A MASH Compliant W-Beam Median Guardrail System

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Abstract

The W-beam median guardrail system is a common guardrail system used by many states as a median barrier in ditches and other median configurations. Unfortunately, the 27-inch design did not pass MASH evaluation criteria in the crash testing program of NCHRP project 22-14(03). In this paper, the researchers modeled and simulated MASH test 3-11 of the 27-inch W-beam median barrier and used the model in the evaluation of a new design of the W-beam median barrier. The simulation indicated that the new 31-inch W-beam median barrier would pass MASH evaluation criteria. Subsequently, MASH tests 3-10 and 3-11 were performed to evaluate the new design. Both tests passed MASH evaluation criteria. Hence, a new MASH complaint W-beam median barrier system is available for TxDOT and other state DOT’s to utilize as a median guardrail system.

Keywords: MASH, Guardrails, Median Barrier, Simulation.
INTRODUCTION

In NCHRP project 22-14(03) (1), Texas A&M Transportation Institute (TTI) researchers performed crash tests for several non-proprietary hardware. One of the systems tested under that project was the G4(1S) median barrier. This system presents a unique performance challenge due to the additional constraint of the posts imposed by the double-sided G4(1S) W-beam median barrier. The added post constraint delays the release of the post from the rail, which results in vehicle climb and vaulting due to a localized drop in rail height. Hence, there was a need to re-design the W-beam median guardrail system to pass MASH (Manual for Assessing Safety Hardware (2)), evaluation criteria.

BACKGROUND

The G4(1S) W-beam median barrier (American Association of State Highway and Transportation Officials (AASHTO) designation SGM04a with non-steel blocks) is a 27-inch tall, strong steel post, W-beam median barrier. In NCHRP project 22-14(03), the median barrier was constructed using 12-gauge W-beam guardrail elements attached to 6 ft long W6×8.5 steel posts spaced 6 ft-3 inch on center. The W-beam guardrail elements were offset from the posts using non-steel blockouts nominally 6 inch × 8 inch × 14 inch long.

The height of the G4(1S) W-beam median barrier test installation was 27 inches. The length-of-need for the installation was 100 ft. The front (impacted) rail was constructed with 37 ft-6 inch long terminals on each end and the rear rail was constructed with 50 ft long terminals on each end. The total overall test installation length was 200 ft.

A cross section of the G4(1S) W-beam median barrier is shown in Figure 1.

Two tests were performed under NCHRP Project 22-14(03) (1), MASH test 3-10 and MASH test 3-11. MASH test 3-10 involves a 1100C vehicle with test inertial mass of 2420 lb impacting the median barrier at an impact speed of 62.2 mi/h and at an angle of 25 degrees. MASH test 3-11 involves a 2270P vehicle weighing 5000 lb and impacting the median barrier at an impact speed of 62.2 mi/h and at an angle of 25 degrees. The W-beam median barrier was able to contain and redirect the 1100C vehicle in MASH test 3-10. However, it did not contain or redirect the 2270P vehicle in MASH test 3-11. During TTI test 476460-1-9(1), the left front tire...
and wheel of the 2270P vehicle rode up on post 14. Then, the front of the vehicle became airborne above the median barrier, and the vehicle lost contact with the barrier as it was airborne over the median barrier. This vaulting behavior is shown in Figure 2.

![Image](image1.jpg)

**FIGURE 2** The 2270P vehicle vaulting the 27-inch W-beam median barrier during MASH 3-11 test.

RESEARCH APPROACH

To improve the performance of the 27-in high median W-beam, TTI researchers analyzed the failed test and incorporated design changes that have the potential of rectifying the performance of the median W-beam barrier. First, the research team developed a detailed finite element model of the W-beam median rail to calibrate the model under the MASH test already conducted. The new Silverado vehicle model developed by the National Crash Analysis Center (NCAC, (3)) was used to simulate the MASH 2270P test vehicle.

In the model, the post comprised of different thicknesses to accurately represent the shape of a W6×9 steel post. A total of 18,240 shell elements were used for modeling the posts. Additionally, the W-beam model contains a more refined element mesh than the previously used W-beam models, so it can capture deformation more realistically. A total of 182,304 shell elements were used for modeling the W-beam segments (4). Both the post and the W-beam models are shown in Figure 3. The end terminals and the remaining portion of the length-of-need rail were represented by spring elements connected to each end of the modeled W-beam. These springs elements have a combined stiffness representative of typical end terminals.

![Image](image2.jpg)
FIGURE 3  Meshing scheme of the 8-ft Post Model (left) and the 12 gauge W-beam rail (right).

The vehicle model used for simulation was the Chevrolet Silverado model, which was developed by NCAC. This vehicle model represents the MASH 2270P test vehicle. The finite element model for the MASH 1100C test vehicle was not available at the time when this research was performed. The vehicle and 27-inch median W-beam barrier models are shown in Figure 4.

FIGURE 4 Finite Element model of the 27-inch median barrier.

The research team started by simulating the failed test using LS-DYNA (5) finite element code. The vaulting phenomena of the vehicle captured in the simulation as shown in Figure 5 below. Hence, the model is considered corroborated with the failed MASH test 3-11 and can be used as a tool to investigate the system performance once modified.
FIGURE 5  Simulation of the MASH 3-11 where the 2270P vehicle vaults over the 27-inch median barrier.
Design modifications included increasing the rail height from 27 inches to 31 inches and moving the splice location from at post to mid-span. The cross-section views of the new system design and the model are shown in Figure 6.

FIGURE 6  Model of the 31-inch median W-beam guardrail with the 2270P vehicle model.

SIMULATION RESULTS
Two simulations were conducted using LS-DYNA (5) finite element code. One was conducted with vehicular impact at post and the other with vehicular impact at mid-span.

1. TL 3-11 Mid-Span Impact
In the first simulation case, the analysis represents vehicular impact at mid-span of the guardrail. The modified barrier system was impacted by 2270P vehicle model at 62.2 mi/h and an angle of 25 degrees. The occupant risk assessments for this model are provided in TABLE 1, and vehicle behavior is shown in Figure 7.
TABLE 1  TRAP Output Summary for Mid-Span Impact Case

<table>
<thead>
<tr>
<th>Occupant Risk Factors</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact Velocity (m/s) at 0.1695 sec on left side of interior</td>
<td></td>
</tr>
<tr>
<td>x-direction:</td>
<td>6.7</td>
</tr>
<tr>
<td>y-direction:</td>
<td>-4.7</td>
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<tr>
<td>THIV (km/hr):</td>
<td>26.9</td>
</tr>
<tr>
<td>THIV (m/s):</td>
<td>7.5</td>
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<tr>
<td>Ridedown Acceleration (G's)</td>
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<tr>
<td>x-direction:</td>
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<tr>
<td>y-direction:</td>
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<tr>
<td>PHD (G's):</td>
<td>11.8</td>
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<tr>
<td>ASI:</td>
<td>0.78</td>
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<tr>
<td>Maximum 50 msec Moving Average Acceleration (G's)</td>
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<tr>
<td>x-direction:</td>
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<tr>
<td>y-direction:</td>
<td>4.9</td>
</tr>
<tr>
<td>z-direction:</td>
<td>2.3</td>
</tr>
</tbody>
</table>

FIGURE 7  Views of vehicle behavior in the at mid-span impact simulation case.

2. TL 3-11 At-Post Impact

The modified system was simulated under impact by the 2270P test at a post location instead of the mid-span using the same MASH TL 3-11 initial conditions of 62.2 mi/h and 25 degrees. The occupant risk assessment for this model is provided in TABLE 2  TRAP Output Summary and vehicle behavior is shown in Figure 8.

TABLE 2  TRAP Output Summary for At-Post Case

<table>
<thead>
<tr>
<th>Occupant Risk Factors</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact Velocity (m/s) at 0.1738 sec on left side of interior</td>
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<tr>
<td>x-direction:</td>
<td>6.1</td>
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<td>y-direction:</td>
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<tr>
<td>THIV (km/hr):</td>
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<tr>
<td>THIV (m/s):</td>
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<tr>
<td>Ridedown Acceleration (G's)</td>
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</tr>
<tr>
<td>x-direction:</td>
<td>-9.5</td>
</tr>
<tr>
<td>y-direction:</td>
<td>9.7</td>
</tr>
</tbody>
</table>
Both simulation cases indicated that the 31-inch W-beam median barrier is able to contain and redirect the test vehicle, and able to pass MASH evaluation criteria as presented in TABLE 1 and TABLE 2. Hence, the research team used the new design for the full-scale crash testing phase of the project.

**FULL SCALE CRASH TESTS**

**Test Article Design and Construction**

The constructed system is a 31-inch tall, strong steel post, W-beam median barrier. This (TxDOT) median barrier was constructed using 12-gauge W-beam guardrails attached to 6 ft long W6×8.5 steel posts spaced 6 ft-3 inch on center. The W-beam guardrails are offset from the posts using wood blockouts nominally 6 inch × 8 inch × 14 inch long. For this installation, the W-beam rail element joints were moved off the posts and centered mid-span between posts. **FIGURE** 9 depicts the cross-section of the TxDOT 31-inch W-Beam Median Barrier. Photographs of the completed installation are shown in Figure 10.
MASH Test 3-10

*MASH* test 3-10 involves an 1100C vehicle weighing 2420 lb and impacting the TxDOT 31-inch W-Beam Median Barrier at an impact speed of 62.2 mi/h and an angle of 25 degrees. The target impact point was 21 inches upstream of post 12. The 2006 Kia Rio used in the test weighed 2444 lb, and the actual impact speed and angle were 62.2 mi/h and 25.0 degrees, respectively. The actual impact point was 22 inches upstream of post 12.

The front bumper, hood, radiator and support, left front strut and tower, left front tire and wheel rim, left front fender, and left front door were damaged. The hood was pushed into the windshield which shattered the lower portion of the windshield. Maximum exterior crush to the 1100C vehicle was 13.0 inches in the side plane at the left front corner just above bumper height. No occupant compartment deformation was noted. Damage to the guardrail and the vehicle is shown in Figure 11.
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FIGURE 11  Vehicle and guardrail damage after MASH test 3-10.

Data from the accelerometer, located at the vehicle’s center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 20.0 ft/s at 0.115 s, the highest 0.010-s occupant ridedown acceleration was 9.6 Gs from 0.172 to 0.182 s, and the maximum 0.050-s average acceleration was -7.3 Gs between 0.076 and 0.126 s. In the lateral direction, the occupant impact velocity was 17.4 ft/s at 0.115 s, the highest 0.010-s occupant ridedown acceleration was 8.3 Gs from 0.155 to 0.165 s, and the maximum 0.050-s average was 6.9 Gs between 0.038 and 0.088 s. The guardrail was able to contain and redirect the vehicle. These data and other pertinent information are provided in Figure 12.
General Information
Test Agency.......................... Texas Transportation Institute (TTI)
Test Standard Test No. .......... MASH Test 3-10
TTI Test No. ........................ 490023-3
Test Date ........................... 2013-06-18

Test Article
Type.................................. Median Barrier
Name .................................. TxDOT 31-inch W-Beam Median Barrier
Installation Length ............... 156 ft
Material or Key Elements ...... 12-gauge W-beam at 31 inch height on
6 ft long W6×8.5 steel posts spaced
6 ft-3 inch on center with 6 inch ×
8 inch × 14 inch routed wood blockouts
with splice midspan between posts
Soil Type and Condition .... Standard soil, dry

Impact Conditions
Impact Velocity
Longitudinal .......................... 62.2 mi/h
Lateral ................................ 25.0 degrees
Location/orientation ................. 27 inches upstrm of post 12
Impact Severity ...................... 56.5 kip-ft

Exit Conditions
Speed ................................ Not obtainable
Angle ................................. Not obtainable

Occupant Risk Values
Impact Velocity
Longitudinal .......................... 20.0 ft/s
Lateral ................................ 17.4 ft/s
Ridedown Accelerations
Longitudinal ....................... 9.6 G
Lateral ............................ 8.3 G
THIV .................................. 7.8 m/s
PHD ................................. 11.0 G
ASI .................................. 0.94
Max. 0.050-s Average
Longitudinal ....................... 7.3 G
Lateral ............................ 6.9 G
Vertical ............................ -3.0 G

Post-Impact Trajectory
Stopping Distance .................. 132.5 ft dwnstrm
Aligned w/cntr rail

Vehicle Stability
Maximum Yaw Angle ............. 36 degrees
Maximum Pitch Angle ............ 9 degrees
Maximum Roll Angle .............. 11 degrees
Vehicle Snagging ................... No
Vehicle Pocketing ................. Yes/No

Test Article Deflections
Dynamic ............................. 25.4 inches
Permanent ......................... 20.25 inches
Working Width ...................... 33.6 inches
Vehicle Intrusion .................. 21.5 inches

Vehicle Damage
VDS .................................. 11KFQ5
CDC .................................. 11FLEW 4
Max. Exterior Deformation ........ 13.0 inches
OCDI ............................... LF000000
Max. Occupant Compartment
Deformation ....................... None

FIGURE 12 Summary of results for MASH test 3-10 on the TxDOT 31-inch W-Beam Median Barrier.
MASH Test 3-11

MASH test 3-11 involves a 2270P vehicle weighing 5000 lb and impacting the TxDOT 31-inch W-Beam Median Barrier at an impact speed of 62.2 mi/h and at an angle of 25 degrees. The target impact point was 10.5 ft upstream of post 13. The 2007 Dodge Ram 1500 pickup truck used in the test weighed 5017 lb, and the actual impact speed and angle were 63.0 mi/h and 25.4 degrees, respectively. The actual impact point was 10.8 ft upstream of post 13.

The left front tie rod, left front lower A-arm, left front frame rail, and left front hub assembly were deformed. Also damaged were the front bumper, grill, left front tire and wheel rim, left front fender, left front door, left rear door, left rear exterior bed, left rear tire, and rear bumper. Maximum exterior crush to the vehicle was 11.0 inches in the side plane at the left front corner just above bumper height. No occupant compartment deformation occurred. Damage to the guardrail and the vehicle is shown in Figure 13.

![Vehicle and guardrail damage after MASH test 3-11.](image)

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 19.0 ft/s at 0.151 s, the highest 0.010-s occupant ridedown acceleration was 10.2 Gs from 0.162 to 0.172 s, and the maximum 0.050-s average acceleration was -6.2 Gs between 0.050 and 0.100 s. In the lateral direction, the occupant impact velocity was 15.1 ft/s at 0.151 s, the highest 0.010-s occupant ridedown acceleration was 6.9 Gs from 0.192 to 0.202 s, and the maximum 0.050-s average was 4.5 Gs between 0.272 and 0.322 s. These data and other pertinent information from the test are provided in Figure 14.
FIGURE 14 Summary of results for MASH test 3-11 on the TxDOT 31-inch W-Beam Median Barrier.
RESULTS AND CONCLUSIONS

A new MASH compliant W-beam median barrier system was developed and tested successfully using MASH TL-3 conditions. Nonlinear finite element simulation was used to evaluate the system performance prior to testing. The modified median barrier system passed the evaluation criteria for both MASH tests 3-10 and 3-11. This modified system utilizes standard blockouts and standard post spacing. The system is 31 inches tall and has splices positioned off post locations. By having a MASH compliant W-beam median barrier, TxDOT and other states DOT’s will have the option of specifying this new design for implementation.

ACKNOWLEDGEMENTS

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