TESTING AND EVALUATION OF MISSOURI THRIE-BEAM BRIDGE RAIL SYSTEM AND TRANSITION
TESTING AND EVALUATION OF MISSOURI THRIE-BEAM BRIDGE RAIL SYSTEM AND TRANSITION

Study 87-4

Prepared for
MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT

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In Cooperation With
U. S. Department of Transportation
Federal Highway Administration

May 1988

"The opinions, findings, and conclusions expressed in this publication are not necessarily those of the Department of Transportation, Federal Highway Administration. This report does not constitute a standard, specification or regulation."
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I. INTRODUCTION

The Missouri Highway and Transportation Commission, in cooperation with the Federal Highway Administration (FHWA), contracted with the Texas Transportation Institute (TTI) to crash test and evaluate the performance of a thrie-beam bridge rail system and transition commonly used in the State of Missouri.

The scope of the project included the design and construction of a simulated bridge deck, fabrication and installation of the thrie-beam bridge rail and transition, conduct of three crash tests in accordance with specifications outlined in NCHRP (National Cooperative Highway Research Program) Report 230, and evaluation of the crash test data.

General descriptions of the study approach, including those of the bridge rail and transition, and the crash test and data analysis procedures, are presented in Section II of this report. Data and evaluation results of the three crash tests are described in Section III and a summary of findings and conclusions is presented in Section IV.
II. STUDY APPROACH

Description of Bridge Rail and Transition

The Missouri thrie-beam bridge rail consists of fabricated W6 x 20 posts spaced 6 ft. 3 in. apart with a C8 x 11.5 channel on top and a thrie-beam rail element. The posts sit directly on top of the bridge deck and the height from the bridge deck to the top of the C-channel is 30-5/8 inches. The heights from the bridge deck to the bottom and top of the thrie-beam are 11 and 31 inches, respectively.

The thrie-beam bridge rail transitions to a standard 27-inch high G4(15) W-beam guardrail with a 6 ft. 3 in. transition section. Two W6 x 20 posts spaced 3 ft. 1-1/2 in. apart are used for the transition section. The standard W-beam guardrail uses W6 x 8.5 posts and block-outs spaced 6 ft. 3 in. apart. The end of the W-beam guardrail is anchored to the ground with a turn-down terminal section.

The dimensions and details of the bridge rail and transition installation used in this study are shown in Figure 1 and photographs of the test installation are shown in Figure 2. The test bridge rail and transition was fabricated by a fabricator under subcontract to TTI.

The 77-ft bridge rail was installed on a simulated bridge deck of the same length. The simulated bridge deck was designed and constructed in accordance with standard bridge specifications used by the Missouri Highway and Transportation Commission, including steel reinforcement and anchorage details.

Description of Crash Tests

According to NCHRP Report 230, two crash tests are recommended for the evaluation of a bridge rail system and one crash test for the transition. The three crash tests conducted are as follows:

1. NCHRP Test Designation 12. 1,800 pound vehicle (1980 Honda Civic) impacting the bridge rail at a speed of 60 mph and an angle of 15 degrees. The point of impact was the centerline of the railing splice, approximately 38 feet downstream from the beginning of the bridge rail.

2. NCHRP Test Designation 10. 4,500 pound vehicle (1979 Oldsmobile Delta 88) impacting the bridge rail at a speed of 60 mph and an angle of 25 degrees. The point of impact was midway between the posts for the span
Figure 1. Missouri bridge rail specifications.
Figure 1. Missouri bridge rail specifications (continued).
Figure 2. Missouri thrie-beam bridge rail before test 0367-1.
containing the railing splice, approximately 41 feet downstream from the
beginning of the bridge rail.

3. NCHRP Test Designation 30. 4,500 pound vehicle (1982 Oldsmobile
Delta 88) impacting the bridge rail at a speed of 60 mph and an angle of 25
degrees. The point of impact was 15 feet upstream from the beginning of the
bridge rail.

The crash test and data analysis procedures were in accordance with
guidelines presented in NCHRP 230. The test vehicles were instrumented
with three rate transducers to measure roll, pitch, and yaw rates and a
triaxial accelerometer near the vehicle center of gravity to measure
acceleration levels. An uninstrumented 50 percentile male dummy was placed
in the driver seat for the 1,800-pound car test, but not for the 4,500-pound
car test.

The electronic signals from the accelerometers and transducers were
telemetered to a base station for recording on magnetic tape and for display
on a real-time strip chart. Provision was made for transmission of
calibration signals before and after the test, and accurate time reference
signal was simultaneously recorded with the data. Contact switches on the
bumper were actuated just prior to impact by wooden dowels to indicate the
elapsed time over a known distance to provide a measurement of impact
velocity. The initial contact also produced an "event" mark on the data
record to establish the exact instant of impact.

Photographic coverage of the tests included two high-speed cameras, one
overhead at the point of impact and the second in line with the barrier
downstream from the point of impact. The films from these high-speed
cameras were used to observe phenomena occurring during collision and to
obtain time-event, displacement and angular data. A 16-mm movie camera, a
3/4-inch videotape, and still cameras were also be used for documentary
purposes.

DATA ANALYSIS PROCEDURES

The analog data from the various accelerometers, transducers and load
cells were digitized, using a microcomputer, for analysis and evaluation of
performance. The digitized data were then analyzed using a number of
computer programs: DIGITIZE, VEHICLE, and PLOTANGLE. Brief descriptions on
each these computer programs are provided as follows.
The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, final occupant displacement, highest 0.010-second average. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period.

The VEHICLE program also uses digitized data from vehicle-mounted linear accelerometers to compute vehicle accelerations, areas enclosed by acceleration-time curves, changes in velocity, changes in momentum, instantaneous forces, average forces, and maximum average accelerations over 0.050-second intervals in each of three directions. The VEHICLE program plots acceleration versus time curves for the longitudinal, lateral, and vertical directions.

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate charts to compute angular displacement in degrees at 0.001-second intervals and then instructs a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. It should be noted that these angular displacements are sequence dependent with the sequence being yaw-pitch-roll for the data presented in this report. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.
III. CRASH TEST RESULTS

As mentioned previously, three crash tests recommended by NCHRP 230 were conducted on this three-beam bridge rail and transition. These three crash tests were:

1. NCHRP Test Designation 12. 1,800 pound vehicle (1980 Honda Civic) impacting the bridge rail at a speed of 60 mph and an angle of 15 degrees. The point of impact was the centerline of the railing splice, approximately 38 feet downstream from the beginning of the bridge rail.

2. NCHRP Test Designation 10. 4,500 pound vehicle (1979 Oldsmobile Delta 88) impacting the bridge rail at a speed of 60 mph and an angle of 25 degrees. The point of impact was midway between the posts for the span containing the railing splice, approximately 41 feet downstream from the beginning of the bridge rail.

3. NCHRP Test Designation 30. 4,500 pound vehicle (1982 Oldsmobile Delta 88) impacting the bridge rail at a speed of 60 mph and an angle of 25 degrees. The point of impact was 15 feet upstream from the beginning of the bridge rail.

Results from these three crash tests are presented as follows.

Test Number 1

A 1980 Honda Civic (shown in Figures 3 and 4) impacted the railing at 15.0 degrees and 59.6 miles per hour (95.9 km/h) using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 1,815 pounds (824 kg) and its gross static mass was 1,984 pounds (901 kg). The height to the lower edge of the vehicle bumper was 14.5 inches (36.8 cm) and 19.75 inches (50.2 cm) to the top of the bumper. Other dimensions and information on the vehicle are given in Figure 5.

The vehicle was free wheeling and unrestrained just prior to impact. The point of impact was the center of the railing splice, approximately 38 feet (11.6 m) downstream from the beginning of the bridge rail. Upon impact, the right front of the vehicle began to deform and shortly thereafter, the vehicle began to redirect and, at 0.099 second, the rear of the vehicle came into contact with the rail.

The vehicle lost contact with the rail at approximately 0.193 seconds after impact, traveling at a speed of 52.2 mph (84.0 km/h) and at an exit
Figure 3. Vehicle before test 0367-1.
Figure 4. Rail/vehicle geometrics for test 0367-1.
Date: 4-1-88  Test No.: 0367-1  VIN: SL-C1026329
Make: Honda  Model: CIVIC  Year: 1980  Odometer: 144275
Tire Size: 6.00-12  Ply Rating: 2  Bias Ply: X  Belted:  Radial: 

Tire Condition: good  fair X  badly worn 

Vehicle Geometry - inches

a  62\frac{1}{2}  b  29\frac{1}{2} 
c  88\frac{1}{2}  d*  52\frac{1}{4} 
e  27\frac{1}{2}  f  
g  h  34
i  j  30\frac{3}{4} 
k  16  l  28
m  19 3/4  n  5
o  14\frac{1}{2}  p  54\frac{1}{4} 
r  22  s  13\frac{1}{4} 

Engine Type: 4 cyl
Engine CID: 
Transmission Type: Automatic or Manual
FWD or RWD or 4WD
Body Type: Hatch
Steering Column Collapse Mechanism:
- Behind wheel units
- Convoluted tube
- Cylindrical mesh units
- Embedded ball
- NOT collapsible
- Other energy absorption
- Unknown

Brakes:
Front: disc X drum
Rear: disc  drum X

Figure 5. Test vehicle properties (0367-1).

* d = overall height of vehicle
angle of 5.7 degrees. The vehicle was in contact with the rail a total of 9.7 feet (3.0 m). As the vehicle exited the rail, the brakes were applied. The vehicle yawed clockwise and continued travelling forward and struck a portable concrete median barrier section placed in front of the ground level high-speed camera. The vehicle then came to rest 198 feet (60 m) from the point of initial impact. Sequential photographs of the test are shown in Figure 6.

It should be noted that the overhead camera malfunctioned during the test and data normally obtained from the overhead camera were obtained from either the ground-mounted camera, field measurements or electronic data.

The rail received relatively minor damages, as shown in Figure 7 and 8. The permanent residual deformation was 1.5 inch (3.8 cm) laterally for the bottom corrugation of the thrie-beam. The only repair required was to straighten out the damaged section of the rail and move that section to the end of the bridge rail installation for the second crash test.

The vehicle received relatively minor damages from impact with the bridge rail, but sustained heavy damages from impact with the portable concrete median barrier section (see Figure 9). Damages sustained from impact with the bridge rail included dents and scraps to the hood and entire right side of the vehicle. The maximum crush is estimated to be 4.0 inches (10.2 cm) at the right front corner of the vehicle. The dummy struck the right door during the bridge rail impact and the window glass was broken. There was also damage to the front bumper, tire rim, and windshield.

A summary of the test results and other information pertinent to this test are given in Figure 10. The maximum 0.050-second average acceleration experienced by the vehicle was -4.0 g in the longitudinal direction and 12.4 g in the lateral direction. Vehicle angular displacements are plotted in Figure 11 and vehicle accelerometer traces are displayed in Figures 12 through 14. Occupant impact velocity in the longitudinal direction was 12.6 feet per second (3.8 m/s) and 21.6 feet per second (6.6 m/s) in the lateral direction. The highest 0.010-second occupant ridedown accelerations were 1.0 g (longitudinal) and 7.1 g (lateral).

In summary, the bridge rail contained and smoothly redirected the vehicle with little damage to the barrier. There was no debris or detached elements. There was minimal deformation and intrusion into the occupant
Figure 6. Sequential photographs for test 0367-1.
Figure 7. Bridge rail after test 0367-1.
Figure 8. Post 14 after test 0367-1.
Before impacting portable CMB

After impact with portable CMB

Figure 9. Vehicle after test 0367-1.
Figure 10. Summary of results for test 0367-1.
Axes are vehicle fixed. 
Sequence for determining orientation is:
1. Yaw
2. Pitch
3. Roll

Figure 11. Vehicle angular displacements for test 0367-1.
Figure 12. Longitudinal accelerometer trace for test 0367-1.
Figure 13. Lateral accelerometer trace for test 0367-1.
Figure 14. Vertical accelerometer trace for test 0367-1.
compartment. The vehicle trajectory at loss of contact with the rail indicates minimum potential intrusion into the adjacent traffic lanes. The vehicle remained upright and stable during the initial test period and after leaving the rail.

Test Number 2

A 1979 Oldsmobile Delta 88 (shown in Figures 15 and 16) impacted the railing at an impact speed of 60.9 miles per hour (98.0 km/h) and at an angle of 24.0 degrees using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 4,495 pounds (2,041 kg) including instrumentation. The height to the lower edge of the vehicle bumper was 11.5 inches (29.2 cm) and 20.25 inches (51.4 cm) to the top of the bumper. Other dimensions and information on the vehicle are given in Figure 17.

The vehicle was free wheeling and unrestrained just prior to impact. The point of impact was midway between the posts for the span containing the railing splice, approximately 41 feet (12.5 m) downstream from the beginning of the bridge rail. Upon impact, the right front of the vehicle began to deform and at 0.045 second, the vehicle contacted the first post downstream from the impact point. The vehicle then began to redirect and, at 0.181 second, the rear of the vehicle came into contact with the rail.

The vehicle lost contact with the rail at approximately 0.267 second after impact, traveling at a speed of 38.9 miles per hour (62.6 km/h) and an exit angle of 4.6 degrees. The vehicle was in contact with the rail a total of 14.7 ft (4.5 m). As the vehicle exited the rail, the brakes were applied. The vehicle yawed clockwise and continued travelling forward and struck a portable concrete median barrier section placed in front of the ground level high-speed camera, as in test number 1. The vehicle then came to rest 135 feet (41 m) from the point of initial impact. Sequential photographs of the test are shown in Figure 18.

The rail itself received fairly severe damages as shown in Figure 19. The maximum lateral deformation was 6.25 inches (15.9 cm) on the lower corrugation of the thrie-beam, located approximately 7.5 feet (2.3 m) downstream from the initial point of impact. The thrie-beam was also displaced upward vertically by 2.0 inches (5.1 cm). The C-channel splice at the second post downstream from the point of impact (post 15) was displaced laterally for 0.5 inch (1.3 cm) and the flanges of the two posts (posts 14...
Figure 15. Vehicle before test 0367-2.
Figure 16. Vehicle/rail geometrics for test 0367-2.
Date: 4-5-88   Test No.: 0367-2   VIN: 3N37N9X168754
Make: Oldsmobile   Model: Delta 88   Year: 1979   Odometer: 75941
Tire Condition: good   fair X   badly worn 
Vehicle Geometry - inches
a 76\(\frac{3}{8}\)  b 42
 c 115 3/4  d* 57\(\frac{3}{8}\)
 e 60  f 217 3/4 
g  h 53.8
 i  j 34
 k 20  \(\ell\) 32\(\frac{1}{2}\)
 m 20\(\frac{3}{4}\)  n 5\(\frac{1}{2}\)
 o 11\(\frac{3}{4}\)  p 62
 r 27\(\frac{3}{4}\)  s 16\(\frac{1}{4}\)
Engine Type: V8
Engine CID: 350
Transmission Type: Automatic
Body Type: 2 Door
Steering Column Collapse Mechanism:
   Behind wheel units
   Convoluted tube
   Cylindrical mesh units
   Embedded ball
   NOT collapsible
   Other energy absorption
   Unknown
Brakes:
   Front: disc X drum
   Rear: disc___ drum X

*\(d\) = overall height of vehicle

Figure 17. Test vehicle properties (0367-2).
Figure 18. Sequential photographs for test 0367-2.
Figure 18. Sequential photographs for test 0367-2. (Continued)
Figure 19. Bridge rail after test 0367-2.
and 15) downstream from the point of impact were bent on the impact side as shown in Figure 20.

Severe damages to the bridge deck were found around the two posts (posts 14 and 15) immediately downstream from the point of impact, especially the second post (post 15). Diagonal stress cracks and spalling were found in the bridge deck around the first post (post 14), as shown in Figure 21. A large piece of concrete was broken off the bridge deck behind the second post (post 15) and severe diagonal stress cracks and deep spalling was found in front of the post, as shown in Figure 22. It appears that these stress cracks and spalling were originated from the anchor bolts.

The vehicle received moderate damages from impact with the bridge rail and severe damages from the impact with the portable concrete median barrier section (see Figure 23). The front end of the car was shifted to the left and the sub-frame was bent. Maximum crush was 12.0 inches (30.5 cm) at the right front corner of the vehicle. The entire right side of the vehicle was dented and scraped. There was also considerable damage to the front bumper, hood, right front tire rim, right front wheel assembly, right front fender, and windshield. The roof was slightly twisted.

A summary of the test results and other information pertinent to this test are given in Figure 24. The maximum 0.050-second average acceleration experienced by the vehicle was -8.8 g in the longitudinal direction and 9.9 g in the lateral direction. Vehicle angular displacements are plotted in Figure 25 and vehicle accelerometer traces are displayed in Figures 26 through 28. Occupant impact velocity in the longitudinal direction was 25.3 feet per second (7.7 m/s) and 23.6 feet per second (7.2 m/s) in the lateral direction. The highest 0.010 s occupant ridedown accelerations were 9.7 g (longitudinal) and 16.9 g (lateral). It should be noted, however, that occupant impact velocity and ridedown accelerations are not applicable for this test and are reported for information purposes only.

In summary, the rail contained and redirected the vehicle with little lateral movement of the barrier. However, both the bridge rail and bridge deck sustained considerable damages from the impact. As for the vehicle, there was minimal deformation and intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicates minimal potential for intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the initial test period and after leaving the rail.
Figure 20. Flanges of posts 14 and 15, test 0367-2.
Figure 21. Damage at post 14, test 0367-2.
Figure 22. Damage at post 15, test 0367-2.
(Before impact with portable CMB)

Figure 23. Vehicle after test 0367-2.

(After impact with portable CMB)
<table>
<thead>
<tr>
<th>Test No.</th>
<th>0367-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>04/05/88</td>
</tr>
<tr>
<td>Test Installation</td>
<td>Missouri Thrie-beam Bridge Rail</td>
</tr>
<tr>
<td>Length of Installation</td>
<td>77 ft (23.5 m)</td>
</tr>
<tr>
<td>Vehicle</td>
<td>1979 Oldsmobile Delta 88</td>
</tr>
<tr>
<td>Vehicle Weight</td>
<td>4,495 lb (2,041 kg)</td>
</tr>
<tr>
<td>Vehicle Damage Classification</td>
<td>TAD. 01RFQ4- CDC. 01FZEK2 &amp; 01RDES3</td>
</tr>
<tr>
<td>Maximum Vehicle Crush.</td>
<td>12.0 in (30.5 cm)</td>
</tr>
<tr>
<td>Maximum Permanent Rail Deformation</td>
<td>6.25 in (15.9 cm)</td>
</tr>
</tbody>
</table>

| Impact Speed | 60.9 mi/h (98.0 km/h) |
| Impact Angle | 24.0 deg |
| Exit Speed   | 38.9 mi/h (62.6 km/h) |
| Exit Angle   | 4.6 deg |

Vehicle Accelerations
(Max. 0.050-sec Avg)
- Longitudinal: -8.8 g
- Lateral: 9.9 g

Occupant Impact Velocity
- Longitudinal: 25.3 ft/s (7.7 m/s)
- Lateral: 23.6 ft/s (7.2 m/s)

Occupant Ridedown Accelerations
- Longitudinal: -9.7 g
- Lateral: 16.9 g

Figure 24. Summary of results for test 0367-2.
Axes are vehicle fixed.
Sequence for determining orientation is:
1. Yaw
2. Pitch
3. Roll

Figure 25. Vehicle angular displacements for test 0367-2.
Figure 26. Longitudinal accelerometer trace for test 0367-2.
Figure 27. Lateral accelerometer trace for test 0367-2.
Figure 28. Vertical accelerometer trace for test 0367-2.
Test Number 3

A 1982 Oldsmobile Delta 88 (see Figures 29 and 30) was directed into the transition section (shown in Figure 31) at 26.0 degrees and 62.4 mi/h (100.4 km/h) using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 4,500 lb (2,043 kg). The height to the lower edge of the vehicle bumper was 11.0 in (27.9 cm) and 19.5 in (49.5 cm) to the top of the bumper. Other dimensions and information on the vehicle are given in Figure 32.

The vehicle was free-wheeling and unrestrained just prior to impact. The vehicle impacted the transition section 15 ft (4.6 m) upstream of the beginning of the Missouri thrie-beam bridge rail (between posts 3 and 4 of the transition). At approximately 0.040 second after impact, the vehicle came into contact with post 4. The vehicle began to redirect at 0.087 second and as the vehicle made contact with post 5 (at about 0.107 second) the front end began to shift to the left. At 0.142 second, the vehicle contacted post 6. The vehicle impacted post 7 (the first post of the bridge rail) at about 0.186 second and the rear of the vehicle slapped the transition rail at 0.199 second. As the vehicle continued forward, it snagged and rode up on post 7 and slowed down considerably and abruptly when the undercarriage came into contact with the post (at about 0.246 second). At this point, the vehicle began to yaw clockwise and roll to the left while the front of the vehicle rode along the bridge rail.

The vehicle subsequently came to rest on its left side with the front against the rail between posts 8 and 9. The vehicle was in contact with the rail a total of 27 ft (8.2 m). Sequential photographs of the test are shown in Figure 33.

The transition section and bridge rail received a considerable amount of damages, as shown in Figures 34 through 41. The maximum dynamic lateral deflection was 2.7 ft (0.8 m), leaving a maximum residual deformation of 1.9 ft (0.6 m) at post 5 of the transition. The bridge deck also received severe damages around the first two posts (posts 7 and 8). As shown in Figure 40, diagonal stress cracks and deep spalling occurred in front of post 7 and a piece of concrete was broken off the deck behind the post. Diagonal stress cracks and spalling also occurred around post 8 as shown in Figure 41. It appears that these stress cracks and spalling were originated from the anchor bolts.
Figure 29. Vehicle before test 0367-3.
Figure 30. Vehicle/transition geometrics for test 0367-3.
Figure 31. Missouri three-beam bridge rail transition to G4(15) W-beam guardrail.
Date: 4-7-88  Test No.: 0367-3  VIN: 1G3AY69N8BX118676
Make: Oldsmobile  Model: Delta 88  Year: 1982  Odometer: 655359
Tire Size: P225-75R15  Ply Rating:  Bias Ply:  Belted:  Radial:  
Tire Condition: good ×  fair _  badly worn _
Vehicle Geometry - inches
a  75 3/4  b  43 1/2  c  116 1/4  d*  57  
e  60  f  219 3/4  g  h  53.0  
i  ---  j  31 3/4  k  18  l  34 1/2  
m  19 1/2  n  5 1/2  o  11  p  62  
r  28  s  16 1/2  
Engine Type: V-8  Engine CID: 350  
Transmission Type: Automatic or Manual  FWD or RWD or 4WD  
Body Type: 4-Door  
Steering Column Collapse Mechanism:
- Behind wheel units  
- Convoluted tube  
- Cylindrical mesh units  
- Embedded ball  
- NOT collapsible  
- Other energy absorption  
- Unknown  
Brakes:
- Front: disc X drum_  
- Rear: disc_ drum X  

* d = overall height of vehicle

Figure 32. Test vehicle properties (0367-3).
Figure 33. Sequential photographs for test 0367-3.
Figure 33. Sequential photographs for test 0367-3. (Continued)
Figure 34. Bridge rail and transition after test 0367-3.
Figure 35. Damage at post 1 and 2, test 0367-3.
Figure 36. Damage to post 3, test 0367-3.
Figure 37. Damage to post 4, test 0367-3.
Figure 38. Damage to post 5, test 0367-3.
Figure 39. Damage to post 6, test 0367-3.
Figure 40. Damage to post 7 (first post of bridge rail), test 0367-3.
Figure 41. Damage to post 8, test 0367-3.
The vehicle sustained extremely severe damages as can be seen in Figure 42. The front end was shifted to the left and the axle, subframe, floor pan, transmission and drive shaft were bent and damaged. The occupant compartment was twisted and the instrument panel was damaged when the floor pan and subframe were bent. A maximum crush of 47.0 in (119.4 cm) was measured at the right front corner of the vehicle at bumper height. Most of the damages to the vehicle occurred as the vehicle snagged on the end of the bridge rail, i.e., post 7 and the end of the C-channel.

The test results and other information pertinent to this test are summarized in Figure 43. During impact, the triaxial accelerometers mounted at the vehicle center-of-gravity were damaged when the floor pan was bent and the data were not usable. Therefore, the occupant risk factors and 0.050-second average accelerations for this test were calculated using data from back-up biaxial accelerometers located in the rear of the vehicle.

The maximum 0.050-second average accelerations experienced by the vehicle were -13.7 g in the longitudinal direction and 14.0 g in the lateral direction. Vehicle angular displacements are plotted in Figure 44 and vehicle accelerometer traces are displayed in Figures 45 through 48. Occupant impact velocities and ridedown accelerations are not applicable for this test; however, these were computed and are reported for information only. Occupant impact velocity in the longitudinal direction was 29.1 ft/s (8.9 m/s) and 32.0 ft/s (9.8 m/s) in the lateral direction. The highest 0.010-second occupant ridedown accelerations were -19.4 g (longitudinal) and 5.6 g (lateral).

In summary, the transition contained the vehicle, but failed to smoothly redirect the vehicle. The vehicle snagged at the end of the bridge rail, resulting in severe damages to the vehicle, the bridge rail and the bridge deck. There were considerable deformation and intrusion into the occupant compartment and the vehicle rolled one-quarter turn onto its left side. The vehicle stopped abruptly adjacent to the bridge rail with little post-impact trajectory.
Figure 42. Vehicle after test 0367-3. (after being uprighted)
Test No. ............... 0367-3
Date ............... 04/07/88
Test Installation ........ Missouri Thrie-beam Bridge Rail to G4(IS) W-Beam
Length of Transition .......... 56.25 ft (17.1 m)
Vehicle ............... 1982 Oldsmobile Delta 88
Vehicle Weight ............... 4,500 lb (2,043 kg)
Vehicle Damage Classification TAD .......... 01FR6 & 01RF07
CDC .......... 01FZEK6 & 01RYAW4
Maximum Vehicle Crush ........ 47.0 in (119.4 cm)
Max. Dyn. Rail Deflection .......... 2.7 ft (0.8 m)
Max. Perm. Rail Deformation .......... 1.9 ft (0.6 m)
Impact Speed ............... 62.4 mi/h (100.4 km/h)
Impact Angle ............... 26.0 deg
Exit Speed ............... Not Applicable*
Exit Angle ............... Not Applicable*
Vehicle Accelerations (Max. 0.050-sec Avg)
Longitudinal ............... -13.7 g
Lateral ............... 14.0 g
Occupant Impact Velocity
Longitudinal ............... 29.1 ft/s (8.9 m/s)
Lateral ............... 32.0 ft/s (9.8 m/s)
Occupant Ridedown Accelerations
Longitudinal ............... -19.4 g
Lateral ............... 5.6 g

*Vehicle rolled and came to rest adjacent to bridge rail.

Figure 43. Summary of results for test 0367-3.
Axes are vehicle fixed. Sequence for determining orientation is:
1. Yaw
2. Pitch
3. Roll

Figure 44. Vehicle angular displacements for test 0367-3.
Figure 45. Longitudinal accelerometer trace for test 0367-3.
Figure 46. Lateral accelerometer trace for test 0367-3.
Figure 47. Longitudinal accelerometer trace for test 0367-3.
Figure 48. Lateral accelerometer trace for test 0367-3.
IV. FINDINGS AND CONCLUSIONS

Results of the three crash tests indicate that the Missouri thrie-beam bridge rail itself generally meets with the guidelines set forth in NCHRP Report 230, but not the transition section. Discussions on the evaluation criteria and results for each of the three crash tests are presented in this section.

Test Number 1

The objectives and criteria for evaluation of the first test - Test 12 (1800S/60mph/15deg) are, according to NCHRP Report 230, the same as that for Test 11 (2250S/60mph/15deg), and are as follows:

The prime purpose of this test is to assess the potential risk or hazard to vehicle occupants during collision with the test article. However, the vehicle must remain upright and be smoothly redirected. .. For vehicles remaining upright and smoothly redirected, occupant risks are projected based on vehicle accelerations and calculated kinematics of occupants within the compartment space.

The Missouri thrie-beam bridge rail generally meets all three criteria outlined above. First, the vehicle was smoothly redirected without any snagging or pocketing. The damages sustained by both the vehicle and the bridge rail were fairly minor. Secondly, the vehicle remained upright throughout the collision without exhibiting any tendency of rollover or instability. The post-impact trajectory of the vehicle did not appear to present any undue hazard to other traffic. The exit angle of the vehicle was only 5.7 degrees, which is substantially less than 60 percent of the impact angle. The speed change of 7.4 miles per hour is less than the recommended maximum of 15 miles per hour.

However, the third criteria on occupant risk factors was met with less success. The lateral occupant impact velocity for this test was 21.6 feet per second, which was slightly higher than the recommended design limit of 20 feet per second, as set forth in NCHRP Report 230. However, rigid barriers with little or no lateral deflection tend to have fairly high lateral occupant impact velocity and it is not uncommon to exceed the recommended design limit. The longitudinal occupant impact velocity and the occupant ridedown accelerations, both longitudinal and lateral, were well within the limits set forth in NCHRP Report 230.
Test Number 2

The objectives and criteria for evaluation of the second test - Test 10 (4500S/60mph/25deg) are, according to NCHRP Report 230, as follows:

This test is considered primarily a strength test of the installation in preventing the vehicle from penetrating or vaulting over the system. The vehicle should be smoothly redirected without exhibiting any tendency to snag on posts or other elements or to pocket. Moreover, the vehicle should remain upright throughout the collision, and its after-collision trajectory should not present undue hazard to the vehicle occupants or to other traffic.

The Missouri thrie-beam bridge rail system generally met the criteria outlined above. First, the bridge rail system successfully contained the vehicle although moderately severe damages were sustained by the bridge rail and the bridge deck. The vehicle was redirected by the bridge rail in a fairly smooth manner. However, there are a couple of items worth noting. The right front tire path was tracked 8 inches behind the front of the baseplate at post 15 and the tire contacted the post, but the contact was very minor in nature and of little consequence. The bottom two corrugations of the thrie beam were flattened out by the impact, thus allowing contact between the vehicle and both posts 14 and 15. There was some indication of abrupt decelerations resulting from these contacts. However, it did not appear that the redirection of the vehicle was significantly affected.

Secondly, the vehicle remained upright throughout the collision without exhibiting any tendency of rollover or instability. Finally, the after-collision trajectory of the vehicle did not appear to present any undue hazard to other traffic. The exit angle of the vehicle was only 4.6 degrees which was substantially less than 60 percent of the impact angle. The speed change of 22.0 miles per hour is higher than the recommended maximum of 15 miles per hour. Part of the speed change could be attributed to the contacts between the vehicle and the posts. However, the slight exit angle of the vehicle would indicate minimal potential for intrusion into the adjacent traffic by the redirected vehicle and the higher than recommended speed change should not pose any undue hazard to the adjacent traffic.

Test Number 3

The objectives and criteria for evaluation of the third test - Test 30 (4500S/60mph/25deg) are, according to NCHRP Report 230, similar to the length-of-need strength test outlined above (Test Number 2).
The G4(1S) W-beam guardrail transition to the Missouri thrie-beam bridge rail did not perform satisfactorily. The transition successfully contained the vehicle, but failed to smoothly redirect the vehicle. It allowed a maximum dynamic deflection of 2.7 feet before starting to redirect the vehicle, at which time the vehicle contacted the end of the more rigid bridge rail system, resulting in severe snagging of the vehicle on the first post of the bridge rail system. The vehicle decelerated abruptly, accompanied by high yaw and roll rates. The vehicle subsequently rolled one-quarter turn onto its left side with the rear intruding into the traffic lane. The vehicle, transition, bridge rail and bridge deck all sustained severe damages.

Summary

In summary, the Missouri thrie-beam bridge rail system generally met with the requirements as set forth in NCHRP Report 230, although some of the criteria are met only marginally. The transition from G4(1S) W-beam guardrail to the bridge rail system performed unsatisfactorily and did not meet with the requirements as set forth in NCHRP Report 230.