This research was undertaken to investigate longitudinal barrier impact performance when placed on nonlevel terrain. Tasks performed in this study included a) a determination of typical conditions for which longitudinal barriers are placed on nonlevel terrain; b) an evaluation of the impact behavior of widely used barrier systems when placed on nonlevel terrain; and c) the development of guidelines for selection and placement of barriers on nonlevel terrain.

This volume describes the development and application of guidelines for placement of longitudinal barriers on nonlevel terrain. Data from full-scale crash tests were used to develop containment criteria for four widely used roadside barrier systems. This containment criteria and HVOSM simulations were then employed to develop barrier placement guidelines. Guidelines are presented for each of three different performance standards and are given in the form of 75 figures.

Volume I of this report is an executive summary, and Volume II describes full-scale crash tests conducted under this study.

Key Words: Slope(s), Nonlevel Terrain, Roadside Barrier(s), Median Barrier(s), Impact Behavior, Safety, Crash Test(s), Highway(s)
DEVELOPMENT OF GUIDELINES FOR PLACEMENT OF LONGITUDINAL BARRIERS ON SLOPES

VOLUME III. GUIDELINES

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I. INTRODUCTION AND SCOPE

Impact behavior of a longitudinal barrier is dependent on a number of factors, including size and spacing of posts, size and mounting height of rail or beam, offset of beam from posts, embedment conditions, and roadside conditions between the edge of the traveled way and the barrier. Little is known about the effects of the latter factor although it may have the greatest influence on performance. In general, barriers have been designed and tested for flat terrain conditions even though roadside and median barriers are commonly placed on side slopes or behind curbs. With regard to placement of barriers on slopes, the 1977 AASHTO Barrier Guide \(^1\) recommended the following:

As a general rule, a roadside barrier should not be placed on an embankment if the slope of the embankment is steeper than 10:1. In addition, a barrier should not be placed on an embankment if the difference between the shoulder slope rate and side slope rate is greater than approximately 0:10.

Tasks performed in this study were: (a) a determination of typical conditions for which longitudinal barriers are placed on nonlevel terrain; (b) an evaluation of the impact behavior of widely used barrier systems when placed on nonlevel terrain; and (c) the development of guidelines for selection and placement of barriers on nonlevel terrain. Barriers evaluated included widely used roadside and median longitudinal barriers identified in the 1977 AASHTO Barrier Guide \(^1\). Evaluation of crash cushions was not within the scope of the study. Nonlevel terrain considered in the evaluation concerned sloping embankments, ditches, and superelevated roadway sections. Evaluation of curb influence on barrier performance was not within the scope of the study.
At the inception of this study, trips were made to several states to survey current barrier placement practices and to solicit input from various state transportation personnel. It was found that there are four basic conditions for which roadside and median barriers are typically placed on nonlevel terrain. These are illustrated in the photographs of Figures 1 through 4. First, barriers used to shield bridge piers, overhead sign bridge supports, or other rigid objects in depressed medians or on side slopes are often placed as near to the object as the barrier design permits. In many cases this places the barrier on the side slope as shown in Figure 1. Secondly, barriers used to shield bridge abutments or other rigid objects near the shoulder are often flared away from the shoulder and terminated. As a consequence, a portion of the barrier is placed on the side slope as illustrated in Figure 2. Thirdly, roadside barriers are sometimes placed on "barn roof" sections in high-fill areas. Typically the roadside is composed of a shoulder, then a relatively flat sloped embankment (usually a 6 to 1 slope) which may extend up to 20 ft (6.1 m) laterally from the shoulder, and finally a relatively steep embankment (usually 2 to 1 or steeper). In this case the barrier is placed on the 6 to 1 slope to shield the steeper embankment. This is illustrated in Figure 3. The last condition, which is not as common as the other conditions mentioned, involves median barriers used to prevent cross-over, head-on accidents that are placed on stepped or depressed medians. This is illustrated in Figure 4.

To evaluate the impact performance of longitudinal barriers placed on sloping terrain, a limited crash test program, supplemented by computer simulations, was employed. A discussion of this phase of the study is given in Chapter II.
Figure 1. Barriers shielding rigid objects.
Figure 2. Flared barriers.
Figure 3. Barrier on barn roof section.
Figure 4. Median barriers.
The tests and simulations were designed to provide data from which placement guidelines were developed. Procedures used in the development of the guidelines and the results are given in Chapter III.
II. RESEARCH APPROACH

Analysis of the impact of a vehicle with a barrier is complex even for ideal conditions such as a flat approach area to the barrier. The problem is compounded if the vehicle is traversing nonlevel or sloped terrain prior to impact. Sloped terrain causes the impacting vehicle to undergo angular motions that are not present on flat terrain. Crash testing is probably the best available method to evaluate vehicle and barrier performance during such impacts. Crash tests are costly, however, and cannot be expected to provide all the answers. Analytical techniques and computer programs must be called on to help fill the void and to supplement the limited number of crash tests.

II-1. Use of GUARD

In the initial phases of the study, an attempt was made to use computer program GUARD (2) to analyze barrier impacts on sloped terrain. At that time, GUARD was in the final stages of development and documentation. Limited validation studies had been conducted to establish its accuracy and limitations. It was a logical choice of available computer programs since it was developed specifically to evaluate the vehicle/guardrail impact problem. It was developed with full three-dimensional vehicle and barrier capabilities.

TTI researchers experienced some difficulty in adapting GUARD and in finding and correcting certain coding errors. Once the program was debugged and made operational, an attempt was made to simulate crash tests of barriers on slopes, conducted as part of this study. This effort met with mixed success and after considerable expense and effort it was concluded that further efforts with GUARD should be discontinued. A summary of TTI's use of GUARD in this study is given in Appendix A.
II-2 Crash Test Program

The second phase of the study involved a limited crash test program. The purpose of these tests was (a) to gain insight into the effect of sloping terrain on barrier performance; (b) to establish a limited number of data points from which placement recommendations could be developed; and (c) to establish a data base from which computer program GUARD could be validated. Tests of a standard G4(1S)a W-beam roadside barrier, a standard G9a thrie-beam roadside barrier, and a standard G1a cable roadside barrier were conducted. The barriers in each test were placed on a 6 to 1 side slope. The reader should refer to Volume II for full details of the crash tests.

II-3 Use of HVOSM

In the final phase of the research, a version of computer program HVOSM as documented in reference 3 was used to supplement crash test results in the development of placement guidelines. Although HVOSM can be used to simulate a limited class of flexible barrier impacts, it was concluded that HVOSM did not have sufficient capabilities to simulate vehicle/barrier impacts for nonlevel approach terrain. Instead, it was used to accurately determine vehicle kinematics upon impact with the barrier. Then, based on observed vehicle behavior from the crash tests, a determination was made as to whether the vehicle would have been contained and redirected. The procedure for making this determination follows.

II-4 Barrier Containment Criteria

After careful study of the crash test film, it was concluded that front bumper position relative to the barrier at impact was the critical factor with regard to vehicle containment and redirection. Other vehicle factors that have an influence on impact behavior include velocity of the

---

aBarrier notations as used in the 1977 AASHTO Barrier Guide (1).
point of contact and the shape and stiffness of the bumper and sheet metal near the contact point. However, the degree to which these factors influenced containment could not be quantified with the limited number of crash tests. Containment criteria for the various types of longitudinal barriers was established as follows.

II-4-a. W-beam and thrie-beam barrier. Four crash tests of a type G4(1S) W-beam barrier and one test of a type G9 thrie-beam barrier were conducted on nonlevel terrain. Shown in Figures 5 and 6 is the trajectory of the midheight of the front bumper, right side\(^a\), with respect to the barrier just prior to and after impact for each test. After careful analysis of these results, including the high-speed film of the tests, it was concluded that (a) vehicle override of a W-beam or thrie-beam barrier is likely if the midheight of the bumper impacts above the center of the rail's top corrugation, and (b) vehicle containment and redirection with a W-beam or thrie-beam barrier is likely if the midheight of the bumper impacts between the centers of the rail's lower and upper corrugation. Although there were no cases of underriding in the tests, it was assumed that vehicle underride of a W-beam or thrie-beam is likely if the midheight of the bumper impacts below the center of the rail's lower corrugation. The consequences of underride could be vehicle snagging on a post and/or vehicle submarining under the barrier. Such problems can be reduced by the addition of a rub rail.

The above containment criteria are illustrated in Figures 7 and 8 for W-beam and thrie-beam barriers. It must be noted that the above criteria and those that follow are predicated on a vehicle striking the barrier at a weight, speed, and angle equal to or less than 4500 lb (2043 kg), 60 mph (96.5 km/h), and 25 degrees, respectively.

\(^a\)In both the simulations and full-scale tests, the right front corner of the vehicle impacted the barrier initially.
Figure 5. Bumper Trajectory, W-beam tests.

Metric Conversions:

\[
1 \text{ lb} = 0.454 \text{ kg} \\
1 \text{ mph} = 1.608 \text{ km/h}
\]
Figure 6. Bumper Trajectory, Three Beam Test.

Metric Conversions:

1 lb = 0.454 kg
1 mph = 1.608 km/h
Override if midheight of bumper above center of top corrugation at impact.

Containment and redirection if midheight of bumper impacts within this zone.

Underride if midheight of bumper below center of lower corrugation at impact.

<table>
<thead>
<tr>
<th>BARRIER</th>
<th>a (in)</th>
<th>b (in)</th>
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<tr>
<td>G4(1W)</td>
<td>7.625</td>
<td>17.063</td>
</tr>
<tr>
<td>G4(2W)</td>
<td>7.625</td>
<td>17.063</td>
</tr>
<tr>
<td>G4(1S)</td>
<td>7.625</td>
<td>17.063</td>
</tr>
<tr>
<td>G4(2S)</td>
<td>7.625</td>
<td>17.063</td>
</tr>
<tr>
<td>MB4W</td>
<td>7.625</td>
<td>20.063</td>
</tr>
<tr>
<td>MB4S</td>
<td>7.625</td>
<td>17.063</td>
</tr>
</tbody>
</table>

Metric Conversions

1 in. = 2.54 cm

Figure 7. Containment Criteria, W-beam Barrier.
Override if midheight of bumper above center of top corrugation at impact.

Containment and redirection if midheight of bumper impacts within this zone.

Underride if midheight of bumper below center of lower corrugation at impact.

15.25"

14.375"

Metric Conversions
1 in. = 2.54 cm

Figure 8. Containment Criteria, Thrie Beam Barrier.
It is also noted that the above criteria were developed for "strong post" W-beam and thrie-beam systems. Tests of the "weak post" W-beam system (G2 system in 1977 AASHTO Barrier Guide) for a nonlevel terrain approach have not been conducted. Although the G2 system has exhibited impact behavior similar to the G1 cable system in level terrain tests, tests are recommended to establish a base from which placement guidelines for nonlevel approaches can be developed. It is noted that the G2 system is used primarily in one state only.

II-4-b. Cable barrier. Two full-scale crash tests of type G1 roadside cable barrier were conducted on nonlevel terrain. Shown in Figure 9 is the trajectory of the midheight of the front bumper, right side, with respect to the barrier just prior to and after impact for each test. Upon analysis of these tests it was concluded that (a) vehicle override of a cable barrier is likely if the midheight of the bumper is above the top cable on impact, and (b) vehicle containment and redirection is likely if at impact the midheight of the bumper is below the top cable and the upper corner of the right front fender is above the lower cable. Analysis of these and other cable barrier tests (4) showed that upon contact the cable(s) creases the sheet metal and it typically remains in the crease during contact. Such behavior enables a cable barrier to redirect a vehicle even if the bumper is below the cable. When the upper corner of the right front fender is below the lower cable, it is assumed that underride will occur. The cable barrier containment criteria are illustrated in Figure 10.

II-4-c. Box-beam barrier. No tests have been conducted on box-beam barriers placed on nonlevel terrain. However, box-beam guardrail behaves similarly to cable barrier in many respects. Upon impact the box-beam
Figure 9. Bumper Trajectory, Cable Barrier.

Metric Conversions:
1 lb = 0.454 kg
1 mph = 1.608 km/h
Override if midheight of bumper above top of cable at impact.

Containment and redirection if midheight of bumper below top cable and upper corner of front fender above lower cable at impact.

Underride if upper corner of front fender below lower cable at impact.

Metric Conversions
1 in. = 2.54 cm

Figure 10. Containment Criteria, Cable Barrier.
separates from the weak posts in the impact zone. Furthermore, the rail typically creases the sheet metal of the vehicle and remains in the crease during contact. Therefore, it was decided to apply the cable guardrail criteria for the development of placement guidelines to box-beam guardrail. Thus, for box-beam guardrail it was assumed that if the bumper mid-height impacts below the top of the box-beam, the vehicle will not over-ride; and if the upper front corner of the vehicle fender is above the base of the box-beam, the vehicle will not underride. This is illustrated in Figure II-11.

II-4-d. Concrete safety shaped barrier. In the absence of crash tests of the concrete safety shaped barrier on nonlevel terrain and the fact that its impact performance is significantly different from other longitudinal barriers, no effort was made to formulate placement criteria for the barrier on nonlevel terrain. The reader should refer to reference 5 for recommended placement of the barrier on superelevated sections.

It must be noted that in the course of developing the barrier containment criteria described above, certain assumptions had to be made with regard to vehicle barrier interaction. These assumptions are believed to be conservative in nature and may overstate the likelihood of vehicle override or underride. Additional research involving crash testing and computer simulation is needed to determine the validity of these assumptions.

II-5. HVOSM Modifications

Changes were made to the TTI version of HVOSM (3) to permit the calculation and output of position, velocity, and height above terrain of the midheight of the right corner of the bumper. These changes are described in Appendix B.
Override if midheight of bumper above top of box beam at impact.

Containment and redirection if midheight of bumper below top of box beam and upper corner of front fender above bottom of beam at impact.

Underride if upper corner of front fender below bottom of box beam at impact.

(a) Roadside Box Beam Barrier

Override if midheight of bumper above top of box beam at impact.

Containment and redirection if midheight of bumper below top of box beam and upper corner of front fender above bottom of beam at impact.

Underride if upper corner of front fender below bottom of box beam at impact.

(b) Box Beam Median Barrier

Metric Conversions
1 in. - 2.54 cm

Figure 11. Containment Criteria, Box Beam Barrier.
III. DEVELOPMENT OF PLACEMENT GUIDELINES

III-i. Performance Standards

Current guidelines for the impact performance of longitudinal barriers are contained in the 1977 AASHTO Barrier Guide (1) and in NCHRP Report 230 (6). In general, for automobile impacts these documents recommend that longitudinal barriers meet the following performance standards:

1. **Strength or Containment** - The barrier should have strength and geometric characteristics sufficient to contain and redirect a full-size automobile weighing approximately 4500 lb (2043 kg) impacting at 25 degrees and 60 mph (96.5 km/h). For these conditions, the vehicle should not override, penetrate, or underride the barrier and it should not pocket and spin out following impact.

2. **Impact Severity** - Impact with the barrier should not cause serious injuries to occupants of the impacting vehicle. Impact severity is evaluated via the response of an automobile weighing approximately 2250 lb (1022 kg) (preferably one weighing 1800 lb (817 kg)), impacting the barrier at 60 mph (96.5 km/h) and 15 degrees.

3. **Post-Impact Trajectory** - The path of the vehicle after impact with the barrier should not impose an undue hazard to other traffic. Desirably, the vehicle should remain near and parallel to the barrier after impact.

Of the above three measures of performance, the first two are recognized as the more significant. The third measure is viewed as desirable but not necessary for acceptable performance.

For the present effort, three sets of performance standards were used to develop placement criteria. For all three sets the basic requirement was that the barrier must satisfy the containment or strength criteria.
Due to limitations of available computer programs, a determination of the "impact severity" and "post-impact trajectory" measures could not be made. It was assumed that the barrier would satisfy these measures if it satisfied the containment criteria. It is noted that with the exception of the "post-impact trajectory" criteria, this assumption was valid for those full-scale tests conducted within this contract in which the containment criteria were satisfied.

The three sets of performance standards selected were as follows:

**Case 1** - Barrier must contain and smoothly redirect both full-size and mini-size automobiles at an impact speed of 60 mph (96.5 km/h) and impact angles up to 25 degrees.

**Case 2** - Barrier must contain and redirect a full-size automobile at an impact speed of 60 mph (96.5 km/h) and impact angles up to 25 degrees, and a mini-size automobile at an impact speed of 60 mph (96.5 km/h) and impact angles up to 15 degrees.

**Case 3** - Barrier must contain and redirect both full-size and mini-size automobiles at an impact speed of 60 mph (96.5 km/h) and impact angles up to 15 degrees.

The question is: Why were three performance standards used in developing placement guidelines and which one is most appropriate? Initially, the researchers felt the guidelines should be based on nationally recognized performance standards as given in NCHRP Report 230 (6). Such standards are incorporated in Case 2 as defined above. For all practical purposes, NCHRP Report 230 assumes the barriers will be tested on flat approach areas. For such conditions, it is believed that most barriers satisfying the Case 2 criteria will satisfy the Case 1 criteria. However, after analysis of the data from the present study it became obvious that
for a nonlevel approach there are impact conditions for which the two standards are not mutually satisfied. As such, it is the writers' opinion that the Case 1 standard should be used in lieu of the Case 2 standard for nonlevel barrier placement. The Case 3 standard is believed to more accurately reflect the large majority of real-world accidents. It may also be viewed as a "lower service level" standard.

Selection of the "most appropriate" standard for a given situation will require some effort. In essence, selection of a standard and subsequent barrier placement should be made in conjunction with and not independent of the process of determining barrier need. The most rational procedure whereby such factors can be objectively evaluated is one that considers the cost-effectiveness or benefit/cost of alternatives. In other words, one should include in a cost-effectiveness analysis the effects of a standard and, hence, barrier placement on the ultimate decision regarding barrier need.

III-2. Roadway and Roadside Geometric Parameters

Geometric parameters that influence the trajectory and attitude of a vehicle encroaching on the roadside include roadway cross slope, shoulder width and cross slope, and embankment slope. There are wide ranges of each parameter that occur in the field, and their possible combinations are infinite. Simulation of all possible combinations obviously could not be done. It was therefore necessary to carefully select a matrix of parameters that would encompass most combinations of interest. The matrix chosen is shown in Table 1. Note there are 26 combinations. Roadway cross slopes varied from +48 to 1 to -10 to 1; shoulder cross slopes varied from +20 to 1 to -10 to 1; and embankment slopes varied from +4 to 1 to -4 to 1.
### TABLE 1. ROADWAY/ROADSIDE GEOMETRIC PARAMETERS

<table>
<thead>
<tr>
<th>$a_t$</th>
<th>+48</th>
<th>-20</th>
<th>-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_s$</td>
<td>+20</td>
<td>+20</td>
<td>+20</td>
</tr>
<tr>
<td>$a_e$</td>
<td>+4</td>
<td>+4</td>
<td>+4</td>
</tr>
</tbody>
</table>

Positive sloping downward to right.

Metric Conversion:

1 ft = 0.305 m
III-3. Vehicle Parameters

To establish adherence to the performance standards of Section III-1, it was necessary to evaluate the trajectory and attitude of two automobile types, namely a full-size and a mini-subcompact car. Furthermore, it was necessary to evaluate vehicle behavior for 60 mph (96.5 km/h) encroachments at angles up to 25 degrees for the roadway/roadside conditions of Section II-2. Encroachment angles of 7.5 degrees, 15 degrees, and 25 degrees were selected. Hence, there were six vehicle/encroachment angle combinations. When combined with the 26 geometric combinations, there were a total of 156 elements in the final matrix, i.e., there were 156 HVOSM computer simulations.

Vehicle data for a "typical" full-size car (1977 Plymouth Fury) were taken from information provided by FHWA (7). Data for a "typical" mini-subcompact car (1976 Honda Civic) were taken from Dynamic Science measurements (8). The actual vehicle data used in the HVOSM simulations are given in Appendix C. Four crucial vehicle dimensions used in the development of the guidelines are given in Table 2.

III-4. Analysis and Graphical Display of HVOSM Data

To facilitate analysis of the voluminous HVOSM output in terms of the containment criteria, plots of bumper position relative to the roadside terrain were generated. Shown in Figure 12 is a plot from one of the 156 runs. Input and output that generated this run are listed in Appendix C.

From these plots, the lateral distances at which a given barrier satisfied the containment criteria of Section II-4 were determined. As an example, for a G4 roadside barrier and the criteria of Figure 7, horizontal lines were projected across each figure at bumper heights of 17.1 in. (43.3 cm) and 24.7 in. (62.7 cm). Overriding is predicted when the
TABLE 2. BUMPER AND FENDER HEIGHTS

<table>
<thead>
<tr>
<th>VEHICLE</th>
<th>BUMPER MIDHEIGHT ABOVE GROUND (in.)*</th>
<th>HEIGHT OF FRONT FENDER ABOVE GROUND (in.)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977 Plymouth Fury</td>
<td>17.5</td>
<td>33.5</td>
</tr>
<tr>
<td>1976 Honda Civic</td>
<td>17.2</td>
<td>28.2</td>
</tr>
</tbody>
</table>

*Based on curb weight configuration.

Metric Conversions
1 in. = 2.54 cm
Figure 12. Plot of 4500 lb Vehicle Right Front Bumper Relative to Terrain.
plot lies above the upper line, and underriding is predicted when the plot lies below the lower line. The significance of this example is as follows:

1. Override of large cars predicted to occur if face of G4 barrier placed between 1.5 ft (0.46 m) and 10.5 ft (3.2 m) of the shoulder's edge for the given geometric conditions.

2. Underride of large car predicted to occur if face of G4 barrier placed between 12.5 ft (3.8 m) and 25.5 ft (7.8 m) of the shoulder's edge for the given geometric conditions.

The above procedure was repeated for each barrier type for each of the 156 runs. This led to the development of a series of placement guidelines for each of the three performance standards (cases), summarized in Table 3, for each of five barrier categories as identified in Table 4. As indicated in Table 4, there are specific barrier types having similar geometric and impact characteristics, as has been discussed in Section II-4. The complete set of guidelines are given in Appendix D. Shown in Figure 13 is one of the series of placement guidelines. This particular figure presents placement guidelines for Category "C" type barriers for the Case 1 performance standard and the given roadway and shoulder slope. Two zones are depicted: (1) combinations of barrier offset, measured from the edge of the travelway to the face of the barrier, and embankment slope in which acceptable barrier performance is predicted; (2) combinations of barrier offset and embankment slope in which vehicle underride may occur. Placement of the barrier in the latter zone is acceptable if provisions are made to prevent potential underriding, e.g., by the use of a rub rail similar to that used on the MB4W barrier system. Barrier override is predicted for combinations of offset and embankment slope not within the
<table>
<thead>
<tr>
<th>PERFORMANCE STANDARD</th>
<th>CONTAINMENT CRITERIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>Barrier must contain and smoothly redirect both full-size and mini-size automobiles at an impact speed of 60 mph (96.5 km/h) and impact angles up to 25 degrees.</td>
</tr>
<tr>
<td>Case 2</td>
<td>Barrier must contain and redirect a full-size automobile at an impact speed of 60 mph (96.5 km/h) and impact angles up to 25 degrees, and a mini-size automobile at an impact speed of 60 mph (96.5 km/h) and impact angles up to 15 degrees.</td>
</tr>
<tr>
<td>Case 3</td>
<td>Barrier must contain and redirect both full-size and mini-size automobiles at an impact speed of 60 mph (96.5 km/h) and impact angles up to 15 degrees.</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>BARRIER CATEGORY</th>
<th>CORRESPONDING BARRIER TYPES</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>G1, MB3</td>
</tr>
<tr>
<td>B</td>
<td>G3</td>
</tr>
<tr>
<td>C</td>
<td>G4(1W), G4(2W), G4(1S), G4(2S), MB4S</td>
</tr>
<tr>
<td>D</td>
<td>G9, MB9</td>
</tr>
<tr>
<td>E</td>
<td>MB4W</td>
</tr>
</tbody>
</table>
FIGURE 13

BARRIER CATEGORY C, PLACEMENT ON NONLEVEL TERRAIN
TRAVELWAY SLOPE = 48:1  CASE-1  SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE

- BARRIER CATEGORY C
- BARRIER CATEGORY C WITH RUBRAIL

EXAMPLE 1
EXAMPLE 2

EMBANKMENT SLOPE (a:1)

LATERAL OFFSET, D, (FT.)

* POSITIVE AS SHOWN
above two zones, and consequently barrier placement is not recommended in this zone.

Use of the guidelines is illustrated in the following examples, both of which are for a Case 1 performance standard:

**Example 1:**

**Barrier:** G4(2W)
**Travelway slope:** 48 to 1
**Shoulder slope:** 20 to 1
**Embankment slope:** 6 to 1
**Desired offset:** 20 ft (6.1 m) or 8 ft (2.4 m) off shoulder

From Figure 13, it is determined that barrier placement at this offset is not recommended. For acceptable performance the barrier should be placed 16.5 ft (5.0 m) or less from the travelway or 4.5 ft (1.4 m) or less from the shoulder.

**Example 2**

Same as Example 1 except embankment slope equals 8 to 1. From Figure 13 it is determined that barrier placement is acceptable for the desired offset.

It should be remembered that evaluation of underride for the G1 cable barrier, the G3 box beam barrier, and the MB3 box beam barrier is based on the height of the front fender above the terrain. Fender heights of the two vehicles used in the simulation are given in Table 2. Fender positions with respect to the terrain were determined from photos of bumper position as follows:

Fender position for full-size car = bumper position for full-size car + 16.0 in. (40.6 cm);
Fender position for mini-subcompact car = bumper position for mini-subcompact car
+ 11.0 in. (27.9 cm).

III-5. **Summary of Results**

Placement guidelines for the widely used roadside and median barriers are listed in Appendix D. The guidelines are composed of 75 figures of the type shown in Figure 13, and are applicable for five longitudinal barrier categories (see Table 4) and three performance standards (see Table 3). To facilitate use of the guidelines, an index was developed and is presented in Table 5. For example, placement guidelines for a G9 (roadside) barrier (Category "D"), Case 1 performance standards, for a +48 to 1 roadway cross slope and a +20 to 1 shoulder slope are given in Figure D-50 of Appendix D.

Regardless of where a longitudinal barrier is placed, the distance between the barrier and the hazard being shielded should not be less than the dynamic deflection expected to occur from impact. Reference 1 contains recommended dynamic deflection distances for widely used barriers.
TABLE 5. AN INDEX FOR PLACEMENT GUIDELINES
BY FIGURE NUMBER

NOTE: Figure numbers in table correspond to those given in Appendix D.

<table>
<thead>
<tr>
<th>Case</th>
<th>Barrier Category</th>
<th>Shoulder Slope</th>
<th>Shoulder Slope</th>
<th>Shoulder Slope</th>
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<tr>
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<td>As=-20</td>
<td>As=20</td>
<td>As=-20</td>
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<tr>
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<td>B</td>
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<td>C</td>
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<td>D-37</td>
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<td>E</td>
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CONCLUSIONS

Detailed guidelines were developed for placement of widely used roadside and median barriers on roadside and median slopes. A limited crash test program coupled with an extensive computer simulation program was used in formulating the guidelines. Parameters included in the formulation were vehicle size and weight, vehicle encroachment speed and angle, roadway cross slope, shoulder cross slope, embankment slope, barrier dimensions, barrier impact characteristics, and barrier offset from the edge of the travelway. The guidelines are contained in 75 figures, according to one of five barrier categories and one of three performance standards. An index is provided for quick reference to the appropriate criteria.

In arriving at the findings and conclusions of the study, certain assumptions had to be made with regard to the barrier containment criteria. The assumptions are believed to be conservative in general, i.e., the containment criteria probably overstate the likelihood of vehicle override or underride. However, additional research involving crash tests and computer simulations may be necessary to ascertain the validity of these assumptions. Discretion is therefore advised in the application of the findings and placement criteria.

Specific conclusions reached during the course of the research were as follows:

(1) Impact performance of a longitudinal barrier is sensitive to the slope of the approach area in front of the barrier.

(2) Where possible, the area between the travelway and the face of the barrier should be flat and unobstructed to afford an errant motorist room to stop or regain control prior to striking the
If struck, the barrier can be expected to perform better if the approach area is flat.

(3) Impact performance of W-beam and thrie-beam longitudinal barriers is more sensitive to variations in approach slope than are cable barriers.

(4) Regardless of where a longitudinal barrier is placed, the distance between the barrier and the hazard being shielded should not be less than the dynamic deflection of the barrier.

(5) Use of the placement guidelines presented herein should be made in conjunction with a cost-effective evaluation of guardrail need. The evaluation should consider factors such as barrier level of service, nature and frequency of predicted accidents, societal costs, and initial and maintenance costs.
APPENDIX A
DISCUSSION OF GUARD

Version 1.0

The first phase of the reported study involved the adoption of computer program GUARD (2) to the local computer facilities. In the referenced form it was referred to as version 1.0 by FHWA. The adoption process was accomplished without any major problems, and the checkout runs were satisfactory. The next step was to apply GUARD to simulate full-scale crash tests planned within the study. Initially, attempts were made to simulate impacts with a G4(1S) roadside barrier placed on a 6 to 1 side slope. Numerical stability problems were encountered once impact occurred. Steps were taken to internally reduce the solution time step to achieve a solution. Several other modifications to the program were made during this phase of the study to improve GUARD's utility and economy. The program was modified to print the position of the right front bumper of the vehicle as part of its output. It was also modified to permit an increased time step for vehicle travel prior to contact with the barrier. These modifications allowed the motion of the front of the vehicle to be easily plotted and reduced computing time since a large time step could be used prior to impact.

Once the above changes were made, version 1.0 was used to simulate four crash tests of the G4(1S) W-beam (3). Figures A1 through A4 compare predicted motions of vehicle center of gravity to movement of test vehicles. Figures A5 through A8 show comparisons of the motion of the right front bumper of the vehicle. Tables A1 through A3 present comparisons of exit conditions, maximum rail deflection, maximum roll and pitch angles, and maximum longitudinal and vertical accelerations. Analysis of these results show the following:
Figure A-1. XZ Plot of Vehicle Center of Gravity, Test 1.
Figure A-2. XZ Plot of Vehicle Center of Gravity, Test 2.
Figure A-3. XZ Plot of Vehicle Center of Gravity, Test 3.
Figure A-8. YZ Plot of Vehicle Right Front Bumper, Test 4.
<table>
<thead>
<tr>
<th>TEST</th>
<th>Weight</th>
<th>Speed</th>
<th>Angle</th>
<th>Barrier Offset</th>
<th>Speed (mph)</th>
<th>Angle (deg)</th>
<th>Test Time (sec)</th>
<th>Defl Time (sec)</th>
<th>Test Defl (ft)</th>
<th>Guard Time (sec)</th>
<th>Defl (ft)</th>
</tr>
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<tbody>
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<td>3659-1</td>
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<td>60</td>
<td>25</td>
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<td>44.35</td>
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<td>1.293</td>
<td>0.450</td>
<td>3.711</td>
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<td>0.790</td>
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<tr>
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<td>12</td>
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<td>0.700</td>
<td>1.027</td>
<td>1.729</td>
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</table>

Table A-1. Comparisons of Exit Conditions and Maximum Rail Deflections.
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<tr>
<th>TEST</th>
<th>Impact Conditions</th>
<th>Maximum Roll Angle</th>
<th>Maximum Pitch Angle</th>
</tr>
</thead>
<tbody>
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<td>Speed (mph)</td>
<td>Angle (deg)</td>
</tr>
<tr>
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<td>60</td>
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</tr>
<tr>
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<td>15</td>
</tr>
</tbody>
</table>

Table A-2. Comparisons of Maximum Roll and Pitch Angles.
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
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<td>Weight (lb)</td>
<td>Speed (mph)</td>
<td>Angle (deg)</td>
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</tr>
<tr>
<td>3659-4</td>
<td>2250</td>
<td>60</td>
<td>15</td>
</tr>
</tbody>
</table>

Table A-3. Comparisons of Maximum Longitudinal and Vertical Accelerations.
1. General vehicle behavior was predicted reasonably well in terms of override and redirection.

2. Vehicle attitude upon impact with barrier, as measured by roll, pitch, and yaw (exit angle) angles, compared reasonably well in some cases and not too good in other cases.

3. GUARD consistently predicted higher vehicle decelerations than those measured in the test vehicle.

4. GUARD consistently predicted higher barrier deflection than those measured in the tests.

Simulations of impacts with the Gl cable barrier on a 6 to 1 slope were attempted next. In essence, this effort was totally unsuccessful. At this time, FHWA informed the TTI researchers that an updated version of GUARD, version 1.1, was available and should be used in lieu of version 1.0.

**Version 1.1**

This version has several advantages over the preceding version of the program: 1) restart capability, 2) thrie-beam model, and 3) ability to model various soil properties. (Version 1.0 had only one specific soil/post force relationship.) Version 1.1 was first checked using a sample data deck obtained from FHWA. Results of this run matched results provided with the sample data. It was then used to model a 4500 lb (2043 kg) vehicle impacting a cable barrier system at an angle of 25° and a velocity of 60 mph (96.6 km/h). The first attempt terminated before the vehicle contacted the barrier due to exponent overflow and attempts to take the square root of a negative number. Upon investigation, errors were found in the program input documentation. Variables KONTR(6) and KONTR(2) had to be reversed. In the next run, the variables KONTR(6) and KONTR(2)
were in the proper order. However, execution was again terminated prior to impact. An error message "IER=-1" was outputted, indicating certain elements had slack. After further investigation, an error in the documentation for the materials cards was found. This was corrected and another run attempted. Execution was terminated again before impact occurred due to exponent overflow and attempts to take the square root of a negative number in subroutine FRCIN.

After additional lengthy investigations and discussions with FHWA, it was decided to change variables in subroutine FRCIN to extended precision to improve numerical accuracy. Sample data from FHWA were again used to check the modifications, and the results agreed with the previous results. The cable barrier system run was then repeated. Execution was again terminated before impact occurred due to exponent overflow and attempts to take the square root of a negative number. Since the changes in subroutine FRCIN had no effect, it was decided to change the entire program to double precision. This modification involved two steps: 1) placing an "IMPLICIT REAL*8 (A-H,O-Z)" statement in the main program and in each subroutine, and 2) changing all built-in FORTRAN functions to the corresponding double precision FORTRAN functions; i.e., SQRT was changed to DSQRT, FLOAT was changed to DFLOAT, etc. The cable system was run using these modifications. Once again execution terminated prior to impact due to exponent overflow and attempts to take the square root of a negative number.

As discussed above, TTI made some modifications to GUARD version 1.0. One modification improved numerical stability of the model by performing a test to avoid taking the square root of a negative number and reducing the time step to eliminate the problem when it arose. It was
decided to add this modification to the double precision version 1.1. A run with the cable barrier system failed due to the same exponent overflow and also exponent underflow, but there were no attempts to take the square root of a negative number. Thus, it appeared that the double precision changes had no positive effect on the stability of the model.

The other TTI changes were added to the original version 1.1. A run using the W-beam barrier system was made. The results of this run were compared to results from the same input data using version 1.0. Vehicle position and velocity compared very well, but there were differences, some quite large, in vehicle orientation and acceleration.
Summary

As can be deduced from the preceding discussion, use of GUARD in this study met with mixed success. The original version (1.0) predicted overall vehicle behavior reasonably well for impacts with a W-beam barrier on a 6 to 1 slope. Barrier response and vehicle accelerations were not accurately predicted. Attempts to simulate a cable barrier were not successful, either with the original version or a later version (1.1). Numerous changes were made in an effort to correct the problems.

After much deliberation and after consulting with FHWA, it was decided that further simulation with GUARD in the present study should be discontinued. It became apparent that although it could provide insight with regard to W-beam barrier impacts, it could not be applied to cable or box-beam barriers. Furthermore, even for the W-beam barriers, its use would be limited due to the cost per run. As discussed in Chapter III, a large matrix of runs was necessary to develop the required placement guidelines.

Finally, it must be stated that the discussion presented in Appendix A is not intended as an indictment of program GUARD. All of the problems encountered are not necessarily attributed to the program or its developers. The program, when first acquired for this study, was still in its final stages of development and had received only minimal validation. Documentation had not been thoroughly checked. Inexperience with GUARD and its limitations undoubtedly led to errors and improper use by TTI researchers. Furthermore, the program as originally designed and developed was intended to evaluate effects of vehicle bumper and structural properties on vehicle behavior during collision with barriers on level terrain. Impact behavior is greatly complicated if the approach terrain is sloped.
A study is planned by FHWA to evaluate and validate programs such as GUARD. This study, which will establish limitations, weaknesses, applications, etc., of these programs, is overdue and should preclude future problems of the type encountered with GUARD.
APPENDIX B

HVOSM MODIFICATIONS
To determine bumper position of a vehicle traveling off the roadway and over an embankment, several geometric quantities must be known. Figure B1 shows a vehicle as it would be initially positioned. The global or space-fixed coordinate system, vehicle-fixed coordinate system, travel­way, shoulder, and embankment are identified. As the vehicle travels off the roadway, the program determines, among other things, the vehicle's acceleration, velocity, and position. These values are determined for the center of gravity of the vehicle, which is also the origin of the vehicle coordinate system. If the vehicle-fixed coordinates of the right corner of the front bumper are known, the velocity and position in space-fixed coordinates may be determined. Once the position of the bumper point is known, the height of the bumper point above the terrain can be calculated. Subroutine BUMPOS was added to HVOSM to calculate the velocity, position, and height of the bumper point above the terrain. BUMPOS also allows the user to save the data so that plots of the bumper point traject­ory may be made.

A single card was added to the program input which activates the sub­routine BUMPOS. This card has an identification of 30 (ICARD=30). If the card is not included in the input data, the program executes as before and the bumper data is not calculated. Figure B2 shows sample input data for the modified program. Figure B3 shows sample bumper position data generated by the modified version of HVOSM. A listing of subroutine BUMPOS follows Figure B3.
Figure B-1. Coordinate Systems.
RF 3659  1700 LB VEHICLE; 60 MPH; IMPACT ANGLE = 15.0 DEGREES
TRAVELWAY SLOPE = 48:1; SHOULDER SLOPE = 20:1; EMBANKMENT SLOPE = 4:1

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Figure B2. Sample Input to Modified Version of HVOSM.
RF J659  1700 LB VEHICLE; 60 MPH; IMPACT ANGLE = 15.0 DEGREES  
TRAVELWAY SLOPE = 48:1; SHOULDER SLOPE = 20:1; EMBANKMENT SLOPE = 4:1

<table>
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<tr>
<th>TIME (SEC.)</th>
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<th>Y (IN.)</th>
<th>Z (IN.)</th>
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Figure B3. Sample Bumper Position Data Generated by Modified Version of HVOSM.
SUBROUTINE BUMPOS (BUMPER POSITION)
***********************************************************************BMPS

SUBROUTINE BUMPOS
PURPOSE

This subroutine calculates the x, y, and z coordinates of a point on the vehicle bumper, the x, y, and z components of the velocity of the point on the bumper, and the height above the terrain of the point.

DESCRIPTION OF INPUT

XUMP - X coordinate of the point on the bumper in the vehicle fixed coordinate system.
YUMP - Y coordinate of the point on the bumper in the vehicle fixed coordinate system.
ZUMP - Z coordinate of the point on the bumper in the vehicle fixed coordinate system.
AMTX - Transformation matrix used to transform from vehicle fixed to space fixed coordinates.
NBX - Number of templates required to define the terrain.
NBY - Number of points in each template.
XGP - X coordinate, in space fixed coordinate system, of a point on a template defining the terrain.
YGP - Y coordinate, in space fixed coordinate system, of a point on a template defining the terrain.
ZGP - Z coordinate, in space fixed coordinate system, of a point on a template defining the terrain.
U - X component of the linear velocity of the vehicle center of gravity.
V - Y component of the linear velocity of the vehicle center of gravity.
W - Z component of the linear velocity of the vehicle center of gravity.
P - X component of the angular velocity vector of the vehicle center of gravity.
Q - Y component of the angular velocity vector of the vehicle center of gravity.
R - Z component of the angular velocity vector of the vehicle center of gravity.
XCF - X coordinate of the sprung mass center of gravity.
YCF - Y coordinate of the sprung mass center of gravity.
ZCF - Z coordinate of the sprung mass center of gravity.
T - Time, in seconds.

DESCRIPTION OF OUTPUT

DELTAZ - Height of point on the bumper above the terrain (inches).
XUPRX - X component of the velocity vector of the point on the bumper, in space fixed coordinates.
XUPRY - Y component of the velocity vector of the point on the bumper, in space fixed coordinates.
XUPRZ - Z component of the velocity vector of the point on the bumper, in space fixed coordinates.

Figure B4. Listing of Subroutine BUMPOS.
Figure B4. Listing of Subroutine BUMPOS (continued).
1. IF(XBUMPR .GE. XGP(I,1)) AND. XGP(IP1,1) .GE. XBUMPR) GO TO 30

10 CONTINUE
20 ZTERAN=0.0
GO TO 120
30 SLOPE=2.0
yy=0.0
I=I+1
JP1=J+1
SLOPE=SLOPE2
YY1=YY2
SLCP2=(YGP(IP1,JP1)-YGP(I,JP1))/(XGP(IP1,JP1)-XGP(I,JP1))
YY2=SLOPE2*SBUMPR+YGP(I,JP1)
IF(YBUMPR .GE. YY1, AND. YBUMPR .LE. YY2) GO TO 50

40 CONTINUE
GO TO 120
50 J=J+1
JP1=J+1
Z2=(YGP(IP1,J)-ZGP(I,J))/(XGP(IP1,J)-XGP(I,J))*(XBUMPR-XGP(I,J))
Z2=(YGP(IP1,J)-ZGP(I,J))/(XGP(IP1,J)-XGP(I,J))*(XBUMPR-XGP(I,J))
DYPG=YGP(IP1,JP1)-YGP(I,JP1)
IF(DYPG .EQ. 0.0) GO TO 60
SLOPE=(ZGP(IP1,JP1)-ZGP(I,JP1))/DYPG
GO TO 70
60 SLOPE=0.0
Z2=SLOPE=(YBUMPR-YGP(IP1,J)+ZGP(I,J)
DYPG=YGP(IP1,JP1)-YGP(IP1,J)
IF(DYPG .EQ. 0.0) GO TO 80
SLOPE=(ZGP(IP1,JP1)-ZGP(IP1,J))/DYPG
GO TO 90
70 SLOPE=0.0
Z2=SLOPE=(YBUMPR-YGP(IP1,J)+ZGP(IP1,J)
DYPG=YYP2-YY1
IF(DYPG .EQ. 0.0) GO TO 100
SLOPE3=(Z2-Z2)/DYPG
GO TO 110
90 SLOPE=0.0
Z2=SLOPE=(YBUMPR-YGP(IP1,J)+ZGP(IP1,J)
DYPG=YYP2-YY1
IF(DYPG .EQ. 0.0) GO TO 120
SLOPE3=(Z2-Z2)/DYPG
GO TO 130
100 SLOPE3=0.0
110 ZTERAN=SLOPE3*(YBUMPR-YY1)+Z2
120 DELTAZ=ZTERAN-XBUMPR
VX=IP*ZBUMP-R*YBUMPR)/12
VY=(V+*XBU*P+*ZBUMP)/12
VZ=(X+*YBUMPR-Q*XBUMPR)/12
VBUMPR=AMTX(I,1)*VX+AMTX(1,2)*VY+AMTX(1,3)*VZ
VBUMPR=AMTX(2,1)*VX+AMTX(2,2)*VY+AMTX(2,3)*VZ
VBUMPR=AMTX(3,1)*VX+AMTX(3,2)*VY+AMTX(3,3)*VZ
BUMPR(LLL,1)=T
BUMPR(LLL,2)=ZBUMPR
BUMPR(LLL,3)=ZBUMPR
BUMPR(LLL,4)=ZBUMPR
BUMPR(LLL,5)=VBUMPR
BUMPR(LLL,6)=VBUMPR
BUMPR(LLL,7)=VBUMPR
BUMPR(LLL,8)=DELTAZ
BUMPR(LLL,9)=ZTERAN
RETURN
END

Figure B4. Listing of Subroutine BUMPOS (continued).
APPENDIX C
SAMPLE HVOSM INPUT/OUTPUT
PF 3639  1700 LB VEHICLE; 60 MPH; IMPACT ANGLE = 15.0 DEGREES
TRAVELWAY SLOPE = -10:1; SHOULDER SLOPE = -10:1; EMBANKMENT SLOPE = 1:1

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<th>SUSPENSION DATA</th>
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<tr>
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<td>KF = 125.000 LB/IN</td>
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<tr>
<td>MU = 0.4940</td>
<td>B = 54.9000</td>
<td>KR = 106,330 LB/IN</td>
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<tr>
<td>WU = 0.3110</td>
<td>TF = 51.0000</td>
<td>CF = 58.000 LBS</td>
</tr>
<tr>
<td>IX = 1756.0 LB-SEC**2-IN</td>
<td>TD = 50.0000</td>
<td>CR = 97.000 LBS</td>
</tr>
<tr>
<td>IT = 4657.0</td>
<td>ZF = 6.4900</td>
<td>EPSILON = 0.001 IN/SEC</td>
</tr>
<tr>
<td>IX = 2698.0</td>
<td>ZR = 6.4900</td>
<td>EPSILON = 0.001 IN/SEC</td>
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<td>IR = 185.0</td>
<td>RW = 11.0000</td>
<td>CR = 3.000 LB-SEC/IN</td>
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<td>G = 386.400 IN/SEC**2</td>
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<th>ACCELEROMETER POSITIONS</th>
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<td>THETAO = 1.460</td>
<td>Y1 = 0.0</td>
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<tr>
<td>PSI0 = 15.000</td>
<td>Y2 = 0.0</td>
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<tr>
<td>PHI0 = 0.000</td>
<td>Z1 = 0.0</td>
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<td>PSI0 = 0.0</td>
<td>Z2 = 0.0</td>
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<th>PROGRAM CONTROL DATA</th>
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<td>SIGMAT = 6.000</td>
<td>END TIME = 4.000</td>
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<td>A2 = 2060.000</td>
<td>UVWMAX (STOP) = 0.0</td>
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<td>A3 = 0.170</td>
<td>ORIGIN STOP =</td>
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<td>A4 = 755.000</td>
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<tr>
<td>WAVE AMJ = 0</td>
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<td>(SPEED AND LOAD) DATA</td>
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Figure C1: Sample HVOSM Input for 1976 Honda Civic.
$X_{VTH} = 0.0 \quad \text{1/MPH}$

$X_{KL} = 0.0 \quad \text{1/LB}$

**VEHICLE MONITOR POINTS**

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Figure C1. Sample HVOSM Input for 1976 Honda Civic (continued).
**RF 3659** 1700 LB VEHICLE@ 60 MPH; IMPACT ANGLE = 16.0 DEGREES
TRAVELWAY SLOPE = -10:1; SHOULDER SLOPE = -10:1; EMBANKMENT SLOPE = 4:1

**FRONT WHEEL CAMBER**

**VS**

**SUSPENSION DEFLECTION**

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**CURB IMPACT DATA**

| YC1' | = | 0.0 | INCHES |
| YC2' | = | 0.0 | '" |
| ZC2' | = | 0.0 | '" |
| DELTC | = | 0.0 | SEC(INTEGR. INCR.) |
| PHIC1 | = | 0.0 | DEGREES |
| PHIC2 | = | 0.0 | '" |

**CUBIC IMPACT DATA**

| IPS1 | = | 200,000 | LB-SEC**2**-IN |
| CPS1 | = | 240,000 | LB-SEC |
| OMEGA PSI | = | 0.400 | RAD |
| KPSI | = | 3000,000 | LB-SEC/RAD |
| EPSILON PSI | = | 0.075 | RAD/SEC |
| TRAIL/Front(PT) | = | 1.100 | INCHES |

**BARRIER DIMENSIONS**

| Y(BR) = 0.3 | INCHES |
| DELTB = 0.0 | '" |
| INT = 0.3 | '" |
| ZBB = 0.0 | '" |
| EPSILON VB = 0.0 | IN/SEC |
| EPSILON OB = 0.0 | LB |
| DELTB = 0.0 | SEC |

**VEHICLE DIMENSIONS**

| XVF = 0.1 | INCHES |
| XYR = 0.0 | '" |
| YZ = 0.0 | '" |
| ZVE = 0.0 | '" |

**VEHICLE IMPACT DATA**

| INDH = 0 | (RIGID BARRIER, INFINITE VERT. DIM.) |
| = 2 | "INFINITE | '" |
| = 3 | "DEFORM, BARRIER, INFINITE | '" |
| = 4 | "" | "" |

**STRUCTURAL HARDPOINTS RELATIVE TO C. G.**

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>STIFFNESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>POINT 1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>POINT 2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>POINT 3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**SPRUNG MASS-BARRIER IMPACT DATA**

| SPRUNG LOAD | 0.0 |
| VS | 0.0 |
| SIGMAR 1 | 0.0 |
| SIGMAR 2 | 0.0 |
| SIGMAR 3 | 0.0 |
| SIGMAR 4 | 0.0 |
| SIGMAR 5 | 0.0 |
| SIGMAR 6 | 0.0 |
| SIGMAR 7 | 0.0 |
| SIGMAR 8 | 0.0 |
| SIGMAR 9 | 0.0 |
| SIGMAR 10 | 0.0 |

*Figure Cl. Sample HVOSM Input for 1976 Honda Civic (continued).*
Figure Cl. Sample HVOSM Input for 1976 Honda Civic (continued).
**Figure C2. Sample HVOSM Input for 1977 Plymouth Fury.**
**AF 3659**

4,500 LB VEHICLE MPH IMPACT ANGLE = 15 DEGREES

TRAVELWAY SLOPE = -10:1
SHOULDER SLOPE = -10:1
EMBANKMENT SLOPE = 4:1

**F RONT WHEEL CAMBER**

**GROUP SUSPENSION DEFLECTION**

<table>
<thead>
<tr>
<th>DECK*</th>
<th>PHI</th>
<th>DEGREES</th>
</tr>
</thead>
<tbody>
<tr>
<td>-4.0</td>
<td>-2.0</td>
<td>0.0</td>
</tr>
<tr>
<td>-3.0</td>
<td>-2.0</td>
<td></td>
</tr>
<tr>
<td>-2.0</td>
<td>-0.9</td>
<td></td>
</tr>
<tr>
<td>-1.0</td>
<td>-0.1</td>
<td></td>
</tr>
<tr>
<td>0.0</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>0.0</td>
<td></td>
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<tr>
<td>3.0</td>
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<td></td>
</tr>
<tr>
<td>4.0</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

**CURVE IMPACT DATA**

<table>
<thead>
<tr>
<th>YC1'</th>
<th>V</th>
<th>0.0 INCHES</th>
</tr>
</thead>
<tbody>
<tr>
<td>YC2'</td>
<td>V</td>
<td>0.0 INCHES</td>
</tr>
<tr>
<td>ZC2'</td>
<td>V</td>
<td>0.0 DEGREES</td>
</tr>
<tr>
<td>DELTC</td>
<td>V</td>
<td>0.0</td>
</tr>
<tr>
<td>R4IC</td>
<td>V</td>
<td>0.0</td>
</tr>
<tr>
<td>HIC</td>
<td>V</td>
<td>0.0</td>
</tr>
<tr>
<td>IPSI</td>
<td>V</td>
<td>0.0</td>
</tr>
<tr>
<td>CPSI</td>
<td>V</td>
<td>1,000,000 LBF-SEC-2-IN</td>
</tr>
<tr>
<td>EPSI</td>
<td>V</td>
<td>0.523 RAD</td>
</tr>
<tr>
<td>FPSI</td>
<td>V</td>
<td>0.010 RAD-SEC</td>
</tr>
<tr>
<td>TRAIL, FRONT (FT)</td>
<td>V</td>
<td>1,500 INCHES</td>
</tr>
</tbody>
</table>

**VEHICLE DIMENSIONS**

<table>
<thead>
<tr>
<th>Y</th>
<th>0.0</th>
<th>INCHES</th>
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</thead>
<tbody>
<tr>
<td>DELTRE</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>ZET</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>MUG</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>EPSILON</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>EPSILON</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>EPSILON</td>
<td>0.0</td>
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<tr>
<td>EPSILON</td>
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<td></td>
</tr>
<tr>
<td>EPSILON</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

**BARRIER DIMENSIONS**

<table>
<thead>
<tr>
<th>KV</th>
<th>0.0</th>
<th>LBF-SEC-2-IN</th>
</tr>
</thead>
<tbody>
<tr>
<td>DELTR</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>CCPN</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>MUG</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>EPSILON</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>EPSILON</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>EPSILON</td>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

**SPRUNG MASS-BARRIER IMPACT DATA**

<table>
<thead>
<tr>
<th>BARRIERS LOAD DEFL.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
</tr>
</tbody>
</table>

**BARRIER LOAD DEFL.**

| SIGMAR 0 | 0.0 |
| SIGMAR 1 | 0.0 |
| SIGMAR 2 | 0.0 |
| SIGMAR 3 | 0.0 |
| SIGMAR 4 | 0.0 |
| SIGMAR 5 | 0.0 |
| SIGMAR 6 | 0.0 |
| SIGMAR 7 | 0.0 |
| SIGMAR 8 | 0.0 |
| SIGMAR 9 | 0.0 |
| SIGMAR 10 | 0.0 |

**STRUCTURAL HARDPOINTS RELATIVE TO C a G.**

| POINT 1 | 0.0 | 0.0 | 0.0 | 0.0 |
| POINT 2 | 0.0 | 0.0 | 0.0 | 0.0 |
| POINT 3 | 0.0 | 0.0 | 0.0 | 0.0 |

**Figure C2. Sample HVOSM Input for 1977 Plymouth Fury (continued).**
Sample HVOSM Input for 1977 Plymouth Fury (continued).
**Figure C3. Sample HVOSM Output for 1976 Honda Civic.**
Figure C4. Sample HVOSM Output for 1977 Plymouth Fury.
APPENDIX D

PLACEMENT GUIDELINES
FIGURE D-1
BARRIER CATEGORY A, PLACEMENT ON NONLEVEL TERRAIN, CASE 1

TRAVELWAY SLOPE = -20:1
SHOULDER SLOPE = -20:1

LEGEND
ZONE OF ACCEPTABLE USE

BARRIER CATEGORY A

* POSITIVE AS SHOWN
**FIGURE D-2**

**BARRIER CATEGORY A, PLACEMENT ON NONLEVEL TERRAIN, CASE 1**

**TRAVELWAY SLOPE = -20:1**

**SHOULDER SLOPE = 20:1**

**LEGEND**

- **ZONE OF ACCEPTABLE USE**
  - BARRIER CATEGORY A

**EMBANKMENT SLOPE (q:1)**

|-------|-----|-----|-----|------|------|------|------|

**LATERAL OFFSET, D, (FT.)**

* POSITIVE AS SHOWN
FIGURE D-3

BARRIER CATEGORY A, PLACEMENT ON NONLEVEL TERRAIN, CASE 1

TRAVELWAY SLOPE = -10:1
SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE

BARRIER CATEGORY A

* POSITIVE AS SHOWN
**FIGURE D-4**

**BARRIER CATEGORY A, PLACEMENT ON NONLEVEL TERRAIN, CASE 1**

**TRAVELWAY SLOPE = -10:1**

**SHOULDER SLOPE = -10:1**

**LEGEND**

- **ZONE OF ACCEPTABLE USE**
- **BARRIER CATEGORY A**

*POSITIVE AS SHOWN*
FIGURE D-5

BARRIER CATEGORY A, PLACEMENT ON NONLEVEL TERRAIN, CASE 1

TRAVELWAY SLOPE = 48:1

SHOULDER SLOPE = 20:1

LEGEND

ZONE OF ACCEPTABLE USE

1/1 BARRIER CATEGORY A

* POSITIVE AS SHOWN
Figure D-6
Barrier Category A, Placement on Nonlevel Terrain, Case 2

Travelway Slope = -20:1
Shoulder Slope = -20:1

Legend
Zone of Acceptable Use

Barrier Category A

Embankment Slope (R:1)

Lateral Offset, D (ft.)

* Positive as shown
FIGURE D-7

BARRIER CATEGORY D PLACEMENT ON NONLEVEL TERRAIN, CASE 2

TRAVELWAY SLOPE = -20:1
SHOULDER SLOPE = 20:1

ZONE OF ACCEPTABLE USE

BARRIER CATEGORY A

EMBANKMENT SLOPE (q:1)

LATERAL OFFSET, D, (FT.)

* POSITIVE AS SHOWN
FIGURE D-8

BARRIER CATEGORY A, PLACEMENT ON NONLEVEL TERRAIN, CASE 2

TRAVELWAY SLOPE = -10:1

SHOULDER SLOPE = 20:1

LEGEND

ZONE OF ACCEPTABLE USE

BARRIER CATEGORY A

*POSITIVE AS SHOWN
**FIGURE D-9**

**BARRIER CATEGORY A PLACEMENT ON NONLEVEL TERRAIN, CASE 2**

**TRAVELWAY SLOPE = -10:1**  
**SHOULDER SLOPE = -10:1**

**LEGEND**

- **ZONE OF ACCEPTABLE USE**
- **BARRIER CATEGORY A**

*POSITIVE AS SHOWN*
**FIGURE D-10**

**BARRIER CATEGORY A, PLACEMENT ON NONLEVEL TERRAIN, CASE 2**

**TRAVELWAY SLOPE = 48:1**  **SHOULDER SLOPE = 20:1**

**LEGEND**

- **ZONE OF ACCEPTABLE USE**
- **BARRIER CATEGORY A**

*POSITIVE AS SHOWN*
**FIGURE D-11**  
**BARRIER CATEGORY A, PLACEMENT ON NONLEVEL TERRAIN, CASE 3**  

**TRAVELWAY SLOPE = -20:1**  
**SHOULDER SLOPE = -20:1**  

**LEGEND**  
ZONE OF ACCEPTABLE USE  

**BARRIER CATEGORY A**

* POSITIVE AS SHOWN
FIGURE D-12
BARRIER CATEGORY A, PLACEMENT ON NONLEVEL TERRAIN, CASE 3

TRAVELWAY SLOPE = -20:1

SHOULDER SLOPE = 20:1

LEGEND
ZONE OF ACCEPTABLE USE

- BARRIER CATEGORY A

EMBANKMENT SLOPE (a::)

LATERNAL OFFSET, D, (FT.)

* POSITIVE AS SHOWN
FIGURE D-13

BARRIER CATEGORY A, PLACEMENT ON NONLEVEL TERRAIN, CASE 3

TRAVELWAY SLOPE = -10:1
SHOULDER SLOPE = 20:1

LEGEND
ZONE OF ACCEPTABLE USE

EMBANKMENT SLOPE (q : 1)

LATERAL OFFSET, D, (FT.)

*POSITIVE AS SHOWN
FIGURE D-14
BARRIER CATEGORY A, PLACEMENT ON NONLEVEL TERRAIN, CASE 3

TRAVELWAY SLOPE = -10:1
SHOULDER SLOPE = -10:1

LEGEND
ZONE OF ACCEPTABLE USE

EMBANKMENT SLOPE (q : 1)

LATERAL OFFSET, D, (FT.)

* POSITIVE AS SHOWN
FIGURE D-15

BARRIER CATEGORY A, PLACEMENT ON NONLEVEL TERRAIN, CASE 3

TRAVELWAY SLOPE = 48:1
SHOULDER SLOPE = 20:1

LEGEND
ZONE OF ACCEPTABLE USE

| BARRIER CATEGORY A |

* POSITIVE AS SHOWN
FIGURE 0-16
BARRIER CATEGORY B, PLACEMENT ON NONLEVEL TERRAIN, CASE 1

TRAVELWAY SLOPE = -20:1

SHOULDER SLOPE = -20:1

LEGEND
ZONE OF ACCEPTANCE USE

BARRIER CATEGORY B

* POSITIVE AS SHOWN
FIGURE D-17
BARRIER CATEGORY B: PLACEMENT ON NONLEVEL TERRAIN, CASE 1

TRAVELWAY SLOPE = -20:1

SHOULDER SLOPE = 20:1

LEGEND
ZONE OF ACCEPTABLE USE

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

LATERAL OFFSET, D (FT.)

* POSITIVE AS SHOWN
**Figure D-18**

**Barrier Category B, Placement on Nonlevel Terrain, Case 1**

- **Travelway Slope = -10:1**
- **Shoulder Slope = 20:1**

**Legend**
- Zone of Acceptance Use
- □ □ Barrier Category B

**Y-axis:** Embankment Slope (q:1)
- 4:1, 6:1, 8:1, 10:1, -8:1, -6:1, -4:1

**X-axis:** Lateral Offset, D (ft.)

* Positive as shown
FIGURE D-19
BARRIER CATEGORY B, PLACEMENT ON NONLEVEL TERRAIN, CASE 1

TRAVELWAY SLOPE = -10:1
SHOULDER SLOPE = -10:1

LEGEND
ZONE OF ACCEPTABLE USE

BARRIER CATEGORY B

* POSITIVE AS SHOWN
FIGURE D-20
BARRIER CATEGORY B, PLACEMENT ON NONLEVEL TERRAIN, CASE 1

TRAVELWAY SLOPE = 48:1
SHOULDER SLOPE = 20:1

LEGEND
ZONE OF ACCEPTABLE USE

/// BARRIER CATEGORY B

EMBANKMENT SLOPE (a : :)

LATERAL OFFSET, D, (FT.)

* POSITIVE AS SHOWN
FIGURE D-21

BARRIER CATEGORY B, PLACEMENT ON NONLEVEL TERRAIN, CASE 2

TRAVELWAY SLOPE = -20:1

SHOULDER SLOPE = -20:1

LEGEND

ZONE OF ACCEPTABLE USE

--- BARRIER CATEGORY B

* POSITIVE AS SHOWN
**Figure D-23**

**Barrier Category B, Placement on Nonlevel Terrain, Case 2**

**Travelway Slope = -10:1**

**Shoulder Slope = 20:1**

**Legend**

<table>
<thead>
<tr>
<th>Zones of Acceptable Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar</td>
</tr>
</tbody>
</table>

**Embankment Slope (q:1)**

- 4:1
- 6:1
- 8:1
- 10:1
- -8:1
- -6:1
- -4:1

**Lateral Offset, D (ft.)**

- 0
- 5
- 10
- 15
- 20
- 25
- 30
- 35
- 40
- 45

*Positive as shown*
FIGURE D-24

BARRIER CATEGORY B PLACEMENT ON NONLEVEL TERRAIN, CASE 2

TRAVELWAY SLOPE = -10:1

SHOULDER SLOPE = -10:1

LEGEND

ZONE OF ACCEPTABLE USE

\[ \text{BARIER CATEGORY B} \]

* POSITIVE AS SHOWN
FIGURE D-25
BARRIER CATEGORY B, PLACEMENT ON NONLEVEL TERRAIN, CASE 2

TRAVELWAY SLOPE = 48:1

SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE

\[ \text{BARRIER CATEGORY B} \]

\[ \text{EMBANKMENT SLOPE (a:b)} \]

\[ \text{LATERAL OFFSET, } D, (\text{ft}) \]

*POSITIVE AS SHOWN*
**Figure D-26**

**Barrier Category B, Placement on Nonlevel Terrain, Case 3**

- Travelway slope = -20:1
- Shoulder slope = -20:1

**Legend**
- Zone of Acceptable Use
- Barrier Category B

**Diagram:**
- Embankment slope (q:1)
- Lateral offset, D, (ft.)

*Positive as shown*
FIGURE D-27
BARRIER CATEGORY B, PLACEMENT ON NONLEVEL TERRAIN, CASE 3

TRAVELWAY SLOPE = -20:1

SHOULDER SLOPE = 20:1

LEGEND
ZONE OF ACCEPTABLE USE

BARRIER CATEGORY B

*POSITIVE AS_SHOWN
FIGURE D-28
BARRIER CATEGORY B, PLACEMENT ON NONLEVEL TERRAIN, CASE 3

TRAVELWAY SLOPE = -10:1

SHOULDER SLOPE = 20:1

LEGEND
ZONE OF ACCEPTABLE USE

BARRIER CATEGORY B

*POSITIVE AS SHOWN
FIGURE D-29
BARRIER CATEGORY B PLACEMENT ON NONLEVEL TERRAIN, CASE 3

TRAVELWAY SLOPE = -10:1

SHOULDER SLOPE = -10:1

LEGEND
ZONE OF ACCEPTABLE USE

BARRIER CATEGORY B

* POSITIVE AS SHOWN
FIGURE D-30
BARRIER CATEGORY B, PLACEMENT ON NONLEVEL TERRAIN, CASE 3

TRAVELWAY SLOPE = 48:1
SHOULDER SLOPE = 20:1

LEGEND
ZONE OF ACCEPTABLE USE

BARRIER CATEGORY B

* POSITIVE AS SHOWN
**FIGURE D-31**

**BARRIER CATEGORY C, PLACEMENT ON NONLEVEL TERRAIN, CASE 1**

TRAVELWAY SLOPE = -20:1

SHOULDER SLOPE = -20:1

**LEGEND**

ZONES OF ACCEPTABLE USE

- // BARRIER CATEGORY C
- /// BARRIER CATEGORY C WITH RUBRAIL

**EMBANKMENT SLOPE (D:1)**

- 4:1
- 6:1
- 8:1
- 10:1

**LATERAL OFFSET, D (FT.)**

0 5 10 15 20 25 30 35 40 45

* POSITIVE AS SHOWN
**FIGURE D-32**

**BARRIER CATEGORY C, PLACEMENT ON NONLEVEL TERRAIN, CASE 1**

**TRAVELWAY SLOPE** = -20:1

**SHOULDER SLOPE** = 20:1

---

**LEGEND**

- **/ / / /** BARRIER CATEGORY C
- **/ / / / / /** BARRIER CATEGORY C WITH RUBRAIL

---

**EMBANKMENT SLOPE (q:1)**

- 4:1
- 6:1
- 8:1
- 10:1
- -8:1
- -4:1

**LATERAL OFFSET, \( D \) (FT.)**

0 5 10 15 20 25 30 35 40 45

*POSITIVE AS SHOWN*
FIGURE D-33
BARRIER CATEGORY C, PLACEMENT ON NONLEVEL TERRAIN, CASE 1

TRAVELWAY SLOPE = -10:1
SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE

- BARRIER CATEGORY C
- BARRIER CATEGORY C WITH RUBRAIL

* POSITIVE AS SHOWN
FIGURE D-34

BARRIER CATEGORY C, PLACEMENT ON NONLEVEL TERRAIN, CASE 1

TRAVELWAY SLOPE = -10:1

SHOULDER SLOPE = -10:1

LEGEND
ZONES OF ACCEPTABLE USE

- BARRIER CATEGORY C
- BARRIER CATEGORY C WITH RUBRAIL

* POSITIVE AS SHOWN
FIGURE D-35
BARRIER CATEGORY C, PLACEMENT ON NONLEVEL TERRAIN
TRAVELWAY SLOPE = 48:1  CASE-I  SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE

\[ \text{SHALLOW} \]
\[ \text{BARRIER CATEGORY C} \]
\[ \text{WITH RUBRAIL} \]

LATERAL OFFSET, D, (FT.)

* POSITIVE AS SHOWN
FIGURE D-36
BARRIER CATEGORY C, PLACEMENT ON NONLEVEL TERRAIN, CASE 2
TRAVELWAY SLOPE = -20:1
SHOULDER SLOPE = -20:1

LEGEND
ZONE OF ACCEPTABLE USE

- BARRIER CATEGORY C
- BARRIER CATEGORY C WITH RUBRAIL

* POSITIVE AS SHOWN
Figure D-37

Barrier Category C Placement on Nonlevel Terrain Case 2

Travelway Slope = -20:1
Shoulder Slope = 20:1

Legend
- Zones of Acceptable Use
  - Barrier Category C
  - Barrier Category C with RUBRAIL

* Positive as shown
Figure D-38
Barrier Category C Placement on Nonlevel Terrain, Case 2

Travelway Slope = -10:1
Shoulder Slope = 20:1

Legend
Zones of Acceptable Use

- BARRIER CATEGORY C
- BARRIER CATEGORY C WITH RUBRAIL

* Positive as shown
**Figure D-39**

**Barrier Category C Placement on Nonlevel Terrain, Case 2**

<table>
<thead>
<tr>
<th>Travelway Slope</th>
<th>Shoulder Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10:1</td>
<td>-10:1</td>
</tr>
</tbody>
</table>

**Legend**

- Zone of Acceptable Use
- Barrier Category C
- Barrier Category C with Rubrail

*Positive as shown*
FIGURE D-40
BARRIER CATEGORY C, PLACEMENT ON NONLEVEL TERRAIN, CASE 2

TRAVELWAY SLOPE = 48:1
SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE

<table>
<thead>
<tr>
<th></th>
<th>BARRIER CATEGORY C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BARRIER CATEGORY C WITH RUBRAIL</td>
</tr>
</tbody>
</table>

*POSITIVE AS SHOWN*
FIGURE D-41
BARRIER CATEGORY C, PLACEMENT ON NONLEVEL TERRAIN, CASE 3
TRAVELWAY SLOPE = -20:1
SHOULDER SLOPE = -20:1

LEGEND
ZONES OF ACCEPTABLE USE

- BARRIER CATEGORY C
- BARRIER CATEGORY C WITH RUBRAIL

EMBANKMENT SLOPE (q:1)

LATERAL OFFSET, D, (FT.)

* POSITIVE AS SHOWN
Figure D-42
Barrier Category C Placement on Nonlevel Terrain, Case 3

Travelway Slope = -20:1
Shoulder Slope = 20:1

Legend:
Zones of Acceptable Use
- Barrier Category C
- Barrier Category C with Rub Rail

Embankment Slope \( (a : 1) \)
Lateral Offset, \( D \) (ft.)

* Positive as shown
**FIGURE D-43**

**BARRIER CATEGORY C, PLACEMENT ON NONLEVEL TERRAIN, CASE 3**

**TRAVELWAY SLOPE = -10:1**

**SHOULDER SLOPE = 20:1**

**LEGEND**

- Zones of Acceptable Use
  - Barriers Category C
  - Barriers Category C with Rubrail

* Positive as shown
FIGURE D-44
BARRIER CATEGORY C, PLACEMENT ON NONLEVEL TERRAIN, CASE 3

TRAVELWAY SLOPE = -10:1
SHOULDER SLOPE = -10:1

LEGEND
ZONES OF ACCEPTABLE USE

BARRIER CATEGORY C
BARRIER CATEGORY C WITH RUBRAIL

*POSITIVE AS SHOWN
FIGURE D-4.5
BARRIER CATEGORY C, PLACEMENT ON NONLEVEL TERRAIN, CASE 3

TRAVELWAY SLOPE = 48:1
SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE

- BARRIER CATEGORY C
- BARRIER CATEGORY C WITH RUBRAIL

EMBANKMENT SLOPE (a : 1)

LATERAL OFFSET, D, (FT.)

*POSITIVE AS SHOWN
**FIGURE D-46**

**BARRIER CATEGORY D, PLACEMENT ON NONLEVEL TERRAIN, CASE 1**

**LEGEND**

- **ZONES OF ACCEPTABLE USE**
  - **Barrier Category D**
  - **Barrier Category D with Rubrail**

**TRAVELWAY SLOPE = -20:1**

**SHOULDER SLOPE = -20:1**

**EMBANKMENT SLOPE (Q:1)**

- 4:1
- 6:1
- 8:1
- 10:1

**LATERAL OFFSET, D, (FT.)**

- 0
- 5
- 10
- 15
- 20
- 25
- 30
- 35
- 40
- 45

*Positive as shown*
FIGURE D-47
BARRIER CATEGORY D; PLACEMENT ON NONLEVEL TERRAIN; CASE 1

TRAVELWAY SLOPE = -20:1

SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE

/ / BARRIER CATEGORY D

/ / BARRIER CATEGORY D WITH RUBRAIL

EMBANKMENT SLOPE (q:1)

LATERAL OFFSET, D, (FT.)

*POSITIVE AS SHOWN
FIGURE D-48
BARRIER CATEGORY D, PLACEMENT ON NONLEVEL TERRAIN, CASE 1

TRAVELWAY SLOPE = -10:1
SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE

- BARRIER CATEGORY D
- BARRIER CATEGORY D WITH RUBRAIL

EMBANKMENT SLOPE (α:1)

LATERAL OFFSET, D, (FT.)

* POSITIVE AS SHOWN
FIGURE D-49
BARRIER CATEGORY D, PLACEMENT ON NONLEVEL TERRAIN, CASE 1

TRAVELWAY SLOPE = -10:1
SHOULDER SLOPE = -10:1

LEGEND
ZONES OF ACCEPTABLE USE

|-----------------|-----------------|
|                 | BARRIER CATEGORY D
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th>-----------------</th>
</tr>
</thead>
</table>
|                 | BARRIER CATEGORY D WITH RUBRAIL

<table>
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<tr>
<th>LAT:3/4</th>
<th>4:1</th>
<th>6:1</th>
<th>8:1</th>
<th>10:1</th>
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<tbody>
<tr>
<td>0</td>
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<tr>
<td>45</td>
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</tbody>
</table>

*POSITIVE AS SHOWN*
FIGURE D-50

BARRIER CATEGORY D, PLACEMENT ON NONLEVEL TERRAIN, CASE 1

TRAVELWAY SLOPE = 48:1

SHOULDER SLOPE = 20:1

LEGEND

ZONES OF ACCEPTABLE USE

/// BARRIER CATEGORY D

/// BARRIER CATEGORY D WITH RUBRAIL

* POSITIVE AS SHOWN
FIGURE D-51

BARRIER CATEGORY D, PLACEMENT ON NONLEVEL TERRAIN, CASE 2

TRAVELWAY SLOPE = -20:1

SHOULDER SLOPE = -20:1

LEGEND

ZONE OF ACCEPTABLE USE

BARRIER CATEGORY D

BARRIER CATEGORY D WITH RUBRAIL

* POSITIVE AS SHOWN
FIGURE D-52
BARRIER CATEGORY D, PLACEMENT ON NONLEVEL TERRAIN CASE 2

TRAVELWAY SLOPE = -20:1
SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE

\[\text{BARRIER CATEGORY D}\]

\[\text{BARRIER CATEGORY D WITH RUBRAIL}\]

*POSITIVE AS SHOWN*
FIGURE D-53
BARRIER CATEGORY D, PLACEMENT ON NONLEVEL TERRAIN, CASE 2

TRAVELWAY SLOPE = -10:1
SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE

- BARRIER CATEGORY D
- BARRIER CATEGORY D WITH RUBRAIL

* POSITIVE AS SHOWN
FIGURE D-54
BARRIER CATEGORY D PLACEMENT ON NONLEVEL TERRAIN, CASE 2

TRAVELWAY SLOPE = -10:1
SHOULDER SLOPE = -10:1

LEGEND

ZONE OF ACCEPTABLE USE

- BARRIER CATEGORY D
- BARRIER CATEGORY D WITH RUBRAIL

* POSITIVE AS SHOWN
FIGURE D-55
BARRIER CATEGORY D, PLACEMENT ON NONLEVEL TERRAIN, CASE 2

TRAVELWAY SLOPE = 48:1
SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE
■ BARRIER CATEGORY D
■■ BARRIER CATEGORY D WITH RUBRAIL

*POSITIVE AS SHOWN
**FIGURE D-56**

**BARRIER CATEGORY D, PLACEMENT ON NONLEVEL TERRAIN, CASE 3**

- **Travelway Slope** = -20:1
- **Shoulder Slope** = -20:1

**Legend**

- ZONES OF ACCEPTABLE USE
  - ■■ BARRIER CATEGORY D
  - ■■■ BARRIER CATEGORY D WITH RUBRAIL

**Embankment Slope** (q:1)

- 4:1
- 6:1
- 8:1
- 10:1

**Lateral Offset, D, (FT.)**

*Positive as shown*
FIGURE D-57
BARRIER CATEGORY D, PLACEMENT ON NONLEVEL TERRAIN, CASE 3

TRAVELWAY SLOPE = -20:1
SHOULDER SLOPE = 20:1

LEGEND

ZONES OF ACCEPTABLE USE

\[ \begin{align*}
\text{SHADY} & : \text{BARRIER CATEGORY D} \\
\text{SHADY} & : \text{BARRIER CATEGORY D WITH RUBRAIL}
\end{align*} \]

EMBANKMENT SLOPE (q : 1)

LATERAL OFFSET, D, (FT.)

*POSITIVE AS SHOWN
**Figure D-58**

Barrier Category D Placement on Nonlevel Terrain, Case 3

**Legend**

- Zones of Acceptable Use
  - **BARRIER CATEGORY D**
  - **BARRIER CATEGORY D WITH RUBRAIL**

**Travelway Slope** = -10:1

**Shoulder Slope** = 20:1

*Positive as shown*
Figure D-59

Barrier Category D, Placement on Nonlevel Terrain, Case 3

Travelway slope = -10:1
Shoulder slope = -10:1

Legend
Zones of Acceptable Use

- BARRIER CATEGORY D
- BARRIER CATEGORY D: WITH RUBRAIL

Embankment slope (q : 1)

Lateral Offset, D, (ft.)

* Positive as shown
**FIGURE D-60**

**BARRIER CATEGORY D PLACEMENT ON NONLEVEL TERRAIN, CASE 3**

**Travelway Slope** = 48:1  
**Shoulder Slope** = 20:1

**LEGEND**

- **Zones of Acceptable Use**
  - **Solid**  BARRIER CATEGORY D
  - **Dotted**  BARRIER CATEGORY D WITH RUBRAIL

**Diagram**

*Positive as shown*
FIGURE D-61
BARRIER CATEGORY E, PLACEMENT ON NONLEVEL TERRAIN, CASE 1
TRAVELWAY SLOPE = -20:1
SHOULDER SLOPE = -20:1

LEGEND
ZONE OF ACCEPTABLE USE

BARRIER CATEGORY E

* POSITIVE AS SHOWN
**FIGURE D-62**

**BARRIER CATEGORY E, PLACEMENT ON NONLEVEL TERRAIN, CASE 1**

**TRAVELWAY SLOPE = -20:1**  **SHOULDER SLOPE = 20:1**

*LEGEND*

*ZONES OF ACCEPTABLE USE*

- **BARRIER CATEGORY E**

*-POSITIVE AS SHOWN*
BARRIER CATEGORY E PLACEMENT

TRAVELWAY SLOPE = -10:1

ZONE OF ACCEPTABLE ZONE OF ACCEPTABLE ZONE OF ACCEPTABLE ZONE OF ACCEPTABLE

LEGEND

BARRIER CATEGORY E

* POSITIVE AS SHOWN

EMBANKMENT SLOPE (a:1)

LATERAL OFFSET, D, (FT.)

0 5 10 15 20 25 30 35 40 45

FIGURE D-64
BARRIER CATEGORY E PLACEMENT ON NONLEVEL TERRAIN, CASE 1

TRAVELWAY SLOPE = -10:1
SHOULDER SLOPE = -10:1

LEGEND
ZONE OF ACCEPTABLE USE

BARRIER CATEGORY E

* POSITIVE AS SHOWN
**FIGURE D-65**

BARRIER CATEGORY E, PLACEMENT ON NONLEVEL TERRAIN, CASE 1

TRAVELWAY SLOPE = 48:1  
SHOULDER SLOPE = 20:1

**LEGEND**
- ZONES OF ACCEPTABLE USE
- \(\text{BARRIER CATEGORY E}\)

*POSITIVE AS SHOWN*
**FIGURE D-66**

**BARRIER CATEGORY E, PLACEMENT ON NONLEVEL TERRAIN, CASE 2**

**TRAVELWAY SLOPE = -20:1**

**SHOULDER SLOPE = -20:1**

**LEGEND**

**ZONE OF ACCEPTABLE USE**

| BARRIER CATEGORY E |

---

**EMBANKMENT SLOPE (A:1)**

- 4:1
- 6:1
- 8:1
- 10:1

**LATERAL OFFSET, D, (FT.)**

- 0
- 5
- 10
- 15
- 20
- 25
- 30
- 35
- 40
- 45

*POSITIVE AS SHOWN*
FIGURE D-67
BARRIER CATEGORY E, PLACEMENT ON NONLEVEL TERRAIN, CASE 2

TRAVELWAY SLOPE = -20:1  SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE
\\\\ BARRIER CATEGORY E

**Positive as shown**
FIGURE D-68
BARRIER CATEGORY E PLACEMENT ON NONLEVEL TERRAIN, CASE 2

TRAVERSE SLOPE = -10:1
SHOULDER SLOPE = 20:1

LEGEND
ZONE OF ACCEPTABLE USE

- BARRIER CATEGORY E

* POSITIVE AS SHOWN
**FIGURE D-69**

**BARRIER CATEGORY E PLACEMENT ON NONLEVEL TERRAIN, CASE 2**

**TRAVELWAY SLOPE** = -10:1

**SHOULDER SLOPE** = -10:1

**LEGEND**

- **ZONE OF ACCEPTABLE USE**
- **BARRIER CATEGORY E**

* POSITIVE AS SHOWN
FIGURE D-70
BARRIER CATEGORY E, PLACEMENT ON NONLEVEL TERRAIN, CASE 2

TRAVELWAY SLOPE = 48:1  SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE

BARRIER CATEGORY E

*POSITIVE AS SHOWN
FIGURE D-71
BARRIER CATEGORY E, PLACEMENT ON NONLEVEL TERRAIN, CASE 3

TRAVELWAY SLOPE = -20:1

SHOULDER SLOPE = -20:1

LEGEND

ZONE OF ACCEPTABLE USE

<table>
<thead>
<tr>
<th>ZONE OF ACCEPTABLE USE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BARRIER CATEGORY E</td>
</tr>
</tbody>
</table>

*POSITIVE AS SHOWN*
FIGURE D-72
BARREL CATEGORY E, PLACEMENT ON NONLEVEL TERRAIN, CASE 3

TRAVELWAY SLOPE = -20:1
SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE
□ □ □ BARRIER CATEGORY E

EMBANKMENT SLOPE (H:V)
-4:1
-8:1
-10:1
-12:1
-14:1
-16:1
-18:1
-20:1
-22:1
-24:1
-26:1
-28:1
-30:1
-32:1
-34:1
-36:1
-38:1
-40:1
-42:1
-44:1

LATERAL OFFSET, D (FT)
0
5
10
15
20
25
30
35
40
45

*POSITIVE AS SHOWN
**Figure D-73**

Barrier Category E Placement on Nonlevel Terrain, Case 3

**Legend**

- Zone of Acceptable Use
- BARRIER CATEGORY E

**Travelway Slope** = -10:1

**Shoulder Slope** = 20:1

*Positive as shown*
**FIGURE D-74**

**BARRIER CATEGORY E PLACEMENT ON NONLEVEL TERRAIN, CASE 3**

**TRAVELWAY SLOPE** = \(-10:1\)  
**SHOULDER SLOPE** = \(-10:1\)

---

**LEGEND**

- **ZONE OF ACCEPTABLE USE**
  - \(\square\) **BARRIER CATEGORY E**

---

**EMBANKMENT SLOPE** \((Q:1)\)

- 4:1
- 6:1
- 8:1
- 10:1

---

**LATERAL OFFSET**, \(D\) (FT.)

---

* **POSITIVE AS SHOWN*
FIGURE D-75

BARRIER CATEGORY E, PLACEMENT ON NONLEVEL TERRAIN, CASE 3

TRAVELWAY SLOPE = 48:1
SHOULDER SLOPE = 20:1

LEGEND
ZONES OF ACCEPTABLE USE

BARRIER CATEGORY E

EMBANKMENT SLOPE (a : 1)

LATERAL OFFSET, D (FT.)

*POSITIVE AS SHOWN
REFERENCES


