splice 6/7 to Post no. 9
- Steel 10 gauge W-Beam to Thrie Beam Transition
    - Segment Location: Post nos. 9 to 11
- Steel 12 gauge Thrie Beam Guardrail
    - Segment Location - Single: Post nos. 11 to 14 and 19 to 21
    - Segment Location - Nested: Post nos. 14 to 19
- Guardrail Posts
    - Post Nos. 1-2: 46 in. long, BCT timber posts
    - Post Nos. 3-15: 72 in. long, W6x8.5
    - Post Nos. 16-18: 84 in. long, W6x15
    - Post Nos. 19-21: 29⅝ in. long, W6x20
- Post Spacing
    - Post Nos. 1-8, 19-21: 75 in.
    - Post Nos. 8-12, 16-19: 37½ in.
    - Post Nos. 12-16: 18¾ in.
- Soil Type: AASHTO Grade B
- Vehicle
    - Make and Model: 2007 Kia Rio
    - Test Inertial: 2,410 lb
    - Gross Static: 2,575 lb
    - Curb: 2,390 lb
- Impact Conditions
    - Speed: 61.3 mph
    - Angle: 25.6 deg
    - Impact Severity (IS): 56.5 kip-ft > 51.0 kip-ft
    - Impact Location: 11¼ in. downstream of post no. 7
- Exit Conditions
    - Speed: 19.6 mph
    - Angle: 11.0 deg
    - Exit Box Criterion: Passed



- Vehicle Stability: Satisfactory
- Vehicle Stopping Distance: 43.0 ft downstream of impact; 3.8 ft laterally in front of system
- Vehicle Damage: Moderate
  VDS (*12*): 11-LFQ5
  CDC (*13*): 11-LFEW2
  Maximum Interior Deformation: 1 in.
- Test Article Damage: Moderate
- Maximum Test Article Deflections
    - Permanent Set: 16.1 in.
    - Dynamic: 16.4 in.
    - Working Width: 32.5 in.
- Maximum Angular Displacements
    - Roll: -13.7° < 75°
    - Pitch: -8.6° < 75°
    - Yaw: -70.7°
- Transducer Data

Evaluation Criteria		Transducer			MASH Limit
		DTS	DTS SLICE	EDR-3	
OIV ft/s	Longitudinal	-22.23	-23.04	-24.21	≤ 40
	Lateral	22.53	24.14	21.19	≤ 40
ORA g's	Longitudinal	-15.65	-16.58	-11.72	≤ 20.49
	Lateral	13.45	12.45	10.88	≤ 20.49
THIV – ft/s		31.66	31.79	NA	Not required
PHD – g's		15.69	18.84	NA	Not required
ASI		1.32	1.40	1.27	Not required

FIGURE 5 Summary of test results, test no. MWTC-2.

0.000 sec

0.076 sec

0.138 sec

0.306 sec

0.472 sec

0.772 sec

FIGURE 6 Sequential photos and system damage, test no. MWTC-2.

FULL-SCALE CRASH TEST NO. MWTC-3

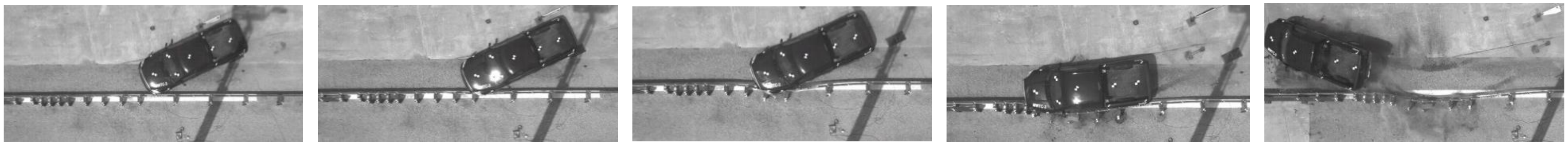
The 2270P pickup impacted the MGS to thrie beam transition with curb at a speed of 61.0 mph and at an angle of 24.4 degrees. The vehicle impacted the target impact point at 75 in. upstream of the W-to-thrie transition element. This impact point was identical to previous testing of the transition without curb and was selected to maximize the potential for pocketing, snag on guardrail posts, and loading to the transition element (*1*-*2*). A summary of the test results and sequential photographs are shown in Figures 7 and 8.

Upon impact, post nos. 7 through 10 began deflecting backward. The left-front tire overrode the curb 0.044 sec after impact and underrode the guardrail 0.070 sec after impact. The tire then contacted post no. 9 and detached from the vehicle. The posts and the rail continued to deflect backward as the vehicle was captured and redirected. The vehicle became parallel to the system at 0.218 sec and exited the system 0.326 sec after impact at an angle of 12 degrees. The vehicle came to rest 101 ft directly downstream of impact. The vehicle trajectory and final position are shown in Figure 7.

Damage to the barrier was moderate, as shown in Figure 8. The guardrail was kinked and flattened throughout the impact region and disengaged from post nos. 6, 8, and 10 through 12. Post nos. 7 through 12 were bent back and downstream. The maximum lateral dynamic post and rail deflections were 23.9 in. and 22.0 in., respectively, at post no. 10. The working width of the system was found to be 40.8 in.

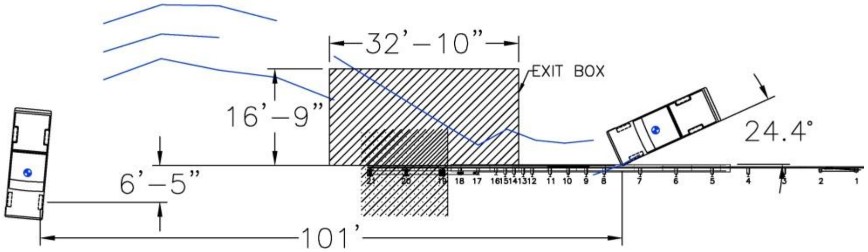
The damage to the vehicle was concentrated on the left-front corner and left side of the vehicle where impact occurred. The left-front bumper and quarter panel was deflected inward, and the left-front wheel was disengaged from the vehicle. The left-front door was dented, and the left side of the windshield had spider-web cracking.

The calculated OIVs and ORAs in both the longitudinal and lateral directions were within the suggested limits provided in MASH and are shown in Figure 7. Also, deformations to the occupant compartment were minor. Therefore, test no. MWTC-3, conducted on the MGS to thrie beam stiffness transition with curb, was determined to be acceptable according to the MASH safety performance criteria for test designation no. 3-21. More comprehensive test results are detailed in the test report by Winkelbauer et al. (*11*).



0.000 sec	0.013 sec	0.035 sec	0.096 sec	0.292 sec

- Test Agency ... MwRSF
- Test Number ... MWTC-3
- Date ... 5/16/13
- MASH Test Designation ... 3-21
- Test Article ... MGS Stiffness Transition with Curb
- Total Length ... 87.5 ft
- Height to Top of Rail ... 31 in.
- Steel 12 gauge W-Beam Guardrail
  - Segment Location - Single ... Post no. 1 to Splice 6/7
  - Segment Location - Nested ... Splice 6/7 to Post no. 9
- Steel 10 gauge W-Beam to Thrie Beam Transition
  - Segment Location ... Post nos. 9 to 11
- Steel 12 gauge Thrie Beam Guardrail
  - Segment Location - Single ... Post nos. 11 to 14 and 19 to 21
  - Segment Location - Nested ... Post nos. 14 to 19
- Guardrail Posts
  - Post Nos. 1-2 ... 46 in. long, BCT timber posts
  - Post Nos. 3-15 ... 72 in. long, W6x9
  - Post Nos. 16-18 ... 84 in. long, W6x15
  - Post Nos. 19-21 ... 29⅝ in. long, W6x20
- Post Spacing
  - Post Nos. 1-8, 19-21 ... 75 in.
  - Post Nos. 8-12, 16-19 ... 37½ in.
  - Post Nos. 12-16 ... 18¾ in.
- Soil Type ... AASHTO Grade B
- Vehicle
  - Make and Model ... 2006 Dodge Ram 1500 Quad Cab
  - Test Inertial ... 4,969 lb
  - Gross Static ... 5,135 lb
  - Curb ... 5,134 lb
- Impact Conditions
  - Speed ... 61.0 mph
  - Angle ... 24.4 deg.
  - Impact Severity ... 105.8 kip-ft > 105.6 kip-ft
  - Impact Location ... 75 in. Upstream of Post No. 9
- Exit Conditions
  - Speed ... 38.3 mph
  - Angle ... 11.7 deg.
- Exit Box Criterion ... Passed



- Vehicle Stability ... Satisfactory
- Vehicle Stopping Distance ... 101 ft downstream of impact
  ... 6.4 ft laterally behind system
- Vehicle Damage ... Moderate
  VDS (*12*) ... 11-LFQ4
  CDC (*13*) ... 11-LFEW2
  Maximum Interior Deformation ... 2½ in.
- Test Article Damage ... Moderate
- Maximum Test Article Deflections
  - Permanent Set ... 17.8 in.
  - Dynamic ... 23.9 in.
  - Working Width ... 40.8 in.
- Maximum Angular Displacements
  - Roll ... -21.8° < 75°
  - Pitch ... -10.8° < 75°
  - Yaw ... 55.4°
- Transducer Data

Evaluation Criteria		Transducer			MASH Limit
		DTS	DTS SLICE	DTS	
OIV ft/s	Longitudinal	-17.62	-17.46	-18.77	≤ 40
	Lateral	16.31	17.79	17.11	≤ 40
ORA g's	Longitudinal	-12.52	-12.29	-13.07	≤ 20.49
	Lateral	10.94	9.18	10.12	≤ 20.49
THIV – ft/s		23.02	23.75	NA	Not required
PHD – g's		15.21	14.83	NA	Not required
ASI		0.88	0.93	0.92	Not required

FIGURE 7 Summary of test results, test no. MWTC-3.

0.000 sec

0.092 sec

0.154 sec

0.216 sec

0.314 sec

0.696 sec

FIGURE 8 Sequential photos and system damage, test no. MWTC-3.

SUMMARY AND CONCLUSIONS

The objective of this study was to evaluate the MGS stiffness transition between W-beam guardrail and thrie beam approach transitions with a 4-in. tall curb. In 2010, the stiffness transition configuration, shown in Figure 9a, was successfully crash tested without a curb (*1*-*2*). However, when a 4-in. tall curb was present with that system, the front end of the 1100C vehicle penetrated under the W-beam rail at the same time that the wheel climbed up and overrode the curb. The combination of these events caused both upward and lateral loads being imparted to the rail elements which eventually caused the W-beam rail to rupture at the splice adjacent to the W-to-thrie transition element. The loss of containment led to the vehicle impacting transition posts head on causing ORA values above the MASH limits. Therefore, the previously tested MGS stiffness transition was not acceptable for use with curbs.

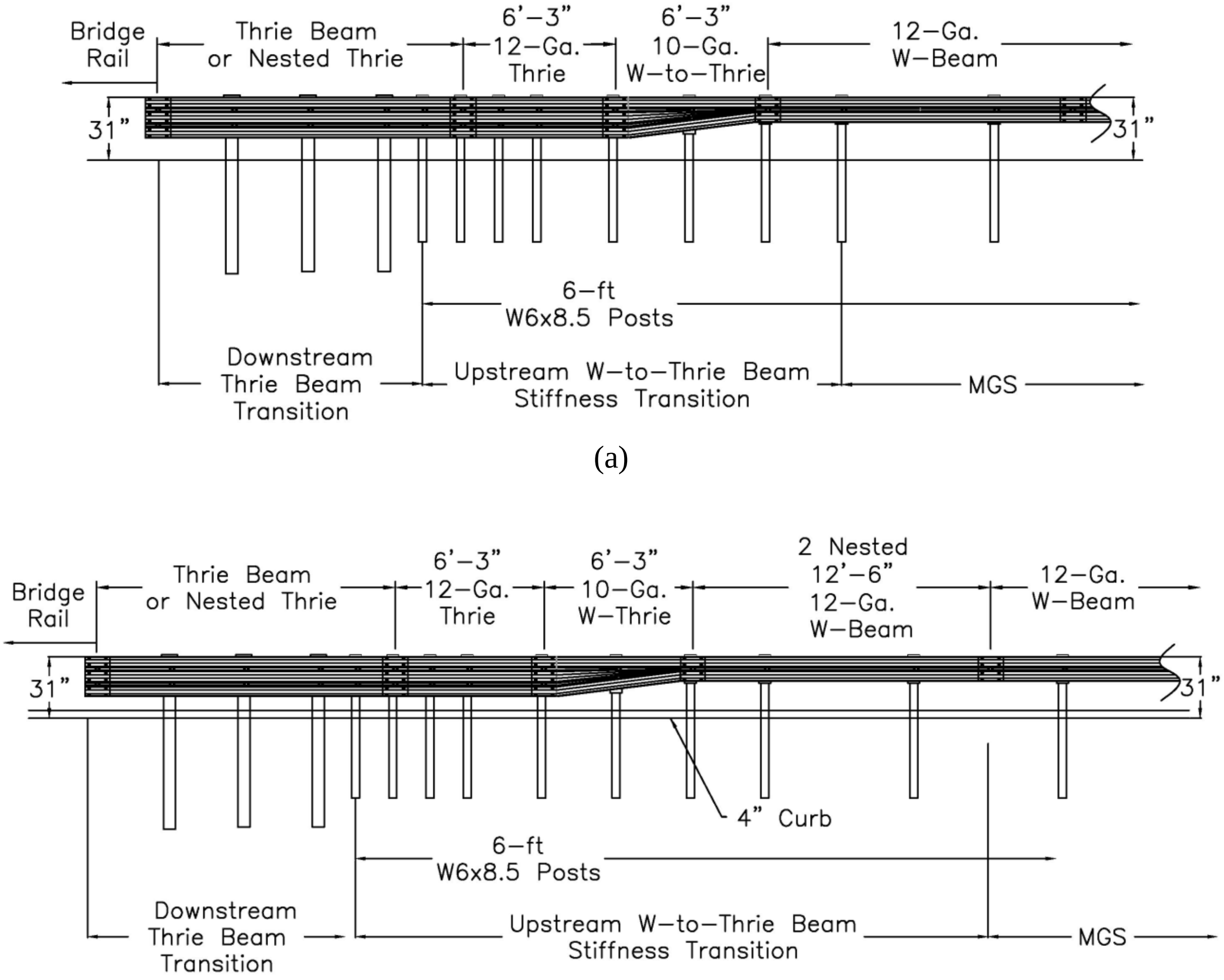
After the failed crash test, the design was modified to incorporate an additional 12-gauge W-beam segment such that 12.5 ft of nested guardrail preceded the asymmetric W-to-thrie transition element. Subsequently, MASH test designation 3-20 was repeated, and the 1100C small car was safely contained and redirected. A second test was then conducted on the modified transition according to MASH test designation 3-21, and the 2270P pickup truck was also safely contained and redirected. Upon the successful completion of the MASH TL-3 testing matrix, the modified upstream stiffness transition (between the MGS and thrie beam approach guardrail transition) with curb was found to satisfy current safety standards

Since a very stiff thrie beam approach guardrail transition was used in the full-scale crash testing program, the upstream stiffness transition developed herein should be applicable to most other thrie beam approach guardrail transition systems. Details concerning the attachment of the upstream stiffness transition to other thrie beam transition systems can be found in the 2010 report on the original development of the stiffness transition (*1*).

The use of nested W-beam rail at the upstream end of the W-to-thrie transition segment will be required for transition installations that utilize lower curbs. The use of nested rail was shown to sufficiently increase the strength of the system and prevent rail tearing. Additionally, rail nesting adjacent to the upstream end of the transition element aided to decrease vehicle pocketing and snag. These same benefits could also be gained if the modified (nested) version of the upstream stiffness transition was utilized for installations without curbs. Thus, system installations without curbs have the option to use either the original MGS stiffness transition design or the modified (nested) MGS stiffness transition. The final configurations of the stiffness transitions with and without a curb are shown in Figure 9.

Although the W-beam to thrie beam stiffness transition (upstream portion of a full approach transition) evaluated herein can be utilized with or without a curb, many of the thrie beam approach transitions (downstream portions of a full transition system that attach to rigid parapets or bridge rails) are sensitive to the use of curbs. As described earlier, the addition or removal of a curb under the downstream end of a transition has been shown to greatly affect the safety performance of transitions during full-scale crash testing, sometimes to the extent of passing or failing the test criteria. As such, care should be taken to only utilize curbs with guardrail transition systems that have been developed, tested, and approved for use with curbs.

The rail tearing and failure observed in test no. MWTC-1 may have implications for guardrail installations over curbs beyond this stiffness transition system. To date, 31-in. high W-beam guardrail systems in combination with curbs have only been evaluated in full-scale testing with large pickups. It is possible that small car impacts on other 31-in. high W-beam systems installed over curbs could impart similar combined lateral and vertical loads to the rail elements and result in similar rail tearing. Therefore, further evaluation of small car impacts into 31-in. high W-beam systems in combination with curbs may be warranted.



(a)

(b)

FIGURE 9 MGS to thrie beam stiffness transitions details (a) without a curb and (b) with or without a curb, 4-in maximum curb height

INSTALLATION RECOMMENDATIONS

In order to ensure the safety performance of the transition, the 4-in. tall curb should be placed through the entire length of the stiffness transition. Thus, the curb should be extended from the bridge and through the nested W-beam section before either being terminated or transitioning to another curb type. Additionally, it is recommended to utilize a minimum length of 3 ft for any curb shape transitions or terminations (e.g. transitioning from 4-in. curb to no curb).

The curb was installed above ground line and without additional soil backfill. Thus, the ground surface underneath and behind the barrier remained level with the roadway surface and not the top of curb. This configuration was selected as a critical test design as it allows vehicle wheels to snag or catch on the backside of the curb, thus potentially leading to increased propensity for vehicle instabilities or wheel/bumper snag on strong posts. However, if the soil behind the curb was backfilled to match the height of the curb, the extra 4 in. of soil backfill would result in increased post embedment, increased post-soil resistance, and a slightly stiffer and stronger barrier system. Impacts into the stiffened transition system would likely result in reduced lateral barrier displacements and less vehicle snag. Thus, it is believed that installations utilizing soil backfill would also perform acceptably.

The tested system had 34 ft – 4.5 in. of standard MGS between the upstream end of the stiffness transition (nested rail segments) and the upstream BCT wood anchor post. Guardrail end terminals are designed, crash tested, and evaluated for use when directly attached to semi-rigid W-beam guardrail systems, instead of stiffer approach guardrail transitions. The introduction of stiffer (nested) rail segments may potentially lead to degraded performance of crashworthy terminals. Additionally, placement of the upstream end anchorage too close to the stiffness transition may negatively affect system performance and potentially result in excessive barrier deflections, vehicle pocketing, wheel snagging on posts, vehicle-to-barrier override, or other vehicle instabilities. Thus, the following implementation guidelines should be considered when utilizing the modified MGS stiffness transition. Although the reference point was changed to the upstream end of the nested rail segment, these recommendations result in the same system lengths upstream of the W-to-thrie transition segment that were recommended previously for the original transition system design without nesting (*1*).

1. The length of W-beam guardrail installed upstream of the nested W-beam section is recommended to be greater than or equal to the total system length of an acceptable TL-3 guardrail end terminal. Thus, the guardrail terminal’s interior end (identified by stroke length) should not intrude into the nested W-beam section of the modified MGS stiffness transition.
2. A recommended minimum barrier length of 34 ft – 4½ in. is to be installed beyond the upstream end of the nested W-beam section, which includes standard MGS, a crashworthy guardrail end terminal, and an acceptable anchorage system.
3. For flared guardrail applications, a minimum length of 12.5 ft is recommended between the upstream end of the nested W-beam section and the start of the flared section (i.e. bend between flare and tangent sections).

The MGS stiffness transition with curb was successfully crash tested with all posts installed in level terrain. Therefore, this upstream stiffness transition (and all other guardrail transitions tested on level terrain) should be implemented with a minimum of 2 ft of level or gently-sloped fill placed behind the posts, unless special design provisions are made to account for decreased post-soil resistance. Additionally, it is unknown as to whether a non-blocked version of the MGS installed adjacent to the new stiffness transition will negatively affect the system. The safety performance of non-blocked MGS in conjunction with the modified stiffness transition can only be verified through the use of full-scale crash testing. As such, it is recommended that a minimum of 12.5 ft of standard MGS with spacer blocks be placed adjacent to the modified stiffness transition (upstream end of the nested rail section) prior to transitioning to a non-blocked, 31-in. tall, W-beam guardrail system.

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