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

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KEY WORDS

Guardrail, deflection, roadside safety, crash testing
GUARDRAIL DEFLECTION ANALYSIS, PHASE I: (2010-11)

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.
### SI* (MODERN METRIC) CONVERSION FACTORS

#### APPROPRIATE CONVERSIONS TO SI UNITS

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*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

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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>
<thead>
<tr>
<th>Table 2.1 Common Guardrail Types Tested under NCHRP Report 350.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified weak post W-beam (G2)</td>
</tr>
<tr>
<td>Modified strong steel-post W-beam (G4(1S))</td>
</tr>
<tr>
<td>Strong wood-post W-beam (G4(2W))</td>
</tr>
<tr>
<td>Modified strong steel-post thrie beam (G9-S)</td>
</tr>
<tr>
<td>Strong wood-post thrie beam (G9-W)</td>
</tr>
<tr>
<td>Modified thrie beam</td>
</tr>
<tr>
<td>Midwest Guardrail System (MGS)</td>
</tr>
</tbody>
</table>

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).
Figure 2.1 Types of Guardrails.

(a) Weak post W-beam (G2)

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

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

<table>
<thead>
<tr>
<th>Run Number</th>
<th>Post Spacing</th>
<th>Beam Description</th>
<th>Impact Angle</th>
<th>Maximum Deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mm [inch]</td>
<td></td>
<td></td>
<td>Simulation mm [inch]</td>
</tr>
<tr>
<td>1</td>
<td>1905 [75]</td>
<td>Sgl W-Beam</td>
<td>15°</td>
<td>589 [23.2]</td>
</tr>
<tr>
<td>3</td>
<td>952 [38]</td>
<td>Sgl W-Beam</td>
<td>15°</td>
<td>389 [15.3]</td>
</tr>
<tr>
<td>4</td>
<td>952 [38]</td>
<td>Sgl W-Beam</td>
<td>25°</td>
<td>541 [21.3]</td>
</tr>
<tr>
<td>*</td>
<td>1905 [75]</td>
<td>Dbl W-Beam</td>
<td>25°</td>
<td>NA [NA]</td>
</tr>
<tr>
<td>5</td>
<td>952 [38]</td>
<td>Dbl W-Beam</td>
<td>15°</td>
<td>358 [14.1]</td>
</tr>
<tr>
<td>6</td>
<td>952 [38]</td>
<td>Dbl W-Beam</td>
<td>25°</td>
<td>437 [17.2]</td>
</tr>
<tr>
<td>11</td>
<td>952 [38]</td>
<td>Sgl Thrie-Beam</td>
<td>15°</td>
<td>386 [15.2]</td>
</tr>
<tr>
<td>12</td>
<td>952 [38]</td>
<td>Sgl Thrie-Beam</td>
<td>25°</td>
<td>480 [18.9]</td>
</tr>
<tr>
<td>13</td>
<td>952 [38]</td>
<td>Dbl Thrie-Beam</td>
<td>15°</td>
<td>333 [13.1]</td>
</tr>
<tr>
<td>14</td>
<td>952 [38]</td>
<td>Dbl Thrie-Beam</td>
<td>25°</td>
<td>414 [16.3]</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Test Vehicle Designation</th>
<th>NCHRP Report 350 Test 3-11</th>
<th>MASH Test 3-11</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Mass = 2000 kg (4409 lb))</td>
<td>(Mass = 2270 kg (5000 lb))</td>
</tr>
<tr>
<td>Test Conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>100 km/h (62 mi/h)</td>
<td>100 km/h (62 mi/h)</td>
</tr>
<tr>
<td>Angle</td>
<td>25 degrees</td>
<td>25 degrees</td>
</tr>
</tbody>
</table>
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 (12⅛ 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.

<table>
<thead>
<tr>
<th>Test No. Agency, Year</th>
<th>Rail Height</th>
<th>Post Size and Material</th>
<th>Spacing</th>
<th>Blockout</th>
<th>Maximum Deflection</th>
<th>Working Width</th>
<th>FHWA Letter No.</th>
<th>System Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>471470-26 TTI, 1994 (18)</td>
<td>27 inches (686 mm)</td>
<td>5 ft-4 inch long 6×8 inch wood</td>
<td>6 ft-3 inch</td>
<td>6×8×14 inch wood</td>
<td>27.2 inches (690 mm)</td>
<td>32.3 inches (820 mm)</td>
<td>N/A N/A</td>
<td>W-beam, strong post G4(2W) guardrail (NCHRP 350 3-11)</td>
</tr>
<tr>
<td>405421-1 TTI, 1995 (19)</td>
<td>27.8 inches (706 mm)</td>
<td>6 ft long W6×8.5 steel</td>
<td>6 ft-3 inch</td>
<td>5¾×7¾×14½ inch timber</td>
<td>27.6 inches (700 mm)</td>
<td>39.4 inches (1000 mm)</td>
<td>N/A N/A</td>
<td>Modified W-beam, strong post G4(1S) guardrail (NCHRP 350 3-11)</td>
</tr>
<tr>
<td>405391-1 TTI, 1995 (20)</td>
<td>27.8 inches (706 mm)</td>
<td>6 ft-3 inch long 7.25 inch dia round wood</td>
<td>6 ft-3 inch</td>
<td>5⅞×5 ¾×14 inch wood</td>
<td>31.1 inches (790 mm)</td>
<td>43.3 inches (1100 mm)</td>
<td>N/A N/A</td>
<td>Round wood post G4(2W) guardrail (NCHRP 350 3-11)</td>
</tr>
<tr>
<td>400001-MPT1 TTI, 1996 (21)</td>
<td>27.8 inches (706 mm)</td>
<td>6 ft long W6×9 steel</td>
<td>6 ft-3 inch</td>
<td>6×7¾×14 inch recycled polyethylene block</td>
<td>28.3 inches (720 mm)</td>
<td>44.5 inches (1130 mm)</td>
<td>N/A N/A</td>
<td>Modified G4(1S) guardrail with recycled blockouts (NCHRP 350 3-11)</td>
</tr>
<tr>
<td>439637-1 TTI, 1997 (22)</td>
<td>27.8 inches (706 mm)</td>
<td>5 ft-6 inch long W6×9 steel</td>
<td>6 ft-3 inch</td>
<td>6×6×14 inch routed wood</td>
<td>17.7 inches (450 mm)</td>
<td>29.5 inches (750 mm)</td>
<td>N/A N/A</td>
<td>Modified G4(1S) guardrail (NCHRP 350 3-11)</td>
</tr>
<tr>
<td>400001-APL1 TTI, 2000 (23)</td>
<td>27.8 inches (706 mm)</td>
<td>4 ft-10.5 inch long 6×7.5 inch recycled plastic</td>
<td>6 ft-3 inch</td>
<td>5¾×7¾×14½ inch timber</td>
<td>31.3 inches (795 mm)</td>
<td>53.6 inches (1362 mm)</td>
<td>5.47 ft (1.67 m)</td>
<td>Modified G4(2W) guardrail with Amity plastic’s recycled posts (NCHRP 350 3-11)</td>
</tr>
<tr>
<td>404201-1 TTI, 2000 (24)</td>
<td>27.8 inches (706 mm)</td>
<td>5 ft-11 inch long 5¾×7¾ inch wood</td>
<td>6 ft-3 inch</td>
<td>5¾×7¾×14½ inch wood</td>
<td>33.9 inches (860 mm)</td>
<td>40.6 inches (1032 mm)</td>
<td>N/A N/A</td>
<td>G4(2W) with 100 mm asphaltic curb (NCHRP 350 3-11)</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Test No. Agency, Year</th>
<th>Rail Height</th>
<th>Post</th>
<th>Blockout</th>
<th>Maximum Deflection</th>
<th>Working Width</th>
<th>FHWA Letter No.</th>
<th>System Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>473750-3 TTI, 2000 (25)¹</td>
<td>32.3 inches (820 mm)</td>
<td>5 ft-3 inch long S3×5.7 steel</td>
<td>12 ft-6 inch</td>
<td>N/A</td>
<td>64.6 inches (1640 mm)</td>
<td>83.5 inches (2120 mm)</td>
<td>N/A</td>
</tr>
<tr>
<td>400001-CFI1 TTI, 2001 (26)²</td>
<td>27.8 inches (706 mm)</td>
<td>5 ft-3 inch long HALCO X-48 steel</td>
<td>6 ft-3 inch</td>
<td>6⅛×7⅛×14⅜ inch Recycled plastic</td>
<td>12.8 inches (326 mm)</td>
<td>31.9 inches (811 mm)</td>
<td>3.8 ft (1.16 m)</td>
</tr>
<tr>
<td>400001-ILP2 TTI, 2001 (27)²</td>
<td>27.8 inches (705 mm)</td>
<td>5 ply laminated 5 ft-4 inch long 5⅛×7⅛ inch wood</td>
<td>6 ft-3 inch</td>
<td>5 ply laminated 5⅛×7⅛×14 inch wood</td>
<td>13.4 inches (340 mm)</td>
<td>31.1 inches (789 mm)</td>
<td>2.87 ft (0.88 m)</td>
</tr>
<tr>
<td>441622-1 TTI, 2001 (28)¹</td>
<td>27 inches (686 mm)</td>
<td>6 ft long W6×9 steel</td>
<td>6 ft-3 inch</td>
<td>6×8×14 inch routed wood</td>
<td>13.4 inches (340 mm)</td>
<td>23 inches (584 mm)</td>
<td>3.43 ft (1.05 m)</td>
</tr>
<tr>
<td>41-1655-001 E-TECH Inc. 2001 (29)²</td>
<td>27.8 inches (706 mm)³</td>
<td>5 ft-3 inch long HALCO X-40 Steel</td>
<td>6 ft-3 inch</td>
<td>6⅛×7⅛×14⅜ inch Recycled plastic</td>
<td>27.6 inches (700 mm)</td>
<td>51.2 inches (1300 mm)</td>
<td>N/A</td>
</tr>
<tr>
<td>441622-2 TTI, 2002 (28)²</td>
<td>27 inches (686 mm)</td>
<td>7 inch dia round wood</td>
<td>6 ft-3 inch</td>
<td>6×8×14 inch routed wood</td>
<td>22.4 inches (570 mm)</td>
<td>27.1 inches (688 mm)</td>
<td>3.88 ft (1.18 m)</td>
</tr>
</tbody>
</table>

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

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>
<thead>
<tr>
<th>Test No.</th>
<th>Agency, Year</th>
<th>Rail Height</th>
<th>Post</th>
<th>Blockout</th>
<th>Maximum Deflection</th>
<th>Working Width</th>
<th>FHWA Letter No.</th>
<th>System Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>41-1792-001</td>
<td>E-TECH Inc., 2003 (35)</td>
<td>27.8 inches (706 mm)</td>
<td>5 ft-3 inch long HALCO X-44 Steel</td>
<td>6 ft-3 inch</td>
<td>6½×7¾×14¾ inch recycled plastic</td>
<td>23.6 inches (600 mm)</td>
<td>27.6 inches (700 mm)</td>
<td>N/A</td>
</tr>
<tr>
<td>2214MG-1</td>
<td>MwRSF, 2004 (36)</td>
<td>31 inches (787 mm)</td>
<td>6 ft long W6×9 steel</td>
<td>6 ft-3 inch</td>
<td>6×12×14¼ inch wood</td>
<td>42.9 inches (1089 mm)</td>
<td>57 inches (1447 mm)</td>
<td>4.78 ft (1.46 m)</td>
</tr>
<tr>
<td>2214MG-2</td>
<td>MwRSF, 2004 (37)</td>
<td>31 inches (787 mm)</td>
<td>6 ft long W6×9 steel</td>
<td>6 ft-3 inch</td>
<td>6×12×14¼ inch wood</td>
<td>31.6 inches (803 mm)</td>
<td>43.9 inches (1114 mm)</td>
<td>4.05 ft (1.23 m)</td>
</tr>
<tr>
<td>2214WB-2</td>
<td>MwRSF, 2005 (38)</td>
<td>27.8 inches (706 mm)</td>
<td>6 ft long W6×9 steel</td>
<td>6 ft-3 inch</td>
<td>6×8×14¼ inch wood</td>
<td>33.3 inches (845 mm)</td>
<td>47.1 inches (1196 mm)</td>
<td>4.58 ft (1.4 m)</td>
</tr>
<tr>
<td>220570-2</td>
<td>TTI, 2005 (39)</td>
<td>31 inches (787 mm)</td>
<td>6-ft long W6×8.5 SYLP</td>
<td>6 ft-3 inch</td>
<td>N/A</td>
<td>28.7 inches (730 mm)</td>
<td>40.9 inches (1040 mm)</td>
<td>3.67 ft (1.12 m)</td>
</tr>
<tr>
<td>220570-8</td>
<td>TTI, 2006 (40)</td>
<td>29 inches (737 mm)</td>
<td>6-ft long W6×8.5 SYLP</td>
<td>6 ft-3 inch</td>
<td>N/A</td>
<td>28.7 inches (730 mm)</td>
<td>37.4 inches (950 mm)</td>
<td>4.04 ft (1.23 m)</td>
</tr>
<tr>
<td>GMS-1</td>
<td>SwRI, 2006 (41)</td>
<td>31 inches (787 mm)</td>
<td>6-ft long W6×8.5 steel</td>
<td>6 ft-3 inch</td>
<td>N/A</td>
<td>22 inches (560 mm)</td>
<td>35 inches (890 mm)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

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).

<table>
<thead>
<tr>
<th>Test No. Agency, Year</th>
<th>Rail Height</th>
<th>Post Size and Material</th>
<th>Spacing</th>
<th>Blockout</th>
<th>Maximum Deflection</th>
<th>Working Width</th>
<th>FHWA Letter No.</th>
<th>System Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>MGSDF-1 MwRSF,2006 (42)¹</td>
<td>31 inches (787 mm)</td>
<td>5 ft-9 inch long 7/4 inch dia Douglas fir wood posts</td>
<td>6 ft-3 inch</td>
<td>6x8x14½ inch &amp; 6x5x14¼ inch wood</td>
<td>35.5 inches (902 mm)</td>
<td>60.2 inches (1529 mm)</td>
<td>5.02 ft (1.53 m)</td>
<td>B175</td>
</tr>
<tr>
<td>MGSSP-1 MwRSF,2006 (42)¹</td>
<td>31 inches (787 mm)</td>
<td>5 ft-9 inch long 8 inch dia Ponderosa pine posts</td>
<td>6 ft-3 inch</td>
<td>6x8x14½ inch &amp; 6x5x14¼ inch wood</td>
<td>27.8 inches (705 mm)</td>
<td>37.6 inches (956 mm)</td>
<td>4.05 ft (1.23 m)</td>
<td>B175</td>
</tr>
<tr>
<td>400001-TGS1 TTI, 2007 (43)²</td>
<td>31 inches (787 mm)</td>
<td>6-ft long W6×8.5 steel</td>
<td>6 ft-3 inch</td>
<td>N/A</td>
<td>31 inches (787 mm)</td>
<td>38.4 inches (975 mm)</td>
<td>3.4 ft (1.04 m)</td>
<td>N/A</td>
</tr>
<tr>
<td>GMS-6 SwRI, 2007 (44)²</td>
<td>27¾ inches (702 mm)</td>
<td>6-ft long W6×8.5 steel</td>
<td>6 ft-3 inch</td>
<td>N/A</td>
<td>31.9 inches (810 mm)</td>
<td>52 inches (1320 mm)</td>
<td>N/A</td>
<td>B150A</td>
</tr>
<tr>
<td>GMS-7 SwRI, 2007 (45)²</td>
<td>27¾ inches (702 mm)</td>
<td>6-ft long W6×8.5 steel</td>
<td>12 ft-6 inch</td>
<td>N/A</td>
<td>20.9 inches (530 mm)</td>
<td>59.8 inches (1520 mm)</td>
<td>N/A</td>
<td>B150B</td>
</tr>
<tr>
<td>057073112 Holmes Solutions, 2007 (46)¹</td>
<td>31 inches (787 mm)</td>
<td>6 ft-6 inch long U-channel steel (Nucor Grade SP-80, galvanized)</td>
<td>6 ft-3 inch</td>
<td>N/A</td>
<td>31.5 inches (800 mm)</td>
<td>41.3 inches (1050 mm)</td>
<td>N/A</td>
<td>B162</td>
</tr>
</tbody>
</table>

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).

<table>
<thead>
<tr>
<th>Test No. Agency, Year</th>
<th>Rail Height</th>
<th>Post</th>
<th>Blockout</th>
<th>Maximum Deflection</th>
<th>Working Width</th>
<th>FHWA Letter No.</th>
<th>System Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>05707b3111 Holmes Solutions, 2007 (46)</td>
<td>27 inches (686 mm)</td>
<td>6 ft-6 inch long U-channel steel (Nucor Grade SP-80)</td>
<td>6 ft-3 inch</td>
<td>4×8×14 in Recycled plastic</td>
<td>35.4 inches (900 mm)</td>
<td>45.3 inches (1150 mm)</td>
<td>N/A B162</td>
</tr>
<tr>
<td>0000-0-0-00-1 Holmes Solutions, 2008 (47)</td>
<td>27 inches (686 mm)</td>
<td>6 ft-6 inch long W6×9 steel and 6 ft long U-channel steel³</td>
<td>6 ft-3 inch</td>
<td>Original plastic</td>
<td>38.6 inches (980 mm)</td>
<td>56.7 inches (1440 mm)</td>
<td>5.41 ft (1.65 m)</td>
</tr>
</tbody>
</table>

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.
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 (6¾×8¼×14¼ 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).

![Figure 3.7 Typical Thrie-beam Guardrail Cross Section.](image)

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.

<table>
<thead>
<tr>
<th>Test No. Agency, Year</th>
<th>Rail Height</th>
<th>Post Size and Material</th>
<th>Post Spacing</th>
<th>Blockout</th>
<th>Maximum Deflection</th>
<th>Working Width</th>
<th>FHWA Letter No.</th>
<th>System Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>471470-30 TTI, 1995 (18)</td>
<td>34 inches (864 mm)</td>
<td>6 ft-9¼ inch long W6×9 steel</td>
<td>6 ft-3 inch</td>
<td>M14×18 spacer with cutout</td>
<td>24 inches (610 mm)</td>
<td>40.2 inches (1020 mm)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>404211-11 TTI, 1998 (49)</td>
<td>31.7 inches (804 mm)</td>
<td>6-ft-9 in long 6×7¾ inch wood⁴</td>
<td>6 ft-3 inch</td>
<td>6×7/8 ×21¼ inch routed wood⁵</td>
<td>15.4 inches (390 mm)</td>
<td>26.6 inches (676 mm)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>404211-10 TTI, 1999 (50)</td>
<td>31.7 inches² (804 mm)</td>
<td>6 ft-9 inch long W6×8.5 steel</td>
<td>6 ft-3 inch</td>
<td>6×7/8 ×21¼ inch routed wood⁵</td>
<td>16.5 inches (420 mm)</td>
<td>22.8 inches (580 mm)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>54-1108-001 E-TECH Inc., 2004 (51)²</td>
<td>31.5 inches (801 mm)</td>
<td>5 ft-11 inch long 3.9×5.5 inch C-Post</td>
<td>6 ft-7 inch</td>
<td>4×5½×21¾ in C section steel</td>
<td>15.7 inches (400 mm)</td>
<td>19.7 inches (500 mm)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>220570-7 TTI, 2006 (52)²</td>
<td>39 inches (991 mm)</td>
<td>6-ft long W6×8.5 SYLP steel</td>
<td>6 ft-3 inch</td>
<td>N/A</td>
<td>23.4 inches (595 mm)</td>
<td>24.7 inches (627 mm)</td>
<td>2.1 ft (0.63 m)</td>
<td>N/A</td>
</tr>
<tr>
<td>GMS-3 SwRI, 2006 (53)⁶</td>
<td>39 inches (991 mm)</td>
<td>6-ft long W6×8.5 steel</td>
<td>6 ft-3 inch</td>
<td>N/A</td>
<td>33.9 inches (860 mm)</td>
<td>51.2 inches (1300 mm)</td>
<td>N/A</td>
<td>B156</td>
</tr>
</tbody>
</table>

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.

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.

<table>
<thead>
<tr>
<th>Test No. Agency, Year</th>
<th>Rail Height</th>
<th>Post</th>
<th>Blockout</th>
<th>Maximum Deflection</th>
<th>Working Width</th>
<th>FHWA Letter No.</th>
<th>System Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buffalo Rail MwRSF, 1995 (54)</td>
<td>30.8 inches (782 mm)</td>
<td>6-ft long 6×8 inch wood</td>
<td>8.2 ft</td>
<td>Two 6×8×17¼ inch routed wood</td>
<td>22.3 inches (567 mm)</td>
<td>33.5 inches (851 mm)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

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 (5 7/8 × 7 7/8 × 14 1/4 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 (6×8×14 1/4 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>
<thead>
<tr>
<th>Test No. Agency, Year</th>
<th>Rail Height</th>
<th>Post</th>
<th>Blockout</th>
<th>Maximum Deflection</th>
<th>Working Width</th>
<th>FHWA Letter No.</th>
<th>System Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>OLS-3 MwRSF, 1999 (55)¹</td>
<td>27.8 inches (706 mm)</td>
<td>6 ft long 5⅛×7⅛ inch CRT wood post</td>
<td>25 ft (center) 6 ft-3 inch (otherelse)</td>
<td>Two 5⅛×7⅛ ×14¼ inch Wood (Post 9-14)</td>
<td>40 inches (1,016 mm)</td>
<td>57.1 inches (1,450 mm)</td>
<td>N/A</td>
</tr>
<tr>
<td>NEC-2 MwRSF, 2000 (56)¹</td>
<td>27.8 inches (706 mm)</td>
<td>6 ft long W6×9 steel</td>
<td>6 ft-3 inch</td>
<td>6×8× 14¼ inch routed wood</td>
<td>28.4 inches (721 mm)</td>
<td>42.2 inches (1072 mm)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

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 (5-⅛×7-⅝×14.2 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>
<thead>
<tr>
<th>Test No. Agency, Year</th>
<th>Rail Height</th>
<th>Post</th>
<th>Blockout</th>
<th>Maximum Deflection</th>
<th>Working Width</th>
<th>FHWA Letter No.</th>
<th>System Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOSW-1 MwRSF, 2000 (57)</td>
<td>27.8 inches (706 mm)</td>
<td>7 ft long W6×9 steel (Post 12-30)</td>
<td>3 ft-1.5 inch (Post 12-30)</td>
<td>5½×7½ ×14⅛ inch wood</td>
<td>23.1 inches (587 mm)</td>
<td>32.3 inches (821 mm)</td>
<td>N/A</td>
</tr>
<tr>
<td>MGS221-2 MwRSF,2006 (58)</td>
<td>31 inches (787 mm)</td>
<td>9 ft long W6×9 steel (Post9-20)</td>
<td>6 ft-3 inch</td>
<td>6×12×14¼ inch wood</td>
<td>42 inches (1067 mm)</td>
<td>56.5 inches (1436 mm)</td>
<td>5.35 ft (1.63m)</td>
</tr>
<tr>
<td>MGSAS-1 MwRSF, 2006 (59)</td>
<td>31 inches (787 mm)</td>
<td>6 ft long W6×9 steel</td>
<td>6 ft-3 inch</td>
<td>6×12×14¼ inch wood</td>
<td>34.3 inches (870 mm)</td>
<td>57.6 inches (1464 mm)</td>
<td>6.9 ft (2.1 m)</td>
</tr>
</tbody>
</table>

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.

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.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Rail Height</th>
<th>Post Size and Material</th>
<th>Spacing</th>
<th>Blockout</th>
<th>Maximum Deflection</th>
<th>Working Width</th>
<th>FHWA Letter No.</th>
<th>System Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>KC-1, MwRSF, 2001 (60)</td>
<td>27.8 inches (706 mm)</td>
<td>3.1 ft long W6×9 steel (Post 15-27)</td>
<td>3 ft-1.5 inch (Post 15-27)</td>
<td>6×8×14 inch routed wood</td>
<td>15.8 inches (401 mm)</td>
<td>16.4 inches (416 mm)</td>
<td>2.95 ft (0.9 m)</td>
<td>N/A</td>
</tr>
<tr>
<td>LSC-1, MwRSF, 2006 (61)</td>
<td>31 inches (787 mm)</td>
<td>6 ft long 6×8 in CRT wood (Post 11-16)</td>
<td>6 ft-3 inch (Post 1-13, 14-26) 25 ft (Post 13-14 in culvert)</td>
<td>6×12×14 ¼ inch wood</td>
<td>28.5 inches (724 mm)</td>
<td>92.2 inches (2343 mm)</td>
<td>7.79 ft (2.37 m)</td>
<td>B189</td>
</tr>
<tr>
<td>LSC-2, MwRSF, 2006 (61)</td>
<td>31 inches (787 mm)</td>
<td>6 ft long 6×8 in CRT wood (Post 11-16)</td>
<td>6 ft-3 inch (Post 1-13, 14-26) 25 ft (Post 13-14 in culvert)</td>
<td>6×12×14 ¼ inch wood</td>
<td>54 inches (1372 mm)</td>
<td>77.5 inches (1968 mm)</td>
<td>7 ft (2.13 m)</td>
<td>B189</td>
</tr>
</tbody>
</table>

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.

![Diagram of 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.

<table>
<thead>
<tr>
<th>Test No. Agency, Year</th>
<th>Rail Height</th>
<th>Post</th>
<th>Blockout</th>
<th>Maximum Deflection</th>
<th>Working Width</th>
<th>FHWA Letter No.</th>
<th>System Configuration</th>
</tr>
</thead>
<tbody>
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<td></td>
</tr>
<tr>
<td>FR-1 MwRSF, 2005 (63)</td>
<td>31 inches (787 mm)</td>
<td>6 ft long W6×9 steel</td>
<td>6 ft-3 inch</td>
<td>6×12×14¼ inch wood</td>
<td>44.9 inches (1140 mm)</td>
<td>66.3 inches (1684 mm)</td>
<td>5.9 ft (1.8 m)</td>
</tr>
<tr>
<td>FR-2 MwRSF, 2005 (63)</td>
<td>31 inches (787 mm)</td>
<td>6 ft long W6×9 steel</td>
<td>6 ft-3 inch</td>
<td>6×12×14¼ inch wood</td>
<td>45.5 inches (1156 mm)</td>
<td>75.8 inches (1925 mm)</td>
<td>7.32 ft (2.23m)</td>
</tr>
<tr>
<td>FR-4 MwRSF, 2006 (63)</td>
<td>31 inches (787 mm)</td>
<td>6 ft long W6×9 steel</td>
<td>6 ft-3 inch</td>
<td>6×12×14¼ inch wood</td>
<td>69 inches (1753 mm)</td>
<td>75.6 inches (1919 mm)</td>
<td>8.12 ft (2.48 m)</td>
</tr>
</tbody>
</table>

1: The report used both SI and USC units.
N/A = Not Available
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/).
REFERENCES


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>
<thead>
<tr>
<th>Guardrail Age</th>
<th>Agency</th>
<th>Test No.</th>
<th>Year</th>
<th>Rail Height</th>
<th>Post Length</th>
<th>Rail Type</th>
<th>Rail Size</th>
<th>Rail Spacing</th>
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<td>471470-26</td>
<td>1994</td>
<td>685.8 mm</td>
<td>1626 mm long</td>
<td>152x203 wood</td>
<td>1900 mm</td>
<td>152x203x356 wood</td>
<td>690 mm</td>
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<td>2 12 gauge TTI</td>
<td>405421-1</td>
<td>1995</td>
<td>706.0 mm *</td>
<td>1830 mm long</td>
<td>W150x12.6 steel</td>
<td>1900 mm</td>
<td>150x200x360 timber</td>
<td>700 mm</td>
</tr>
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<td>3 12 gauge TTI</td>
<td>403591-1</td>
<td>1995</td>
<td>706.0 mm *</td>
<td>1900 mm long</td>
<td>184 mm dia. wood</td>
<td>1900 mm</td>
<td>146x146x356 wood</td>
<td>790 mm</td>
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<td>400001-MPT1</td>
<td>1996</td>
<td>706.0 mm *</td>
<td>1830 mm long</td>
<td>W150x13.5 steel</td>
<td>1905 mm</td>
<td>152x200x356 recycled wood</td>
<td>720 mm</td>
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<tr>
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<td>439637-1</td>
<td>1997</td>
<td>706.0 mm *</td>
<td>1676 mm long</td>
<td>W150x13.5 steel</td>
<td>1905 mm</td>
<td>152x152x356 routed wood</td>
<td>450 mm</td>
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<td>400001-APL1</td>
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<td>706.0 mm *</td>
<td>1486 mm long</td>
<td>152x191 recycled wood</td>
<td>1905 mm</td>
<td>150x200x360 timber</td>
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<td>706.0 mm *</td>
<td>1800 mm long</td>
<td>150x200 wood</td>
<td>1905 mm</td>
<td>150x200x350 wood</td>
<td>860 mm</td>
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<td>473750-3</td>
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<td>1600 mm long</td>
<td>S75x8 steel</td>
<td>3810 mm</td>
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<td>1600 mm long</td>
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<td>155x200x360 Recycled plastic</td>
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<td>150x200x355 wood</td>
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<td>1829 mm long</td>
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<td>1905 mm</td>
<td>152x203x356 routed wood</td>
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<td>1600 mm long</td>
<td>HALCO-X-40 steel</td>
<td>1900 mm</td>
<td>155x200x360 routed wood</td>
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<td>178 mm dia. wood</td>
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<td>152x203x356 routed wood</td>
<td>570 mm</td>
<td>688 mm</td>
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<td>14 12 gauge TTI</td>
<td>400001-MON1</td>
<td>2002</td>
<td>706.0 mm</td>
<td>1830 mm long</td>
<td>W150x13.5 steel</td>
<td>1905 mm</td>
<td>152x203x356 Mondom polyethylene</td>
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<td>15 12 gauge MwRSF</td>
<td>NPG-4</td>
<td>2002</td>
<td>787.0 mm</td>
<td>1829 mm long</td>
<td>W152x13.4 steel</td>
<td>1905 mm</td>
<td>152x205x356 routed wood</td>
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<td>16 12 gauge MwRSF</td>
<td>NPG-5</td>
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<td>787.0 mm</td>
<td>1829 mm long</td>
<td>W152x13.4 steel</td>
<td>1905 mm</td>
<td>152x205x356 routed wood</td>
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<td>17 12 gauge MwRSF</td>
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<td>1372 mm</td>
<td>1968 mm</td>
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Table B.2 Excel Sheet Entries (SI units) (Continued)
Table B.3 Excel Sheet Entries (SI units) (Continued)

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<th>Agency</th>
<th>Test No.</th>
<th>Year</th>
<th>Rail Height</th>
<th>Post Length</th>
<th>Size</th>
<th>Type</th>
<th>Spacing</th>
<th>Blockout Maximum Deflection Width</th>
<th>Working Width</th>
<th>Test designation</th>
<th>HWA Approv</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>51 with various flares</td>
<td>MwRSF</td>
<td>FR-1</td>
<td>2005</td>
<td>787.0 mm</td>
<td>1829 mm</td>
<td>W152x13.4 steel</td>
<td>1905 mm</td>
<td>152x305x362 wood</td>
<td>1140 mm</td>
<td>1684 mm</td>
<td>1.80 m</td>
<td>NCHRP 350 3-11</td>
<td>N/A</td>
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<tr>
<td>52 with various flares</td>
<td>MwRSF</td>
<td>FR-2</td>
<td>2005</td>
<td>787.0 mm</td>
<td>1829 mm</td>
<td>W152x13.4 steel</td>
<td>1905 mm</td>
<td>152x305x362 wood</td>
<td>1156 mm</td>
<td>1925 mm</td>
<td>2.23 m</td>
<td>NCHRP 350 3-11</td>
<td>N/A</td>
</tr>
<tr>
<td>53 with various flares</td>
<td>MwRSF</td>
<td>FR-4</td>
<td>2005</td>
<td>787.0 mm</td>
<td>1829 mm</td>
<td>W152x13.4 steel</td>
<td>1905 mm</td>
<td>152x305x362 wood</td>
<td>1753 mm</td>
<td>1919 mm</td>
<td>2.48 m</td>
<td>NCHRP 350 3-11</td>
<td>N/A</td>
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</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Guardrail Agency</th>
<th>Test No.</th>
<th>Year</th>
<th>Rail Height</th>
<th>Post Size</th>
<th>Post Type</th>
<th>Blockout Spacing</th>
<th>Maximum Deflection</th>
<th>Working Width</th>
<th>Test designation</th>
<th>HWA Approval Letter</th>
<th>Unit SI or USC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 12 gauge TTI 471470-26</td>
<td>1994</td>
<td>27.0 in</td>
<td>5 ft-4 in. long</td>
<td>6×8 in.</td>
<td>wood</td>
<td>6×6-1/4 in.</td>
<td>6-8-1/14 in. wood</td>
<td>27.2 in.</td>
<td>32.3 in.</td>
<td>N/A</td>
<td>NCHRP 350 3-11</td>
</tr>
<tr>
<td>2 12 gauge TTI 405421-1</td>
<td>1995</td>
<td>27.8 in *</td>
<td>6 ft long</td>
<td>W6×8.5</td>
<td>steel</td>
<td>6×6-3 in.</td>
<td>5-7-1/8-7-7-8/14-1/8 in.</td>
<td>27.6 in.</td>
<td>39.4 in.</td>
<td>N/A</td>
<td>NCHRP 350 3-11</td>
</tr>
<tr>
<td>3 12 gauge TTI 405391-1</td>
<td>1995</td>
<td>27.8 in *</td>
<td>6-8-3 in. long</td>
<td>7-1/4 in. dia wood</td>
<td>6×6-3 in.</td>
<td>5-3-3/4-5-3-4-14 in.</td>
<td>wood</td>
<td>31.1 in.</td>
<td>43.3 in.</td>
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<td>NCHRP 350 3-11</td>
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<tr>
<td>4 12 gauge TTI 400001-MPT</td>
<td>1996</td>
<td>27.8 in *</td>
<td>6 ft long</td>
<td>W6×9</td>
<td>steel</td>
<td>6×6-3 in.</td>
<td>6-7-8-7-8-14 in.</td>
<td>28.3 in.</td>
<td>44.5 in.</td>
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</tr>
<tr>
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<td>1997</td>
<td>27.8 in *</td>
<td>5 ft-6 in. long</td>
<td>W6×9</td>
<td>steel</td>
<td>6×6-3 in.</td>
<td>6-6-14 in.</td>
<td>17.7 in.</td>
<td>29.5 in.</td>
<td>N/A</td>
<td>NCHRP 350 3-11</td>
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<td>6 12 gauge TTI 400001-APL1</td>
<td>2000</td>
<td>27.8 in</td>
<td>5-10-1/2 in. long</td>
<td>6×7-1/2 in. recycled wood</td>
<td>6×6-3 in.</td>
<td>6-6-14 in.</td>
<td>17.8 in.</td>
<td>29.5 in.</td>
<td>5.47 ft</td>
<td>NCHRP 350 3-11</td>
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<td>7 12 gauge TTI 404201-1</td>
<td>2000</td>
<td>27.8 in *</td>
<td>6 ft-11 in. long</td>
<td>5-7-8-7-8-7-8 in.</td>
<td>wood</td>
<td>6×6-3 in.</td>
<td>6-7-8-7-8-14 in. wood</td>
<td>33.9 in.</td>
<td>40.6 in.</td>
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<td>NCHRP 350 3-11</td>
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<tr>
<td>8 12 gauge TTI 473750-3</td>
<td>2000</td>
<td>32.3 in</td>
<td>5 ft-3 in. long</td>
<td>S3x5.7</td>
<td>steel</td>
<td>12 ft-6 in.</td>
<td>steel</td>
<td>64.6 in.</td>
<td>83.5 in.</td>
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<tr>
<td>9 12 gauge TTI 400001-CPF1</td>
<td>2001</td>
<td>27.8 in</td>
<td>5 ft-3 in. long</td>
<td>HALCO-X-48</td>
<td>steel</td>
<td>6×6-3 in.</td>
<td>6-1-8x7-7-8-14-1/8 in.</td>
<td>12.8 in.</td>
<td>31.9 in.</td>
<td>3.80 ft</td>
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<tr>
<td>10 12 gauge TTI 400001-ILP2</td>
<td>2001</td>
<td>27.8 in</td>
<td>5 ft-4 in. long</td>
<td>5-7-8-7-7-7/8 in.</td>
<td>wood</td>
<td>6×6-3 in.</td>
<td>5-7-8-7-8-14-1/8 in.</td>
<td>13.4 in.</td>
<td>31.1 in.</td>
<td>2.87 ft</td>
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<tr>
<td>11 12 gauge TTI 441622-1</td>
<td>2001</td>
<td>27.0 in</td>
<td>6 ft long</td>
<td>W6×9</td>
<td>steel</td>
<td>6×6-14 in.</td>
<td>31.3 in.</td>
<td>43.3 in.</td>
<td>3.43 ft</td>
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<td>B 64B</td>
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<tr>
<td>12 12 gauge E-TECH Inc. 41-1655-001</td>
<td>2001</td>
<td>27.8 in *</td>
<td>5 ft-3 in. long</td>
<td>HALCO-X-40</td>
<td>steel</td>
<td>6×6-14 in.</td>
<td>27.6 in.</td>
<td>51.2 in.</td>
<td>N/A</td>
<td>NCHRP 350 3-11</td>
<td>B 80A</td>
</tr>
<tr>
<td>13 12 gauge TTI 441622-2</td>
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<td>27.0 in</td>
<td>6 ft-11 in. long</td>
<td>5 in. dia wood</td>
<td>6×6-14 in.</td>
<td>22.4 in.</td>
<td>27.1 in.</td>
<td>3.88 ft</td>
<td>NCHRP 350 3-11</td>
<td>B 64B</td>
<td>SI</td>
</tr>
<tr>
<td>14 12 gauge TTI 400001-MON</td>
<td>2002</td>
<td>27.8 in</td>
<td>6 ft long</td>
<td>W6×9</td>
<td>steel</td>
<td>6×6-14 in.</td>
<td>10.4 in.</td>
<td>33.0 in.</td>
<td>3.94 ft</td>
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<tr>
<td>15 12 gauge MwRSF NPG-4</td>
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<td>6 ft-3 in. long</td>
<td>W6×9</td>
<td>steel</td>
<td>6×12-14 in.</td>
<td>25.7 in.</td>
<td>43.1 in.</td>
<td>4.13 ft</td>
<td>NCHRP 350 3-11</td>
<td>B 133</td>
</tr>
<tr>
<td>16 12 gauge MwRSF NPG-5</td>
<td>2002</td>
<td>31.0 in</td>
<td>6 ft long</td>
<td>W6×9</td>
<td>steel</td>
<td>6×12-14 in.</td>
<td>24.1 in.</td>
<td>40.3 in.</td>
<td>4.77 ft</td>
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<td>B 133</td>
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<tr>
<td>17 12 gauge MwRSF NPG-6</td>
<td>2002</td>
<td>31.0 in</td>
<td>6 ft long</td>
<td>W6×9</td>
<td>steel</td>
<td>6×12-14 in.</td>
<td>12.0 in.</td>
<td>17.6 in.</td>
<td>3.05 ft</td>
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<td>B 133</td>
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<td>18 12 gauge MwRSF PR-1</td>
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<td>27.8 in</td>
<td>4-5-1/2 in. long</td>
<td>W6×9</td>
<td>steel</td>
<td>6×8-14 in.</td>
<td>N/A</td>
<td>38.2 in.</td>
<td>3.31 ft</td>
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<td>B 64B</td>
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<tr>
<td>19 12 gauge SwRI N/A_1</td>
<td>2002</td>
<td>27.8 in</td>
<td>6 ft long</td>
<td>O-post steel</td>
<td>6×8-14 in.</td>
<td>N/A</td>
<td>26.0 in.</td>
<td>N/A</td>
<td>N/A</td>
<td>NCHRP 350 3-11</td>
<td>N/A</td>
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<td>20 12 gauge SwRI N/A_2</td>
<td>2002</td>
<td>27.8 in</td>
<td>6 ft long</td>
<td>O-post steel</td>
<td>6×8-14 in.</td>
<td>N/A</td>
<td>26.0 in.</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>21 12 gauge E-TECH Inc. 41-1792-001</td>
<td>2003</td>
<td>27.8 in</td>
<td>6 ft-3 in. long</td>
<td>HALCO-X-44</td>
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<td>27.6 in.</td>
<td>2.68 ft</td>
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<td>B 80C</td>
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<tr>
<td>22 12 gauge MwRSF 2214MG -1</td>
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<td>31.0 in</td>
<td>6 ft-3 in. long</td>
<td>W6×9</td>
<td>steel</td>
<td>6×12-14 in.</td>
<td>42.9 in.</td>
<td>57.0 in.</td>
<td>4.78 ft</td>
<td>MASH 3-11</td>
<td>N/A</td>
</tr>
<tr>
<td>23 12 gauge MwRSF 2214MG -2</td>
<td>2004</td>
<td>31.0 in</td>
<td>6 ft-3 in. long</td>
<td>W6×9</td>
<td>steel</td>
<td>6×12-14 in.</td>
<td>31.6 in.</td>
<td>43.9 in.</td>
<td>4.05 ft</td>
<td>MASH 3-11</td>
<td>N/A</td>
</tr>
<tr>
<td>24 12 gauge MwRSF 2214WB-2</td>
<td>2005</td>
<td>27.8 in</td>
<td>6 ft long</td>
<td>W6×9</td>
<td>steel</td>
<td>6×8-14 in.</td>
<td>33.3 in.</td>
<td>47.1 in.</td>
<td>4.58 ft</td>
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<td>N/A</td>
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<tr>
<td>25 12 gauge TTI 220570-8</td>
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<td>29.0 in</td>
<td>6 ft long</td>
<td>W6×8.5 SYLP</td>
<td>steel</td>
<td>6×8-14 in.</td>
<td>28.7 in.</td>
<td>37.4 in.</td>
<td>4.04 ft</td>
<td>NCHRP 350 3-11</td>
<td>N/A</td>
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<tr>
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<td>Test No.</td>
<td>Year</td>
<td>Rail Height</td>
<td>Post</td>
<td>Blockout</td>
<td>Maximum Deflection</td>
<td>Spacing</td>
<td>Working Length</td>
<td>Permanent</td>
<td>Dynamic Width</td>
<td>Working Width</td>
</tr>
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<td>27</td>
<td>SwRI</td>
<td>GMS-1</td>
<td>2006</td>
<td>51.0 in</td>
<td>6 ft long</td>
<td>W6×8.5 steel</td>
<td>6 ft-3 in</td>
<td>#/N/A</td>
<td>22.0 in</td>
<td>35.0 in</td>
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<tr>
<td>28</td>
<td>MwRSF</td>
<td>MGSDF-1</td>
<td>2006</td>
<td>51.0 in</td>
<td>6 ft-9 in long</td>
<td>7-1/4 in dia gus Fir w</td>
<td>6 ft-3 in</td>
<td>6×8×14-1/4 in wood</td>
<td>35.5 in</td>
<td>60.2 in</td>
<td>5.02 ft</td>
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<td>29</td>
<td>MwRSF</td>
<td>MGSPP-1</td>
<td>2006</td>
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<td>6 ft-9 in long</td>
<td>8 in dia Pine wood</td>
<td>6 ft-3 in</td>
<td>6×8×14-1/4 in wood</td>
<td>27.8 in</td>
<td>37.6 in</td>
<td>4.04 ft</td>
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<tr>
<td>30</td>
<td>TTI</td>
<td>400001-TGSI</td>
<td>2007</td>
<td>51.0 in</td>
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<td>6 ft-3 in</td>
<td>#/N/A</td>
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<td>3.41 ft</td>
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<td>SRI</td>
<td>GMS-6</td>
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<td>6 ft long</td>
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<td>6 ft-3 in</td>
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<td>SRI</td>
<td>GMS-7</td>
<td>2007</td>
<td>27.6 in</td>
<td>6 ft long</td>
<td>W6×8.5 steel</td>
<td>12 ft-6 in</td>
<td>#/N/A</td>
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<td>59.8 in</td>
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<td>2007</td>
<td>51.0 in</td>
<td>6 ft-6 in long</td>
<td>L-channel Nuco steel</td>
<td>6 ft-3 in</td>
<td>#/N/A</td>
<td>31.5 in</td>
<td>41.3 in</td>
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<td>Holmes Solution</td>
<td>057073111</td>
<td>2007</td>
<td>51.0 in</td>
<td>6 ft-6 in long</td>
<td>L-channel Nuco steel</td>
<td>6 ft-3 in</td>
<td>4×8×14 in Recycled</td>
<td>35.4 in</td>
<td>45.3 in</td>
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<td>Holmes Solution</td>
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<td>6 ft-6 in long</td>
<td>L-channel Nuco steel</td>
<td>6 ft-3 in</td>
<td>4×8×14 in Recycled</td>
<td>35.4 in</td>
<td>45.3 in</td>
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<td>Thrie Beam</td>
<td>TTI</td>
<td>471470-30</td>
<td>1995</td>
<td>51.0 in</td>
<td>6 ft-9-1/4 in long</td>
<td>W6×9 steel</td>
<td>6 ft-3 in</td>
<td>M14×18 in spacer w/ cutout</td>
<td>24.0 in</td>
<td>40.2 in</td>
</tr>
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<td>37</td>
<td>Thrie Beam</td>
<td>TTI</td>
<td>404211-11</td>
<td>1998</td>
<td>51.0 in</td>
<td>6 ft-9 in long</td>
<td>6×7-7/8 in wood</td>
<td>6 ft-3 in</td>
<td>6×7-7/8×21-3/4 in routed wood</td>
<td>15.4 in</td>
<td>26.6 in</td>
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<td>38</td>
<td>Thrie Beam</td>
<td>TTI</td>
<td>404211-10</td>
<td>1999</td>
<td>51.0 in</td>
<td>6 ft-9 in long</td>
<td>6×8-1/4 in steel</td>
<td>6 ft-3 in</td>
<td>6×7-7/8×21-3/4 in routed wood</td>
<td>16.5 in</td>
<td>22.8 in</td>
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<td>Thrie Beam</td>
<td>E-TECH Inc.</td>
<td>54-1108-001</td>
<td>2004</td>
<td>51.0 in</td>
<td>5 ft-11 in long</td>
<td>4×5-1/2 in C-Post</td>
<td>6 ft-3 in</td>
<td>4x5-1/2x1-3/4 in C-Blockout</td>
<td>15.7 in</td>
<td>19.7 in</td>
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<td>Thrie Beam</td>
<td>TTI</td>
<td>220570-7</td>
<td>2006</td>
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<td>6 ft long</td>
<td>W6×8.5 SYLP</td>
<td>6 ft-3 in</td>
<td>#/N/A</td>
<td>23.4 in</td>
<td>24.7 in</td>
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<td>Thrie Beam</td>
<td>SRI</td>
<td>GMS-3</td>
<td>2006</td>
<td>51.0 in</td>
<td>6 ft long</td>
<td>W6×8.5 steel</td>
<td>6 ft-3 in</td>
<td>#/N/A</td>
<td>33.9 in</td>
<td>51.2 in</td>
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<tr>
<td>42</td>
<td>13 gauge</td>
<td>MwRSF</td>
<td>Buffalo Rail</td>
<td>1995</td>
<td>51.0 in</td>
<td>6 ft long</td>
<td>6×8 in wood</td>
<td>8.2 ft</td>
<td>6×8×17-1/4 in routed wood</td>
<td>22.3 in</td>
<td>33.5 in</td>
</tr>
<tr>
<td>43</td>
<td>Nested</td>
<td>MwRSF</td>
<td>OLS-3</td>
<td>1999</td>
<td>27.8 in</td>
<td>6 ft long</td>
<td>5-7/8×7-7/8×. CRT post</td>
<td>25 ft</td>
<td>5-7/8×7-7/8×14-1/8 in 2 routed wood</td>
<td>40.0 in</td>
<td>57.1 in</td>
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<td>44</td>
<td>Nested</td>
<td>MwRSF</td>
<td>NEC-2</td>
<td>2000</td>
<td>27.8 in</td>
<td>6 ft long</td>
<td>W6×9 steel</td>
<td>6 ft-3 in</td>
<td>6×8×14-1/8 in wood</td>
<td>28.4 in</td>
<td>42.2 in</td>
</tr>
<tr>
<td>45</td>
<td>W-beam on slop</td>
<td>MwRSF</td>
<td>MOSW-1</td>
<td>2000</td>
<td>27.8 in</td>
<td>7 ft long</td>
<td>W6×9 steel</td>
<td>#/N/A</td>
<td>5-7/8×7-7/8×14-1/8 in wood</td>
<td>23.1 in</td>
<td>32.3 in</td>
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<tr>
<td>46</td>
<td>W-beam on slop</td>
<td>MwRSF</td>
<td>MGSS212-1</td>
<td>2006</td>
<td>31.0 in</td>
<td>9 ft long</td>
<td>W6×9 steel</td>
<td>6 ft-3 in</td>
<td>6×12-14-1/4 in wood</td>
<td>42.0 in</td>
<td>56.5 in</td>
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<tr>
<td>47</td>
<td>W-beam on slop</td>
<td>MwRSF</td>
<td>MGASAS-1</td>
<td>2006</td>
<td>31.0 in</td>
<td>9 ft long</td>
<td>W6×9 steel</td>
<td>6 ft-3 in</td>
<td>6×12-14-1/4 in wood</td>
<td>34.3 in</td>
<td>57.6 in</td>
</tr>
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<td>48</td>
<td>W-beam for culvert</td>
<td>MwRSF</td>
<td>KC-1</td>
<td>2001</td>
<td>27.8 in</td>
<td>3.1 ft long</td>
<td>W6×9 steel</td>
<td>#/N/A</td>
<td>6×8×14 in wood</td>
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<td>16.4 in</td>
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<td>W-beam for culvert</td>
<td>MwRSF</td>
<td>LSC-1</td>
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<td>6 ft long</td>
<td>6×8 in BCT</td>
<td>25 ft</td>
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<td>W-beam for culvert</td>
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<td>LSC-2</td>
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<td>6×8 in BCT</td>
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<td>6×12-14-1/4 in wood</td>
<td>54.0 in</td>
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<td>Post</td>
<td>Blockout</td>
<td>Maximum Deflection</td>
<td>Working Width</td>
<td>Test designation</td>
<td>HWA Approv.</td>
<td>Unit</td>
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<td>75.6 in</td>
<td>8.14 ft</td>
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