
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Evaluation of Existing Roadside Safety Hardware Using Manual for Assessing Safety Hardware (MASH) Criteria

DETAILS

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EVALUATION OF EXISTING ROADSIDE SAFETY HARDWARE USING *MANUAL FOR ASSESSING SAFETY HARDWARE* (*MASH*) CRITERIA

This digest presents the results of NCHRP Project 22-14(03), "Evaluation of Existing Roadside Safety Hardware Using Updated Criteria." The project was conducted by the Texas Transportation Institute with Principal Investigator D. Lance Bullard, Jr., Roger P. Bligh, Wanda L. Menges, and Rebecca R. Haug.

RESEARCH PROBLEM STATEMENT

National Cooperative Highway Research Program (NCHRP) *Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features* contains guidelines for evaluating the safety performance of roadside features, such as longitudinal barriers, terminals, crash cushions, and breakaway structures. This document was published in 1993 and was formally adopted as the national standard by the Federal Highway Administration (FHWA) later that year with an implementation date for late 1998. In 1998, the American Association of State Highway and Transportation Officials (AASHTO) and FHWA agreed that most types of safety features installed along the National Highway System (NHS) must meet *NCHRP Report 350* safety-performance evaluation criteria.

An update to *NCHRP Report 350* was developed under NCHRP Project 22-14(02), "Improved Procedures for Safety-Performance Evaluation of Roadside Features." This document, *Manual for Assessing Safety Hardware* (*MASH*), published by AASHTO in 2009, contains revised criteria for safety-performance evaluation of virtually all roadside safety features. For example, *MASH* recommends testing with heavier light truck vehicles to better represent the current fleet of vehicles in the pickup/van/sport-utility vehicle class. Further, *MASH* increases the impact angle for most small car crash tests to the same angle as the light truck test conditions. These changes place greater safety-performance demands on many of the current roadside safety features.

RESEARCH OBJECTIVE

The objective of this project was to evaluate the safety performance of widely used non-proprietary roadside safety features by using *MASH*. Features recommended for evaluation included longitudinal barriers (excluding bridge railings), terminals and crash cushions, transitions, and breakaway supports. Evaluation methods included, but were not limited to, engineering assessment, simulation, full-scale crash testing, pendulum testing, and component testing. Where practical, cost-effective modifications to systems that do not meet the new criteria were recommended for future evaluation.

PHASE I RESEARCH—STATE-OF-THE-ART ASSESSMENT

Since its publication in 1993, *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features* established guidance

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for evaluating the safety performance of roadside features, such as longitudinal barriers, terminals, crash cushions, and breakaway structures. This document was formally adopted as the national standard by FHWA later that year with an implementation date of late 1998.

An update to *NCHRP Report 350,* now known as the *Manual for Assessing Safety Hardware* (*MASH*), was developed under NCHRP Project 22-14(02), "Improved Procedures for Safety-Performance Evaluation of Roadside Features." This document contains revised criteria for safety-performance evaluation of virtually all roadside safety features. Changes to the design test vehicles and impact conditions will place greater impact performance demands on many current roadside safety features.

It may be of interest to note that as the development of *MASH* progressed, it appeared that the new design test vehicle for structural adequacy tests would be a 5000-lb, ¾-ton, standard cab pickup. The rationale was to keep the same body style pickup used under *NCHRP Report 350* with a test inertia weight adjusted to reflect the upsizing trend indicated in sales of new passenger vehicles. Previous research had concluded that the ¾-ton, standard cab pickup was a reasonable surrogate for light truck vehicles, and there was a tremendous amount of experience and investment in designing for and testing with this truck.

The implications of specifying the heavier, 5000-lb, ¾-ton pickup truck as the new design test vehicle were not completely understood, but it was known that it would be more critical than the existing 4409-lb, ¾-ton pickup used under *NCHRP Report 350.* The 13 percent increase in weight and impact severity would place more demand on the structural adequacy of barrier systems and would aggravate problems with vehicle stability and occupant compartment deformation. As an example, it was demonstrated in a full-scale crash test that standard strong steel post W-beam guardrail would not accommodate the new vehicle under Test Level 3 (TL-3) impact conditions.

It was not until well into the development of *MASH* that the design test vehicle changed to a 5000-lb, ½-ton, 4-door pickup truck. The rationale for this change is that this body style pickup has characteristics that more closely resemble large SUVs than the ¾-ton, standard cab pickup. Subsequent crash testing and analyses conducted under NCHRP Project 22-14(02) and other projects indicate that the 5000-lb, ½-ton, 4-door, pickup truck will impart impact loads that are comparable to those of the 4409-lb, ¾-ton, standard cab pickup. Further, the ½-ton, 4-door, pickup truck appears to be more stable and have less propensity for occupant compartment intrusion than the ¾-ton pickup.

When these vehicle factors are combined with much more liberal thresholds for occupant compartment deformation, the need for revising existing hardware to comply with *MASH* does not appear to be as extensive as once anticipated. This fact is reflected in the performance assessment ratings assigned to the hardware assessed. The researchers do note that the dramatic increase in impact severity of the pickup truck redirection tests and other changes in the test matrices for terminals and crash cushions will likely necessitate the modification of some of these systems. However, most of these devices are proprietary in nature and therefore, an assessment of their performance has not been addressed under NCHRP Project 22-14(03).

In addition to changes in the pickup truck vehicle, the test conditions for TL-4 have changed significantly. Most notably, the weight for the single-unit truck (SUT) vehicle increased from 17,640 lb to 22,050 lb and the impact speed increased from 50 mi/h to 56 mi/h. The increased weight and speed of the SUT vehicle increased the impact severity of longitudinal redirection test 4-12 by 56 percent. In addition, the estimated impact force of 76 kips for *MASH* test 4-12 represents a 41 percent increase from the 54-kip design load used for *NCHRP Report 350* test 4-12. Consequently, some barriers that meet the *NCHRP Report 350* guidelines as a TL-4 barrier may not have adequate strength to comply with the same test level under *MASH.*

Another aspect of the structural adequacy criteria is that the test vehicle should not override the barrier. Adequate barrier height is required to prevent heavy trucks with high centers of gravity from rolling over a barrier. Full-scale crash testing has shown that 32-in. tall barriers are capable of meeting TL-4 impact conditions under *NCHRP Report 350.* However, when *MASH* test 4-12 was conducted on a 32-in. tall New Jersey safety shape concrete barrier, the SUT rolled over the top of the barrier.

After the unsatisfactory outcome of the test performed under Project 22-14(02), it was proposed to reduce the center-of-gravity (C.G.) height of the ballast of the SUT from 67 in. to 63 in. This effectively decreases the overturning moment by decreasing the moment arm between the C.G. of the truck and the reactive force applied by the barrier. Additional testing was performed under this project to determine whether the decrease in C.G. height was sufficient to permit 32-in. tall barriers to contain the SUT or whether taller barriers would be needed to comply with *MASH*. Testing under this project demonstrated that the decrease in ballast C.G. height was not sufficient to prevent the SUT from rolling over a 32-in. tall New Jersey safety shape barrier.

State DOTs make considerable use of non-proprietary roadside safety systems. Although some barrier testing was conducted under NCHRP Project 22-14(02) during the development of the *MASH* criteria, many barrier systems and other roadside safety features have yet to be evaluated under the proposed guidelines. Therefore, evaluation of the remaining widely used roadside safety features following the impact performance requirements of *MASH* was needed.

Under this research project, researchers conducted a survey of the state DOTs for use and frequency rates for non-proprietary hardware and reviewed the test reports of the crash tests performed under NCHRP Project 22-14(02) and TXDOT project FHWA/TX-07/0-5526-1, as well as numerous tests performed under *NCHRP Report 350* guidelines. A performance assessment of existing roadside safety devices was performed to help evaluate the impact of adopting *MASH*. Crash test results, engineering analyses, and engineering judgment were used to assist with the hardware evaluation. Categories of roadside features that were considered under the project include guardrail, median barriers, transitions from approach guard fence to barriers, breakaway sign supports, and precast and permanent concrete barriers. Proprietary devices were not considered. The manufacturers of these devices will be required to assess the impact performance of their devices and ultimately demonstrate compliance of their devices with the new test and evaluation guidelines.

Results of the performance assessment were used to develop a prioritization scheme for further testing and evaluation required to bring roadside safety features into compliance with the new impact performance guidelines.

PHASE II RESEARCH—FULL-SCALE CRASH TESTING

The objective of Phase II of this project was to evaluate the safety performance of widely used non-proprietary roadside safety hardware using *MASH* performance and evaluation criteria. Highway safety hardware proposed for evaluation included longitudinal barriers (excluding bridge railings); terminals and crash cushions; transitions; and breakaway sign supports that had previously been accepted under *NCHRP Report 350*.

Researchers identified use and frequency of specific non-proprietary roadside safety hardware by surveying the state DOTs. In conjunction with the NCHRP project panel, a final test matrix consisting of nine roadside safety hardware features was chosen from 89 identified non-proprietary roadside safety hardware features. Researchers performed a total of 10 full-scale crash tests on nine different types of roadside safety hardware.

New Jersey Safety Shape Barrier

Test 4-12

Test Vehicle:	1999 Ford F-800 single-unit truck
Test Inertia Weight:	22,090 lb
Gross Static Weight:	22,090 lb
Impact Speed:	57.4 mi/h
Impact Angle:	14.4 degrees

The 32-in. New Jersey safety shape bridge rail failed to contain and redirect the SUT vehicle under the new TL-4 impact conditions with a ballast C.G. height of 63 in. The SUT rolled 101 degrees before exiting the end of the barrier. Although subsequent contact with the ground enabled the vehicle to right itself as it came to rest, there is no question that the SUT would have continued to roll over the top of the rail had the barrier test installation length been longer. The 32-in. New Jersey safety shape bridge rail failed to demonstrate satisfactory performance according to the TL-4 evaluation criteria in *MASH*.

Test 3-11

Test Vehicle:	2007 Chevrolet Silverado 4-door pickup
Test Inertia Weight:	5049 lb
Gross Static Weight:	5049 lb
Impact Speed:	62.6 mi/h
Impact Angle:	25.2 degrees

The New Jersey safety shape barrier contained and redirected the 2270P vehicle under TL-3 impact conditions. The vehicle did not penetrate, underride, or override the installation. No measurable deflection of the barrier occurred. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment or to present hazard to others in the area. Maximum occupant compartment deformation was 2.0 in. at the right kickpanel. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 29 and –16 degrees, respectively. Occupant risk factors were within the limits specified in *MASH*. The 2270P exited the barrier within the exit box.

The New Jersey safety shape barrier performed acceptably when impacted by the 2270P vehicle (2007 Chevrolet Silverado pickup) and evaluated in accordance with the safety-performance evaluation criteria presented in *MASH*.

G4(2W) W-Beam Guardrail

Test Vehicle:	2007 Chevrolet Silverado 4-door pickup
Test Inertia Weight:	5009 lb
Gross Static Weight:	5009 lb
Impact Speed:	64.4 mi/h
Impact Angle:	26.1 degrees

The G4(2W) W-beam guardrail did not perform acceptably when impacted by the 2270P vehicle (2007 Chevrolet Silverado pickup). The vehicle penetrated the guardrail after the W-beam rail element ruptured and then subsequently rolled 180 degrees. It should be noted that the impact speed and angle for this test were 64.4 mi/h and 26.1 degrees, respectively. The impact speed and angle were within the acceptable limits prescribed in *MASH*. However, the impact condition represented an impact severity 16.4 percent greater than the target *MASH* condition (62.2 mi/h and 25 degrees).

Various modifications to W-beam guardrail have demonstrated improved performance. Modifications that have demonstrated improved performance in crash tests include increasing the rail height to 31 in., moving the rail splices to mid-span of the posts, and using 12-in. deep block-outs. It is believed that any one or more of these changes will improve the performance of the G4(2W) W-beam guardrail. Additionally, it is known that W-beam guardrail has historically been performing at or very near 100 percent of structural design capacity. If the speed and angle in the test were nearer to target impact conditions, the rail may not have ruptured.

G4(1S) W-Beam Median Barrier

Test-3-10

Test Vehicle:	2002 Kia Rio
Test Inertia Weight:	2418 lb
Gross Static Weight:	2584 lb
Impact Speed:	61.4 mi/h
Impact Angle:	26.0 degrees

The G4(1S) W-beam median barrier contained and redirected the 1100C vehicle. The vehicle did not penetrate, override, or underride the installation. Maximum dynamic deflection was 11.25 in. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment or to present a hazard to others in the area. Maximum occupant compartment deformation was 2.0 in. in the left front driver's area at the level of the floor pan. The 1100C vehicle remained upright during and after the collision event. Maximum roll angle was 8 degrees. Occupant risk factors were within the limits specified in *MASH*. The 1100C vehicle exited the median barrier within the exit box.

The G4(1S) W-beam median barrier performed acceptably when impacted by the 1100C vehicle (2002 Kia Rio).

Test-3-11

Test Vehicle:	2007 Chevrolet Silverado 4-door pickup
Test Inertia Weight:	5029 lb
Gross Static Weight:	5029 lb
Impact Speed:	64.0 mi/h
Impact Angle:	25.1 degrees

The G4(1S) W-beam median barrier did not perform acceptably when impacted by the 2270P vehicle (2007 Chevrolet Silverado pickup). The 2270P Silverado pickup truck overrode the installation. It should be noted that the impact speed and angle for this test were 64.0 mi/h and 25.1 degrees, respectively. The impact speed and angle were within the acceptable limits prescribed in *MASH*. However, the impact condition represented an impact severity 7.5 percent greater than the target *MASH* condition (62.2 mi/h and 25 degrees). If the speed and angle in the test were nearer to target impact conditions, the vehicle may not have vaulted over the test installation.

Typically, when the G4(1S) W-beam barrier is impacted in a roadside application, the support posts displace through the soil and help dissipate the energy of the impacting vehicle. When the displacement or deformation of the post becomes large enough, the rail detaches from the post by means of the post bolt pulling out of the rail slot. However, in the G4(1S) W-beam median barrier, the addition of the rear W-beam rail element provides additional stiffness and constrains the lateral displacement of the posts. Because the rail cannot readily detach from the posts, the rail is pulled down by the posts and the effective rail height is reduced in the region of impact. In the test presented herein, a guardrail post was impacted by the left front tire and the vehicle climbed the post and W-beam rail element.

A 30-in. tall version of the G4(1S) W-beam median barrier (AASHTO Designation SGM06a-b) incorporates a C6x8.2 rub-rail channel that is mounted 12 in. above the ground to the center of the rub-rail. The addition of the rub-rail will prevent the wheel from contacting the face of the posts and thus help mitigate vehicle-post snagging. The rub-rail will also increase the barrier stiffness, which should reduce post displacement and rail deflection. However, the rub-rail may still permit the pickup to climb the barrier. The researchers recommend evaluating the 30-in. tall G4(1S) W-beam median barrier (AASHTO Designation SGM06a) with *MASH* Test 3-11.

W-Beam Transition

Test Vehicle:	2007 Chevrolet Silverado 4-door pickup
Test Inertia Weight:	5029 lb
Gross Static Weight:	5029 lb
Impact Speed:	62.8 mi/h
Impact Angle:	25.7 degrees

The W-beam transition to concrete bridge parapet successfully contained and redirected the 2270P vehicle. The vehicle did not penetrate, override, or underride the installation. Maximum dynamic deflection was 3.8 in. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment or to present a hazard to others in the area. Maximum occupant compartment deformation was 0.6 in. in the left rear area at hip height. The 2270P vehicle remained upright during and after the collision event. Maximum roll angle was 54 degrees. Occupant risk factors were within the limits specified in *MASH*. The 2270P vehicle exited the W-beam transition within the exit box.

The W-beam transition to concrete parapet performed acceptably when impacted by the 2270P vehicle (2007 Chevrolet Silverado 4-door pickup).

Sign Supports

Test Vehicle:	2003 Dodge Ram 1500 quad-cab pickup
Test Inertia Weight:	4958 lb
Gross Static Weight:	4958 lb
Impact Speed:	63.3 mi/h
Impact Angle:	0 degrees

The U-channel and perforated square steel tube (PSST) small sign supports both readily activated upon impact by the 2270P vehicle by fracturing at bumper height and at the ground stub interface. The detached sign supports rotated around the front of the vehicle, and the sign panels struck near or at the windshield and roof area and subsequently traveled with the vehicle. The 2270P vehicle remained upright during and after both collision events. Minimal roll and pitch were noted. Occupant risk factors were within acceptable limits. The 2270P vehicle came to rest behind the test articles.

Contact of the U-channel support with the windshield and roof was minimal, and the support did not penetrate nor show potential for penetrating the occupant compartment. The largest detached piece of this support weighed 33.6 lb, but the trajectory was relatively low and should not cause undue hazard to others in the area. No occupant compartment deformation related to impact with the U-channel support was measured.

The upper section of the PSST support and sign panel contacted and shattered the windshield. No tear of the windshield plastic lining occurred. However, the windshield was deformed inward 3.5 in. *MASH* (Section 5.3 and Appendix E) limits deformation of the windshield to 3 in.

The 4 lb/ft steel U-channel support manufactured by NuCor Steel Marion successfully met the *MASH* evaluation criteria for Test 3-62. The 12-gauge perforated, 2-in. square, steel tube (PSST) support manufactured by Northwest Pipe failed to meet the *MASH* evaluation criteria for Test 3-62 due to excessive occupant compartment deformation at the windshield.

The primary observed difference in the performance of the two sign support types is the manner in which the sign panel reacted during the impact sequence. Both sign support types fractured at bumper height and near the ground stub interface. The U-channel sign support installation kept the sign panel attached to the support for much of the impact event. The sign panel remained attached until the support and panel impacted the roof of the truck as an assembly. Upon separation, both the sign and support passed over the cab of the pickup truck.

During the test of the PSST sign support, the sign panel released from the support at approximately the same time the support failed at bumper height. The failure of the sign attachment and release of the sign panel changed the dynamics of the impact and permitted the sign panel to impact the windshield more directly. The PSST sign support stayed in the front of the vehicle and displaced forward with the vehicle with very little angular momentum. It is the opinion of the researchers that had the sign panel remained attached to the support, the PSST sign support installation performance would have been similar to the U-channel performance, and the PSST would have likely met the *MASH* performance evaluation criteria. Further testing with enhanced sign panel-to-post connection can be performed to verify this opinion.

G3 Weak Post Box-Beam Guardrail

Test Vehicle:	2007 Chevrolet Silverado 4-door pickup
Test Inertia Weight:	5011 lb
Gross Static Weight:	5011 lb
Impact Speed:	63.2 mi/h
Impact Angle:	25.4 degrees

The G3 weak post box-beam guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the weak post guardrail. Maximum dynamic deflection of the rail during the test was 4.8 ft. Two rail brackets detached from their posts, but they did not penetrate or show potential for penetrating the occupant compartment or present a hazard to others in the area. Maximum occupant compartment deformation was 0.75 in. in the lateral area across the cab at the driver's side kick-panel. The 2270P vehicle remained upright during and after the collision event. Maximum roll angle was −14 degrees. Occupant risk factors were within the limits specified in *MASH*. The 2270P vehicle exited within the exit box.

The G3 weak post box-beam guardrail performed acceptably when impacted by the 2270P vehicle (2007 Chevrolet Silverado pickup).

Modified G2 Weak Post W-Beam Guardrail

Test Vehicle:	2007 Chevrolet Silverado 4-door pickup
Test Inertia Weight:	5004 lb
Gross Static Weight:	5004 lb
Impact Speed:	62.4 mi/h
Impact Angle:	24.6 degrees

The modified G2 weak post W-beam guardrail contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the weak post W-beam guardrail. Maximum dynamic deflection of the rail during the test was 8.6 ft. There was no debris from the test installation that penetrated or showed potential for penetrating the occupant compartment or presented a hazard to others in the area. Maximum occupant compartment deformation was 0.25 in. in the lateral area across the cab at the driver's side hip area. The 2270P vehicle remained upright during and after the collision event. Maximum roll angle was −12 degrees. Occupant risk factors were within the limits specified in *MASH*. The 2270P vehicle remained within the exit box.

The modified G2 weak post W-beam guardrail performed acceptably when impacted by the 2270P vehicle (2007 Chevrolet Silverado pickup).

G9 Thrie Beam Guardrail

Test Vehicle:	2007 Chevrolet Silverado 4-door pickup
Test Inertia Weight:	5019 lb
Gross Static Weight:	5019 lb
Impact Speed:	63.3 mi/h
Impact Angle:	26.4 degrees

The G9 thrie beam guardrail did not perform acceptably when impacted by the 2270P vehicle (2007 Chevrolet Silverado pickup). After being contained and redirected, the 2270P Silverado pickup rolled 360 degrees. Maximum dynamic deflection of the thrie beam during the test was 33.2 in. Maximum occupant compartment deformation was 3.56 in. in the right rear passenger area. It should be noted that the impact speed and angle for this test were 63.3 mi/h and 26.4 degrees, respectively. The impact speed and angle were within the acceptable limits prescribed in *MASH*. However, the impact condition represented an impact severity 15.3 percent greater than the target *MASH* condition (62.2 mi/h and 25 degrees). If the speed and angle in the test were nearer to target impact conditions, the vehicle may not have rolled over.

CONCLUSION

Nine different types of roadside safety hardware were crash tested and evaluated in accordance with *MASH*. Six of the 10 crash tests performed on these nine safety devices successfully met the *MASH* evaluation criteria. Table 1 summarizes the non-proprietary roadside safety hardware tested under NCHRP Projects 22-14(02) and 22-14(03) that successfully met the *MASH* evaluation criteria. Table 2 identifies the non-proprietary roadside safety hardware tested under these projects that failed to meet the *MASH* evaluation criteria.

REPORT AVAILABILITY

The complete report for NCHRP Project 22-14(03) is available on TRB's website (www.trb.org) as *NCHRP Web-Only Document 157*.

Copies of the crash test reports (Appendices B through K) are available on the National Crash Analysis Center website (www.nac.gwu.edu).

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Table 1 Crash tests performed under NCHRP Project 22-14 that met *MASH* (passed).

Ref. Test No.*	Agency Test No.	Test Designation	Test Article	Vehicle Make and Model	Vehicle Mass (lb)	Impact Speed (mph)	Impact Angle (deg)	OIV (ft/s)	Ridedown (G)
1	2214WB-1[1]	3-11	Modified G4(1S) Guardrail	2002 GMC 2500 ¾-ton Pickup	5000	61.1	25.6	X = 17.3 Y = 16.2	X = –19.7 Y = –8.5
2	2214WB-2	3-11	Modified G4(1S) Guardrail	2002 Dodge Ram 1500 Quad Cab Pickup	5000	62.4	26.0	X = 17.6 Y = 13.1	X = 6.9 Y = –6.6
3	2214MG-1	3-11	Midwest Guardrail System (MGS)	2002 GMC 2500 ¾-ton Pickup	5000	62.6	25.2	X = 17.1 Y = 14.8	X = –8.8 Y = –5.3
4	2214MG-2	3-11	MGS	2002 Dodge Ram 1500 Quad Cab Pickup	5000	62.8	25.5	X = 15.3 Y = 15.6	X = –8.2 Y = –6.9
5	2214MG-3	3-10	MGS (Max. Height)	2002 Kia Rio	2588	60.8	25.4	X = 14.8 Y = 17.1	X = –16.1 Y = –8.4
6	2214TB-1	3-11	Free-Standing Temporary F-Shape Barrier	2002 GMC 2500 ¾-ton Pickup	5000	61.8	25.7	X = 18.5 Y = 18.9	X = –11.9 Y = –6.5
7	2214TB-2	3-11	Free-Standing Temporary F-Shape Barrier	2002 Dodge Ram 1500 Quad Cab Pickup	5000	61.9	25.4	X = 17/0 Y = 17/3	X = –7.2 Y = –11.4
8	2214NJ-1	3-10	32-in. Permanent New Jersey Safety Shape Barrier	2002 Kia Rio	2579	60.8	26.1	X = 16.5 Y = 35.0	X = –5.5 Y = –8.1

9	2214T-1	3-21	Guardrail to Concrete Barrier Transition	2002 Chevrolet C1500HD Crew Cab Pickup	5083	60.3	24.8	X = 24.4 Y = 25.0	X = 12.7 Y = 8.7
10	2214TT-1	3-34	Sequential Kinking Terminal (SKT)-MGS (Tangent)	2002 Kia Rio	2597	64.4	14.5	X = 17.8 Y = 13.4	X = −7.5 Y = −9.1
13	476460-1-4	3-11	32-in. Permanent New Jersey Safety Shape Barrier	2007 Chevrolet Silverado Pickup	5049	62.6	25.2	X = 14.1 Y = 30.2	X = −5.6 Y = −9.6
14	476460-1-2	3-62	4 lb/ft U-Channel Sign Support	2003 Dodge Ram 1500 Quad Cab Pickup	4958	63.3	0	No contact	N/A
15	476460-1-3	3-21	W-Beam Transition	2007 Chevrolet Silverado Pickup	5029	62.8	25.7	X = 16.4 Y = 28.5	X = −8.1 Y = 16.4
16	476460-1-6	3-11	G3 Weak Post Box-Beam Guardrail	2007 Chevrolet Silverado Pickup	5011	63.2	25.4	X = 11.2 Y = 15.1	X = −5.7 Y = 7.2
17	476460-1-7	3-11	G2 Weak Post W-Beam Guardrail	2007 Chevrolet Silverado Pickup	5004	62.4	24.6	X = 9.5 Y = 10.5	X = −3.4 Y = 4.5
18	476460-1-10	3-10	G4(1S) W-Beam Median Barrier	2002 Kia Rio	2584	61.4	26.0	X = 16.4 Y = 24.3	X = −16.5 Y = 10.5

[1]Rail ruptured. Passed by FHWA.

Table 2 Crash tests performed under NCHRP Project 22-14 that did not meet *MASH* (failed).

Ref. Test No.*	Agency Test No.	Test Designation	Test Article	Vehicle Make and Model	Vehicle Mass (lb)	Impact Speed (mi/h)	Impact Angle (deg)	OIV (ft/s)	Ridedown (G)	Mode of Failure
11	2214NJ-2	4-12	32-in. Permanent New Jersey Safety Shape Barrier	1989 Ford F-800	22,045	56.5	16.2	X = 6.5 Y = 13.6	X = –22.4 Y = –8.8	Truck rolled over rail
12	476460-1b	4-12	32-in. Permanent New Jersey Safety Shape Barrier	1999 Ford F-800	22,090	57.4	14.4	X = 8.2 Y = 13.8	X = –4.3 Y = 7.7	Truck rolled over rail
15	476460-1-2	3-62	Perforated Square Steel Tube Sign Support	2003 Dodge Ram 1500 Quad Cab Pickup	4958	61.7	0	X = 4.3 Y = 2.3	X = –08 Y = –0.4	Excessive deformation
19	476460-1-5	3-11	G4(2W) W-Beam Guardrail	2007 Chevrolet Silverado Pickup	5009	64.4	26.1	X = 21.6 Y = 14.1	X = –10.2 Y = 9.6	Pickup penetrated and rolled
20	476460-1-8	3-11	G9 Thrie Beam Guardrail	2007 Chevrolet Silverado Pickup	5019	63.3	26.4	X = 17.1 Y = 17.4	X = –6.9 Y = 7.7	Pickup rolled
21	476460-1-9	3-11	G4(1S) W-Beam Median Barrier	2007 Chevrolet Silverado Pickup	5029	64.0	25.1	X = 17.2 Y = 17.1	X = –5.2 Y = 5.3	Penetrated rail element

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