SAFETY TREATMENT OF ROADSIDE DRAINAGE STRUCTURES

by

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ABSTRACT

The purpose of the research was to develop traffic-safe end treatments for (1) cross-drainage structures and (2) parallel-drainage structures that would not appreciably restrict water flow. Cross-drainage culverts are used to convey water under the highway. Parallel-drainage culverts are used to convey water under driveways, side roads, ramps, or median crossovers that abut the highway.

Preliminary designs were first evaluated by computer simulation, by use of a test pit in which the clear open space and grate spacing could be varied, and by use of an earth berm similar in geometry to a driveway. Promising designs were then subjected to full-scale prototype testing with both subcompact and full-size automobiles.

Traffic-safe culvert end treatments can be achieved as follows:

Cross-drainage structures - (a) All culvert ends should be made to match the existing side slope with no protrusion in excess of 4 in. (10.2 cm) above grade; (b) culverts with clear openings 30 in. (76.2 cm) or less need no safety treatment other than as mentioned in (a); (c) culverts with clear openings greater than 30 in. (76.2 cm) can be made traffic-safe by grate members placed on 30 in. (76.2 cm) centers oriented parallel to the flow and in the plane of the side slope.

Parallel-drainage structures - (a) The roadway side slope (or ditch slope) should be 6 to 1 or flatter in the vicinity of the driveway; (b) the driveway slope should be 6 to 1 or flatter; (c) the transition between the side slope and the driveway slope should be rounded; and (d) safety treatment of the culvert opening should include an end section cut to match the driveway slope with cross members (grates) spaced every 24 in. (61.0 cm) perpendicular to the direction of flow.
Application of these findings will result in improved safety for the motorist. They will also result in more hydraulically efficient and more economical safety treatments than have been used in the past.

INTRODUCTION

In designing drainage culverts, the primary objective is to properly accommodate surface runoff along the highway right-of-way. However, a second important goal should be to provide a traffic-safe design that would be traversable by an out-of-control vehicle without rollover or abrupt change in speed.

Guidelines for designing traffic-safe grates have been very limited. NCHRP published guidelines for traffic-safe drainage structures in 1969 (1). The recommendations dealt primarily with the geometry of adjoining slopes. Computer simulations have also been used to further investigate the dynamic behavior of automobiles traversing various slope and ditch configurations near driveways and median crossovers (2,3). Criteria for the structural design of inlet grates was published in 1973 (4). However, the study did not address the problem of grate design as related to safety.

Recent field reviews of drainage culverts in Texas revealed that improvements and some modification of design details could improve both drainage and safety (5). Many of the safety grates used in the past to cover the open ends of culverts have small openings and the grates are easily clogged with debris, causing water to back up and flow over the roadway, the ditch crossing, or adjacent property. In some cases safety grates do not possess enough strength to be effective or they are used on small pipe culverts which need no safety treatment.
The objective of this study was to develop guidelines for safety treatment of both cross-drainage and parallel-drainage structures that (1) can be safely traversed by an errant vehicle and (2) will exhibit desirable hydraulic behavior. Although no hydraulic analyses were made it was assumed that hydraulic efficiency increases as the number of grate members decrease. It was therefore a goal of the research to meet safety requirements with as few grate members as possible.

This paper summarizes the findings of two research studies, one conducted in 1979 (6) and the other in 1980 (7). Reference should be made to the cited literature for complete details of the studies.

EVALUATION CRITERIA

A review of the literature showed that there are no nationally recognized safety performance standards for roadside drainage structures. Deceleration and stability of a vehicle during and following impact are the two primary measures of performance for safety appurtenances such as guardrails, crash cushions, etc. (8). For the cross-drainage structures, performance was judged satisfactory if the vehicle smoothly traversed the culvert and the adjoining ditch slope without rollover for speeds from 20 mph (32.2 km/h) through 60 mph (96.5 km/h).

Previous research (2,6) indicated that a very flat ditch slope, a very flat driveway slope, and a very long culvert would be necessary to satisfy the above criteria for parallel-drainage structures. In view of the economic and hydraulic implications of such a design it was concluded that tradeoffs would be necessary to achieve an acceptable balance between the controlling elements. Performance of parallel-drainage structures was therefore judged acceptable if the vehicle smoothly traversed the adjoining slopes and culvert
without rollover for speeds from 20 mph (32.2 km/h) through 50 mph (96.5 km/h).

RESEARCH APPROACH

A three-phase approach was taken in the development of safety treatments of both cross-drainage and parallel-drainage structures. In the first two phases computer simulations in combination with a preliminary test program were used to develop tentative design concepts. In the latter phase prototypes were constructed using the results of the preliminary studies and tested under representative roadside configurations.

Cross-Drainage Structures

Simulation studies - A computer simulation study was conducted, using the Highway-Vehicle-Object-Simulation-Model (HVOSM)(9), to evaluate wheel drop into various culvert openings on flat terrain. HVOSM was also used to investigate the effect a ramp at the leading edge of the culvert opening would have on vehicle behavior. Ramps having the following dimensions were evaluated:

<table>
<thead>
<tr>
<th>Ramp</th>
<th>Horizontal Dimension (in.)</th>
<th>Vertical Dimension (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>2</td>
<td>6.0</td>
<td>3.0</td>
</tr>
<tr>
<td>3</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>4</td>
<td>12.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

A 1974 Honda Civic was simulated in each of the computer runs since it was assumed a mini-size automobile would be more critical than a larger vehicle for the given conditions. A speed of 20 mph (32.2 km/h) was used in each run since it was deemed a critical speed. At higher speeds it was felt the
vehicle would clear the opening easier. At lower speeds, although the vehi­

Preliminary tests - In the second phase a test pit was constructed on

flat terrain as shown in Figure 1 to study the behavior of a vehicle as it

traversed various openings. The objectives of these tests were to determine

preliminary values for (1) the maximum clear opening permissible on a non-
grated culvert end and (2) the maximum spacing permissible when grates are

necessary. All runs were live-driver tests at various speeds and encroach-

ment angles. Figure 2 is a photograph of the test pit after installation. A

total of 31 runs were made to determine the maximum clear opening. Test

speeds ranged from 5 mph (8.0 km/h) to 35 mph (56.3 km/h); encroachment angles

varied from 0 degrees to 15 degrees; and clear openings ranged from 12 in.

(30.5 cm) to 36 in. (91.4 cm). All tests were with a 1974 Honda Civic having

a curb weight of approximately 1800 lb (817.2 kg). Limiting values were
determined by the severity of the ride as judged by the driver. The driver

was a Texas Transportation Institute (TTI) technician with a nonprofessional
driving history. Sequential photos of a 20 mph (32.2 km/h) run with a 30

in. (76.2 cm) clear opening are shown in Figure 3.

Upon completion of the clear opening tests the pit was used to determine

maximum permissible grate spacing. A total of 22 live-driver tests were con-
ducted for this purpose. Test speeds ranged from 5 mph (8.0 km/h) to 25 mph
(40.2 km/h); encroachment angles varied from 0 degrees to 30 degrees; and
grate spacing varied from 16 in. (40.6 cm) to 30 in. (76.2 cm). The grates
were 3 in. (7.6 cm) schedule 40 steel pipe anchored to a steel beam with pro-
vision to allow adjustments of the pipe to any desired spacing. Figure 4
shows the pit setup for a 16 in. (40.6 cm) grate spacing. Each grate config-
uration was evaluated with the 1974 Honda Civic. A 1975 Plymouth Fury
Figure 1. Plan View of Culvert Test Pit.

Figure 2. Test Pit Installation.
Figure 3. Sequential Photos of Nongrated Culvert Test, 30 in. Clear Opening, 1974 Honda Civic
Figure 4. Test Pit With 16 in. Grate Spacing.
weighing about 4500 lb (2043 kg) was also used to evaluate the larger grate spacings.

As part of the second phase of the study a limited number of live-driver tests were conducted to further evaluate the effects of a ramp at the leading edge of the culvert opening. Based on the HVOSM results, a ramp with a horizontal dimension of 12 in. (30.5 cm) and a vertical dimension of 6 in. (15.2 cm) was selected and constructed. HVOSM indicated this combination would produce the greatest wheel hop of all combinations considered. The 1974 Honda Civic and the 1975 Plymouth Fury were used in the ramp test. Each test was conducted at 20 mph (32.2 km/h).

Prototype tests - Based on results obtained from the preliminary studies, two culvert structures were constructed for full-scale testing. They consisted of a 30 in. (76.2 cm) diameter corrugated steel pipe culvert and a 5 ft (1.5 m) wide by 3 ft (0.92 m) high concrete box culvert with adjoining head and wing walls. Grate members on the box culvert consisted of 3 in. (7.6 cm) schedule 40 steel pipe on 30 in. (76.2 cm) centers. Photos of both installations are shown in Figure 5.

General details of the six tests conducted are shown in Figure 6. Note that the culverts were subjected to tests with both the mini-size and full-size automobiles. In each test, with the exception of test 5, all four wheels of the test vehicle crossed the sloped culvert opening. In test 5 the vehicle straddled the cross member at the end of the box culvert, allowing the left side wheels to drop approximately 1.5 ft (0.46 m) to the ditch bottom. Sequential photos of test 3 are shown in Figure 7.

Analysis of the strength requirements of grate members indicated that a 3 in. (7.6 cm) I.D. schedule 40 pipe was adequate for spans up to 12 ft (3.7 m). Since grate spans on many box culverts would exceed 12 ft (3.7 m) it was
Figure 5. Prototype Test Installations.

a) Corrugated Steel Pipe Culvert.

b) Grated Box Culvert.
### VEHICLE DATA

<table>
<thead>
<tr>
<th>Car 1</th>
<th>Car 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Make</strong></td>
<td>Honda</td>
</tr>
<tr>
<td><strong>Model</strong></td>
<td>CVCC</td>
</tr>
<tr>
<td><strong>Year</strong></td>
<td>1974</td>
</tr>
<tr>
<td><strong>Test Weight (lb)</strong></td>
<td>1800</td>
</tr>
<tr>
<td><strong>Test No.</strong></td>
<td>2, 3, 5</td>
</tr>
<tr>
<td><strong>Velocity (mph)</strong></td>
<td>20</td>
</tr>
</tbody>
</table>

**Metric Conversions:**

- $1\text{ lb}_m = 0.454 \text{ kg}$
- $1\text{ mph} = 1.609 \text{ km/h}$

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**Figure 6** Plan View of Site for Prototype Tests.

- **Edge of Runway**
- **Ditch Front Slope Approx. 5:1**
- **Pipe Culvert**
- **Box Culvert with Grating**
- **Vehicles towed with cable**
- $V = 20\text{ mph}, \text{Tests 1 and 2}$
- $V = 20\text{ mph}, \text{Tests 3, 4, and 5.}$
- $60\text{ mph}, \text{Test 6.}$
Figure 7. Sequential Photos, Test 3.
concluded that a limited test program should be undertaken to determine pipe size requirements for larger spans. To accomplish this another test pit was constructed on flat terrain. The pit was of 20 ft (6.1 m) long, 10 ft (3.1 m) wide, and 1.5 ft (0.46 m) deep. A total of four full-scale vehicular tests were conducted with a 4500 lb (2043 kg) vehicle, each at 20 mph (32 km/h) and each at a head-on approach, perpendicular to the 20 ft (6.1 m) dimension of the pit. Further details of each test are given in Table 1, including the permanent deformations noted after each test. With the exception of test 4 the grates had a 20 ft (6.1 m) clear span. In test 4, vertical supports consisting of 3 in. (7.6 cm) I.D. schedule 40 pipe were placed at midspan of each of the three grate members. The grates were attached to the walls of the pit with a pin connection, constructed according to TSDHPT standards.

Parallel-Drainage Structures

Simulation studies - Design of a traffic-safe parallel drainage structure not only involves the culvert itself but adjoining slopes as well. In fact, the slopes can in many cases be a greater hazard than the culvert structure. Studies of median cross-over geometry pointed to the need for relatively flat slopes to minimize vehicle rollover (2,3). To gain further insight, HVOSM was used to examine the behavior of a vehicle traversing various driveway conditions. Parameters investigated included departure angle, departure speed, and the path of vehicle encroachment; the side slopes of both the ditch and the driveway; the type of transition zone between the two slopes; depth of the ditch; and vehicle size. These parameters are illustrated in the definition sketch of Figure 8.

Following is the range of each parameter evaluated:

DEPARTURE ANGLE: 15° and head-on
Table 1. Cross Member Deflections of Box Culvert Grating Strength Tests

<table>
<thead>
<tr>
<th>TEST NO.</th>
<th>PIPE I.D. (in.)</th>
<th>GRATE MEMBER</th>
<th>VERTICAL DEFLECTION (in.)</th>
<th>HORIZONTAL DEFLECTION (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>First</td>
<td>-0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Second</td>
<td>-0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Third</td>
<td>-15/16</td>
<td>3/8</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>First</td>
<td>-1/8</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Second</td>
<td>-1/2</td>
<td>1/4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Third</td>
<td>-3</td>
<td>1 7/8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>First</td>
<td>-1 3/4</td>
<td>2 7/8</td>
</tr>
<tr>
<td>3</td>
<td>3.5</td>
<td>Second</td>
<td>-4 3/4</td>
<td>3 1/16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Third</td>
<td>-4 1/8</td>
<td>1 7/16</td>
</tr>
<tr>
<td>4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3</td>
<td>First</td>
<td>-0 3/4</td>
<td>1 1/2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Second</td>
<td>+0 1/2</td>
<td>1 7/8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Third</td>
<td>+0 1/8</td>
<td>4 3/4</td>
</tr>
</tbody>
</table>

a. Schedule 40 Steel Pipe.

b. Grate Members Spaced on 30 in. Centers.

c. Midspan Vertical Supports Used On Each Grate.
Figure 8. Definition Sketch
Figure 8. Definition Sketch (continued)
DEPARTURE SPEED: 30 mph (48.3 km/h), 40 mph (64.4 km/h), 50 mph (80.5 km/h), and 60 mph (96.6 km/h)

PATH: 15° angled path across transition (path 1), 15° angled path across ditch bottom (path 2), and head-on path into driveway slope (path 3)

ROADWAY SLOPE: 4:1 and 6:1

DRIVEWAY SLOPE: 4:1, 5:1, and 6:1

TRANSITION TYPE: Abrupt and rounded

DITCH DEPTH: 2 ft (0.61 m) and 3 ft (0.92 m)

VEHICLE SIZE: 2250 lb (1022 kg) and 4500 lb (2044 kg)

A total of 68 computer runs were made to evaluate the various parameters.

Preliminary tests - Ten full-scale vehicular tests were conducted to (1) evaluate vehicle response as a function of the driveway slope and (2) to develop a tentative safety treatment for parallel-drainage structures. The test vehicles were 1974 and 1975 Chevrolet Vegas weighing approximately 2250 lb (1022 kg). In each test the vehicle was towed to the test site along a guidance cable, released, and then allowed to traverse the test area in a free-wheel (no steer input), no-braking mode. A summary of the 10 tests is given in Table 2, tests 1-1 through 7-6. Tests 1-1 through 5-1 were designed to evaluate the relative hazard of the driveway slope. An earth berm was constructed to simulate the driveway. The berm for tests 1-1 through 1-4 had a 3.8 to 1 slope, was approximately 3 ft (0.92 m) high, and was approximately 20 ft (6.1 m) wide at the top. Sequential photos of test 1-4 are shown in Figure 9.

After test 1-4 the berm slopes were flattened to the dimensions shown on the first page of Figure 10. In this case the slope on the approach side was
6.7 to 1. It was obvious from test 1-3 that an automobile could traverse the 6.7 to 1 slope at speeds in excess of 40 mph (64.4 km/h) without rolling over. Hence, test 5-1 was conducted at 50 mph (80.5 km/h) with the automobile approaching from a head-on path. Although the vehicle was airborne for approximately 75 ft (22.9 m) it remained upright with no appreciable pitching.

The next series of tests (7-1 through 7-6) were conducted to determine if safety treatment of the culvert end was needed in addition to the sloped end treatment. The 6.7 to 1 driveway slope was used in each test. It was assumed that a head-on path into the driveway culvert would be as critical, or more critical, than any other path regarding the culvert itself. Based on this assumption, a 24 in. (61.0 cm) diameter corrugated steel pipe culvert with a sloped end was installed in the earth berm as shown on the first page of Figure 10. This culvert size was selected since the diameter of most driveway culverts in Texas are equal to or less than 24 in. (61.0 cm). Vehicle impact point for this series of tests was selected such that the right side wheels of the test vehicle traversed the center of the culvert end.

Details of the culvert configuration for each of the culvert tests are given in Figure 10. Test 7-1 was conducted at 50 mph (80.5 km/h) with an open culvert, i.e., no grate members. Photos of the installation are given in Figure 11 and sequential photos of the test are given in Figure 12. Large pitch and roll rates occurred after impact with the culvert, and the vehicle rolled over. In test 7-2 a single grate member was placed across the culvert as shown in details 3 and 4 of Figure 10. Very little improvement in vehicle behavior was realized and rollover again occurred.

Analysis of test 7-2 showed that grates spaced approximately on 2 ft (0.61 m) centers was needed to avoid excessive wheel drop and wheel snagging.
The next treatment therefore incorporated this feature as shown in details 5 and 6 of Figure 10. Grate members consisted of 2 lb/ft (2.98 kg/m) steel flanged channel sections. The channel section was chosen since it is widely used as a delineator post by TSDHPT and would therefore be readily available. The first test on this treatment, test 7-4, was conducted at 20 mph (32.2 km/h) and the results were acceptable. Test 7-5 was conducted at 50 mph (80.5 km/h) and rollover occurred due to structural failure of the grates.

In test 7-6, 2-1/2 in. (6.35 cm) I.D. standard steel pipe (schedule 40) were used as a grate member. Details 7 through 10 of Figure 10 show how the pipe was attached to the culvert. Although the vehicle was airborne approximately 65 ft (19.8 m) it remained upright and the test was deemed acceptable. The culvert was only slightly damaged.

Prototype tests - The final two tests, 9-1 and 9-2, were selected to verify the tentative conclusions reached as a result of the simulation work and the full-scale slope and culvert testing. A full-scale prototype of a ditch-driveway configuration was constructed as shown in Figure 13 and the photos of Figure 14. Test 9-1 was conducted at 40 mph (64.4 km/h) and the approach path into the driveway was as shown in Figure 13 such that the left side wheels crossed the culvert. No adverse vehicle behavior occurred during the test and the results were considered acceptable.

Test 9-2 was identical to test 9-1 except the speed was increased to 50 mph (80.5 km/h). Sequential photos of the test are shown in Figure 15. The vehicle remained upright and sustained only minor damage. The culvert was only slightly damaged and could have been used without repair.
**TABLE 2. SUMMARY OF FULL-SCALE TEST RESULTS**

<table>
<thead>
<tr>
<th>TEST NO.</th>
<th>VEHICLE SPEED (mph)</th>
<th>VEHICLE PATH (See Fig. 1)</th>
<th>DRIVEWAY SLOPE</th>
<th>DITCH SLOPE</th>
<th>CULVERT CONFIGURATION</th>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>30</td>
<td>3</td>
<td>3.8:1</td>
<td>N/A</td>
<td>No Culvert</td>
<td>Satisfactory - no rollover</td>
</tr>
<tr>
<td>1-2</td>
<td>35</td>
<td>3</td>
<td>3.8:1</td>
<td>N/A</td>
<td>No Culvert</td>
<td>Satisfactory - no rollover</td>
</tr>
<tr>
<td>1-3</td>
<td>40</td>
<td>3</td>
<td>3.8:1</td>
<td>N/A</td>
<td>No Culvert</td>
<td>Satisfactory - no rollover</td>
</tr>
<tr>
<td>1-4</td>
<td>50</td>
<td>3</td>
<td>3.8:1</td>
<td>N/A</td>
<td>No Culvert</td>
<td>Unsatisfactory - vehicle pitched over</td>
</tr>
<tr>
<td>5-1</td>
<td>50</td>
<td>3</td>
<td>6.7:1</td>
<td>N/A</td>
<td>No Culvert</td>
<td>Satisfactory - no rollover</td>
</tr>
<tr>
<td>7-1</td>
<td>50</td>
<td>3</td>
<td>6.7:1</td>
<td>N/A</td>
<td>(See Fig. 10)</td>
<td>Unsatisfactory - vehicle rolled over</td>
</tr>
<tr>
<td>7-2</td>
<td>50</td>
<td>3</td>
<td>6.7:1</td>
<td>N/A</td>
<td>(See Fig. 10)</td>
<td>Unsatisfactory - vehicle rolled over</td>
</tr>
<tr>
<td>7-4</td>
<td>20</td>
<td>3</td>
<td>6.7:1</td>
<td>N/A</td>
<td>(See Fig. 10)</td>
<td>Satisfactory - no rollover</td>
</tr>
<tr>
<td>7-5</td>
<td>50</td>
<td>3</td>
<td>6.7:1</td>
<td>N/A</td>
<td>(See Fig. 10)</td>
<td>Unsatisfactory - vehicle rolled over</td>
</tr>
<tr>
<td>7-6</td>
<td>50</td>
<td>3</td>
<td>6.7:1</td>
<td>N/A</td>
<td>(See Fig. 10)</td>
<td>Satisfactory - no rollover</td>
</tr>
<tr>
<td>9-1</td>
<td>40</td>
<td>2</td>
<td>6.5:1</td>
<td>6.8:1</td>
<td>(See Fig. 13)</td>
<td>Satisfactory - no rollover</td>
</tr>
<tr>
<td>9-2</td>
<td>50</td>
<td>2</td>
<td>6.5:1</td>
<td>6.8:1</td>
<td>(See Fig. 13)</td>
<td>Satisfactory - no rollover</td>
</tr>
</tbody>
</table>

Metric Conversions: 1 mph = 1.609 km/h
Figure 9. Sequential Photos, Test 1-4.
Figure 10. Berm and Culvert Details, Tests 5-1 through 7-6.
Figure 10. Berm and Culvert Details, Tests 5-1 through 7-6. (continued)
Figure 10. Berm and Culvert Details, Tests 5-1 through 7-6. (continued)
Figure 17. Test Installation Before Test 7-1.
Figure 12. Sequential Photos, Test 7-1.
24" DIA. GALV. CORRUGATED PIPE WITH 4 - 2 1/2" DIA. STEEL PIPES (SCHED 40)

APRON

PLAN

SECTION "A"

Figure 13. Test Site Conditions, Tests 9-1 and 9-2.
Figure 14. Test Site, Tests 9-1 and 9-2.
Figure 15. Sequential Photos, Test 9-2.
FINDINGS

Cross-Drainage Structures

Based on the computer simulations and the preliminary test program, it was shown that clear openings of at least 30 in. (76.2 cm) could easily be traversed at a speed of 20 mph (32.2 km/h). A 36 in. (91.4 cm) spacing was easily traversed at 25 mph (40.2 km/h). For clear openings in excess of 30 to 36 in. (76.2 to 91.4 cm) it was shown that grates spaced on 30 in. (76.2 cm) centers would provide satisfactory safety treatment. These findings were in fact borne out through six full-scale prototype tests. Tests of a 30 in. (76.2 cm) diameter corrugated steel pipe culvert end, cut to match a 5 to 1 side slope, were successfully conducted. The culvert opening was readily traversed by both a full-size automobile and a mini-size automobile at 20 mph (32.2 km/h). Tests of a relatively large box culvert constructed to match the existing 5 to 1 side slope also verified that grates spaced on 30 in. (76.2 cm) centers provide a satisfactory safety treatment. Tests of this treatment at 20 mph (32.2 km/h) and 60 mph (96.5 km/h) by both full-size and mini-size automobiles were conducted. It was also shown that the grates should be extended and anchored at the flow line to avoid any appreciable dropoff at the end of the culvert treatment. In one test, vehicle rollover occurred when the left side wheels dropped off an 18 in. (45.7 cm) opening at the end of the culvert.

Preliminary tests and the prototype tests showed that 3 in. (7.6 cm) I.D. schedule 40 steel pipe grates were of sufficient strength to support a full-size automobile for simple-supported spans up to approximately 12 ft (3.7 m). Additional full-scale tests were conducted with a test pit to determine pipe size requirements for larger spans. Results of these tests provided the following guidelines:
Suggested Standard Schedule 40 Pipe Size

<table>
<thead>
<tr>
<th>Span Length (ft)</th>
<th>I.D. (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 12</td>
<td>3.0</td>
</tr>
<tr>
<td>12 to 16</td>
<td>3.5</td>
</tr>
<tr>
<td>16 through 20</td>
<td>4.0</td>
</tr>
</tbody>
</table>

If midspan vertical supports are used, 3.0 in. (7.62 cm) I.D. standard schedule 40 pipe can be used for spans up to 20 ft (6.1 m). Other sections having equivalent strengths could of course be used. Reference may also be made to an FHWA report (4) for strength requirements of grates.

Results of the study to evaluate the effect of a ramp at the leading edge of a culvert opening were inconclusive. HVOSM results indicated that appreciable wheel hop could be achieved by a small ramp, thus enabling the vehicle to clear larger culvert openings. An attempt to verify these findings via a full-scale test program was made. However, due in part to the test procedure, the tests did not provide sufficient data to reach any firm conclusions. To minimize damage to test vehicles the area behind the ramp was not excavated and as a consequence the total wheel drop that would have occurred otherwise was unobtainable. Further evaluation and testing of ramp treatments appear warranted.

Parallel-Drainage Structures

Based on the computer simulations and the preliminary test program it was shown that the driveway slope should be 6 to 1 or flatter to avoid vehicle rollover for speeds up to 50 mph (80.5 km/h). The computer simulations indicated that the ditch side slope should also be 6 to 1 or flatter. Even at these relatively flat slopes a vehicle traveling at 50 mph (80.5 km/h) will become airborne for approximately 65 ft (19.8 m). The computer simulations
4. Grate members should extend to and be anchored at the flow line. Drop-offs at the end of the culvert should be avoided.

5. Necessary grate member sizes will depend on the span of the grates, the manner in which the grates are supported and the design vehicle weight. To support a full-size automobile the following sizes or their equivalent are adequate.

<table>
<thead>
<tr>
<th>Suggested Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schedule 40 Pipe Size</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Span Length (ft)</th>
<th>I.D. (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 12</td>
<td>3.0</td>
</tr>
<tr>
<td>12 to 16</td>
<td>3.5</td>
</tr>
<tr>
<td>16 through 20</td>
<td>4.0</td>
</tr>
</tbody>
</table>

A 3.0 in. (7.62 cm) I.D. standard schedule 40 pipe can be used for spans up to 20 ft (6.1 m) if a midspan vertical support is used.

Parallel-Drainage Structures (for driveways, median crossovers, ramps, etc.)

1. The roadway side slope (or ditch slope) in the vicinity of the driveway slope should be 6 to 1 or flatter.

2. The driveway slope should be 6 to 1 or flatter.

3. The transition area between the roadway side slope and the driveway slope should be rounded or smoothed as opposed to an abrupt transition.

4. Safety treatment of the culvert opening should include an end section cut to match the driveway slope with cross members (grates) spaced approximately every 24 in. (61.0 cm) perpendicular to the direction of flow.

5. The cross members should be designed to support a concentrated wheel load of approximately 10,000 lb (44,480 N) applied at midspan.
REFERENCES


