THREE-BEAM GUARDRAILS
FOR SCHOOL AND INTERCITY BUSES

Based on work for the
Office of Research
Federal Highway Administration
U. S. Department of Transportation
Contract DOT-FH-11-9485

by
Don L. Ivey, Richard Robertson,
C. Eugene Buth and Charles F. McDevitt

A Technical Paper for Presentation
at the 60th Annual Meeting of the
Transportation Research Board
Washington, D.C.

January, 1982
We are sorry but some of the older reports or AS IS. The pictures are of poor quality.
NOTICE

The contents of this report reflect the views of the Texas Transportation Institute, which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of the Department of Transportation.

This report does not constitute a standard, specification or regulation.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.
I. INTRODUCTION

As the effort continues to provide safer highway auxiliary structures to the public, there is increasing pressure to design structures such as guardrails and bridge rails for a wider spectrum of highway vehicles. Witness the growing emphasis on designing guardrail terminals for mini-compacts as they become a more significant part of the vehicle fleet, and the efforts to design bridge rails for both school and inter-city buses.

This report describes work which is also responsive to enlarging the spectrum of vehicles included in the auxiliary structure design process. Up until now, guardrails have been designed to accommodate a 2041 kg (4500 lb) automobile at 96.5 kph (60 mph) and 25 deg as the most critical test. This work is an effort to determine if a relatively conventional guardrail design is suitable to safely redirect a 9072 kg (20,000 lb) school bus moving at 96.5 kph (60 mph) with an impact angle of 15 deg and, if this is not the case, if reasonably economical guardrails can be designed to accomplish this task.

To accomplish this the tests shown by Table 1 were conducted.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Vehicle</th>
<th>Impact Velocity</th>
<th>Impact Angle</th>
<th>Point of Impact</th>
<th>Rail Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9072 kg (20,000 lb) school bus</td>
<td>96.5 (60)</td>
<td>15</td>
<td>Midstream</td>
<td>Thrie-Beam</td>
</tr>
<tr>
<td>2</td>
<td>9072 kg (20,000 lb) school bus</td>
<td>96.5 (60)</td>
<td>15</td>
<td>Midstream</td>
<td>W-Beam</td>
</tr>
<tr>
<td>3</td>
<td>9072 kg (20,000 lb) school bus</td>
<td>96.5 (60)</td>
<td>15</td>
<td>Midstream</td>
<td>Modified Thrie-Beam</td>
</tr>
</tbody>
</table>

Table 1. Description of Tests
The tests were conducted in the order shown in Table 1. The cross sections of the guardrail for each test are shown in Figures 1, 2, and 3.

The Thrie-Beam guardrail shown in Figure 1 was selected for the first test. Since it was a choice between the Conventional W-Beam guardrail and the Conventional Thrie-Beam guardrail, the following reasoning dictated the choice of the Thrie-Beam. If the Thrie-Beam failed to redirect a school bus, there was no reason to test the W-Beam since it was certainly of lower capacity. This might save one test which could be used to evaluate a modified Thrie-Beam rail. If the Thrie-Beam functioned reasonably well, there was a chance the W-Beam would also perform adequately. The W-Beam then would be selected for the second test. The testing program would prove the latter situation to be the one encountered. Although detailed accounts of these individual tests will be given in subsequent parts of this report, a brief description of each test will be presented here.
THRIE-BEAM BACK-UP PLATE, (AT POSTS WHERE THRIE-BEAM SPLICE DOES NOT OCCUR)

NOTE: TYPICAL FOR POSTS 7-37

Figure 1. Conventional Thrie-Beam Guardrail (Test No. 1).
W-Beam Back-Up Plate, (at posts where W-Beam splice does not occur)

5/8" Ø bolts

W 6 x 8.5 post

W 6 x 8.5 block

5/8" Ø button head bolt

Figure 2. Conventional W-Beam Guardrail (Test No. 2).
THRIE-BEAM BACK-UP PLATE, (AT POSTS WHERE THRIE-BEAM SPLICE DOES NOT OCCUR)

5/8" Ø BUTTON HEAD BOLT

5/8" Ø BOLTS

W6 x 3.5 POST

M 14 x 17.2 SPACER

NOTE: TYPICAL FOR POSTS NO. 7-37.

Figure 3. Modified Thrie-Beam Guardrail (Test No. 3).
II. DISCUSSION OF TEST RESULTS

In the first test, conducted on the Thrie-Beam guardrail shown in Figure 1, the 9072 kg (20,000 lb) bus at 91.7 kph (57 mph) and 15 deg was contained and redirected with the bus going through a slow, smooth 90 deg counterclockwise roll before falling onto its left side and sliding to a stop. Although the 90 deg roll was not an ideal reaction, it was a slow, fairly smooth roll which should not be extremely hazardous to passengers if the integrity of the left side windows is maintained. The test was therefore considered a qualified success. The guardrail exhibited enough strength and maintained continuity so that the bus was contained and redirected. Accelerations on the bus during the event were low, while permanent deflection was about .53 m (21 in.). Based on the results of the first test it was decided that the Conventional W-Beam guardrail had a good chance of containing and redirecting a school bus. The W-Beam had about as much post support as the Thrie-Beam and, after impact deflection, the height of the point of resistance of the Thrie-Beam. This is true as the rail begins to deflect at least up to the time the bus rolls enough to make contact with the top part of the deflecting, and rotating W or Thrie-Beam. Countering these arguments that the W-Beam guardrail had a chance of containing and redirecting a bus were the facts that the barrier height would be reduced 13.3 cm (5 1/4 in.) and the bending stiffness of the W-Beam was much lower than the Thrie-Beam, a factor resulting in the transmission of lateral load to fewer support posts during an impact. The factors against a successful containment were dominant.
In the second test, conducted on a W-Beam guardrail shown by Figure 2, the bus was not contained. At a speed slightly higher than in the first test, 96.5 kph (60 mph) compared to 91.7 kph (57 mph), the bus started to redirect as the left front corner made contact but, as it rolled left and yawed to the right, the rear went over the barrier, penetrating into the zone behind the rail. At one point the bus was sliding upside down across the guardrail resulting in a shredding of the bus top. This reaction would have resulted in many severe passenger injuries and was considered unacceptable.

With the experience gained from the first two tests it was obvious that significant changes had to be made if a guardrail was designed which would keep a bus from rolling while containing and redirecting. The Thrie-Beam guardrail used in Test 1 had proven strong enough, but had exerted its resistance at a point too low to prevent the bus from rolling. It was considered the prime candidate for redesign. The emphasis would be to make design changes that would elevate the point of resistance during a collision. Design sessions were held involving several engineers at TTI and discussions were held with FHWA engineers in the effort to develop a practical design which would have a high probability of success.

The guardrail illustrated by Figure 3 is the result of those efforts. The following design changes were made.

1) The overall height of the barrier was increased by .05 m (2 in.), from .84 m (33 1/4 in.) (Figure 1) to .90 m (35 1/4 in.) (Figure 3).
2) The block out was increased by .20 m (8 in.), from .15 m (6 in.) to .36 m (14 in.). (This results in the rail moving up as the support post rotates.)

3) A triangular shaped segment was cut from the web of the M 14 x 17.2 spacer as shown in Figure 3. (This allows the lower portion of the Thrie-Beam and the adjacent spacer block flange to bend in during a collision. This reduces the contact load between an impacting vehicle and the lower part of the Thrie-Beam, requiring the load to move up on the fully supported part. The net effect is that the resisting force of the rail is raised to a position which produces a smaller roll moment on the vehicle c.g. position.)

4) The embedment length of the guardrail posts was increased slightly from 1.14 m (44 3/4 in.) to 1.17 m (46 in.). (Consideration was given to welding bearing plates on the support posts to significantly increase post capacity. This option was not taken since it was not determined that additional post capacity was necessary and the addition of the plates would significantly increase fabrication costs.)

The modifications described and shown by Figure 3 proved adequate. The third test of a school bus at 96.5 kph (60 mph) and 15 deg produced a bus reaction that was quite reasonable. The bus was contained and smoothly redirected, remaining upright throughout the event. There was approximately 25 deg of bus roll to the left, or counterclockwise when viewed from the rear, during contact with the Modified Thrie-Beam guardrail. Overall it was interpreted as a very stable rail collision.

The following three summary sheets give additional details of each test.
Test No. ....... 4098-1
Date ............ 6/2/80
Rail ............ Thrie Beam
Posts and Blockouts ... W 6x8.5 (steel)
Post Spacing ....... 1.91 m (6.25 ft)
Moisture Content of Soil .7.1%
Length of Installation .76.2 m (250 ft)
Vehicle Damage
TAD ............ 11FL2
SAE ............. 11FEN7
09LDAQ9
Rail Deflection, Perm. : .053 m'(1.33 ft)

Vehicle ............ 1971 International
School Bus, 9081 kg
(20,020 lb)

Dummy Restraints
Alpha ............ Lap Belt
Beta ............ None
Impact Speed ....... 89.49 kph (55.62 mph)
Impact Angle ..... 12.5°
Exit Speed ......... Vehicle
Exit Angle ......... Rolls
Vehicle Acceleration
(Max. 0.050 sec. Avg.)
Longitudinal ........ -1.13g
Transverse .......... -2.95g
Vertical ........... -1.35g

Note: All measurements are approximate and subject to error.
Test No. ............ 4098-2
date ............ 6/11/80
rail ............ W-beam
posts and blockouts .... W 6x8.5 (steel)
post spacing ........ 1.91 m (6.25 ft)
moisture content of soil .... 6.5%
length of installation ........ 76.2 m (250 ft)
vehicle damage
  TAD. ............ 11FL2
  SAE. ............ 11FREE3
  09LDA05
rail deflection, perm. ........ 1.0 m (3.3 ft)

vehicle ............ 1971 International School Bus, 9095 kg (20,050 lb)
dummy restraints
  alpha ............ Lap Belt
  beta ............ No Restraints
impact speed ........ 95.96 kph (59.62 mph)
impact angle ........ 15 deg
exit speed ........ .distortion
exit angle ........ .
vehicle acceleration
  (max. 0.050 sec. avg.)
  longitudinal .... -1.84g
  transverse ........ -2.45g
  vertical .......... -3.04g
Figure 6. Sequential Photographs and Data Summary for Test 4098-3.
VI. CONCLUSION

Conventional guardrail designs using standard W-Beam guardrail are not adequate to safely redirect school buses. The W-Beam guardrail shown in Figure 2 and subjected to Test 2 is representative of the best W-Beam systems. Similar rails with longer post spacings, shorter post embedment lengths, lower rail heights, or without blockouts would be expected to perform in an even less acceptable manner.

The Conventional Thrie-Beam guardrail will perform marginally to contain and redirect school buses, but it is not likely to keep the bus upright during collision. Although the 90 deg roll documented by Test 2 was fairly slow and reasonably smooth, any roll which results in the bus ending up on its side is potentially hazardous. The Conventional Thrie-Beam guardrail does seem to be a significant improvement in performance over the Conventional W-Beam. If the redirection of vehicles, like school buses, becomes an accepted performance criterion, significant modifications of current guardrail systems will be necessary to assure safe performance.

The Modified Thrie-Beam guardrail shown by Figure 3 and subjected to Test 3 performed well in the single school bus test which it has sustained. The test illustrates the fact that Thrie-Beam guardrail designs have the potential to function adequately for a class of vehicles much larger than automobiles. A question remains whether the increased height and the blockout modification, which allows the lower part of the Thrie-Beam to bend inward, will compromise the rail performance on small automobiles. Of special concern is the performance of mini-compacts.
Another question is related to the maximum vehicle size the Modified Thrie-Beam guardrail can accommodate. Intercity buses weigh roughly twice as much as school buses and apply loads to nondeformable structures much higher than do school buses. Conversely, intercity buses are generally more stable in guardrail or bridge rail collisions than school buses, having a center of gravity position significantly lower than that of a school bus. These somewhat compensating factors may allow an intercity bus to be redirected in a stable condition. Deflections significantly larger than the .85 m (2.8 ft) produced by the school bus would be likely. Intuitively, it would be on the order of 50% higher, or 1.2 to 1.5 m (4 to 5 ft).

The Modified Thrie-Beam guardrail should be tested using minicompacts before experimental field installations are made. Tests should also be considered using intercity buses. If the guardrail is not currently adequate for these larger buses, minor modifications such as increasing embedment length, increasing support post size, or placing soil bearing plates on the embedded part of the posts could result in improved characteristics.

The final test has shown that guardrails can be designed to contain and redirect vehicles much larger than automobiles. How far this performance can be practically extended is still open to question, primarily an economic question. Constructing guardrails to accommodate the relatively rare bus or truck collision may not be justifiable on a benefit-cost basis for all installations. It is likely, however, that special traffic or roadway conditions will justify use of these high performance rails on a very selective basis, just as in the case of
bridge rails. With a few additional tests, a high performance guardrail may be available for use under special circumstances.

Note to TRB Reviewer:

There are some references that need to be added especially one by Bronstad and Kimble on Thrie Beam and Guardrail. These references will be put in before the paper is reproduced for distribution at TRB.