Use of Guardrails on Low Fill Bridge Length Culverts

T. J. Hirsch and Dale Beggs

When multiple box culverts span more than 20 feet, the American Association of State Highway Transportation Officials (AASHTO) defines them as bridge length and, thus, normally require the use of a full-strength, rigid bridgerrail. Using a rigid bridgerrail creates a transition problem between the flexible metal beam guard fence, which is commonly used upstream of the bridgerrail. It would be safer and more economical to continue the flexible metal beam guard fence across the culvert even when the culvert is more than 20 feet long and when the soil fill depth over the culvert is less than the standard guardrail post embedment depth (38 inches in Texas). It was believed that more post could be used (reduced post spacing) with a shallow embedment to achieve the desired guardrail strength. A metal beam guard fence design of this type was crash tested in this study and proved to be unsatisfactory. Another concept investigated was to rigidly mount the beam guard fence post to the top of the culvert deck when full soil embedment could not be achieved. A design of this type was also crash tested in this study and proved to be satisfactory.

Another concept investigated was to rigidly mount the guard fence post to the top of the culvert deck when full soil embedment could not be achieved. A design of this type was also crash tested in this study and proved to be satisfactory.

METAL BEAM GUARD FENCE DESIGNS AND CRASH TESTS

At the beginning of this research, it was believed that more guardrail posts could be used with a shallow embedment to achieve the necessary guardrail strength. Figure 1 shows the standard 38-inch embedment with the Texas standard 27-inch W-beam mounting height. Figure 2 shows static load test results on these posts in a cohesionless soil (3) for various embedment depths. Figure 3 summarizes the maximum force and energy absorbed for various embedment depths. These data are from figure 2 and The Effects of Embedment Depth, Soil Properties, and Post Type on the Performance of Highway Guardrail Posts (2) and have been modified slightly so the maximum force and energy could be presented on the same graph. The energy...
absorbed was computed to 18 inches of deflection. Impact tests (4) with a pendulum traveling 17 mph will yield results four to five times these values. These data were used in selecting the modified guardrail designs presented.

The plan view of the typical modified guard fence designs to be tested is shown by Figure 4. As can be seen, a 50-foot long segment of the modified guard fence design was installed over a simulated concrete culvert. Standard guard fence with the standard turned down terminal was installed on the upstream and downstream ends of the test section. The standard turned down terminal is still used in Texas and many other states.

The single crash test conducted on each modified design was with a 4,500-pound car impacting at 60 mph and a 25 degree angle (3).

Modified Guard Fence No. 1

The first modification is shown by Figure 5 using 7-inch diameter timber as shown in Figure 1. Originally, it was intended to use twice as many posts with one-half the strength of a fully embedded post: for example, posts spaced at 3 feet 1½ inches and embedded 24 or 27 inches (see Figures 2 and 3). However, another hypothesis prevailed. Since a strong guardrail and turned-down end anchor were to be used upstream and downstream of the 50-foot long simulated culvert, the post only needed to hold up the W-beam to make initial contact with the car. The hypothesis was that the W-beam firmly anchored on each end could redirect the car over this 50-foot length by itself.

This hypothesis was investigated using the BARRIER VII computer program, and a summary of the results is presented in Table 1. This table indicates the standard guard fence (6 feet-3 inch post spacing with 38-inch embedment) would deflect 20.8 inches when impacted with a 4,500 pound car at 60 mph and 25 degree angle. The modified guard fence No. 1 shown in Figure 5 (6 feet-3 inch post spacing with 18-inch embedment) would deflect 34.4 inches.

One problem with the analysis, which Crash Test 1 will demonstrate, is that BARRIER VII is a planar, two-dimensional analysis. BARRIER VII cannot indicate that the W-beam will drop vertically and the car will vault vertically over the guardrail.
Crash Test 1

Figure 6 shows the modified guard fence installation and car before and after Crash Test 1. In this test, a 4,400-pound Chrysler Newport impacted modified guard fence No. 1 at 61.9 mph and 26.2 degree angle. At 0.2 seconds into the impact, the car began to parallel the deflected (about 46.8 inches) W-beam rail, the W-beam dropped, and the car ramped over it. The car penetrated behind the rail and rolled over. The test was unsuccessful.

Figure 7 presents a summary of the Crash Test 1 data.

Modified Guard Fence No. 2

This guard fence design was in accordance with the original hypothesis that one could use twice as many posts with one-half the strength to achieve the desired strength for vehicle redirection. Figure 3 was used to select the 7-inch diameter timber post embedded 27 inches in cohesionless soil to obtain half the strength (both force and energy absorbed) of the standard 38-inch embedded post. This yields the design shown by Figure 8. Interpolating the data in Table 1 would indicate that this guard fence design would deflect laterally about 20 inches, which is about the same as the standard guard fence.

Crash Test 2

Figure 9 shows modified guard fence No. 2 and car before and after the test. In this test, a 4,500-pound Cadillac Deville impacted modified guard fence No. 2 at 61.8 mph and 23.2 degree angle. At about 0.15 seconds, the rail had deflected about 28 inches, the car was beginning to redirect (yaw about 10 degrees), and the W-beam broke into two. At 0.3 seconds, the car paralleled the guardrail and rode down it about 50 feet before coming to a stop and rolling on its side beside and behind the guardrail.
TABLE 1 SUMMARY OF BARRIER VII COMPUTER PROGRAM ANALYSIS OF MODIFIED METAL BEAM GUARD FENCE DESIGNS

<table>
<thead>
<tr>
<th>POST SPACING (ft-in.)</th>
<th>POST EMBEDMENT (in.)</th>
<th>POST STATIC LOAD CAPACITY (kips)</th>
<th>MAX. GUARD FENCE DEFLECTION (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6'-3&quot;</td>
<td>38</td>
<td>3.0</td>
<td>20.8</td>
</tr>
<tr>
<td>6'-3&quot;</td>
<td>24</td>
<td>1.5</td>
<td>31.0</td>
</tr>
<tr>
<td>6'-3&quot;</td>
<td>18</td>
<td>1.0</td>
<td>34.4</td>
</tr>
<tr>
<td>3'-1 1/2&quot;</td>
<td>24</td>
<td>1.5</td>
<td>22.0</td>
</tr>
<tr>
<td>3'-1 1/2&quot;</td>
<td>18</td>
<td>1.0</td>
<td>25.6</td>
</tr>
</tbody>
</table>

NOTE: 50 ft length of guardrail with 25 ft turn-down terminal on each end. Elastic-plastic post-soil model which yields at 2 in. deflection.

\[ F_{dyn} = F_{static} (1 + \frac{V}{J}) \]

where \( V \) is ft/sec and \( J = 0.14 \) sec/ft.

Impact by 4500 lb car at 60 mph and 25° angle.

Tensile tests of coupons from the broken W-beam indicated its yield strength as 80 ksi, ultimate strength as 106 ksi, and ductility of 17 percent. The steel in the W-beam easily satisfied the AASHTO-required yield strength of 50 ksi (minimum), ultimate strength of 70 ksi (minimum), and 12 percent minimum ductility.

Close examination of the timber posts indicated that they bent over and pulled out of the soil simultaneously. The car's right front tire literally rode up the inclined posts, which were spaced close together, trying to push them down. While this was happening, the car's right front bumper was firmly nestled in the groove of the W-beam and began exerting an upward force on the beam. This combination of forces—downward force from post plus tire, upward force from bumper,
FIGURE 7  Summary of Crash Test 1.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>2405-1</th>
<th>Vehicle</th>
<th>1977 Chrysler Newport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>7/22/85</td>
<td>Vehicle Weight</td>
<td>1996 kg (4400 lb)</td>
</tr>
<tr>
<td>Face Rail</td>
<td>12 ga. steel W-shape</td>
<td>Impact Speed</td>
<td>99.4 km/h (61.8 mph)</td>
</tr>
<tr>
<td>Post</td>
<td>standard timber</td>
<td>Impact Angle</td>
<td>26.2 degrees</td>
</tr>
<tr>
<td>Post Spacing</td>
<td>1.9 m (6 ft 3 in)</td>
<td>Exit Speed</td>
<td></td>
</tr>
<tr>
<td>Length of Installation</td>
<td>53.3 m (175 ft)</td>
<td>Exit Angle</td>
<td></td>
</tr>
<tr>
<td>Beam Rail Deflection</td>
<td>1.19 m (3.9 ft)</td>
<td>Vehicle Acceleration</td>
<td>(Max. 0.050 sec. avg.)</td>
</tr>
<tr>
<td>Max. Dynamic</td>
<td>1.19 m (3.9 ft)</td>
<td>Longitudinal</td>
<td>-3.1 g</td>
</tr>
<tr>
<td>Max. Permanent</td>
<td>1.12 m (3.7 ft)</td>
<td>Transverse</td>
<td>2.7 g</td>
</tr>
<tr>
<td>Vehicle Damage</td>
<td>TAE</td>
<td>Vertical</td>
<td>3.5 g</td>
</tr>
<tr>
<td></td>
<td>01RFQ4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>01RFEK5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
and large tensile redirection force—caused the W-beam to split longitudinally down the center of the W (about a 6.25-foot long split) then break transversely.

Tests 1 and 2 have indicated that guardrail posts need sufficient embedment to develop enough friction to keep them from pulling out of the ground. They also need sufficient embedment to develop the required bending strength or lateral load capacity. Figure 10 summarizes the test data from Crash Test 3.

Modified Guard Fence No. 3

After the unsuccessful crash tests on modified guard fence designs Nos. 1 and 2, it was decided that the post would have to be attached to the culvert deck when the soil fill was less than the standard 38 inches. The modified guard fence No. 3 design was as shown by Figures 11 and 12.

The W6 x 9 standard steel guardrail post with blockout was fitted with a steel base plate and bolted to the simulated culvert deck.
### FIGURE 10  Summary of Crash Test 2.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Date</th>
<th>Face Rail</th>
<th>Post Spacing</th>
<th>Length of Installation</th>
<th>Beam Rail Deflection</th>
<th>Vehicle Damage</th>
<th>TAE</th>
<th>SAE</th>
<th>Vehicle Weight</th>
<th>Impact Speed</th>
<th>Impact Angle</th>
<th>Exit Speed</th>
<th>Exit Angle</th>
<th>Vehicle Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>2405-2</td>
<td>4/18/86</td>
<td>12 ga. steel W-shape</td>
<td>0.95 m (3 ft 1.5 in)</td>
<td>53.3 m (175 ft)</td>
<td>2.56 m (8.4 ft)</td>
<td>fracture</td>
<td>OIRFQ4</td>
<td>OIRFEK4</td>
<td>2401 kg (4500 lb)</td>
<td>99.6 km/h (61.9 mph)</td>
<td>23.2 deg.</td>
<td>5.3 g</td>
<td>5.1 g</td>
<td>5.8 g</td>
</tr>
</tbody>
</table>

Impact Angle

Vehicle Acceleration
(Max. 0.050 sec. avg.)
- Longitudinal: 5.8 g
- Transverse: 5.3 g
- Vertical: 5.1 g
50 ft Modified Guard Fence No. 3

37'-6"

7 posts @ 6'-3" spacing
18" embedment in cohesionless soil and bolted to culvert slab

W6x9 Steel Posts
with Blockout

Culvert Deck Under
18" of Soil Fill

Vehicle Impact
Between Posts
1 and 2

Standard 12 Gauge W-beam

50 ft Modified Guard Fence No. 3

FIGURE 11 Plan view of modified guard fence No. 3 installation for Crash Test 3.

1"x1 1/2" slotted holes

3 1/4"

3/8"

1"

5 7/8"

3 1/8"

2'-0" Min.

W-beam guardfence
6'-3" post spacing

W8x9x14" spacer
or W8x8.5x14"

W6x9 steel post

3/4" A307 bolts with
washers
Length is slab thickness +2"
10"x6"x5/8" A36 steel plate

1 1/4" formed or
drilled holes

18" tested,
0" to 37"

W8x9x9x14"

-8"x6"x1/4" A36 steel plate
with 15/16" Q holes

18" tested, 6'

Culvert Slab

FIGURE 12 Detail of steel guard fence post and attachment to culvert slab.
culvert slab as shown by Figure 12. The 6-inch thick culvert slab was reinforced as a typical Texas culvert slab. The centers of the posts were located 30 inches from the outer edge of the culvert. This design should not crack the culvert slab. Static load test results of this post (without soil fill) is shown by Figure 13. Yielding then local buckling of the compression flange caused failure. Damaged posts could be replaced relatively easily by bolting on a new post.

Figure 14 presents the results of an analysis of how the guard fence post load capacity would change with different soil fill depths. The 18-inch fill depth was chosen for this test because the load capacity is low (about 7.8 kips) and the probability of the car tire snagging a post is highest with low fill depths. At 37 inches, the post plus soil strength will be about 8 kips static load. The Effects of Embedment Depth, Soil Properties, and Post Type on the Performance of Highway Guardrail Posts (2) showed the dynamic load factor of such posts in soil is about 4 when impacted at 15 to 20 mph. This means the dynamic strength of this post is about 32 kips. At a 4-inch embedment, the strength of this post is about 14 kips static load. The Effects of Embedment Depth, Soil Properties, and Post Type on the Performance of Highway Guardrail Posts (5) showed that the dynamic load factor of such steel posts alone is about 2. This means the dynamic strength of such posts with little to no soil embedment is about 28 kips. Therefore, the impact strengths of these posts at various soil embedment depths are close to each other (28 kips to 32 kips).

A typical guardrail post has a static strength of about 5.5 kips and a dynamic load factor of 4.5 (2). Therefore, the guardrail's dynamic impact strength is 5.5 kips times 4.5, or about 25 kips. Since all these posts have similar impact strength (25 to 32 kips) and deformation characteristics (deflect a foot or more), there should be no transition problems.

**Crash Test 3**

Figure 15 shows the modified guard fence No. 3 and car before and after Crash Test 3. The 4,450-pound Cadillac Deville impacted the guard fence at 61.8 mph and 25.3 degree angle. The car was smoothly redirected as intended. The maximum rail deflection was 2.7 feet, and four posts were severely damaged. This flexible behavior is almost identical to that of the guardrail, indicating there should be no transition problem.
FIGURE 14 Analysis of guard fence post load capacity for various soil fill depths.

FIGURE 15 Modified guard fence No. 3 and car before and after Crash Test 3.
FIGURE 16  Summary of Crash Test 3.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Date</th>
<th>Face Rail</th>
<th>Post</th>
<th>Post Spacing</th>
<th>Length of Installation</th>
<th>Beam Rail Deflection</th>
<th>Max. Dynamic</th>
<th>Max. Permanent</th>
<th>Vehicle Damage</th>
<th>Vehicle</th>
<th>Vehicle Weight</th>
<th>Impact Speed</th>
<th>Impact Angle</th>
<th>Exit Speed</th>
<th>Exit Angle</th>
<th>Vehicle Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>2405-3</td>
<td>7/6/86</td>
<td>12 ga. steel W-shape</td>
<td>W6x9</td>
<td>1.9 m (6 ft 3 in)</td>
<td>53.3 m (175 ft)</td>
<td>0.82 m (2.7 ft)</td>
<td>0.67 m (2.2 ft)</td>
<td></td>
<td></td>
<td>1978 Cadillac DeVille</td>
<td>2019 kg (4450 lb)</td>
<td>99.4 km/h (61.8 mph)</td>
<td>25.3 deg.</td>
<td>59.9 km/h (37.2 mph)</td>
<td>15.6 deg.</td>
<td>-2.78 g</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>01RFQ3</td>
<td>01RFQ4</td>
<td></td>
<td>4.59 g</td>
<td>Vertical</td>
<td>-3.43 g</td>
<td></td>
</tr>
</tbody>
</table>
Figure 16 summarizes the test data for Test 3. Presented in Figures 17–20 are the accelerometer and other electronic data from this successful crash test.

This test and modified guard fence No. 3 was very successful. With this design, the guard fence can now be used over culverts even when full embedment depth of the guardrail post cannot be achieved.

SUMMARY AND CONCLUSIONS

The culvert-mounted modified guard fence No. 3 design should meet all crash test performance requirements. Its strength and geometry are essentially identical to that of the typical 27-inch-high guardrail used widely. Figure 14 shows that the strength of these modified guardrail posts will be relatively constant over a wide range of soil embedment depths. The new guard fence smoothly redirected a 2,019 kg (4,450 pounds) vehicle traveling 99.4 km/hr (61.8 mph) and impacting the rail at an angle of 25.3 degrees. This guard fence system does not have the transition problem that the presently required rigid system does because it is flexible along its entire length as is the standard Texas guard fence on each end.

This new guard fence system is also cheaper than using more rigid bridge rails. The new system has an approximate
FIGURE 19 Vehicle vertical accelerometer trace for Test 2405-3.

Axes are vehicle fixed. Sequence for determining orientation is:
1. Yaw
2. Pitch
3. Roll

FIGURE 20 Vehicle angular displacements for Test 2405-3.
installation cost of $17 per foot as opposed to the $35 per foot cost of typical T101 steel bridgerail.

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REFERENCES


The contents of this report reflect the views of the authors, who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.