Report No. 405160-24
Report Date: August 2011

GUARDRAIL DEFLECTION ANALYSIS, PHASE I: (2010-11)

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Contract No.: T4541-AW
Project No.: 405160-24

Sponsored by
Roadside Safety Research Program Pooled Fund Study

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DISCLAIMER

KEY WORDS

Guardrail, deflection, roadside safety, crash testing

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle
GUARDRAIL DEFLECTION ANALYSIS, PHASE I: (2010-11)

5. Report Date
August 2011

6. Performing Organization Code

7. Author(s)
Akram Y. Abu-Odeh, Kang-Mi Kim, and Roger P. Bligh

8. Performing Organization Report No.
405160-24

9. Performing Organization Name and Address
Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3135

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
T4541-AW

12. Sponsoring Agency Name and Address
Washington State Department of Transportation
Transportation Building, MS: 47372
Olympia, Washington, 98504-7372

13. Type of Report and Period Covered
Final Report:
April 2010 – April 2011

14. Sponsoring Agency Code

15. Supplementary Notes
Research Study Title: Guardrail Deflection Analysis, Phase I: (2010-11)
Name of Contacting Representative: Dave Olson

16. Abstract

Designers are often faced with having to design beam guardrail systems to accommodate a variety of allowable maximum deflections to fit specific site conditions. Tools for determining those deflections are limited, and it is time consuming to research crash test data to review work that is already conducted. With the wealth of information available through crash test reports and Federal Highway Administration (FHWA) acceptance letters, information can be categorized and tabulated into a table for use by designers for selecting appropriate beam guardrail for the desired maximum deflection.

The research team reviewed full-scale crash test reports to tabulate guardrail deflection. These crash tests were performed at Texas Transportation Institute, Midwest Roadside Safety Facility, Southwest Research Institute, and other testing facilities. Acceptance letters issued by Federal Highway Administration were also reviewed. Deflection results for 53 different guardrail configuration are presented herein.

Based on these literature reviews, the following guardrail systems are synthesized herein;

- 12 gauge W-beam guardrail,
- Thrie-beam guardrail,
- 13 gauge buffalo guardrail,
- Nested W-beam guardrail,
- W-beam guardrail for special placement need such as for placement on a slope, with simulated culvert applications, and with various flare rates.

The tabulated guardrail systems include related specifications regarding the rail height, post size, post material, post spacing, blockout, and test designation. The rail height is from the top of the rail to the ground level. These tables present the maximum permanent and dynamic deflection, and working width.

17. Key Words
Guardrail, deflection, roadside safety, crash testing

18. Distribution Statement

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	66	

Form DOT F 1700.7 **(8-72)** **Reproduction of completed page authorized**

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

ACKNOWLEDGMENTS

This research project was performed under a pooled fund program between the State of Alaska Department of Transportation and Public Facilities, California Department of Transportation (Caltrans), Louisiana Department of Transportation and Development, Minnesota Department of Transportation, Pennsylvania Department of Transportation, Tennessee Department of Transportation, Washington State Department of Transportation, and the Federal Highway Administration. The authors acknowledge and appreciate their guidance and assistance. The authors also acknowledge the help of Ronald K. Faller from Midwest Roadside Safety Facility, Brian Smith from Trinity Industries, Chris Sanders and Steve J. Conway from Nucor Steel-Marion, Inc., Maggie Ellis from Mondo Polymer Technologies, Inc., and Rick Mauer from Gregory Industries, Inc. for providing data regarding various guardrail systems..

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Revised February 2010

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1 INTRODUCTION

1.1 Problem Statement

Designers are often faced with having to design beam guardrail systems to accommodate a variety of maximum allowable deflections to fit specific site conditions. Tools for determining those deflections are limited, and it is time consuming to research crash test data to review work that is already conducted. With the wealth of information available through crash test reports and Federal Highway Administration (FHWA) acceptance letters, information can be categorized and tabulated into a table for use by designers for selecting appropriate beam guardrail for the desired maximum deflection.

1.2 Objective

The objective of this study is to review available crash test data on beam guardrail systems to provide current information on dynamic deflections of a variety of beam guardrail systems. The beam guardrails to be included in this study are W-Beam and Thrie-Beam rail elements of various gauge thickness.

A subsequent phase (Phase II) to be proposed in the next cycle shall have the objective of simulating additional systems to broaden the range of system configurations available in such synthesis.

1.3 Study Approach

The researchers reviewed available literature of crash tests conducted using beam guardrails with a focus on National Cooperative Highway Research Program (NCHRP) *Report 350 (*1*)* and American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) *(*2*)* test 3-11. The researcher categorized present guardrail systems according to:

A. Single, 12 gauge, W-beam rail
B. Thrie beam rail
C. Nested rail
D. 13 gauge rail
E. W-beam rail designed for special applications

Additional distinction was made for post spacing, rail heights, blockout…etc. The researchers did not investigate guardrail terminals or transitions.

2 BACKGROUND

2.1 Background of Roadside Barriers

As stated in the AASHTO *Roadside Design Guide (3)*, "A roadside barrier (e.g., guardrail) is a longitudinal barrier used to shield motorists from natural or man-made obstacles located along either side of a traveled way." Roadside barriers have more exposure on our nation's highways any other type of roadside safety device. It is important to remember that although these barrier systems are considered safety features, they are objects that may be struck by a motorist and should only be used when justified. A barrier is typically warranted when the consequences of a vehicle leaving the traveled way and striking a fixed object or traversing a terrain feature is judged to be more severe than striking the barrier. The barrier functions by containing and either capturing or redirecting errant vehicles. The most definitive means of demonstrating the adequacy of the barrier for this purpose is through full-scale crash tests. Note that application of a barrier often results in increased frequency of crashes. However, the overall severity of these crashes is expected to be less than the crashes that would occur in the absence of a barrier.

While several different types of guardrails are currently being used on the national highway system, some types are used more frequently than the others. Table 2.1 presents common guardrail types tested under *NCHRP Report 350* impact performance guidelines *(1)*. Each of these barriers has different impact performance characteristics, limits of performance, and failure modes.

Table 2.1 Common Guardrail Types Tested under *NCHRP Report 350*.

Modified weak post W-beam (G2)
Modified strong steel-post W-beam (G4(1S))
Strong wood-post W-beam (G4(2W))
Modified strong steel-post thrie beam (G9-S)
Strong wood-post thrie beam (G9-W)
Modified thrie beam
Midwest Guardrail System (MGS)

These guardrail systems can be generally classified as weak post systems and strong post systems. Weak post systems are more flexible and have the greater dynamic deflection. The "weak" posts serve primarily to support the rail elements at their proper elevation for contact with an impacting vehicle. The posts are readily detached from the rail element(s) and dissipate little energy as they yield to the impacting vehicle and are pushed to the ground. Provided there is adequate space to accommodate the deflection, these barriers impose lower deceleration on an impacting vehicle and are, therefore, more forgiving and less likely to cause injury. It is noteworthy to mention that the modified weak post W-beam has successfully met the new *MASH* impact performance guidelines *(4, 5)*.

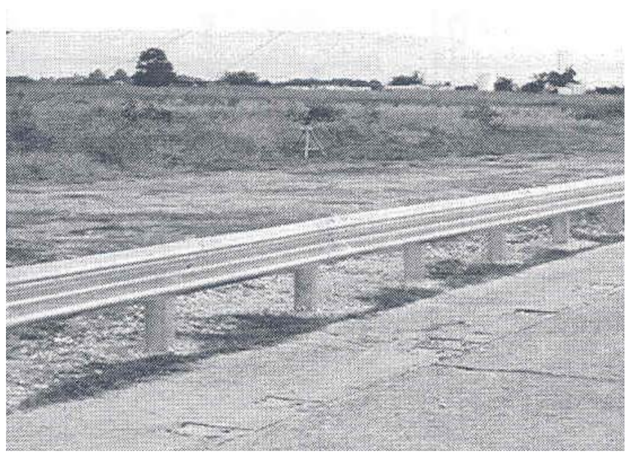
In contrast, strong-post guardrail systems incorporate larger, stronger posts that absorb significant energy as they rotate through the soil during an impact. The increased post stiffness results in reduced dynamic deflection and increased deceleration rates. Spacer blocks are often used to offset the rail element from the posts to minimize vehicle snagging on the posts. Severe post snagging can impart high decelerations to the vehicle and lead to vehicle instability or significant occupant compartment deformation. Examples of strong post barriers include the strong post W-beam and thrie beam. Both of these barrier systems have wood (e.g. 152 mm × 203 mm (6 inch × 8 inch)) and steel (e.g., W150×14 (W6×9)) post variations. Strong-post W-beam is the most common barrier system in use in the U.S. Figure 2.1(c) and (e) show strong steel post W-beam (modified G4(1S)) and strong wood post W-beam (G4(2W)) guardrails, respectively.

The strong steel post W-beam guardrail system, G4(1S), failed to meet *NCHRP Report 350* when tested with the ¾-ton, two-door, pickup truck design vehicle (denoted 2000P). Collapse of the W150×14 (W6×9) steel offset blocks permitted the wheel of the pickup truck to snag severely on the steel support posts *(6, 7)*. The snagging precipitated rollover of the truck as it exited the barrier. Subsequent testing demonstrated that a modified G4(1S) system with 8-inch (203 mm) deep wood or structural plastic offset blocks between the W-beam rail element and W150×14 (W6×9) steel posts could accommodate the 2000P pickup truck and comply with *NCHRP Report 350* guidelines *(8)*.

The strong wood post W-beam guardrail system, G4(2W), which utilizes 152 mm × 203 mm (6 inch × 8 inch) wood posts and offset blocks, successfully contained and redirected the 2000P pickup *(6, 7)*. However, instability of the pickup truck resulted in the test being classified as marginally acceptable.

Both of these strong-post W-beam guardrail systems continue to be widely used national standards. Recent testing under the new *MASH* guidelines has demonstrated that these strong-post W-beam guardrail systems are at or near their performance limits. Under NCHRP Projects 22-14(02) and 22-14(03), a series of crash tests were performed to assess the impact performance of commonly used barrier systems when impacted by the new ½-ton, four-door, pickup truck design vehicle (designated 2270P) under the AASHTO *MASH* guidelines. The increase in the weight of the new pickup truck from approximately 2000 kg to 2270 kg (4400 lb to 5000 lb) increases the impact severity of the structural adequacy test (Test 3-11) for longitudinal barriers by 13 percent from 137.8 kJ (101635 ft-lbf) to 156.4 kJ (115354 ft-lbf).

(a) Weak post W-beam (G2)



(b) Strong steel post W-beam (G4(1S))

(c) Strong wood post W-beam (G4(2W))

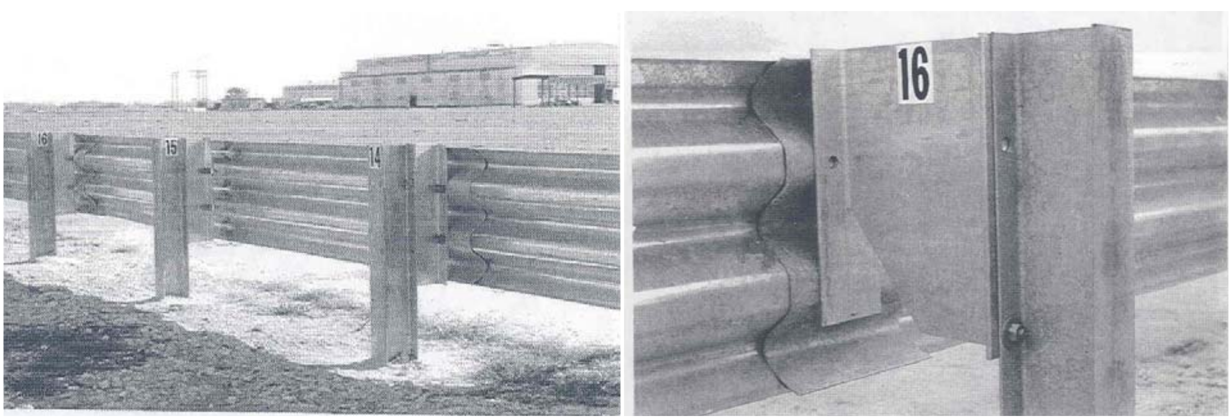
Figure 2.1 Types of Guardrails.

In a test of a modified G4(1S) steel post W-beam guardrail, the pickup truck was contained and redirected *(9)*. However, the rail had a vertical tear through approximately half of its cross section, indicating that the modified G4(1S) guardrail is at its performance limits. In a test of the G4(2W) wood post W-beam guardrail, the rail ruptured and failed to contain the pickup truck *(10)*.

The implications of these tests will need to be further considered by FHWA and AASHTO. Several states are considering or have already implemented the use of alternate strong-post guardrail systems that offer enhanced capacity. As an example, a modified guardrail design known as the Midwest Guardrail System (MGS) *(11)* has successfully met the *MASH* guidelines and has been shown to have additional capacity or factor of safety beyond the design impact conditions. The MGS guardrail increases the W-beam rail height from 686 mm to 787 mm (27 inches to 31 inches), increases the depth of the offset blocks between the rail and posts from 203 mm to 305 mm (8 inches to 12 inches), and moves the rail splice locations from the posts to mid-span between posts.

Thrie beam guardrails were originally developed to extend the performance range of strong post guardrails. The concept is that the taller, stronger element will have expanded containment capacity and offer improved stability for a broader range of vehicles. However, full-scale crash testing performed under *NCHRP Report 350* and, more recently, *MASH* indicates this assumption is not entirely accurate.

There are two basic types of thrie beams guardrails: standard strong steel and wood post thrie-beam (G9) and modified thrie-beam. The modified thrie-beam is the result of improvements made to the standard thrie-beam that were specifically designed to reduce rollover probability when impacted by larger vehicles such as school and intercity buses *(12)*. Figure 2.2(a) and (b) show strong steel post thrie-beam (G9-S) and modified thrie-beam guardrail, respectively.



(a) Strong steel post thrie-beam (G9-S) (b) Modified thrie-beam

Figure 2.2 Thrie-Beam Guardrail Section.

The strong steel post thrie-beam with steel offset blocks (G9-S) failed to meet *NCHRP Report 350* impact performance requirements *(*6, 7*)*. During the impact event, the left front wheel of the pickup severely snagged the flanges of two posts. This caused the pickup to pitch forward as it was redirecting. Consequently, the backslap contact between the vehicle and rail occurred at a lower point on the pickup, and induced a roll moment. The vehicle instability was aggravated by the ramp-like deflected shape of the thrie beam rail. These events caused the pickup truck to rollover as it exited the barrier system.

Following the failure of the standard G9 thrie-beam guardrail system, a modified steel post thrie-beam guardrail system with routed wood offset blocks was tested and evaluated. The system successfully contained and redirected the pickup and met all *NCHRP Report 350* evaluation criteria *(13)*.

Under NCHRP Project 22-14(03), this same modified steel post thrie-beam guardrail system with routed wood offset blocks was tested in accordance with the new *MASH* guidelines *(14)*. Somewhat unexpectedly, the pickup truck rolled over 360 degrees while exiting barrier. The behavior looked similar to the unsuccessful test of the original strong steel post thrie-beam with steel offset blocks that failed *NCHRP Report 350* test 3-11. Additional research and testing will be required to arrive at a design modification for addressing the failure.

2.2 Design Guideline

The *AASHTO Roadside Design Guide (15)* contains a table in Chapter 5 that lists deflections for various beam guardrail configurations as shown in Table 2.2. The majority of values listed in the table are based on simulations and few field tests to support deflection values using a 2000 kg (4400 lb) sedan only. The impact speed and angle were 97 km/h (60 mi/h) and 25 degrees, respectively. This table includes the post spacing, beam description, impact angle, and the maximum deflection.

Once the vehicle impacts the guardrail, the measured maximum deflection of the guardrail during impact is defined as the maximum dynamic deflection. After the test is completed, the maximum deflection of the guardrail is defined as the maximum permanent deflection.

The working width is defined in *MASH* as the distance between the traffic face of the test article before the impact and the maximum lateral position of any major part of the system or vehicle after the impact *(*2*)*.

A Guide to Standardized Highway Barrier Hardware (16) is used to review the beam guardrail systems currently used in United States. The components and systems in this Guide are a representative sample of what has been crash tested in accordance with the *NCHRP Report 350* and what is used throughout the United States.

Table 2.2 Summary of Maximum Deflection in AASHTO Roadside Design Guide (Table 5.4) *(15)*.

Run Number	Post Spacing mm	Post Spacing [inch]	Beam Description	Impact Angle	Maximum Deflection: Simulation mm	Simulation [inch]	Field Test mm	Field Test [inch]
1	1905	[75]	Sgl W-Beam	15°	589	[23.2]	NA	[NA]
2	1905	[75]	Sgl W-Beam	25°	907	[35.7]	754	[29.7]
3	952	[38]	Sgl W-Beam	15°	389	[15.3]	NA	[NA]
4	952	[38]	Sgl W-Beam	25°	541	[21.3]	597	[23.5]
*	1905	[75]	Dbl W-Beam	25°	NA	[NA]	902	[35.5]
5	952	[38]	Dbl W-Beam	15°	358	[14.1]	NA	[NA]
6	952	[38]	Dbl W-Beam	25°	437	[17.2]	498	[19.6]
7	476	[19]	Dbl W-Beam	15°	NA	[NA]	NA	[NA]
8	476	[19]	Dbl W-Beam	25°	320	[12.3]	NA	[NA]
9	1905	[75]	Sgl Thrie-Beam	15°	488	[19.2]	NA	[NA]
10	1905	[75]	Sgl Thrie-Beam	25°	716	[28.2]	NA	[NA]
11	952	[38]	Sgl Thrie-Beam	15°	386	[15.2]	NA	[NA]
12	952	[38]	Sgl Thrie-Beam	25°	480	[18.9]	NA	[NA]
13	952	[38]	Dbl Thrie-Beam	15°	333	[13.1]	NA	[NA]
14	952	[38]	Dbl Thrie-Beam	25°	414	[16.3]	NA	[NA]
15	476	[19]	Sgl Thrie-Beam	15°	NA	[NA]	NA	[NA]
16	476	[19]	Sgl Thrie-Beam	25°	353	[13.9]	NA	[NA]
17	476	[19]	Dbl Thrie-Beam	15°	NA	[NA]	NA	[NA]
18	476	[19]	Dbl Thrie-Beam	25°	307	[12.1]	NA	[NA]

Sgl = Single
Dbl = Double
NA = Not applicable

The researchers reviewed available literature of guardrail crash tests conducted using test level 3-11 for both *NCHRP Report 350 (1)* and *MASH (2)*. The weight and body style of the pickup truck changed from a 2000 kg (4409 lb), ¾-ton, standard cab pickup (*NCHRP Report 350*) to a 2270 kg (5000 lb), ½-ton, 4-door pickup (*MASH*) as shown in Table 2.3. The pickup truck impacts at a speed of 100 km/h (62 mph) and an angle of 25 degrees under both specifications.

Table 2.3 *NCHRP Report 350* and *MASH* Test 3-11.

	NCHRP Report 350 **Test 3-11**	***MASH*** **Test 3-11**
Test Vehicle Designation	2000P (Mass = 2000 kg (4409 lb))	2270P (Mass = 2270 kg (5000 lb))
Test Conditions		
Speed	100 km/h (62 mi/h)	100 km/h (62 mi/h)
Angle	25 degrees	25 degrees

3 SYNTHESIS OF GUARDRAIL DEFLECTION

The research team reviewed full-scale crash test reports of guardrail systems to tabulate the guardrails maximum deflection. These crash tests were performed at Texas Transportation Institute (TTI), Midwest Roadside Safety Facility (MwRSF), Southwest Research Institute (SwRI), and other testing facilities. Acceptance letters issued by Federal Highway Administration (FHWA) were also reviewed. A total of 53 guardrail configuration and deflection results are presented herein.

Each system was tabulated in chronological order in the following section. The research team tabulated 35 crash tests of 12 gauge W-beam guardrail, six thrie beam guardrails, one 13 gauge W-beam guardrail, two nested W-beam guardrail, and nine W-beam guardrail systems designed for special applications (e.g. placement on a slope, with simulated culvert applications, and with various flare rates, etc.).

The tabulated guardrail systems include the specification regarding the rail height, post size, post material, post spacing, blockout, and test designation. The rail height is from the top of the rail to the ground level. These tables present the maximum permanent and dynamic deflection, and working width.

Most of the reports used different units among the International System (SI) and US customary (USC) units. Exact (hard) conversion is utilized in this report. For example, if the guardrail has 150 mm wide × 200 mm deep × 360 mm long timber blockout, this blockout dimensions are converted to be 5⅞ inch wide × 7⅞ inch deep × 14 ⅛ inch long. However, if reports present both SI and USC units, the unit conversion is not used for this case and original numbers presented in the reports are used.

3.1 12 Gauge W-Beam Guardrail

The research team tabulated 35 crash tests of 12 gauge W-beam guardrail as shown in Table 3.1 through Table 3.6. These W-beam guardrail systems can be classified into four categories below:

- modified W-beam, weak-post guardrail system (G2),
- strong W-beam with wood post (G4(2W)),
- modified strong W-beam with steel post (G4(1S)), and
- Midwest Guardrail System (MGS).

Examples of 12 gauge W-beam guardrail systems are shown in Figure 3.1 and Figure 3.2. The rail height is from the top of the rail to the ground level. In some reports, the height of the guardrail to the center of the W-beam rail element is mentioned to be 550 mm (21.7 inches) as shown in Figure 3.2. The researchers computed the total height of rail using AASHTO RWM02a (W-beam rail section) rail properties *(17)*. The height of W-beam is presented to be 312 mm (12¼ inches) in this sheet. Therefore, the total height of W-beam was computed to be 706 mm (27.8 inches) (550 mm + 156 mm = 706 mm).

Table 3.1 12 gauge W-Beam Guardrail.

Test No. Agency, Year	Rail Height	Post		Blockout	Maximum Deflection		Working Width	FHWA Letter No.	System Configuration
		Size and Material	Spacing		Permanent	Dynamic			
471470-26 TTI, 1994 *(18)* [1]	27 inches (686 mm)	5 ft-4 inch long 6×8 inch wood	6 ft-3 inch	6×8×14 inch wood	27.2 inches (690 mm)	32.3 inches (820 mm)	N/A	N/A	W-beam, strong post G4(2W) guardrail (*NCHRP 350* 3-11)
405421-1 TTI, 1995 *(19)* [2]	27.8 inches (706 mm) [3]	6 ft long W6×8.5 steel	6 ft-3 inch	5⅞×7⅞× 14⅛ inch timber	27.6 inches (700 mm)	39.4 inches (1000 mm)	N/A	N/A	Modified W-beam, strong post G4(1S) guardrail (*NCHRP 350* 3-11)
405391-1 TTI, 1995 *(20)* [1]	27.8 inches (706 mm) [3]	6 ft-3 inch long 7.25 inch dia round wood	6 ft-3 inch	5¾×5 ¾ ×14 inch wood	31.1 inches (790 mm)	43.3 inches (1100 mm)	N/A	N/A	Round wood post G4(2W) guardrail (*NCHRP 350* 3-11)
400001-MPT1 TTI, 1996 *(21)* [2]	27.8 inches (706 mm) [3]	6 ft long W6×9 steel	6 ft-3 inch	6×7⅞× 14 inch recycled polyethylene block	28.3 inches (720 mm)	44.5 inches (1130 mm)	N/A	N/A	Modified G4(1S) guardrail with recycled blockouts (*NCHRP 350* 3-11)
439637-1 TTI, 1997 *(22)* [2]	27.8 inches (706 mm) [3]	5 ft-6 inch long W6×9 steel	6 ft-3 inch	6×6×14 inch routed wood	17.7 inches (450 mm)	29.5 inches (750 mm)	N/A	N/A	Modified G4(1S) guardrail (*NCHRP 350* 3-11)
400001-APL1 TTI, 2000 *(23)* [2]	27.8 inches (706 mm) [3]	4 ft-10.5 inch long 6×7.5 inch recycled plastic	6 ft-3 inch	5⅞×7⅞× 14⅛ inch timber	31.3 inches (795 mm)	53.6 inches (1362 mm)	5.47 ft (1.67 m)	N/A	Modified G4(2W) guardrail with Amity plastic's recycled posts (*NCHRP 350* 3-11)
404201-1 TTI, 2000 *(24)* [2]	27.8 inches (706 mm) [3]	5 ft-11 inch long 5⅞×7⅞ inch wood	6 ft-3 inch	5⅞ × 7⅞ ×14⅛ inch wood	33.9 inches (860 mm)	40.6 inches (1032 mm)	N/A	N/A	G4(2W) with 100 mm asphaltic curb (*NCHRP 350* 3-11)

[1] The report used both SI and USC units. [2.] The report used SI units only.

[3.] In these reports, the height of the guardrail to the center of the W-beam rail element is depicted to be 550 mm. The researchers calculated the total height of rail based on AASHTO RWM02a rail properties *(17)*. Thus, 550 mm (center of W-beam height) + 156 mm (half height of W-beam section) = 706 mm.

N/A = Not Available

Table 3.2 12 gauge W-Beam Guardrail (Continued).

Test No. Agency, Year	Rail Height	Post		Blockout	Maximum Deflection		Working Width	FHWA Letter No.	System Configuration
		Size and Material	Spacing		Permanent	Dynamic			
473750-3 TTI, 2000 *(25)* [1]	32.3 inches (820 mm)	5 ft-3 inch long S3×5.7 steel	12 ft-6 inch	N/A	64.6 inches (1640 mm)	83.5 inches (2120 mm)	N/A	N/A	Modified PennDOT Type 2 weak post guiderail (G2) (*NCHRP 350* 3-11)
400001-CFI1 TTI, 2001 *(26)* [2]	27.8 inches (706 mm)	5 ft-3 inch long HALCO X-48 steel	6 ft-3 inch	6⅛×7⅞×14⅛ inch Recycled plastic	12.8 inches (326 mm)	31.9 inches (811 mm)	3.8 ft (1.16 m)	B80	G4 guardrail with HALCO X-48 steel posts and recycled plastic blockouts (*NCHRP* 350 3-11)
400001-ILP2 TTI, 2001 *(27)* [2]	27.8 inches (705 mm)	5 ply laminated 5 ft-4 inch long 5⅞×7⅞ inch wood	6 ft-3 inch	5 ply laminated 5⅞ × 7⅞ ×14 inch wood	13.4 inches (340 mm)	31.1 inches (789 mm)	2.87 ft (0.88 m)	B92	G4(2W) guardrail with imperial 5-Lam posts and blockouts (*NCHRP 350* 3-11)
441622-1 TTI, 2001 *(28)* [1]	27 inches (686 mm)	6 ft long W6×9 steel	6 ft-3 inch	6×8×14 inch routed wood	13.4 inches (340 mm)	23 inches (584 mm)	3.43 ft (1.05 m)	B64B	Modified G4(1S) guardrail on concrete mow strip (*NCHRP 350* 3-11)
41-1655-001 E-TECH Inc. 2001 *(29)* [2]	27.8 inches (706 mm) [3]	5 ft-3 inch long HALCO X-40 Steel	6 ft-3 inch	6⅛×7⅞×14⅛ inch Recycled plastic	27.6 inches (700 mm)	51.2 inches (1300 mm)	N/A	B80A	G4 guardrail with light weight HALCO X-40 steel posts and recycled plastic blockouts (*NCHRP 350* 3-11)
441622-2 TTI, 2002 *(28)* [2]	27 inches (686 mm)	7 inch dia round wood	6 ft-3 inch	6×8×14 inch routed wood	22.4 inches (570 mm)	27.1 inches (688 mm)	3.88 ft (1.18 m)	B64B	G4(2W) guardrail on round posts in mow strip (*NCHRP 350* 3-11)

1. The report used both SI and USC units.
2. The report used SI units only.
3. In these reports, the height of the guardrail to the center of the W-beam rail element is depicted to be 550 mm. The researchers calculated the total height of rail based on AASHTO RWM02a rail properties *(17)*. Thus, 550 mm (center of W-beam height) + 156 mm (half height of W-beam section) = 706 mm.

N/A = Not Available

Table 3.3 12 gauge W-Beam Guardrail (Continued).

Test No. Agency, Year	Rail Height	Post		Blockout	Maximum Deflection		Working Width	FHWA Letter No.	System Configuration
		Size and Material	Spacing		Permanent	Dynamic			
400001-MON1 TTI, 2002 *(30)* [1]	27.8 inches (706 mm)	6-ft long W6×9 steel	6 ft-3 inch	Mondo polymer blocks	10.4 inches (265 mm)	33 inches (837 mm)	3.93 ft (1.2 m)	N/A	Modified G4(1S) guardrail with Mondo Polymer blockouts (*NCHRP 350* 3-11)
NPG-4 MwRS, 2002 *(31)* [2]	31 inches (787 mm)	6 ft long W6×9 steel	6 ft-3 inch	6×12× 14 inch routed wood	25.7 inches (652 mm)	43.1 inches (1094 mm)	4.13 ft (1.26 m)	B133	Modified MGS (G4(1S) guardrail) (*NCHRP 350* 3-11)
NPG-5 MwRSF, 2002 *(31)* [2]	31 inches (787 mm)	6 ft long W6×9 steel	6 ft-3 inch	6×12× 14 inch routed wood	24.1 inches (611 mm)	40.3 inches (1024 mm)	4.77 ft (1.45 m)	B133	Same system of NPG-4 with 6 inch tall concrete curb (*NCHRP 350* 3-11)
NPG-6 MwRSF, 2002 *(31)* [2]	31 inches (787 mm)	6 ft long W6×9 steel	18¾ inch (Post 11-51)	6×12× 14 inch routed wood	12 inches (305 mm)	17.6 inches (447 mm)	3.05 ft (0.93 m)	B133	Modified MGS with reduced post spacing (*NCHRP 350* 3-11)
PR-1 MwRSF, 2002 *(32)* [2]	27.8 inches (706 mm)	4 ft-5 inch long W6×9 steel	6 ft-3 inch	6×8× 14 inch wood	N/A	38.2 inches (970 mm)	3.31 ft (1.01 m)	B64B	G4(1S) guardrail with posts installed in rock (*NCHRP 350* 3-11)
N/A_1 SwRI, 2002 *(33)* [1]	27.8 inches (706 mm) [3]	6 ft long O-Post (Posts 12-18)	6 ft-3 inch	5.5×7.7× 14.25 inch routed timber	N/A	40.6 inches (1030 mm)	N/A	B95	O-Post as an alternative to a standard W6×8.5 steel post for use for W-beam guardrail (*NCHRP 350* 3-11)
N/A_2 SwRI, 2002 *(34)* [1]	27.8 inches (706 mm) [3]	6 ft long O-Post (Posts 12-18)	6 ft-3 inch	5.5×7.7× 14.25 inch routed timber	N/A	43.7 inches (1110 mm)	N/A	B95A	O-Post impacting at the open side (*NCHRP 350* 3-11)

[1] The report used SI units only.
[2.] The report used both SI and USC units.
[3.] In these reports, the height of the guardrail to the center of the W-beam rail element is depicted to be 550 mm. The researchers calculated the total height of rail based on AASHTO RWM02a rail properties *(17)*. Thus, 550 mm (center of W-beam height) + 156 mm (half height of W-beam section) = 706 mm.
N/A = Not Available

Table 3.4 12 gauge W-Beam Guardrail (Continued).

Test No. Agency, Year	Rail Height	Post		Blockout	Maximum Deflection		Working Width	FHWA Letter No.	System Configuration
		Size and Material	Spacing		Permanent	Dynamic			
41-1792-001 E-TECH Inc., 2003 *(35)* [1]	27.8 inches (706 mm)[2]	5 ft-3 inch long HALCO X-44 Steel	6 ft-3 inch	6⅛×7⅞× 14¼ inch recycled plastic	23.6 inches (600 mm)	27.6 inches (700 mm)	N/A	B80C	G4 guardrail with light weight, strong HALCO X-44 steel posts (*NCHRP 350* 3-11)
2214MG -1 MwRSF, 2004 *(36)* [3]	31 inches (787 mm)	6 ft long W6×9 steel	6 ft-3 inch	6×12× 14¼ inch wood	42.9 inches (1089 mm)	57 inches (1447 mm)	4.78 ft (1.46 m)	N/A	Modified MGS guardrail (*MASH* 3-11)
2214MG -2 MwRSF, 2004 *(37)* [3]	31 inches (787 mm)	6 ft long W6×9 steel	6 ft-3 inch	6×12× 14¼ inch wood	31.6 inches (803 mm)	43.9 inches (1114 mm)	4.05 ft (1.23 m)	N/A	Modified MGS guardrail (*MASH* 3-11)
2214WB-2 MwRSF, 2005 *(38)* [1]	27.8 inches (706 mm)	6 ft long W6×9 steel	6 ft-3 inch	6×8× 14¼ inch wood	33.3 inches (845 mm)	47.1 inches (1196 mm)	4.58 ft (1.4 m)	N/A	Modified MGS guardrail (*MASH* 3-11)
220570-2 TTI, 2005 *(39)* [4]	31 inches (787 mm)	6-ft long W6×8.5 SYLP	6 ft-3 inch	N/A	28.7 inches (730 mm)	40.9 inches (1040 mm)	3.67 ft (1.12 m)	B140	W-beam guardrail on SYLP (G2 guardrail) (*MASH* 3-11)
220570-8 TTI, 2006 *(40)* [3]	29 inches (737 mm)	6-ft long W6×8.5 SYLP	6 ft-3 inch	N/A	28.7 inches (730 mm)	37.4 inches (950 mm)	4.04 ft (1.23 m)	N/A	29 inch tall T-31 W-beam guardrail on SYLP (G2 guardrail) (*NCHRP 350* 3-11)
GMS-1 SwRI, 2006 *(41)* [4]	31 inches (787 mm)	6-ft long W6×8.5 steel	6 ft-3 inch	N/A	22 inches (560 mm)	35 inches (890 mm)	N/A	B150	Modified G4(1S) Longitudinal Barrier using GMS fastener (*MASH* 3-11)

[1] The report used SI units only.

[2.] In these reports, the height of the guardrail to the center of the W-beam rail element is depicted to be 550 mm. The researchers calculated the total height of rail based on AASHTO RWM02a rail properties *(17)*. Thus, 550 mm (center of W-beam height) + 156 mm (half height of W-beam section) = 706 mm.

[3.] The report used both SI and USC units.

[4] The report used USC units only.

SYLP = Steel Yielding Line Posts

GMS = Gregory Mini Spacer

MGS = Midwest Guardrail System

N/A = Not Available

Table 3.5 12 gauge W-Beam Guardrail (Continued).

Test No. Agency, Year	Rail Height	Post		Blockout	Maximum Deflection		Working Width	FHWA Letter No.	System Configuration
		Size and Material	Spacing		Permanent	Dynamic			
MGSDF-1 MwRSF,2006 *(42)* [1]	31 inches (787 mm)	5 ft-9 inch long 7¼ inch dia Douglas fir wood posts	6 ft-3 inch	6×8× 14¼ inch & 6×5× 14¼ inch wood	35.5 inches (902 mm)	60.2 inches (1529 mm)	5.02 ft (1.53 m)	B175	MGS with Douglas fir wood post (*NCHRP 350* 3-11)
MGSPP-1 MwRSF,2006 *(42)* [1]	31 inches (787 mm)	5 ft-9 inch long 8 inch dia Ponderosa pine posts	6 ft-3 inch	6×8× 14¼ inch and 6×5× 14¼ inch wood	27.8 inches (705 mm)	37.6 inches (956 mm)	4.05 ft (1.23 m)	B175	MGS with Round Ponderosa pine posts (*NCHRP 350* 3-11)
400001-TGS1 TTI, 2007 *(43)* [2]	31 inches (787 mm)	6-ft long W6×8.5 steel	6 ft-3 inch	N/A	31 inches (787 mm)	38.4 inches (975 mm)	3.4 ft (1.04 m)	N/A	Trinity Guardrail System (TGS) (*MASH* 3-11)
GMS-6 SwRI, 2007 *(44)* [2]	27⅝ inches (702 mm)	6-ft long W6×8.5 steel	6 ft-3 inch	N/A	31.9 inches (810 mm)	52 inches (1320 mm)	N/A	B150A	Modified GMS guardrail (*MASH* 3-11)
GMS-7 SwRI, 2007 *(45)* [2]	27⅝ inches (702 mm)	6-ft long W6×8.5 steel	12 ft-6 inch	N/A	20.9 inches (530 mm)	59.8 inches (1520 mm)	N/A	B150B	Modified GMS guardrail with longer spacing (*MASH* 3-11)
057073112 Holmes Solutions, 2007 *(46)* [1]	31 inches (787 mm)	6 ft-6 inch long U-channel steel (Nucor Grade SP-80, galvanized)	6 ft-3 inch	N/A	31.5 inches (800 mm)	41.3 inches (1050 mm)	N/A	B162	Nucor strong post W-beam guardrail system without blockout (*MASH* 3-11)

[1] The report used both SI and USC units.
GMS = Gregory Mini Spacer

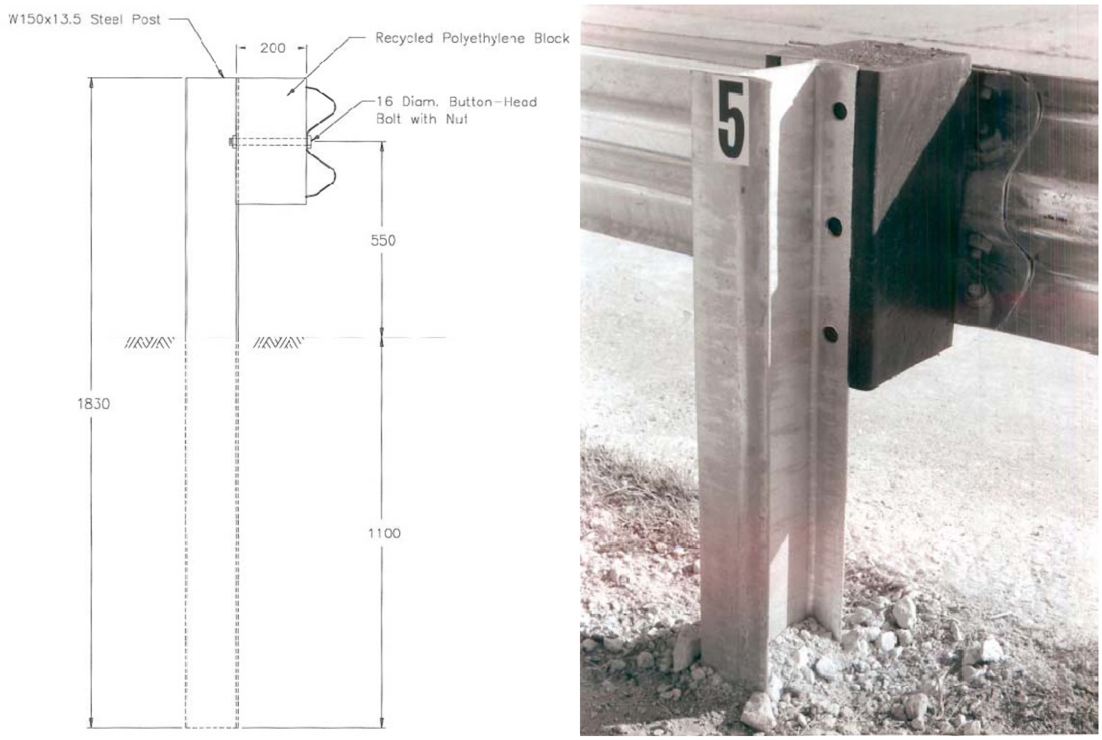
[2] The report used USC units only.
N/A = Not Available

Table 3.6 12 gauge W-Beam Guardrail (Continued).

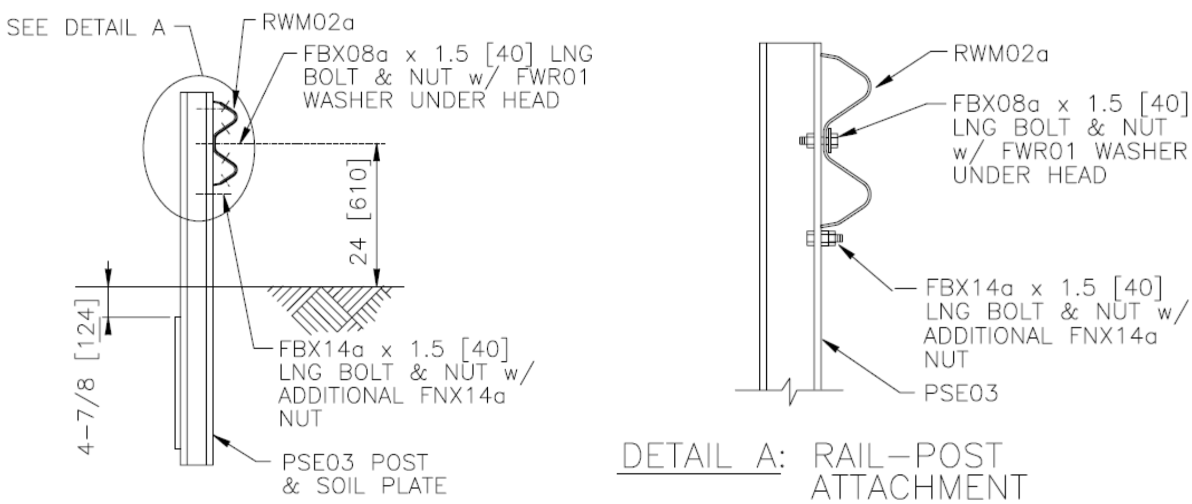
Test No. Agency, Year	Rail Height	Post		Blockout	Maximum Deflection		Working Width	FHWA Letter No.	System Configuration
		Size and Material	Spacing		Permanent	Dynamic			
05707b3111 Holmes Solutions, 2007 *(46)* [1]	27 inches (686 mm)	6 ft-6 inch long U-channel steel (Nucor Grade SP-80)	6 ft-3 inch	4×8×14 in Recycled plastic	35.4 inches (900 mm)	45.3 inches (1150 mm)	N/A	B162	Nucor Strong Post W-beam guardrail system (*NCHRP 350* 3-11)
0000-0-0-00-1 Holmes Solutions, 2008 *(47)* [2]	27 inches (686 mm)	6 ft-6 inch long W6×9 steel and 6 ft long U-channel steel [3]	6 ft-3 inch	Original plastic	38.6 inches (980 mm)	56.7 inches (1440 mm)	5.41 ft (1.65 m)	B186	NU-Guard posts mixed in strong post guardrail using Mazda Proceed vehicle (*NCHRP 350* 3-11)

1. The report used both SI and USC units.
2. The report used USC units only.
3. U-channel Nucor steel posts were installed for the three posts in the center.

GMS = Gregory Mini Spacer
N/A = Not Available



(a) Strong post with Steel Post Guardrail (G4(1S)) (TTI 400001-MPT1) ***(21)*****.**



(b) Weak Post, W-Beam Guardrail (G2) ***(16)*****.**

Figure 3.1 Typical 12 gauge W-Beam Guardrail System.

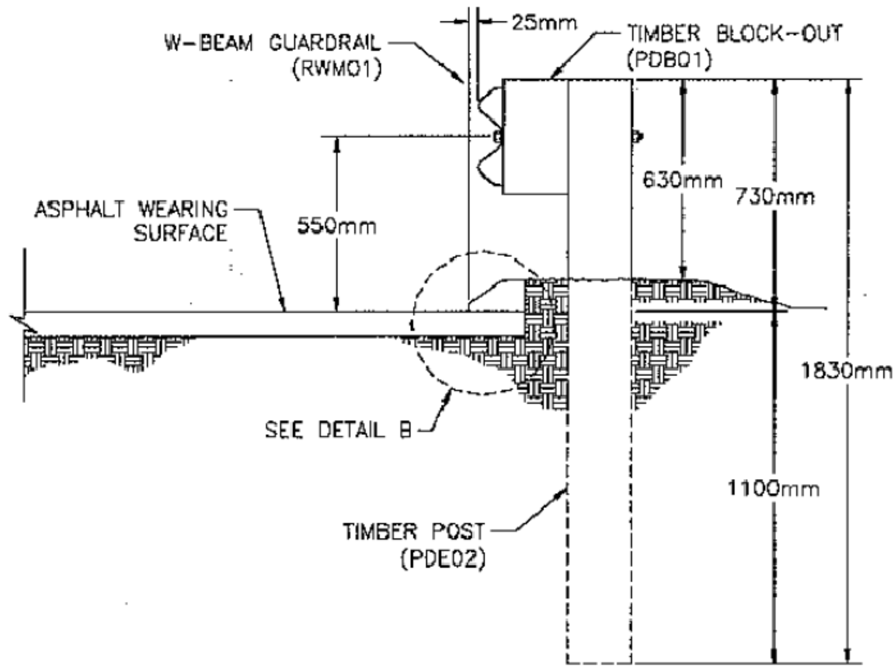


Figure 3.2 12 gauge W-Beam Guardrail with Curb (TTI 404201-1, 2000) *(24)*.

The rail height ranges from 686 mm (27 inches) to 820 mm (32.3 inches). Figure 3.3 shows the percentage of the rail height of 12 gauge W-beam guardrail used in full-scale crash tests. As shown in Figure 3.3, about 43 percent of W-beam guardrails have a rail height of 706 mm (27.8 inches). The posts vary in size and material (e.g. steel and wood posts). The most used post spacing is the standard post spacing which is 1905 mm (6 ft-3 inches). The researchers identified four systems that have post spacing from 476 mm (18¾ inches) to 3810 mm (12 ft-6 inches). The most standard post blockout used in 16 crash tests measures 152×203×356 mm (6×8×14 inches). The blockouts vary from 102×203×356 mm (4×8×14 inches) to 156×210×362 mm (6⅛×8¼×14¼ inches). Twenty six crash tests were conducted in accordance with *NCHRP Report 350* test 3-11 and the remaining nine crash tests were performed under *MASH* test 3-11 test conditions.

The maximum permanent deflection ranges from 89 mm (3.5 inches) to 1640 mm (64.6 inches). The maximum dynamic deflection of W-beam guardrail is in range of 416 mm (16.4 inches) to 2343 mm (92.2 inches). The range of maximum deflection is shown in Figure 3.4. Figure 3.5 and Figure 3.6 shows the range of maximum deflection with the rail height of 706 mm (27.8 inches) and 787 mm (31 inches), respectively. The working width was reported in 22 crash tests and ranged from 0.88 m (2.87 ft) to 2.37 m (7.78 ft).

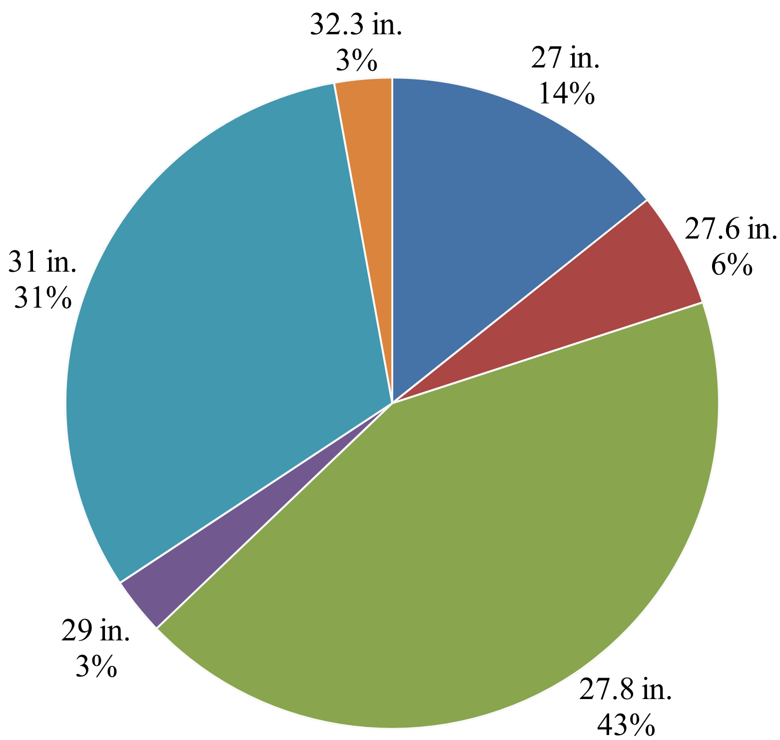


Figure 3.3 Percentage of Rail Height for 12 gauge W-Beam Guardrail Systems.

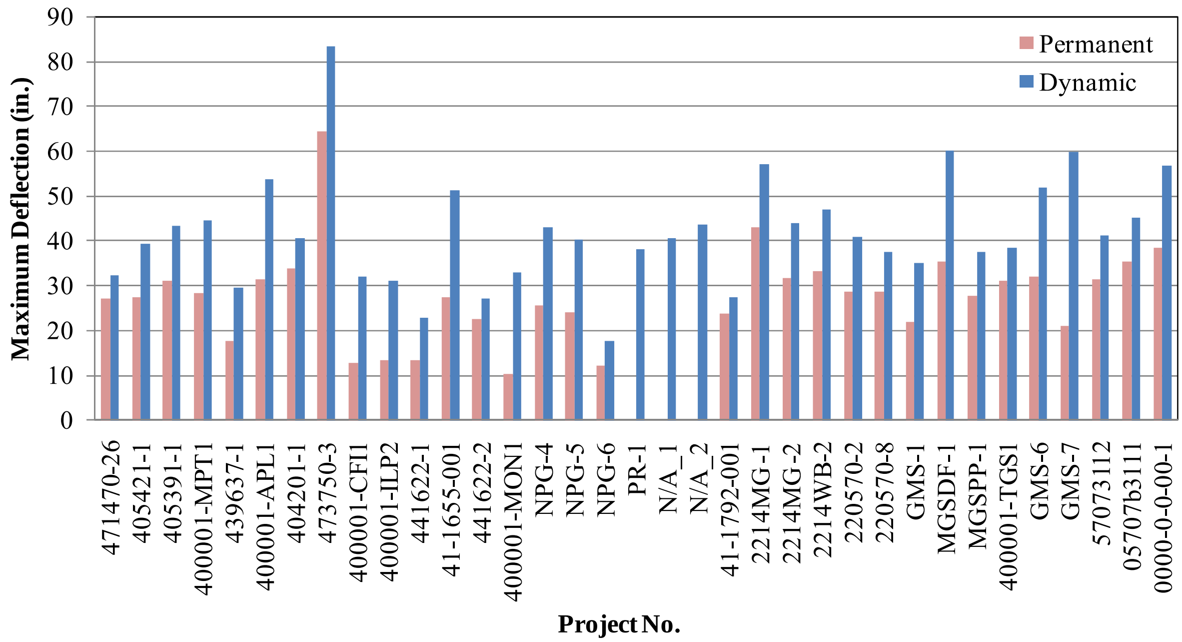


Figure 3.4 Range of Maximum Deflection of 12 gauge W-Beam Guardrail Systems.

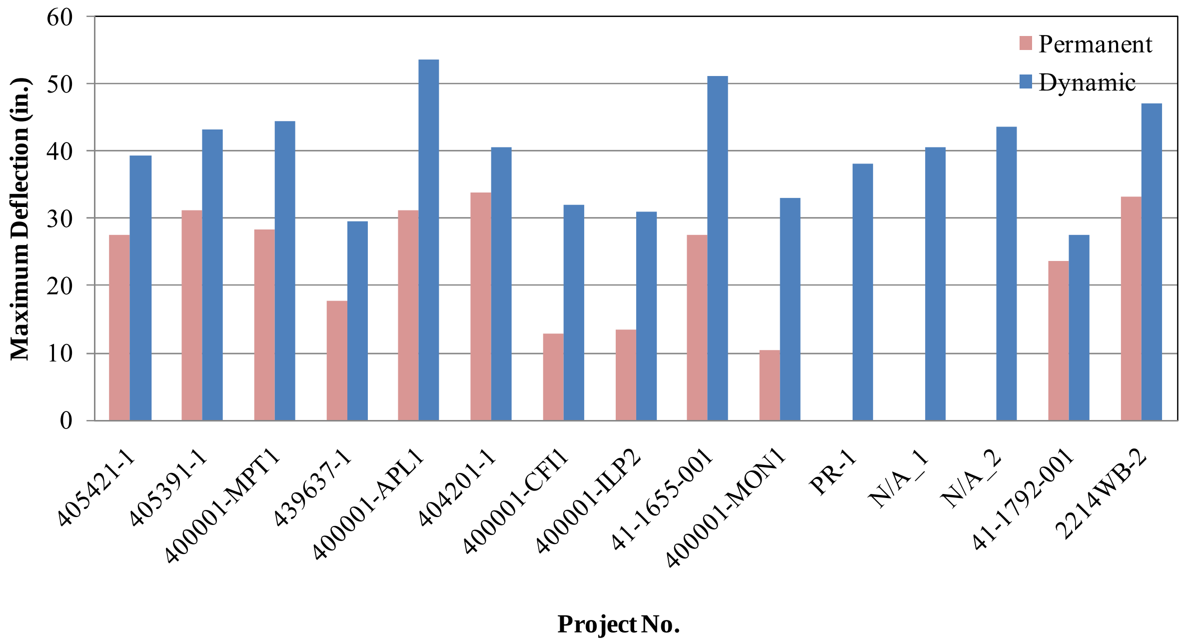


Figure 3.5 Range of Maximum Deflection of 27.8-inch Tall W-beam Systems.

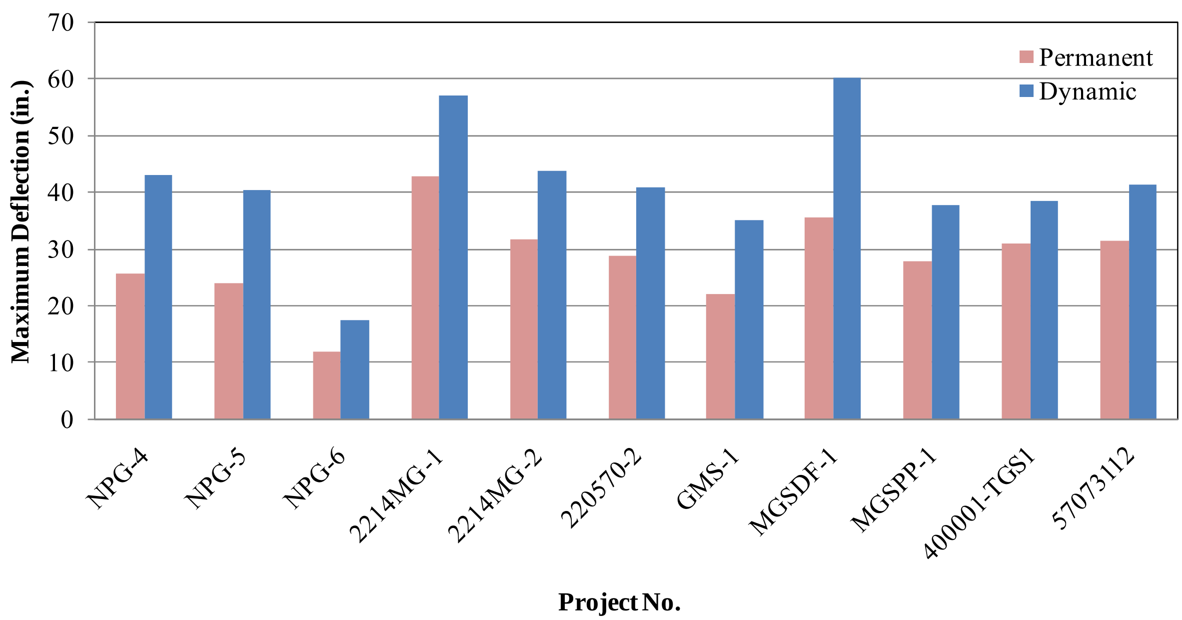
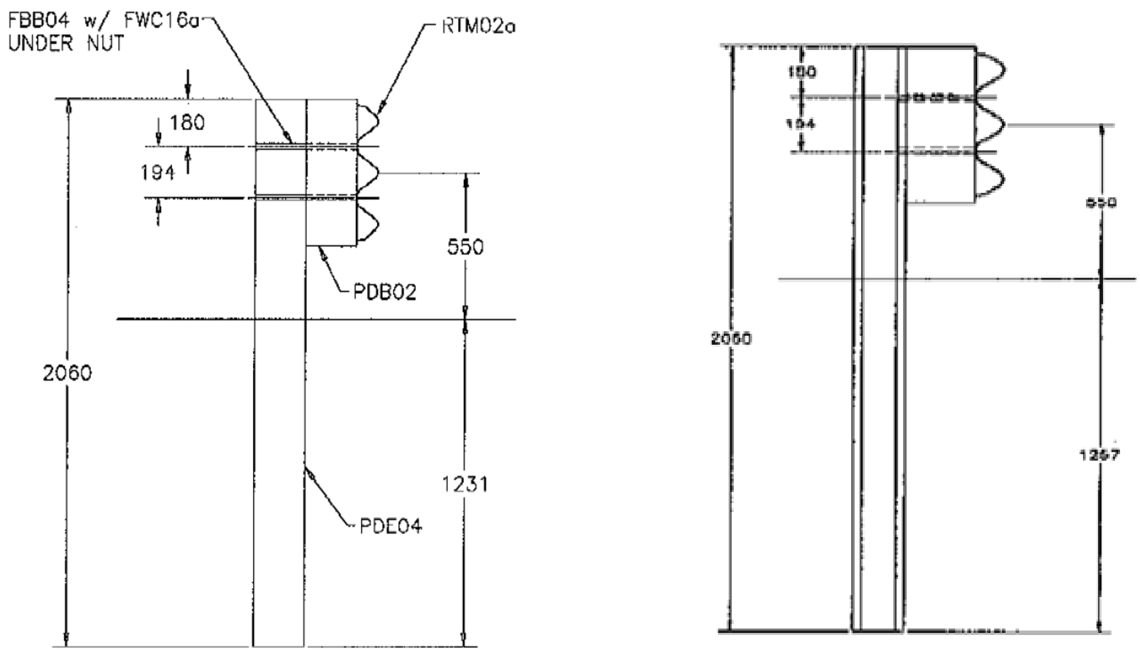


Figure 3.6 Range of Maximum Deflection of 31-inch Tall W-beam Systems.

3.2 Thrie-beam Guardrail

Six thrie-beam guardrail system tests are summarized in Table 3.7. Four crash tests were conducted in accordance with *NCHRP Report 350* test 3-11 and the remaining two tests were conducted using *MASH* test 3-11 test conditions.

As mentioned in the previous section, some tests reports give only the height from the middle of the thrie-beam to the ground level to be 550 mm (1.8 ft) as shown in Figure 3.7. The height of thrie-beam section is 508 mm (20 inches) per AASHTO RTM02a sheet *(48)*. The top rail height of the thrie-beam system is calculated to be 804 mm (31.65 inches) (550 mm + 254 mm = 804 mm).



(a) TTI 404211-11 *(49)* (b) TTI 404211-10 *(50)*

Figure 3.7 Typical Thrie-beam Guardrail Cross Section.

The rail height ranges from 804 mm (31.7 inches) to 991 mm (39 inches). Figure 3.8 shows the percentage of the rail height of thrie-beam guardrail installations for the reviewed crash tests. The posts vary in size and material (steel or wood). The most common post spacing is 1905 mm (6 ft-3 inches) except for one system which uses a 2000 mm (6 ft-7 inches) post spacing. The blockouts vary from 100×140×550 mm (3.9×5.5×21.7 inches) to 152×152×554 mm (6×6×21.8 inches).

The maximum permanent deflection ranges from 400 mm (15.7 inches) to 860 mm (33.9 inches). The maximum dynamic deflection of thrie-beam guardrail is in range of 500 mm (19.7 inches) to 1300 mm (51.2 inches). The range of maximum deflection is shown in Figure 3.9. The working width was reported in only one test, which was 0.63 m (2.1 ft).

Table 3.7 Thrie-beam Guardrail.

Test No. Agency, Year	Rail Height	Post		Blockout	Maximum Deflection		Working Width	FHWA Letter No.	System Configuration
		Size and Material	Spacing		Permanent	Dynamic			
471470-30 TTI, 1995 *(18)* [1]	34 inches (864 mm)	6 ft-9¼ inch long W6×9 steel	6 ft-3 inch	M14×18 spacer with cutout	24 inches (610 mm)	40.2 inches (1020 mm)	N/A	N/A	Modified thrie beam guardrail (*NCHRP 350* 3-11)
404211-11 TTI, 1998 *(49)* [2]	31.7 inches[3] (804 mm)	6-ft-9 in long 6×7⅞ inch wood[4]	6 ft-3 inch	6×7⅞ ×21¾ inch routed wood[5]	15.4 inches (390 mm)	26.6 inches (676 mm)	N/A	N/A	Strong wood post thrie beam guardrail (*NCHRP 35*0 3-11)
404211-10 TTI, 1999 *(50)* [2]	31.7 inches[2] (804 mm)	6 ft-9 inch long W6×8.5 steel	6 ft-3 inch	6×7⅞ ×21¾ inch routed wood[4]	16.5 inches (420 mm)	22.8 inches (580 mm)	N/A	N/A	Thrie beam guardrail (*NCHRP 35*0 3-11)
54-1108-001 E-TECH Inc., 2004 *(51)* [2]	31.5 inches (801 mm)	5 ft-11 inch long 3.9×5.5 inch C-Post	6 ft-7 inch	4×5½× 21¾ in C section steel	15.7 inches (400 mm)	19.7 inches (500 mm)	N/A	N/A	Wang Dong Hop Yi Iron Manufacturing Company Thrie-Beam Guardrail (*NCHRP 350* 3-11)
220570-7 TTI, 2006 *(52)* [2]	39 inches (991 mm)	6-ft long W6×8.5 SYLP steel	6 ft-3 inch	N/A	23.4 inches (595 mm)	24.7 inces (627 mm)	2.1 ft (0.63 m)	N/A	T-39 thrie beam guardrail on SYLP (*MASH* 3-11)
GMS-3 SwRI, 2006 *(53)* [6]	39 inches (991 mm)	6-ft long W6×8.5 steel	6 ft-3 inch	N/A	33.9 inches (860 mm)	51.2 inches (1300 mm)	N/A	B156	Modified G4(1S) Longitudinal Barrier using GMS fastener (*MASH* 3-11)

1. The report used both SI and USC units.
2. The report used SI units only.
3. In these reports, the height of the guardrail to the center of the Thrie-beam rail element is depicted to be 550 mm. The researchers calculated the total height of rail based on AASHTO RTM02a rail properties *(48)*. Thus, 550 mm (center of Thrie-beam height) + 254 mm (half height of Thrie-beam section) = 804 mm.
4. AASHTO PDE04 post specification is used.
5. AASHTO PDB02 blockouts specification is used.
6. The report used USC units only.

N/A = Not Available

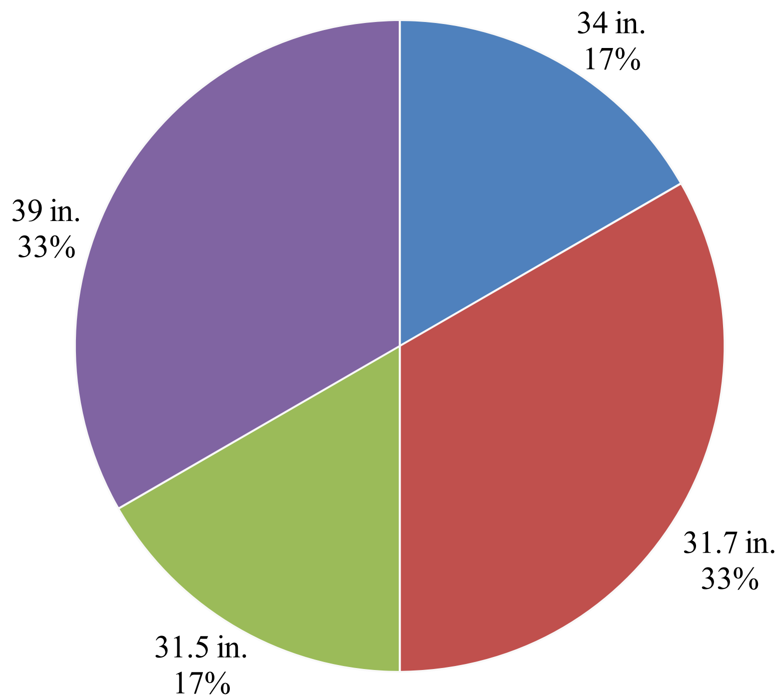


Figure 3.8 Percentage of Rail Height for Thrie-beam Guardrail Systems.

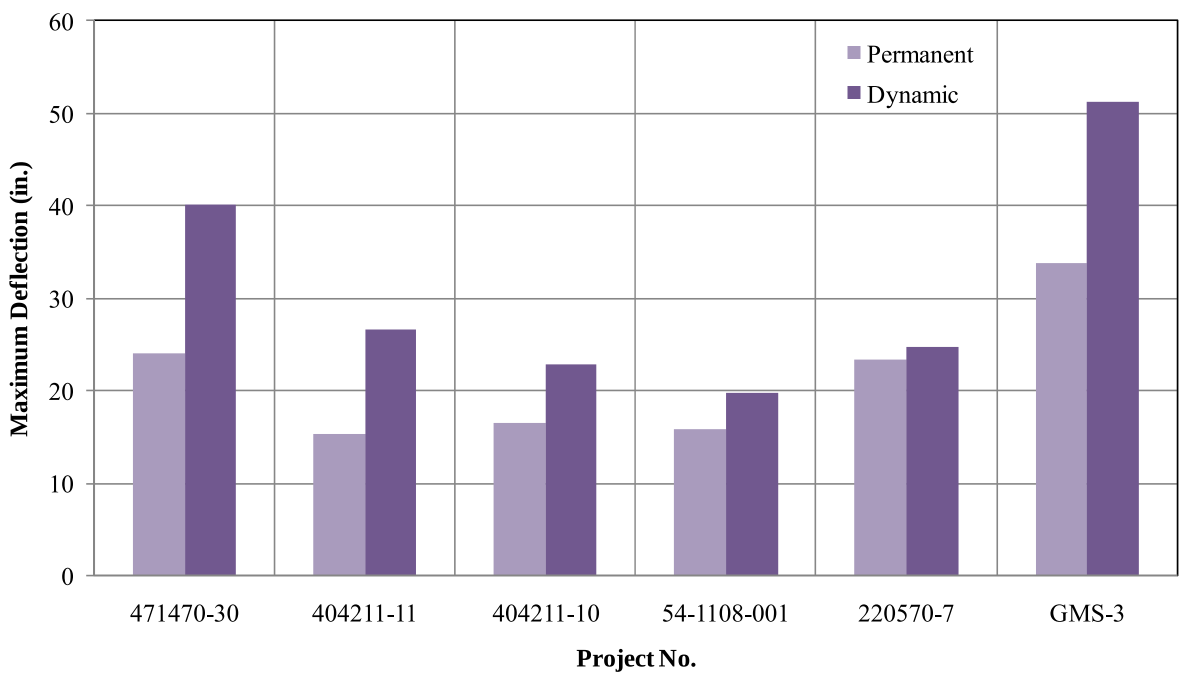
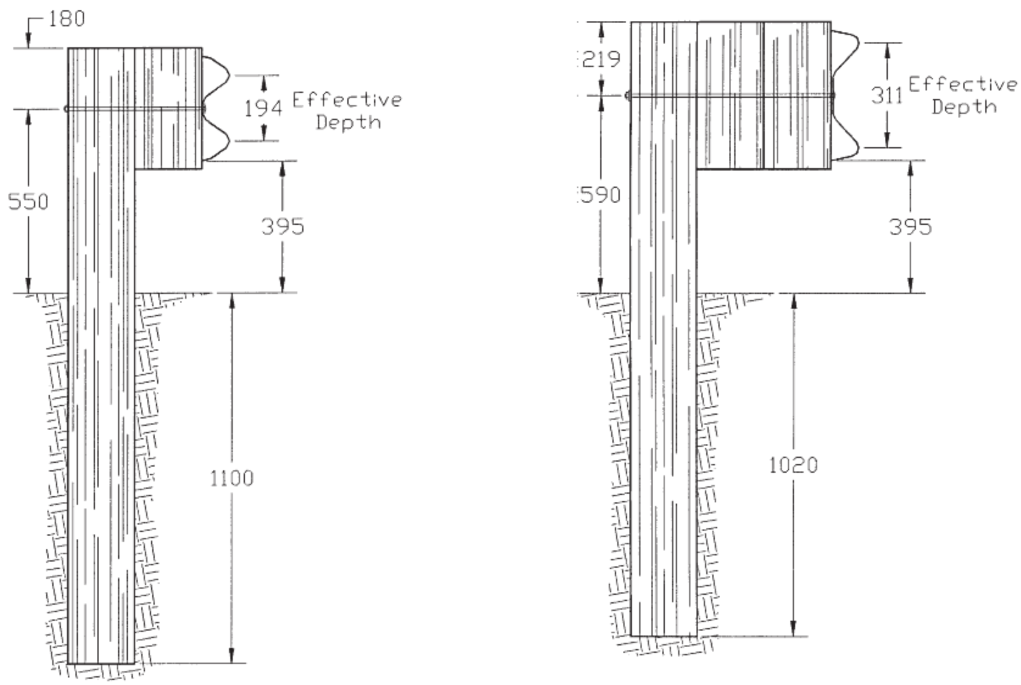


Figure 3.9 Range of Maximum Deflection of Thrie-beam Guardrail Systems.

3.3 13 Gauge Buffalo Guardrail

The performance of the buffalo guardrail system (13 gauge rail element) *(54)* is summarized in Table 3.8. While the thickness of the metal is 2.66 mm (0.1 inch) for 12 gauge W-beam guardrail, it is reduced to 2.28 mm (0.09 inch) for the 13 gauge Buffalo guardrail system. The system is similar in construction to the current W-beam system, and consists of a guardrail attached to wood posts that are imbedded in soil. However, major design changes were made to the rail shape, the material thickness, the rail splice, and the post spacing. The cross section of 13 gauge buffalo guardrail is shown in Figure 3.10. This test was performed under *NCHRP Report 350* test 3-11 test designation.



(a) W-beam rail **(b) Buffalo rail**

Figure 3.10 Cross Section View of W-Beam and Buffalo Rail.

The rail height is 784 mm (30.8 inches). A 1.83 m (6 ft) long 152×203 mm (6×8 inches) wood post was used with spacing of 2499 mm (8.2 ft). Two 152×203×432 mm (6×8×17 inches) routed blockouts were used per each post.

The maximum permanent and dynamic deflection was 567 mm (22.3 inches) and 851 mm (33.5 inches), respectively. The working width is not reported for this test.

Table 3.8 13 gauge W-Beam Guardrail.

Test No. Agency, Year	Rail Height	Post		Blockout	Maximum Deflection		Working Width	FHWA Letter No.	System Configuration
		Size and Material	Spacing		Permanent	Dynamic			
Buffalo Rail MwRSF, 1995 *(54)* [1]	30.8 inches (782 mm)	6-ft long 6×8 inch wood	8.2 ft	Two 6×8×17¼ inch routed wood	22.3 inches (567 mm)	33.5 inches (851 mm)	N/A	N/A	13 gauge Buffalo rail guardrail (*NCHRP 350* 3-11)

[1] The report used SI units only.
N/A = Not Available

3.4 Nested W-Beam Guardrail

Two nested W-beam guardrail systems tests are presented in Table 3.9. The nested W-beam was considered a way to provide increased rail capacity and/or for decreased rail deflection for some special applications. Details of tested nested W-beam guardrail systems are shown in Figure 3.11. These tests were performed under *NCHRP Report 350* test 3-11 test designation.

The rail heights are 706 mm (27.8 inches). In OLS-3 test, three 1.83 m (6 ft) long 150 × 200 mm (5 7/8 × 7 7/8 inches) CRT wood posts were used at each end of the 7620 mm (25 ft) long span. Two 150×200×360 mm (5⅞×7⅞×14¼ inch) wood blockouts were used for each CRT post. The maximum permanent and dynamic deflection was 1016 mm (40 inches) and 1450 mm (57.1 inches), respectively.

In NEC-2 test, 1.83 m (6 ft) long W152 × 13.4 mm (W6×9 inches) steel post was used with standard span 1905 mm (6 ft 3 inches). The 152×203×360 mm (6×8×14¼ inches) wood blockouts were used. The maximum permanent and dynamic deflection was 721 mm (28.4 inches) and 1072 mm (42.2 inches), respectively. The working width is not reported for this test.

Table 3.9 Nested W-Beam Guardrail.

Test No. Agency, Year	Rail Height	Post		Blockout	Maximum Deflection		Working Width	FHWA Letter No.	System Configuration
		Size and Material	Spacing		Permanent	Dynamic			
OLS-3 MwRSF, 1999 *(55)* [1]	27.8 inches (706 mm)	6 ft long 5⅞×7⅞ inch CRT wood post	25 ft (center) 6 ft-3 inch (otherelse)	Two 5⅞×7⅞ ×14⅛ inch Wood (Post 9-14)	40 inches (1,016 mm)	57.1 inches (1,450 mm)	N/A	B58	Nested W-beam Long-Span guardrail system (*NCHRP 350* 3-11)
NEC-2 MwRSF, 2000 *(56)* [1]	27.8 inches (706 mm)	6 ft long W6×9 steel	6 ft-3 inch	6×8× 14⅛ inch routed wood	28.4 inches (721 mm)	42.2 inches (1072 mm)	N/A	N/A	Nested W-beam guardrail with curb (*NCHRP 350* 3-11)

1. The report used SI units only.
N/A = Not Available

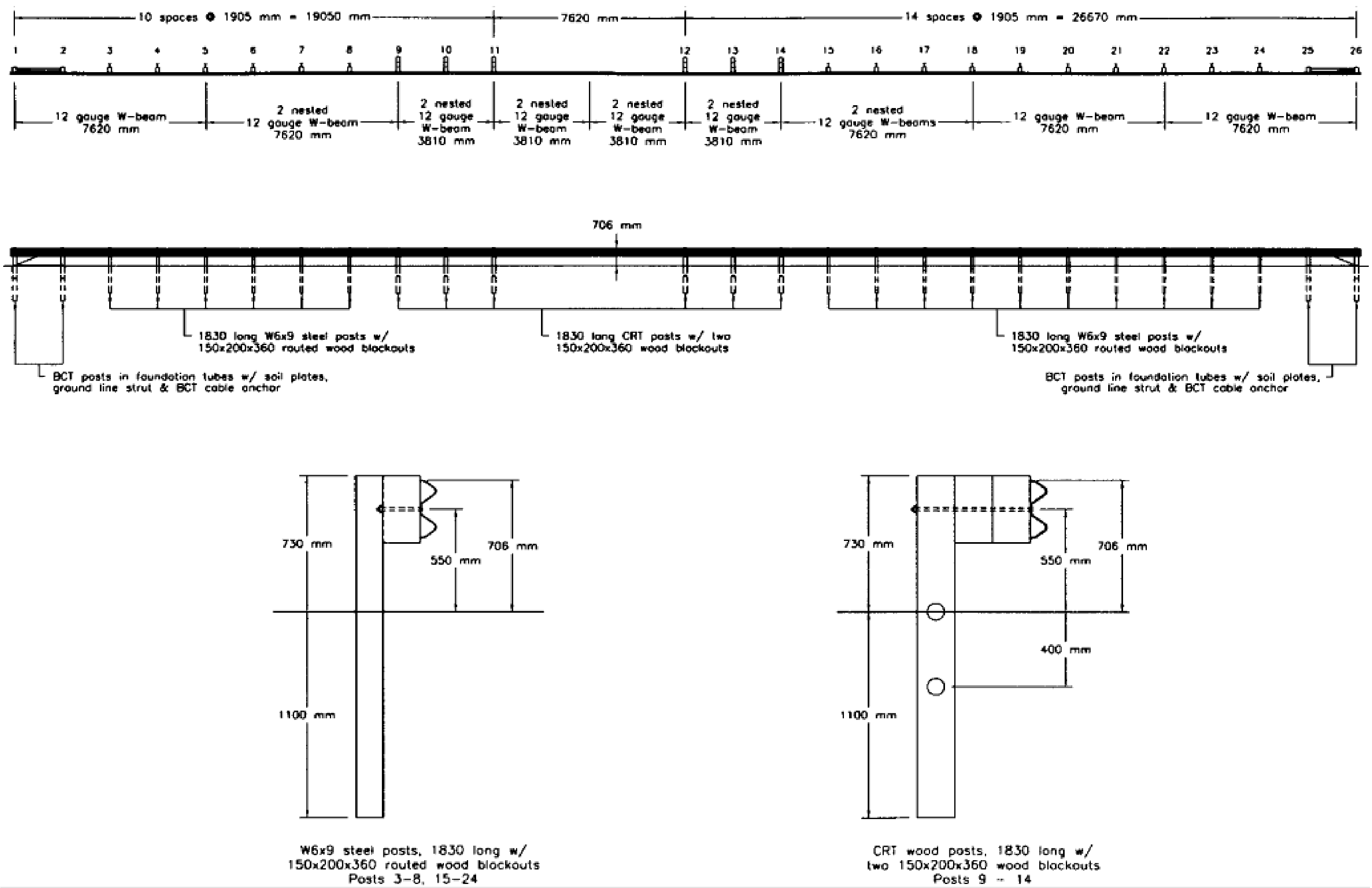


Figure 3.11 Nested W-Beam Guardrail (MwRSF, OLS-3) ***(55)*****.**

3.5 W-Beam Guardrail for Special Placement Need

Three special applications for W-beam guardrail systems were tested; (a) W-beam guardrail for placement on a slope, (b) W-beam guardrail on the simulated low-fill culvert, and (c) MGS with various flare rates. A total of nine special application guardrail systems were reviewed herein.

3.5.1 W-beam Guardrail for Placement on a Slope

Three W-beam guardrail systems placed on a slope are presented in Table 3.10. An example of a W-beam guardrail system for placement on a slope is shown in Figure 3.12. These tests were performed under *NCHRP Report 350* test 3-11 and *MASH* 3-11 test designation.

The rail height ranges from 706 mm (27.8 inches) to 787 mm (31 inches). The W152×13.4 (W6×9) steel post were used with 1905 mm (6 ft 3 inches). 150×200×360 mm (5-⅞×7⅞×14.2 inches) and 152×203×360 mm (6×8×14¼ inches) wood blockouts were used. The maximum permanent deflection ranged from 587 mm (23.1 inches) to 1067 mm (42 inches). The maximum dynamic deflection ranged from 821 mm (32.3 inches) to 1464 mm (57.6 inches).

Table 3.10 W-Beam Guardrail for Placement on a Slope.

Test No. Agency, Year	Rail Height	Post		Blockout	Maximum Deflection		Working Width	FHWA Letter No.	System Configuration
		Size and Material	Spacing		Permanent	Dynamic			
MOSW-1 MwRSF, 2000 *(57)* [1]	27.8 inches (706 mm)	7 ft long W6×9 steel (Post 12-30)	3 ft-1.5 inch (Post 12-30)	5⅞×7⅞ ×14⅛ inch wood	23.1 inches (587 mm)	32.3 inches (821 mm)	N/A	B64C	W-beam guardrail system for use on a 2:1 foreslope (*NCHRP 350* 3-11)
MGS221-2 MwRSF,2006 *(58)* [1]	31 inches (787 mm)	9 ft long W6×9 steel (Post9-20)	6 ft-3 inch	6×12× 14¼ inch wood	42 inches (1067 mm)	56.5 inches (1436 mm)	5.35 ft (1.63m)	N/A	Midwest Guardrail System adjacent to a 2:1 foreslope (*MASH* 3-11)
MGSAS-1 MwRSF, 2006 *(59)* [2]	31 inches (787 mm)	6 ft long W6×9 steel	6 ft-3 inch	6×12× 14¼ inch wood	34.3 inches (870 mm)	57.6 inches (1464 mm)	6.9 ft (2.1 m)	N/A	W-beam guardrail system for use on a 8:1 approach slope (*NCHRP 350* 3-11)

[1.] The report used SI units only.
[2] The report used both SI and USC units.
N/A = Not Available

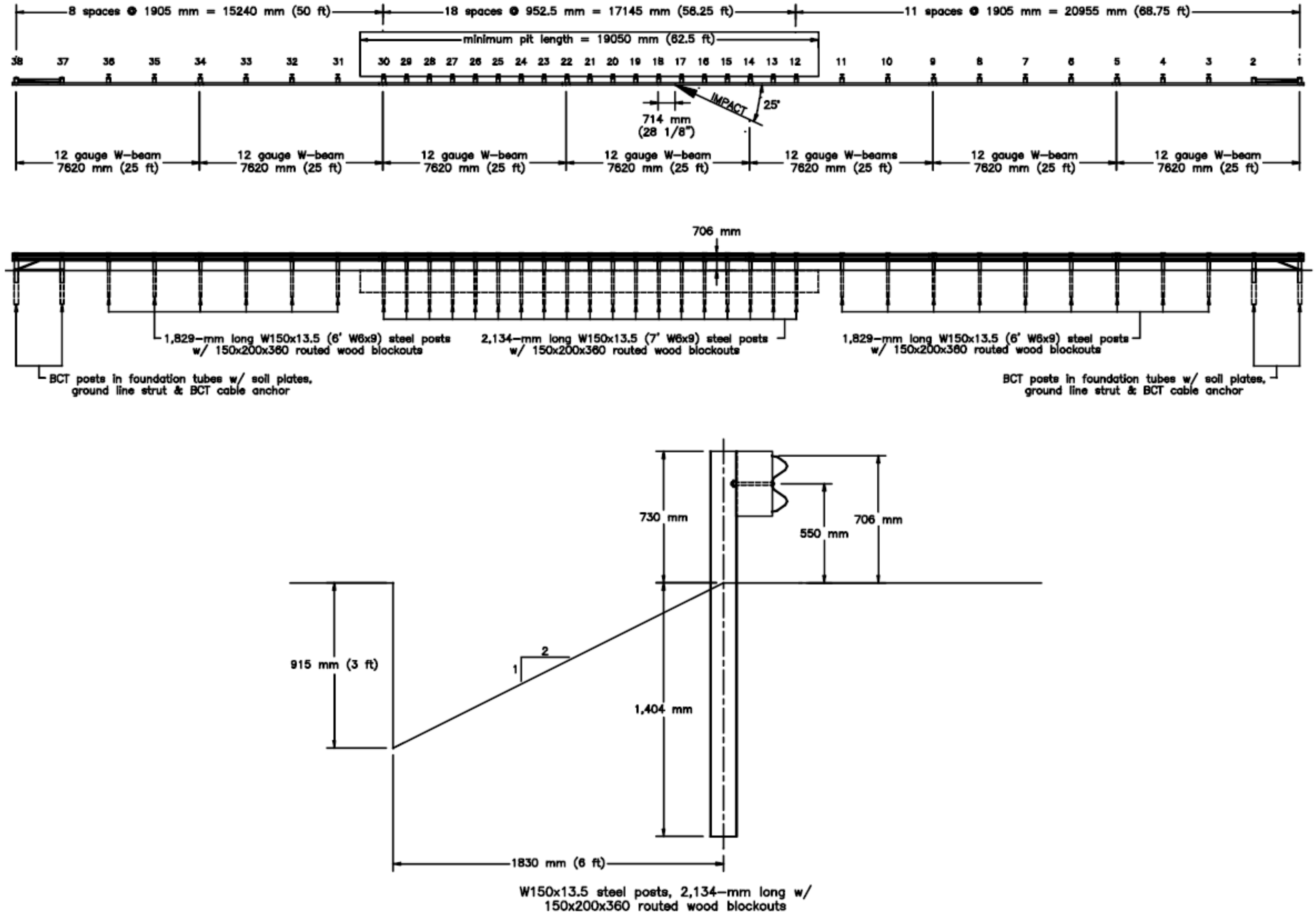


Figure 3.12 W-Beam Guardrail for Placement on a Slope (MwRSF, MOSW-1) ***(57)*.**

3.5.2 W-beam Guardrail on the Simulated Culvert Application

Three W-beam guardrail systems placed on the simulated culvert are presented in Table 3.11. A typical detail of W-beam guardrail system on the simulated culvert application is shown in Figure 3.7. These tests were performed under *NCHRP Report 350* 3-11 and *MASH* 3-11 test designations.

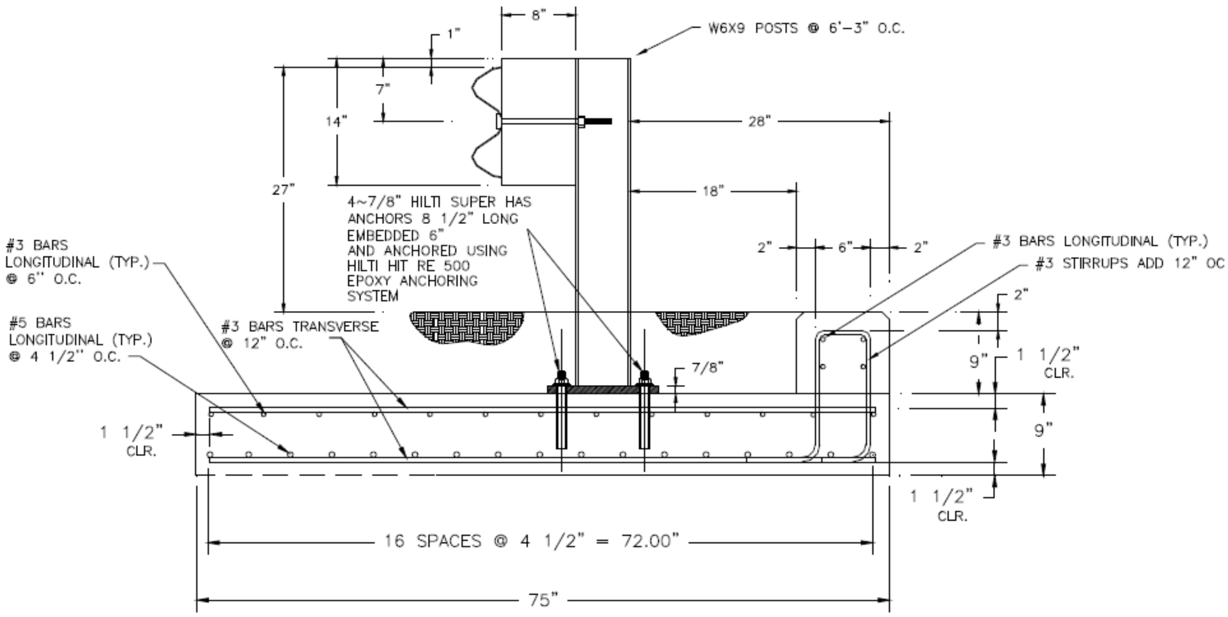


Figure 3.13 W-beam guardrail on the simulated culvert application (MwRSF, KC-1)

The rail height ranged from 686 mm (27 inches) to 787 mm (31 inches). The W152×13.4 (W6×9) steel posts and 152×203 mm (6×8) CRT wood posts were used with various length of post from 940 mm (3 ft 1 inches) to 1829 mm (6 ft). Tests LSC-1 and LSC-2 used long span of 7620 mm (25 ft) from Post No. 13 to Post No. 14.

The maximum permanent deflection ranges from 401 mm (15.8 inches) to 1372 mm (54 inches). The maximum dynamic deflection in these applications is in range of 416 mm (16.4 inches) to 2343 mm (92.2 inches). The working width is in range of 0.9 m (2.95 ft) to 2.37 m (7.79 ft).

Table 3.11 W-Beam Guardrail for Simulated Culvert Applications.

Test No. Agency, Year	Rail Height	Post		Blockout	Maximum Deflection		Working Width	FHWA Letter No.	System Configuration
		Size and Material	Spacing		Permanent	Dynamic			
KC-1, MwRSF, 2001 *(60)*[1]	27.8 inches (706 mm)	3.1 ft long W6×9 steel (Post 15-27)	3 ft-1.5 inch (Post 15-27)	6×8× 14 inch routed wood	15.8 inches (401 mm)	16.4 inches (416 mm)	2.95 ft (0.9 m)	N/A	Strong W-beam guardrail attached to concrete culvert (*NCHRP 350* 3-11)
LSC-1 MwRSF,2006 *(61)*[2]	31 inches (787 mm)	6 ft long 6×8 in CRT wood (Post 11-16)	6 ft-3 inch (Post 1-13, 14-26) 25ft (Post 13-14 in culvert)	6×12× 14¼ inch wood	28.5 inches (724 mm)	92.2 inches (2343 mm)	7.79 ft (2.37 m)	B189	Midwest Guardrail System with culvert (*MASH* 3-11)
LSC-2 MwRSF,2006 *(61)*[2]	31 inches (787 mm)	6 ft long 6×8 in CRT wood (Post 11-16)	6 ft-3 inch (Post 1-13, 14-26) 25 ft (Post 13-14 in culvert)	6×12× 14¼ inch wood	54 inches (1372 mm)	77.5 inches (1968 mm)	7 ft (2.13 m)	B189	Midwest Guardrail System long-span with culvert (*MASH* 3-11)

1. The report used SI units only.
2. The report used both SI and USC units.

N/A = Not Available

3.5.3 Midwest Guardrail System with Various Flare Rates

Three MGS with flare rates in range from 13:1 to 5:1 are presented in Table 3.12. The detail of MGS with various flare rates is shown in Figure 3.8. These tests were performed under *NCHRP Report 350* test 3-11 test designation.

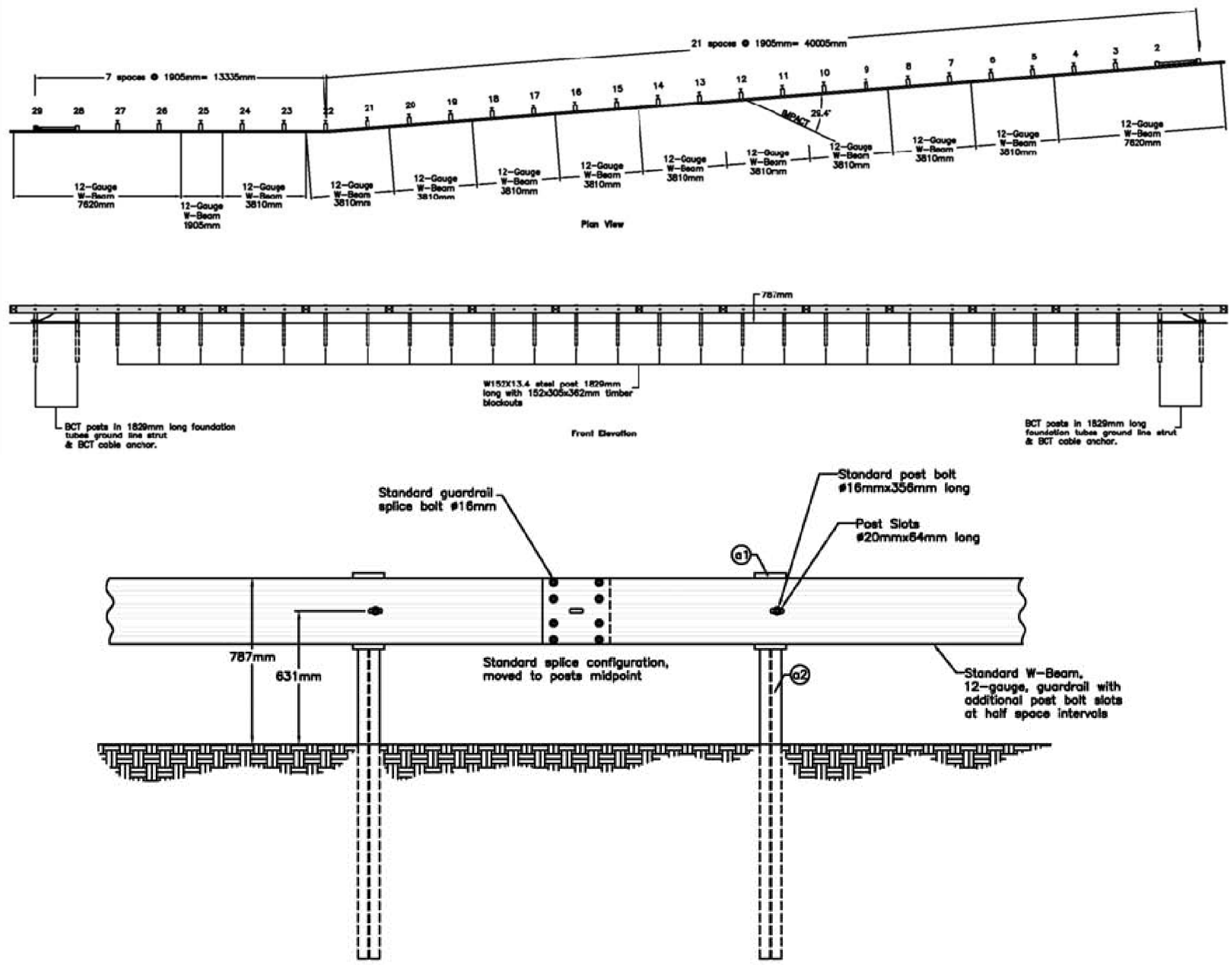


Figure 3.14 W-beam guardrail on flare rate (MwRSF, FR-1) ***(63)***

The rail height used in three tests is 787 mm (31 inches). A 1.83 m (6 ft) long W152×13.4 (W6×9) steel posts were used with the standard post spacing which is 1905 mm (6 ft-3 inches). The 152×305×362 mm (6×12×14¼ inches) wood blockouts were used in these tests.

The maximum permanent deflection ranges from 1140 mm (44.9 inches) to 1753 mm (69 inches). The maximum dynamic deflection in these applications is in range of 1684 mm (66.3 inches) to 1925 mm (75.8 inches). The working width is in range of 1.8 m (5.9 ft) to 2.48 m (8.12 ft).

Table 3.12 W-Beam Guardrail on flare rate.

Test No. Agency, Year	Rail Height	Post		Blockout	Maximum Deflection		Working Width	FHWA Letter No.	System Configuration
		Size and Material	Spacing		Permanent	Dynamic			
FR-1 MwRSF, 2005 *(63)* [1]	31 inches (787 mm)	6 ft long W6×9 steel	6 ft-3 inch	6×12× 14¼ inch wood	44.9 inches (1140 mm)	66.3 inches (1684 mm)	5.9 ft (1.8 m)	N/A	Midwest Guardrail System on 13:1 flare rate (*NCHRP 350* 3-11)
FR-2 MwRSF,2005 *(63)* [1]	31 inches (787 mm)	6 ft long W6×9 steel	6 ft-3 inch	6×12× 14¼ inch wood	45.5 inches (1156 mm)	75.8 inches (1925 mm)	7.32 ft (2.23m)	N/A	Midwest Guardrail System on 7:1 flare rate (*NCHRP 350* 3-11)
FR-4 MwRSF, 2006 *(63)* [1]	31 inches (787 mm)	6 ft long W6×9 steel	6 ft-3 inch	6×12× 14¼ inch wood	69 inches (1753 mm)	75.6 inches (1919 mm)	8.12 ft (2.48 m)	N/A	Midwest Guardrail System on 5:1 flare rate (*NCHRP 350* 3-11)

[1.] The report used both SI and USC units.
N/A = Not Available

4 SUMMARY AND CONCLUSION

The research team reviewed full-scale crash test reports to tabulate the guardrail deflection. These crash tests were performed at TTI, MwRSF, SwRI, and other testing facilities. Acceptance letters issued by FHWA were also reviewed. A total of 53 guardrail systems test results are presented herein.

Each system was tabulated in chronological order in the previous sections. The research team tabulated 35 crash tests of 12 gauge W-beam guardrail, six thrie-beam guardrails, one 13 gauge W-beam guardrail, two nested W-beam guardrail, and nine W-beam guardrail systems with special applications.

The tabulated guardrail systems include the rail height, post size, post material, post spacing, blockout, and test designation. The rail height is defined from the top of the rail to the ground level. These tables present the maximum permanent and dynamic deflections, and working width if available.

The research team also developed an electronic spreadsheet of these tabulated guardrail systems as a useful utility for highway engineers. This spreadsheet has easy-to-sort guardrail systems data using both the US Customary and SI units. The spreadsheet is shown in Appendix B. The interactive digital version is available for download on the Roadside Safety Pooled Fund website (http://roadsidepooledfund.org/).

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APPENDIX A: BEAM GUARDRAIL DETAILS

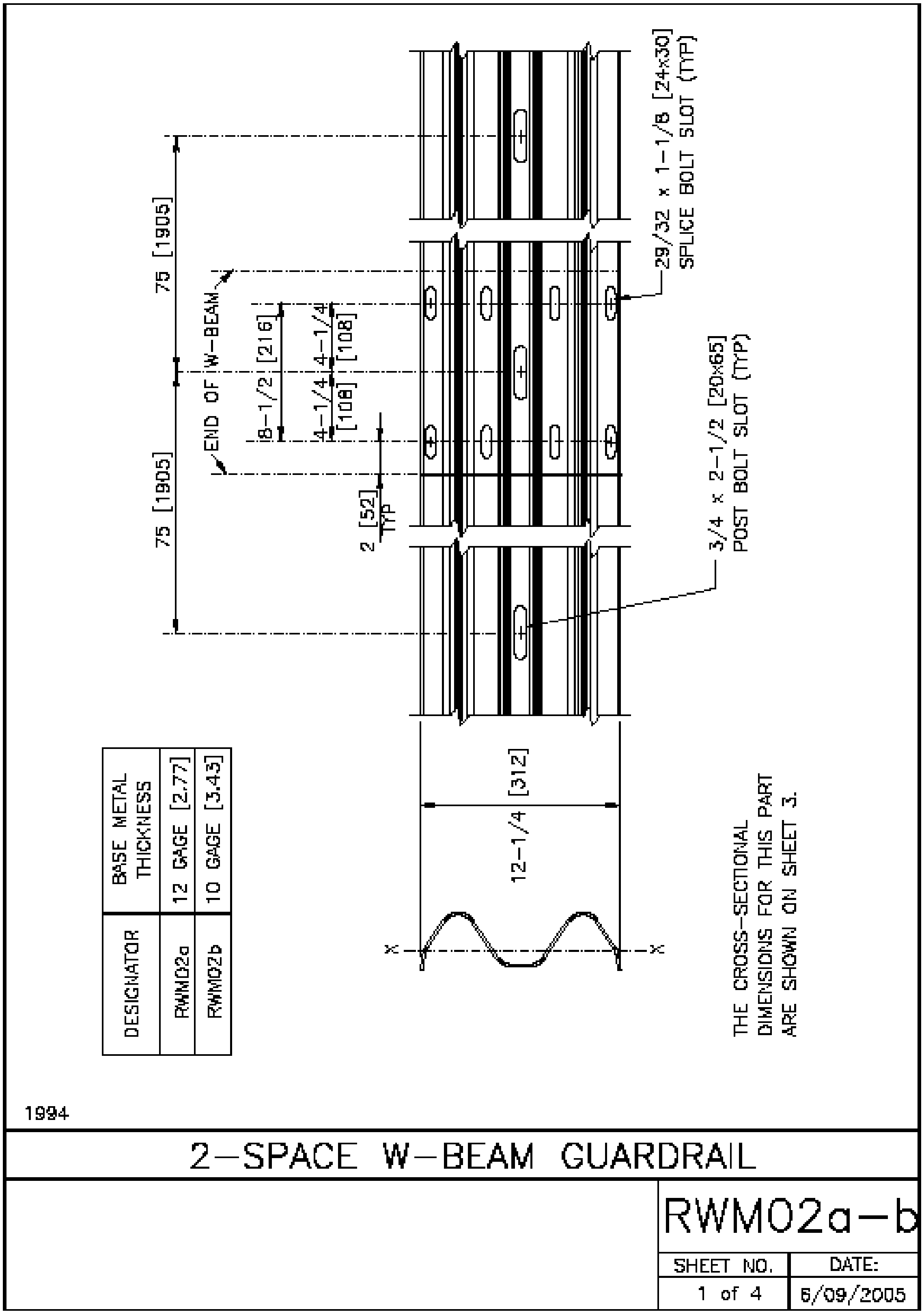

Figure A.1 AASHTO 2-space W-beam guardrail (RWM02a-b)

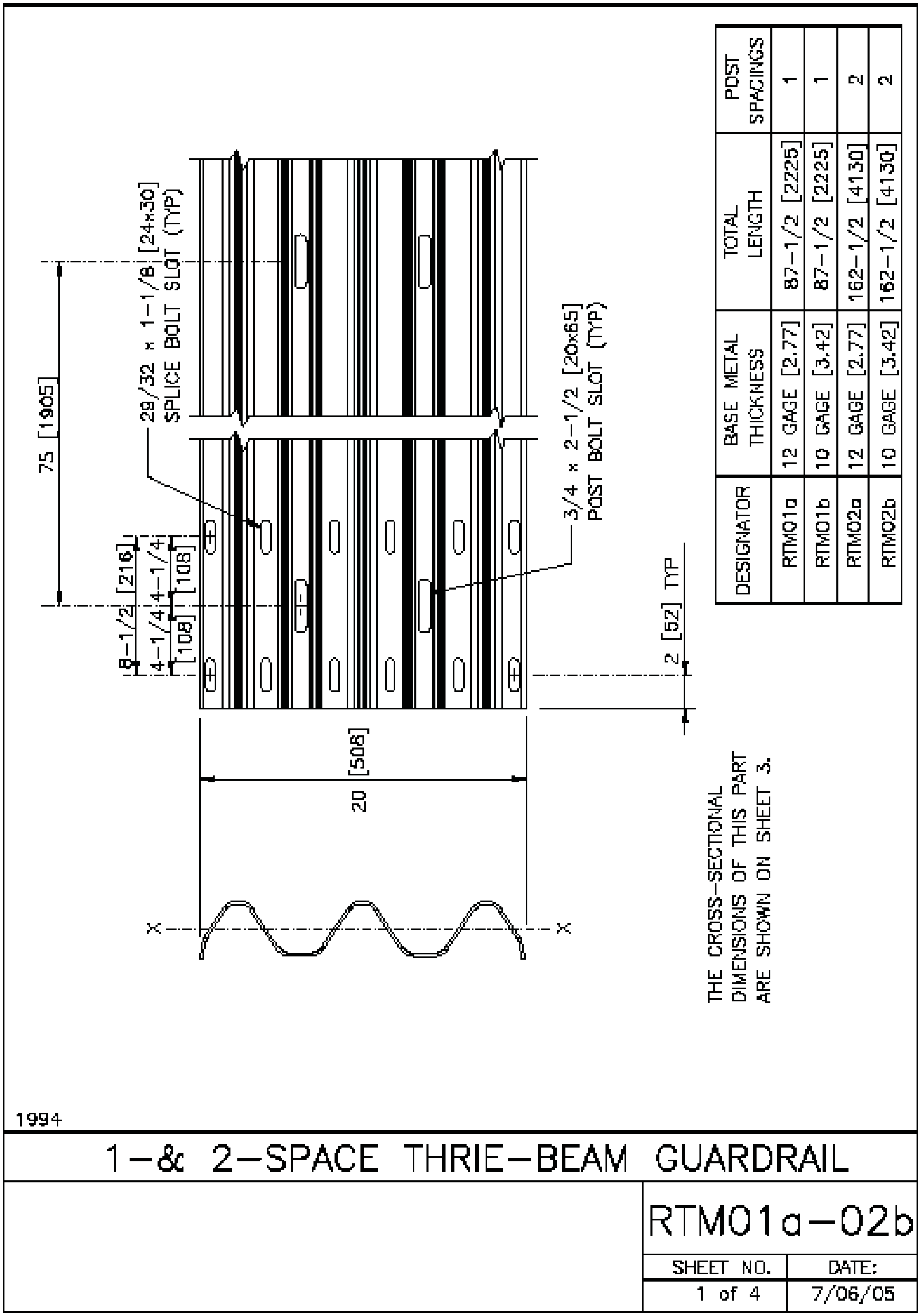

Figure A.2 AASHTO 1-& 2-space Thrie-beam guardrail (RTM01a-02b)

APPENDIX B: SPREADSHEET OF TABULATED GUARDRAIL SYSTEM

Table B.1 Excel Sheet Entries (SI units)

* In the reports, the height of the guardrail to the center of the W-beam rail element is mentioned to be 550 mm. The researchers calculated the total height of rail using AASHTO RWM02a rail properties. 550 mm + 156 mm = 706 mm.
** In the reports, the height of the guardrail to the center of the thrie-beam rail element is mentioned to be 550 mm. The researchers calculated the total height of rail using AASHTO RTM02a rail properties. 550 mm + 254 mm = 804 mm
† Test vehicle(MASH 2270P) and test designation(NCHRP 350 3-11) are different.

	Guardrail	Agency	Test No.	Year	Rail Height	Post				Blockout	Maximum Deflection		Working	Test designation	FHWA Approva	Unit
						Length	Size	Type	Spacing		Permanent	Dynamic	Width		Letter No.	SI or USC
1	12 gauge	TTI	471470-26	1994	685.8 mm	1626 mm long	152x203	wood	1900 mm	152x203x356 wood	690 mm	820 mm	N/A	NCHRP 350 3-11	N/A	SI/US
2	12 gauge	TTI	405421-1	1995	706.0 mm *	1830 mm long	W150x12.6	steel	1900 mm	150x200x360 timber	700 mm	1000 mm	N/A	NCHRP 350 3-11	N/A	SI
3	12 gauge	TTI	405391-1	1995	706.0 mm *	1900 mm long	184 mm dia.	wood	1900 mm	146x146x356 wood	790 mm	1100 mm	N/A	NCHRP 350 3-11	N/A	SI/US
4	12 gauge	TTI	400001-MPT1	1996	706.0 mm *	1830 mm long	W150x13.5	steel	1905 mm	152x200x356 recycled polyeth	720 mm	1130 mm	N/A	NCHRP 350 3-11	N/A	SI
5	12 gauge	TTI	439637-1	1997	706.0 mm *	1676 mm long	W150x13.5	steel	1905 mm	152x152x356 routed wood	450 mm	750 mm	N/A	NCHRP 350 3-11	N/A	SI
6	12 gauge	TTI	400001-APL1	2000	706.0 mm *	1486 mm long	152x191	recycled	1905 mm	150x200x360 timber	795 mm	1362 mm	1.67 m	NCHRP 350 3-11	N/A	SI
7	12 gauge	TTI	404201-1	2000	706.0 mm *	1800 mm long	150x200	wood	1905 mm	150x200x350 wood	860 mm	1032 mm	N/A	NCHRP 350 3-11	N/A	SI
8	12 gauge	TTI	473750-3	2000	820.0 mm	1600 mm long	S75×8	steel	3810 mm	N/A	1640 mm	2120 mm	N/A	NCHRP 350 3-11	N/A	SI/US
9	12 gauge	TTI	400001-CFI1	2001	706.0 mm	1600 mm long	HALCO-X-48	steel	1905 mm	155x200x360 Recycled plastic	326 mm	811 mm	1.16 m	NCHRP 350 3-11	B 80	SI
10	12 gauge	TTI	400001-ILP2	2001	705.0 mm	1625 mm long	150x200	wood	1905 mm	150x200x355 wood	340 mm	790 mm	0.88 m	NCHRP 350 3-11	B 92	SI
11	12 gauge	TTI	441622-1	2001	686.0 mm	1829 mm long	W150x13	steel	1905 mm	152x203x356 routed wood	340 mm	584 mm	1.05 m	NCHRP 350 3-11	B 64B	SI/US
12	12 gauge	E-TECH Inc	41-1655-001	2001	706.0 mm *	1600 mm long	HALCO-X-40	steel	1900 mm	155x200x360 routed wood	700 mm	1300 mm	N/A	NCHRP 350 3-11	B 80A	SI
13	12 gauge	TTI	441622-2	2002	686.0 mm		178 mm dia.	wood	1905 mm	152x203x356 routed wood	570 mm	688 mm	1.18 m	NCHRP 350 3-11	B 64B	SI
14	12 gauge	TTI	400001-MON1	2002	706.0 mm	1830 mm long	W150x13.5	steel	1905 mm	152x203x356 Mondo polymer	265 mm	837 mm	1.20 m	NCHRP 350 3-11	N/A	SI
15	12 gauge	MwRSF	NPG-4	2002	787.0 mm	1829 mm long	W152x13.4	steel	1905 mm	152x305x356 routed wood	652 mm	1094 mm	1.26 m	NCHRP 350 3-11	B 133	SI/US
16	12 gauge	MwRSF	NPG-5	2002	787.0 mm	1829 mm long	W152x13.4	steel	1905 mm	152x305x356 routed wood	611 mm	1024 mm	1.45 m	NCHRP 350 3-11	B 133	SI/US
17	12 gauge	MwRSF	NPG-6	2002	787.0 mm	1829 mm long	W152x13.4	steel	476 mm	152x305x356 routed wood	305 mm	447 mm	0.93 m	NCHRP 350 3-11	B 133	SI/US
18	12 gauge	MwRSF	PR-1	2002	706.0 mm	1346 mm long	W152x13.4	steel	1905 mm	152x203x356 wood	N/A	970 mm	1.01 m	NCHRP 350 3-11	B 64B	SI/US
19	12 gauge	SwRI	N/A_1	2002	706.0 mm *	1830 mm long	O-post	steel	1900 mm	140x195x360 routed wood	N/A	1030 mm	N/A	NCHRP 350 3-11	B 95	SI
20	12 gauge	SwRI	N/A_2	2002	706.0 mm *	1830 mm long	O-post	steel	1900 mm	140x195x360 routed wood	N/A	1110 mm	N/A	NCHRP 350 3-11	B 95A	SI
21	12 gauge	E-TECH Inc	41-1792-001	2003	706.0 mm *	1600 mm long	HALCO-X-44	steel	1900 mm	155x200x360 Recycled plastic	600 mm	700 mm	N/A	NCHRP 350 3-11	B 80C	SI
22	12 gauge	MwRSF	2214MG -1	2004	787.0 mm	1829 mm long	W152x13.4	steel	1905 mm	152x305x362 timber	1089 mm	1447 mm	1.46 m	MASH 3-11	N/A	SI/US
23	12 gauge	MwRSF	2214MG -2	2004	787.0 mm	1829 mm long	W152x13.4	steel	1905 mm	152x305x362 timber	803 mm	1114 mm	1.23 m	MASH 3-11	N/A	SI/US
24	12 gauge	MwRSF	2214WB-2	2005	706.0 mm	1829 mm long	W152x13.4	steel	1905 mm	152x203x362 wood	845 mm	1196 mm	1.40 m	MASH 3-11	N/A	SI
25	12 gauge	TTI	220570-2	2005	787.0 mm	1829 mm long	W152×12.6	SYLP	1905 mm	N/A	730 mm	1040 mm	1.12 m	MASH 3-11	B 140	US
26	12 gauge	TTI	220570-8	2006	737.0 mm	1800 mm long	W150×14	SYLP	1900 mm	N/A	730 mm	950 mm	1.23 m	NCHRP 350 3-11	N/A	SI/US

Table B.2 Excel Sheet Entries (SI units) (Continued)

	Guardrail	Agency	Test No.	Year	Rail Height	Post Length	Post Size	Post Type	Post Spacing	Blockout	Maximum Deflection Permanent	Maximum Deflection Dynamic	Working Width	Test designation	FHWA Approva Letter No.	Unit SI or USC
27	12 gauge	SwRI	GMS-1	2006	787.0 mm	1829 mm long	W152×12.6	steel	1905 mm	N/A	560 mm	890 mm	N/A	MASH 3-11	B 150	US
28	12 gauge	MwRSF	MGSDF-1	2006	788.0 mm	1753 mm long	184 mm dia.	Douglas F	1905 mm	152x203x362 wood	902 mm	1529 mm	1.53 m	NCHRP 350 3-11	B 175	SI/US
										152x127x362 wood						
29	12 gauge	MwRSF	MGSPP-1	2006	788.0 mm	1753 mm long	203 mm dia.	Pine woo	1905 mm	152x203x362 wood	705 mm	956 mm	1.23 m	NCHRP 350 3-11	B 175	SI/US
										152x127x362 wood						
30	12 gauge	TTI	400001-TGS1	2007	787.0 mm	1829 mm long	W152×12.6	steel	1905 mm	N/A	787 mm	975 mm	1.04 m	MASH 3-11	N/A	US
31	12 gauge	SRI	GMS-6	2007	702.0 mm	1829 mm long	W152×12.6	steel	1905 mm	N/A	810 mm	1320 mm	N/A	MASH 3-11	B 150A	US
32	12 gauge	SRI	GMS-7	2007	702.0 mm	1829 mm long	W152×12.6	steel	3810 mm	N/A	530 mm	1520 mm	N/A	MASH 3-11	B 150B	US
33	12 gauge	Holmes Solutions	57073112	2007	787.0 mm	1980 mm long	U-channel Nuco	steel	1905 mm	N/A	800 mm	1050 mm	N/A	MASH 3-11	B 162	SI/US
34	12 gauge	Holmes Solutions	05707b3111	2007	686.0 mm	1980 mm long	U-channel Nuco	steel	1905 mm	102x203x356 Recycled plasti	900 mm	1150 mm	N/A	NCHRP 350 3-11	B 162	SI/US
35	12 gauge	Holmes Solutions	0000-0-0-00-1	2008	686.0 mm	1980 mm long	U-channel Nuco	steel	1905 mm	102x203x356 Recycled plasti	980 mm	1440 mm	1.65 m	NCHRP 350 3-11	B 186	US
36	Thrie Beam	TTI	471470-30	1995	864.0 mm	2064 mm long	W152x13.4	steel	1900 mm	M14×18 in. spacer with cutout	610 mm	1020 mm	N/A	NCHRP 350 3-11	N/A	SI/US
37	Thrie Beam	TTI	404211-11	1998	804.0 mm **	2060 mm long	150x200	wood	1905 mm	150x200x554 routed wood	390 mm	676 mm	N/A	NCHRP 350 3-11	N/A	SI
38	Thrie Beam	TTI	404211-10	1999	804.0 mm **	2060 mm long	W150×14	steel	1905 mm	150x200x554 routed wood	420 mm	580 mm	N/A	NCHRP 350 3-11	N/A	SI
39	Thrie Beam	E-TECH Inc	54-1108-001	2004	801.0 mm	1800 mm long	100x140	C-Post	2000 mm	100x140x550 C-Blockout	400 mm	500 mm	N/A	NCHRP 350 3-11	N/A	SI
40	Thrie Beam	TTI	220570-7	2006	991.0 mm	1829 mm long	W150×14	SYLP	1905 mm	N/A	595 mm	627 mm	0.63 m	NCHRP 350 3-11	N/A	SI
41	Thrie Beam	SRI	GMS-3	2006	991.0 mm	1829 mm long	W152×12.6	steel	1905 mm	N/A	860 mm	1300 mm	N/A	MASH 3-11	B 156	US
42	13 gauge	MwRSF	Buffalo Rail	1995	782.0 mm	1829 mm long	152x203	wood	2500 mm	152x203x438 2 routed wood	567 mm	851 mm	N/A	NCHRP 350 3-11	N/A	SI
43	Nested	MwRSF	OLS-3	1999	706.0 mm	1830 mm long	150x200	CRT post	7620 mm	150x200x360 2 routed wood	1016 mm	1450 mm	N/A	NCHRP 350 3-11	B58	SI
44	Nested	MwRSF	NEC-2	2000	706.0 mm	1830 mm long	W152x13.4	steel	1905 mm	152x203x360 wood	721 mm	1072 mm	N/A	NCHRP 350 3-11	N/A	SI
45	W-beam on slope	MwRSF	MOSW-1	2000	706.0 mm	2134 mm long	W150x13.5	steel	953 mm	150x200x360 wood	587 mm	821 mm	N/A	NCHRP 350 3-11	B 64C	SI
46	W-beam on slope	MwRSF	MGS221-2	2006	787.0 mm	2743 mm long	W152x13.4	steel	1905 mm	152x305x362 wood	1067 mm	1436 mm	1.63 m	MASH 3-11	N/A	SI
47	W-beam on slope	MwRSF	MGSAS-1	2006	787.0 mm	1829 mm long	W152x13.4	steel	1905 mm	152x305x362 wood	870 mm	1464 mm	2.10 m	NCHRP 350 3-11	N/A	SI/US
48	W-beam for culve	MwRSF	KC-1	2001	706.0 mm	946 mm long	W152x13.4	steel	953 mm	152x203x356 routed wood	401 mm	416 mm	0.90 m	NCHRP 350 3-11	N/A	SI
49	W-beam for culve	MwRSF	LSC-1	2006	787.0 mm	1829 mm long	152x203	BCT	7620 mm	152x305x362 wood	724 mm	2343 mm	2.37 m	MASH 3-11	B189	SI/US
50	W-beam for culve	MwRSF	LSC-2	2006	787.0 mm	1829 mm long	152x203	BCT	1905 mm	152x305x362 wood	1372 mm	1968 mm	2.13 m	MASH 3-11	B189	SI/US

Table B.3 Excel Sheet Entries (SI units) (Continued)

	Guardrail	Agency	Test No.	Year	Rail Height	Post				Blockout	Maximum Deflection		Working	Test designation	FHWA Approva	Unit
						Length	Size	Type	Spacing		Permanent	Dynamic	Width		Letter No.	SI or USC
51	with various flare	MwRSF	FR-1	2005	787.0 mm	1829 mm long	W152x13.4	steel	1905 mm	152x305x362 wood	1140 mm	1684 mm	1.80 m	NCHRP 350 3-11	N/A	SI/US
52	with various flare	MwRSF	FR-2	2005	787.0 mm	1829 mm long	W152x13.4	steel	1905 mm	152x305x362 wood	1156 mm	1925 mm	2.23 m	NCHRP 350 3-11	N/A	SI/US
53	with various flare	MwRSF	FR-4	2006	787.0 mm	1829 mm long	W152x13.4	steel	1905 mm	152x305x362 wood	1753 mm	1919 mm	2.48 m	NCHRP 350 3-11	N/A	SI/US

Table B.4 Excel Sheet Entries (USC units)

* In the reports, the height of the guardrail to the center of the W-beam rail element is mentioned to be 550 mm. The researchers calculated the total height of rail using AASHTO RWM02a rail properties. 550 mm + 156 mm = 706 mm.
** In the reports, the height of the guardrail to the center of the thrie-beam rail element is mentioned to be 550 mm. The researchers calculated the total height of rail using AASHTO RTM02a rail properties. 550 mm + 254 mm = 804 mm
† Test vehicle(MASH 2270P) and test designation(NCHRP 350 3-11) are different.

	Guardrail	Agency	Test No.	Year	Rail Height	Post				Blockout	Maximum Deflection		Working Width	Test designation	FHWA Approval Letter No.	Unit SI or USC
						Length	Size	Type	Spacing		Permanent	Dynamic				
1	12 gauge	TTI	471470-26	1994	27.0 in	5 ft-4 in. long	6×8 in.	wood	6 ft-3 in	6×8×14 in. wood	27.2 in.	32.3 in.	N/A	NCHRP 350 3-11	N/A	SI/US
2	12 gauge	TTI	405421-1	1995	27.8 in *	6 ft long	W6×8.5	steel	6 ft-3 in	5-7/8×7-7/8×14-1/8 in. timber	27.6 in.	39.4 in.	N/A	NCHRP 350 3-11	N/A	SI
3	12 gauge	TTI	405391-1	1995	27.8 in *	6-ft-3 in. long	7-1/4 in. dia	wood	6 ft-3 in	5-3/4×5-3/4×14 in. wood	31.1 in.	43.3 in.	N/A	NCHRP 350 3-11	N/A	SI/US
4	12 gauge	TTI	400001-MPT1	1996	27.8 in *	6 ft long	W6×9	steel	6 ft-3 in	6×7-7/8×14 in. recycled p	28.3 in.	44.5 in.	N/A	NCHRP 350 3-11	N/A	SI
5	12 gauge	TTI	439637-1	1997	27.8 in *	5 ft-6 in. long	W6×9	steel	6 ft-3 in	6×6×14 in. routed wo	17.7 in.	29.5 in.	N/A	NCHRP 350 3-11	N/A	SI
6	12 gauge	TTI	400001-APL1	2000	27.8 in *	4 ft-10-1/2 in. long	6×7-1/2 in.	recycled	6 ft-3 in	5-7/8×7-7/8×14-1/8 in. timber	31.3 in.	53.6 in.	5.47 ft	NCHRP 350 3-11	N/A	SI
7	12 gauge	TTI	404201-1	2000	27.8 in *	5 ft-11 in. long	5-7/8×7-7/8 in.	wood	6 ft-3 in	5-7/8×7-7/8×14 1/8 in. wood	33.9 in.	40.6 in.	N/A	NCHRP 350 3-11	N/A	SI
8	12 gauge	TTI	473750-3	2000	32.3 in	5 ft-3 in. long	S3x5.7	steel	12 ft-6 in	#N/A	64.6 in.	83.5 in.	N/A	NCHRP 350 3-11	N/A	SI/US
9	12 gauge	TTI	400001-CFI1	2001	27.8 in	5 ft-3 in. long	HALCO-X-48	steel	6 ft-3 in	6-1/8x7-7/8x14-1/8 in. Recycled	12.8 in.	31.9 in.	3.80 ft	NCHRP 350 3-11	B 80	SI
10	12 gauge	TTI	400001-ILP2	2001	27.8 in	5 ft-4 in. long	5-7/8×7-7/8 in.	wood	6 ft-3 in	5-7/8×7-7/8×14 in. wood	13.4 in.	31.1 in.	2.87 ft	NCHRP 350 3-11	B 92	SI
11	12 gauge	TTI	441622-1	2001	27.0 in	6 ft long	W6×9	steel	6 ft-3 in	6×8×14 in. routed wo	13.4 in.	23.0 in.	3.43 ft	NCHRP 350 3-11	B 64B	SI/US
12	12 gauge	E-TECH Inc.	41-1655-001	2001	27.8 in *	5 ft-3 in. long	HALCO-X-40	steel	6 ft-3 in	6-1/8x7-7/8x14-1/8 in. routed wo	27.6 in.	51.2 in.	N/A	NCHRP 350 3-11	B 80A	SI
13	12 gauge	TTI	441622-2	2002	27.0 in		7 in. dia	wood	6 ft-3 in	6×8×14 in. routed wo	22.4 in.	27.1 in.	3.88 ft	NCHRP 350 3-11	B 64B	SI
14	12 gauge	TTI	400001-MON	2002	27.8 in	6 ft long	W6×9	steel	6 ft-3 in	6×8×14 in. Mondo po	10.4 in.	33.0 in.	3.94 ft	NCHRP 350 3-11	N/A	SI
15	12 gauge	MwRSF	NPG-4	2002	31.0 in	6 ft long	W6×9	steel	6 ft-3 in	6×12×14 in. routed wo	25.7 in.	43.1 in.	4.13 ft	NCHRP 350 3-11	B 133	SI/US
16	12 gauge	MwRSF	NPG-5	2002	31.0 in	6 ft long	W6×9	steel	6 ft-3 in	6×12×14 in. routed wo	24.1 in.	40.3 in.	4.77 ft	NCHRP 350 3-11	B 133	SI/US
17	12 gauge	MwRSF	NPG-6	2002	31.0 in	6 ft long	W6×9	steel	1 ft-6-3/4 in.	6×12×14 in. routed wo	12.0 in.	17.6 in.	3.05 ft	NCHRP 350 3-11	B 133	SI/US
18	12 gauge	MwRSF	PR-1	2002	27.8 in	4 ft-5 in. long	W6×9	steel	6 ft-3 in	6×8×14 in. wood	N/A	38.2 in.	3.31 ft	NCHRP 350 3-11	B 64B	SI/US
19	12 gauge	SwRI	N/A_1	2002	27.8 in *	6 ft long	O-post	steel	6 ft-3 in	5-1/2x7-3/4x14-1/8 in. routed wo	N/A	40.6 in.	N/A	NCHRP 350 3-11	B 95	SI
20	12 gauge	SwRI	N/A_2	2002	27.8 in *	6 ft long	O-post	steel	6 ft-3 in	5-1/2x7-3/4x14-1/8 in. routed wo	N/A	43.7 in.	N/A	NCHRP 350 3-11	B 95A	SI
21	12 gauge	E-TECH Inc.	41-1792-001	2003	27.8 in *	5 ft-3 in. long	HALCO-X-44	steel	6 ft-3 in	6-1/8x7-7/8x14-1/8 in. Recycled	23.6 in.	27.6 in.	N/A	NCHRP 350 3-11	B 80C	SI
22	12 gauge	MwRSF	2214MG -1	2004	31.0 in	6 ft long	W6×9	steel	6 ft-3 in	6×12×14-1/4 in. timber	42.9 in.	57.0 in.	4.78 ft	MASH 3-11	N/A	SI/US
23	12 gauge	MwRSF	2214MG -2	2004	31.0 in	6 ft long	W6×9	steel	6 ft-3 in	6×12×14-1/4 in. timber	31.6 in.	43.9 in.	4.05 ft	MASH 3-11	N/A	SI/US
24	12 gauge	MwRSF	2214WB-2	2005	27.8 in	6 ft long	W6×9	steel	6 ft-3 in	6×8×14-1/4 in. wood	33.3 in.	47.1 in.	4.58 ft	MASH 3-11	N/A	SI
25	12 gauge	TTI	220570-2	2005	31.0 in	6 ft long	W6×8.5	SYLP	6 ft-3 in	#N/A	28.7 in.	40.9 in.	3.67 ft	MASH 3-11	B 140	US
26	12 gauge	TTI	220570-8	2006	29.0 in	6ft long	W6×8.5	SYLP	6 ft-3 in	#N/A	28.7 in.	37.4 in.	4.04 ft	NCHRP 350 3-11	N/A	SI/US

Table B.5 Excel Sheet Entries (USC units) (Continued)

	Guardrail	Agency	Test No.	Year	Rail Height	Post Length	Post Size	Post Type	Post Spacing	Blockout		Maximum Deflection Permanent	Maximum Deflection Dynamic	Working Width	Test designation	FHWA Approva Letter No.	Unit SI or USC
27	12 gauge	SwRI	GMS-1	2006	31.0 in	6 ft long	W6×8.5	steel	6 ft-3 in	#N/A		22.0 in.	35.0 in.	N/A	MASH 3-11	B 150	US
28	12 gauge	MwRSF	MGSDF-1	2006	31.0 in	5 ft-9 in. long	7-1/4 in. dia	uglas Fir w	6 ft-3 in	6×8×14-1/4 in.	wood	35.5 in.	60.2 in.	5.02 ft	NCHRP 350 3-11	B 175	SI/US
										6×5×14-1/4 in.	wood						
29	12 gauge	MwRSF	MGSPP-1	2006	31.0 in	5 ft-9 in. long	8 in. dia	Pine wood	6 ft-3 in	6×8×14-1/4 in.	wood	27.8 in.	37.6 in.	4.04 ft	NCHRP 350 3-11	B 175	SI/US
										6×5×14-1/4 in.	wood						
30	12 gauge	TTI	400001-TGS1	2007	31.0 in	6 ft long	W6×8.5	steel	6 ft-3 in	#N/A		31.0 in.	38.4 in.	3.41 ft	MASH 3-11	N/A	US
31	12 gauge	SRI	GMS-6	2007	27.6 in	6 ft long	W6×8.5	steel	6 ft-3 in	#N/A		31.9 in.	52.0 in.	N/A	MASH 3-11	B 150A	US
32	12 gauge	SRI	GMS-7	2007	27.6 in	6 ft long	W6×8.5	steel	12 ft-6 in	#N/A		20.9 in.	59.8 in.	N/A	MASH 3-11	B 150B	US
33	12 gauge	Holmes Soluti	57073112	2007	31.0 in	6-ft-6 in. long	U-channel Nucor	steel	6 ft-3 in	#N/A		31.5 in.	41.3 in.	N/A	MASH 3-11	B 162	SI/US
34	12 gauge	Holmes Soluti	05707b3111	2007	27.0 in	6-ft-6 in. long	U-channel Nucor	steel	6 ft-3 in	4×8×14 in.		35.4 in.	45.3 in.	N/A	NCHRP 350 3-11	B 162	SI/US
35	12 gauge	Holmes Soluti	0000-0-0-00-1	2008	27.0 in	6-ft-6 in. long	U-channel Nucor	steel	6 ft-3 in	4×8×14 in.	Recycled	38.6 in.	56.7 in.	5.41 ft	NCHRP 350 3-11	B 186	US
36	Thrie Beam	TTI	471470-30	1995	34.0 in	6-ft-9-1/4 in. long	W6×9	steel	6 ft-3 in	M14×18 in. spacer with cutout		24.0 in.	40.2 in.	N/A	NCHRP 350 3-11	N/A	SI/US
37	Thrie Beam	TTI	404211-11	1998	31.7 in **	6-ft-9 in. long	6×7-7/8 in.	wood	6 ft-3 in	6×7-7/8×21-3/4 in.	routed wo	15.4 in.	26.6 in.	N/A	NCHRP 350 3-11	N/A	SI
38	Thrie Beam	TTI	404211-10	1999	31.7 in **	6-ft-9 in. long	W6×8.5	steel	6 ft-3 in	6×7-7/8×21-3/4 in.	routed wo	16.5 in.	22.8 in.	N/A	NCHRP 350 3-11	N/A	SI
39	Thrie Beam	E-TECH Inc.	54-1108-001	2004	31.5 in	5 ft-11 in. long	4×5-1/2 in.	C-Post	6 ft-7 in	4x5-1/2x21-3/4 in.	C-Blockou	15.7 in.	19.7 in.	N/A	NCHRP 350 3-11	N/A	SI
40	Thrie Beam	TTI	220570-7	2006	39.0 in	6 ft long	W6×8.5	SYLP	6 ft-3 in	#N/A		23.4 in.	24.7 in.	2.06 ft	NCHRP 350 3-11	N/A	SI
41	Thrie Beam	SRI	GMS-3	2006	39.0 in	6 ft long	W6×8.5	steel	6 ft-3 in	#N/A		33.9 in.	51.2 in.	N/A	MASH 3-11	B 156	US
42	13 gauge	MwRSF	Buffalo Rail	1995	30.8 in	6 ft long	6×8 in.	wood	8.2 ft	6×8×17-1/4 in.	2 routed w	22.3 in.	33.5 in.	N/A	NCHRP 350 3-11	N/A	SI
43	Nested	MwRSF	OLS-3	1999	27.8 in	6 ft long	5-7/8×7-7/8 in.	CRT post	25 ft	5-7/8×7-7/8×14-1/8 in.	2 routed w	40.0 in.	57.1 in.	N/A	NCHRP 350 3-11	B58	SI
44	Nested	MwRSF	NEC-2	2000	27.8 in	6 ft long	W6×9	steel	6 ft-3 in	6×8×14-1/8 in.	wood	28.4 in.	42.2 in.	N/A	NCHRP 350 3-11	N/A	SI
45	W-beam on slope	MwRSF	MOSW-1	2000	27.8 in	7 ft long	W6×9	steel	#N/A	5-7/8×7-7/8×14-1/8 in.	wood	23.1 in.	32.3 in.	N/A	NCHRP 350 3-11	B 64C	SI
46	W-beam on slope	MwRSF	MGS221-2	2006	31.0 in	9 ft long	W6×9	steel	6 ft-3 in	6×12×14-1/4 in.	wood	42.0 in.	56.5 in.	5.35 ft	MASH 3-11	N/A	SI
47	W-beam on slope	MwRSF	MGSAS-1	2006	31.0 in	6 ft long	W6×9	steel	6 ft-3 in	6×12×14-1/4 in.	wood	34.3 in.	57.6 in.	6.90 ft	NCHRP 350 3-11	N/A	SI/US
48	W-beam for culv	MwRSF	KC-1	2001	27.8 in	3.1 ft long	W6×9	steel	#N/A	6×8×14 in.	wood	15.8 in.	16.4 in.	2.95 ft	NCHRP 350 3-11	N/A	SI
49	W-beam for culv	MwRSF	LSC-1	2006	31.0 in	6 ft long	6×8 in.	BCT	25 ft	6×12×14-1/4 in.	wood	28.5 in.	92.2 in.	7.78 ft	MASH 3-11	B189	SI/US
50	W-beam for culv	MwRSF	LSC-2	2006	31.0 in	6 ft long	6×8 in.	BCT	6 ft-3 in	6×12×14-1/4 in.	wood	54.0 in.	77.5 in.	6.99 ft	MASH 3-11	B189	SI/US

Table B.6 Excel Sheet Entries (USC units) (Continued)

	Guardrail	Agency	Test No.	Year	Rail Height	Post				Blockout	Maximum Deflection		Working	Test designation	FHWA Approva	Unit
						Length	Size	Type	Spacing		Permanent	Dynamic	Width		Letter No.	SI or USC
51	MGS with variou	MwRSF	FR-1	2005	31.0 in	6 ft long	W6×9	steel	6 ft-3 in	6×12×14-1/4 in. wood	44.9 in.	66.3 in.	5.91 ft	NCHRP 350 3-11	N/A	SI/US
52	MGS with variou	MwRSF	FR-2	2005	31.0 in	6 ft long	W6×9	steel	6 ft-3 in	6×12×14-1/4 in. wood	45.5 in.	75.8 in.	7.32 ft	NCHRP 350 3-11	N/A	SI/US
53	MGS with variou	MwRSF	FR-4	2006	31.0 in	6 ft long	W6×9	steel	6 ft-3 in	6×12×14-1/4 in. wood	69.0 in.	75.6 in.	8.14 ft	NCHRP 350 3-11	N/A	SI/US