Safety Treatment of Roadside Drainage Structures

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The purpose of the research was to develop traffic-safe end treatments for cross-drainage and parallel-drainage structures that would not appreciably restrict water flow. 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 by using both subcompact and full-sized automobiles. Finally, guidelines for implementation of designs were developed by using a cost/benefit analysis. Traffic-safe culvert end treatments can be achieved as follows. For cross-drainage structures, (a) all culvert ends not shielded by a traffic barrier 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 that mentioned in a, and (c) culverts with clear openings greater than 30 in can be made traffic-safe by grate members placed on 30-in centers oriented parallel to the flow and in the plane of the side slope. For parallel-drainage structures, (a) the roadway side slope (or ditch slope) should be 6:1 or flatter in the vicinity of the driveway, (b) the driveway slope should be 6:1 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 and have cross members (grates) spaced every 24 in (61.0 cm) perpendicular to the direction of water flow.

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. The National Cooperative Highway Research Program (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 modifications of design details could improve both drainage and safety (5). Many of the older safety grates used to cover the open ends of culverts have small openings and the grates are easily clogged with debris, which causes 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 that 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 (a) can be safely traversed by an errant vehicle and (b) will exhibit desirable hydraulic behavior. Although no hydraulic analyses were made, it was assumed that hydraulic efficiency increases as the number of grate members decreases. It was therefore a goal of the research to meet the safety requirements by using 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 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 trade-offs 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 through 50 mph (80.5 km/h).

RESEARCH APPROACH

A four-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 by using the results of the preliminary studies and tested under representative roadside configurations. Final designs were then studied by using a cost/benefit analysis to develop guidelines for their implementation.

Cross-Drainage Structures

Simulation Studies

A computer simulation study was conducted that used 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 that a ramp at the leading edge of the culvert opening would have on vehicle behavior. (Figure 5, which is shown later in this paper, illustrates the ramp.) Ramps that have the following dimensions were evaluated (1 in = 2.54 cm):

	Dimension (in)	
Ramp	Horizontal	Vertical
1	3.0	3.0
2	6.0	3.0
3	6.0	6.0
4	12.0	6.0

A 1974 Honda Civic was simulated in each of the computer runs because it was assumed that a mini-sized automobile would be more critical than a larger vehicle for the given conditions. A speed of 20 mph was used in each run, since it was deemed a critical speed. At higher speeds it was felt that it would be easier for the vehicle to clear the opening. At lower speeds, even though the vehicle would tend to drop more, velocity changes would be tolerable.

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 (a) the maximum clear opening permissible on a nongrated culvert end and (b) the maximum spacing permissible when grates are necessary. All runs were live-driver tests at various speeds and encroachment angles. Figure 2 is a photograph of the test pit after installation. A total of 30 runs were made to determine the maximum clear opening. A test matrix for this series of tests is shown in Table 1. All tests were with a

Figure 1. Plan view of culvert test pit.

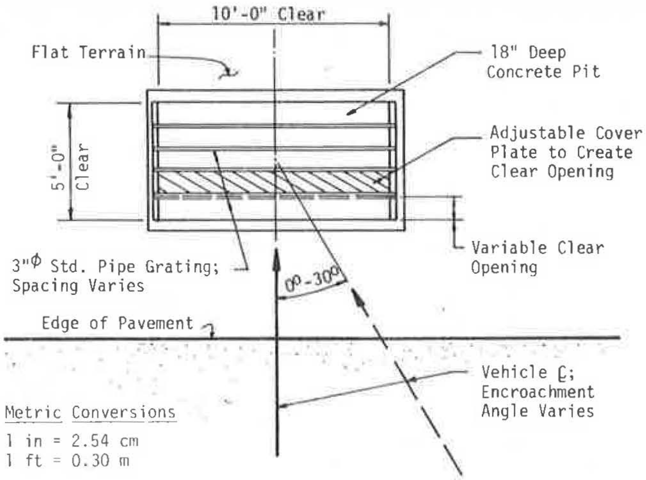


Figure 2. Test pit installation.

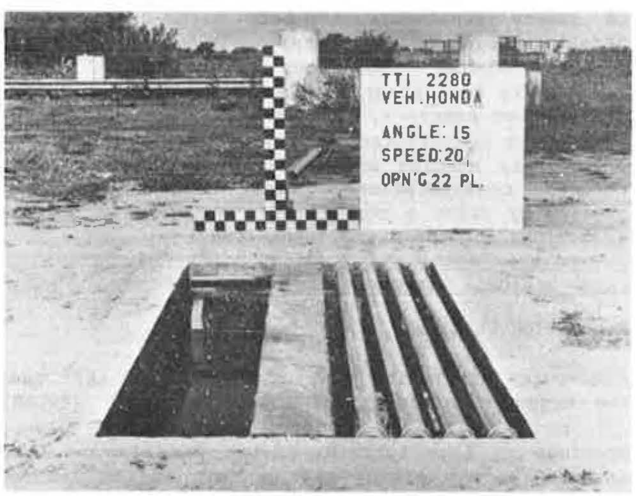


Figure 3. Sequential photographs of nongrated culvert test, 30-in clear opening, 1974 Honda Civic.

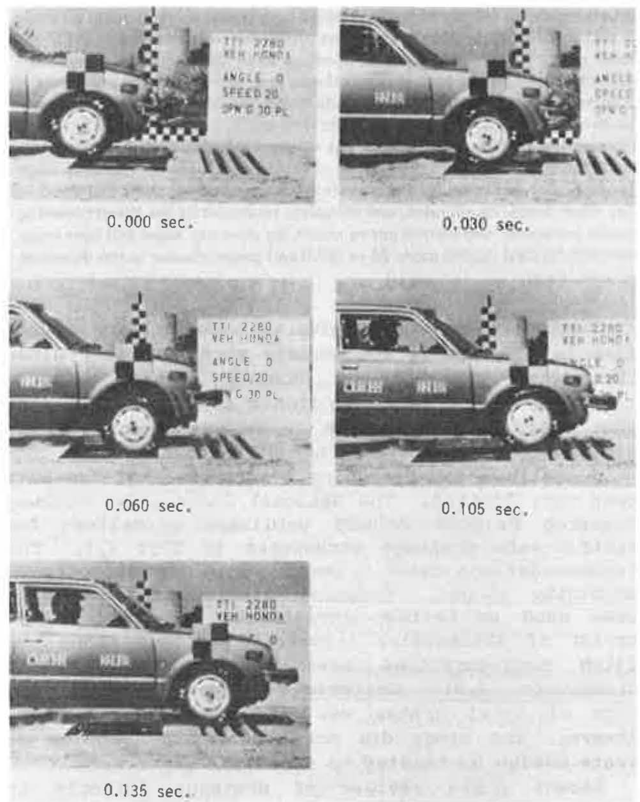


Table 1. Clear opening tests.

Test No.	Test Speed (mph)	Clear Opening (in)	Impact Angle (°)	Test No.	Test Speed (mph)	Clear Opening (in)	Impact Angle (°)
1	5	16	0	16	15	24	15
2	10	18	0	17	20	26	0
3	20	20	0	18	20	26	15
4	20	20	15	19	15	26	0
5	10	20	0	20	15	26	15
6	10	20	15	21	20	28	0
7	20	22	0	22	20	28	15
8	20	22	15	23	25	30	0
9	15	22	0	24	25	30	15
10	15	22	15	25	20	30	0
11	10	22	0	26	20	30	15
12	10	22	15	27	35	36	0
13	20	24	0	28	30	36	0
14	20	24	15	29	25	36	0
15	15	24	0	30	25	36	15

Note: 1 mph = 1.609 km/h; 1 in = 2.54 cm.

Table 2. Grate spacing tests.

Test No.	Vehicle Weight (lb)	Test Speed (mph)	Grate Spacing (in)	Encroachment Angle (°)
1	1970	10	16	0
2	1970	10	16	15
3	1970	10	16	30
4	1970	5	16	0
5	1970	5	16	15
6	1970	20	20	0
7	1970	20	20	15
8	1970	15	20	0
9	1970	15	20	15
10	1970	10	20	0
11	1970	10	20	15
12	1970	20	24	0
13	1970	20	24	15
14	1970	15	24	0
15	1970	15	24	15
16	1970	25	30	0
17	1970	25	30	15
18	4500	25	30	0
19	1970	20	30	0
20	1970	20	30	15
21	4500	20	30	0
22	4500	20	30	15

Note: 1 lb = 0.454 kg; 1 mph = 1.609 km/h; 1 in = 2.54 cm.

1974 Honda Civic that has 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 who was a nonprofessional driver. Sequential photographs of a 20-mph run with a 30-in (76.2-cm) clear opening are shown in Figure 3.

On completion of the clear-opening tests, the pit was used to determine the maximum permissible grate spacing. A total of 22 live-driver tests were conducted for this purpose. Table 2 gives a matrix of the grate-spacing tests conducted. The grates were 3-in (7.6-cm) schedule-40 steel pipe anchored to a steel beam that allowed 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 configuration was evaluated with the 1974 Honda Civic. A 1975 Plymouth Fury that weighed 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 HVOSM results, a ramp that had 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 that this combination would produce the greatest wheel hop of all combinations considered. The 1974 Honda Civic and the 1975 Plymouth Fury were used on the ramp test. Each test was conducted at 20 mph. Wheel hop and sprung mass center-of-gravity (cg) position for the test of the Plymouth Fury are shown in Figure 5.

Figure 4. Test pit with 16-in grate spacing.

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-diameter corrugated steel-pipe culvert and a 5-ft (1.5-m) wide by 3-ft (0.92-m) high concrete box culvert that had adjoining head and wing walls. Grate members on the box culvert consisted of 3-in schedule-40 steel pipe on 30-in centers. Photographs of both installations are shown in Figure 6.

General details of the six tests conducted are shown in Figure 7. Note that the culverts were subjected to tests with both mini- and full-sized 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, which allowed the left-side wheels to drop approximately 1.5 ft (0.46 m) to the ditch bottom and caused the vehicle to roll over. Sequential photographs of test 4 are shown in Figure 8.

Analysis of the strength requirements of grate members indicated that a 3-in inner diameter (ID) schedule-40 pipe was adequate for spans up to 12 ft (3.7 m). Because grate spans on many box culverts would exceed 12 ft, it was 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 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 vehicle tests were conducted by using a 4500-lb (2043-kg) vehicle, each at 20 mph and each

Figure 5. Wheel hub and car displacement versus time for ramp run, 20 mph, 1975 Plymouth Fury.

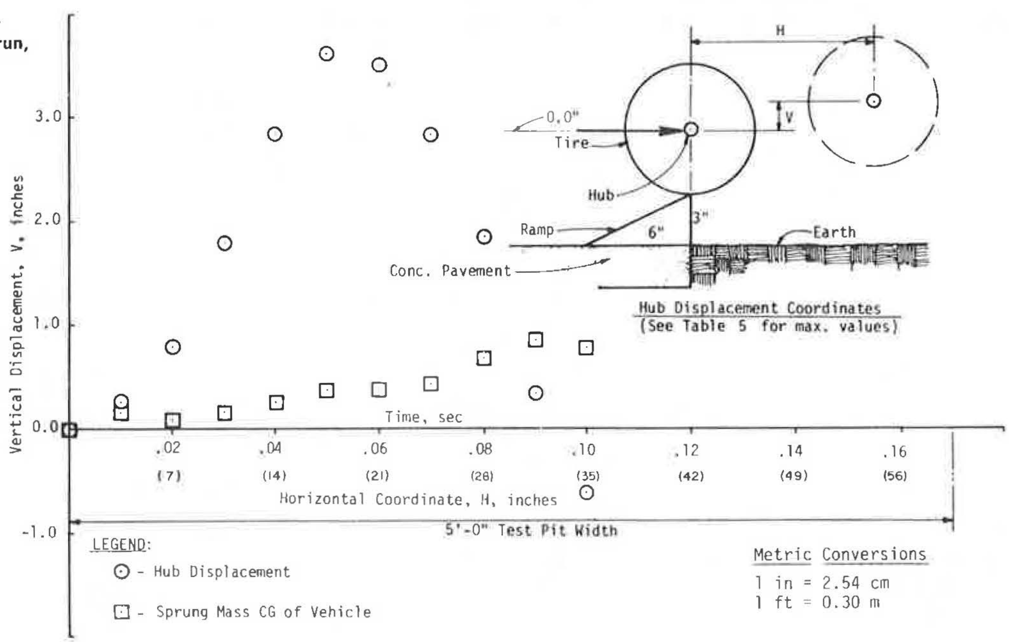


Figure 6. Prototype test installations.

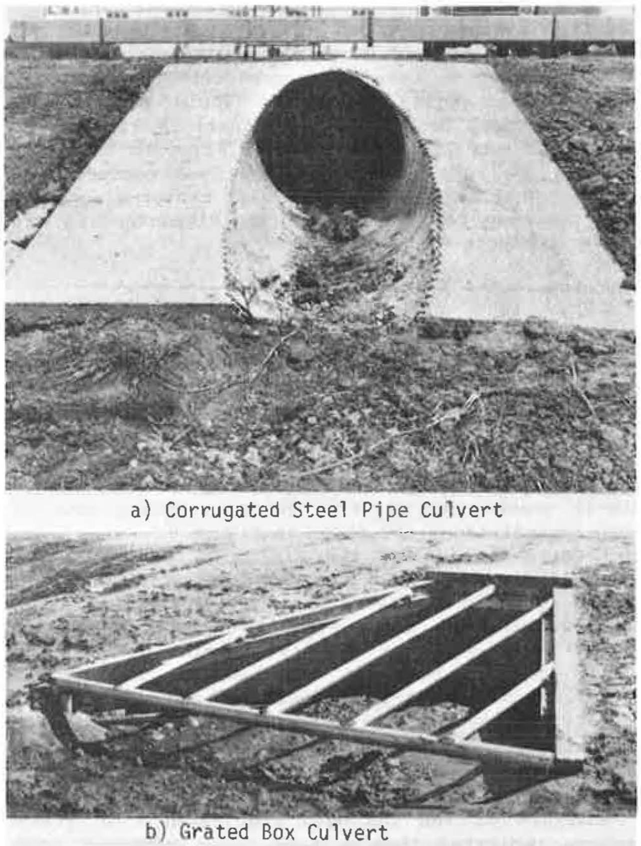
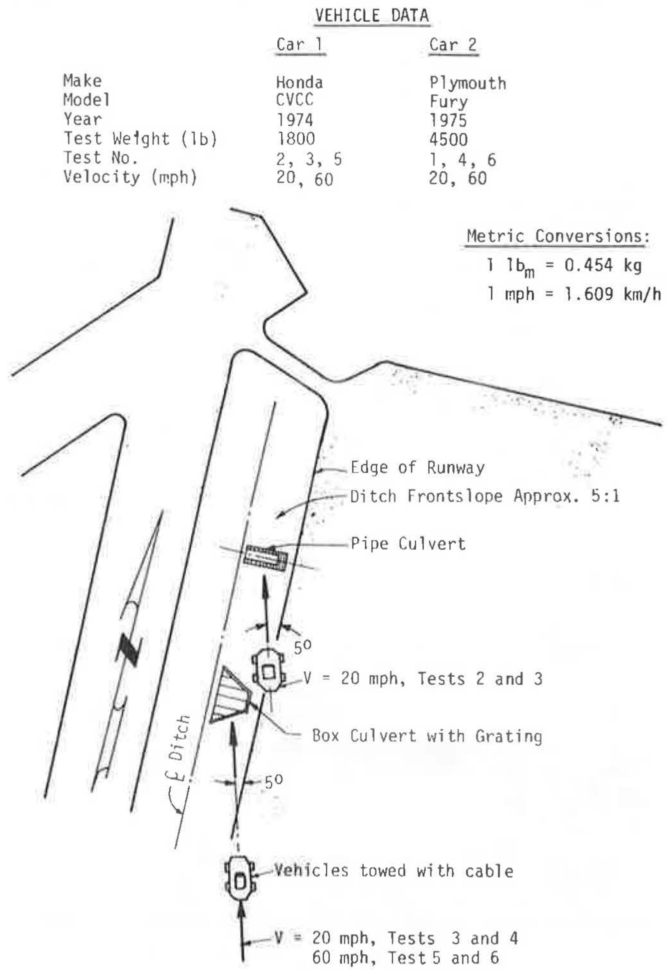


Figure 7. Plan view of site for prototype tests.



at a head-on approach perpendicular to the 20-ft dimension of the pit. Further details of each test are given in Table 3, including the permanent deformations noted after each test. With the exception of test 4, the grates had a 20-ft clear span. In test 4, vertical supports that consisted of 3-in ID 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, which was constructed according to Texas State Department of Highways and Public Transportation (TSDHPT) standards.

Cost/Benefit Analysis

Guidelines for safety treatment of cross-drainage structures were developed in 1978 by using a cost/benefit analysis (10). Alternatives considered included (a) no treatment or baseline option [it was assumed, however, that the culvert end would be made to match the existing side slope with no protrusions greater than 4.0 in (10.2 cm) above grade for the baseline option], (b) extend the culvert end to 30 ft (9.2 m) from the edge of the travelway, (c) install guardrail, or (d) place a traffic-safe grate as recommended herein. Initial costs of grates recommended here are significantly less than similar costs for culvert grates studied by Kohutek and Ross (10). Their analysis was therefore repeated. Current cost data for recommended grates were discounted back to 1978 at a discount rate of 10 percent. Adjusted 1978 cost figures for the addition of culvert grates on six different slope and culvert combinations are shown in the table below (1 in = 2.54 cm; 1 ft = 0.30 m):

Embankment Slope	Culvert	Grate Cost ($)
2.5:1	36-in-diameter pipe	380
6:1	36-in-diameter pipe	4 600
2.5:1	4x6-ft single box	1 270
6:1	4x6-ft single box	5 100
2.5:1	4x6-ft double box	2 100
6:1	4x6-ft double box	11 800

The reader should refer to Kohutek and Ross (10) for further information on costs of other options and a description of the cost-effectiveness model used in the analysis.

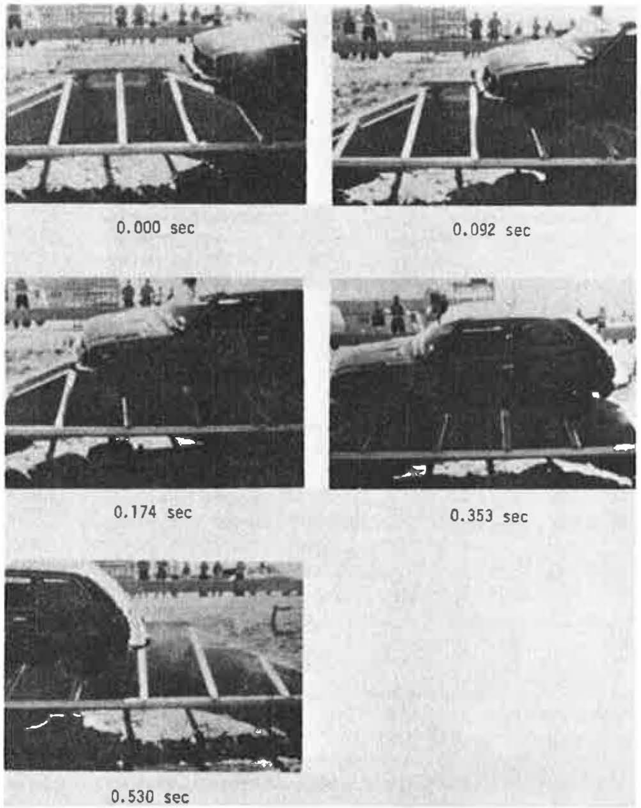
The cost/benefit analysis revealed that safety treatment beyond the baseline option of 36-in (91.4-cm) diameter or smaller cross-drainage pipe culverts is generally not warranted for traffic volumes of 20 000 vehicles/day or less. Safety treatment of larger box culverts was cost beneficial in most cases for traffic volumes greater than approximately 750 vehicles/day. Figure 9 shows warrants for a 4x6-ft single-box culvert on a 2.5:1 slope. Similar figures for other configurations are available in Ross and others (6).

Parallel-Drainage Structures

Simulation Studies

Design of a traffic-safe parallel-drainage structure not only involves the culvert itself but the adjoining slopes as well. In fact, the slopes can in many

Figure 8. Sequential photographs, test 4.



cases be a greater hazard than the culvert structure. Studies of median crossover 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 10.

The following is the range of each parameter evaluated:

1. Departure angle--15° and head on;
2. Departure speed--30, 40, 50, and 60 mph (48.3, 64.4, 80.5, and 96.6 km/h);
3. 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);
4. Roadway slope--4:1 and 6:1;
5. Driveway slope--4:1, 5:1, and 6:1;
6. Transition type--abrupt and rounded;
7. Ditch depth--2 and 3 ft (0.61 and 0.92 m); and
8. Vehicle size--2250 and 4500 lb (1022 and 2044 kg).

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

Preliminary Tests

Ten full-scale vehicle tests were conducted to (a) evaluate vehicle response as a function of the driveway slope and (b) develop a tentative safety treatment for parallel-drainage structures. The test vehicles were 1974 and 1975 Chevrolet Vegas weighing approximately 2250 lb. 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 4 (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 3.8:1 slope, was approximately 3 ft (0.92 m) high, and was approximately 20 ft (6.1 m) wide at the top. Sequential photographs of test 1-4 are shown in Figure 11.

After test 1-4, the berm slopes were flattened to the dimensions shown on the upper part of Figure 12. In this case the slope on the approach side was 6.7:1. It was obvious from test 1-3 that an automobile could traverse the 6.7:1 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) and had the automobile approach 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

Table 3. Cross member deflections of box culvert grating strength tests.

Test No.	Pipe ID[a] (in)	Grate Member[b]	Deflection (in) Vertical	Deflection (in) Horizontal
1	5	First	0.0	0.0
		Second	0.0	0.0
		Third	-0.94	0.4
2	4	First	-0.13	0.0
		Second	-0.50	0.3
		Third	-3.00	1.9
3	3.5	First	-1.75	2.9
		Second	-4.75	3.1
		Third	-4.13	1.4
4[c]	3	First	-0.75	1.5
		Second	+0.25	1.9
		Third	+0.13	4.8

Note: 1 in = 2.54 cm.
[a]Schedule-40 steel pipe.
[b]Grate members spaced on 30-in (76.2-cm) centers.
[c]Midspan vertical supports used on each grate.

Figure 9. Warrants for safety treatment of a 4x6-ft single box culvert on a 2.5:1 slope.

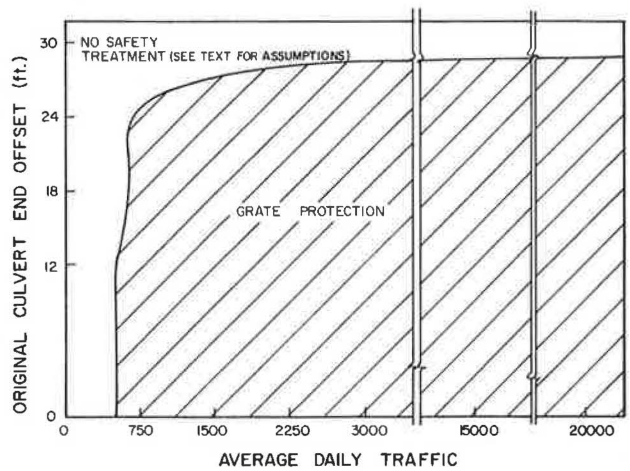


Figure 10. Definition sketch.

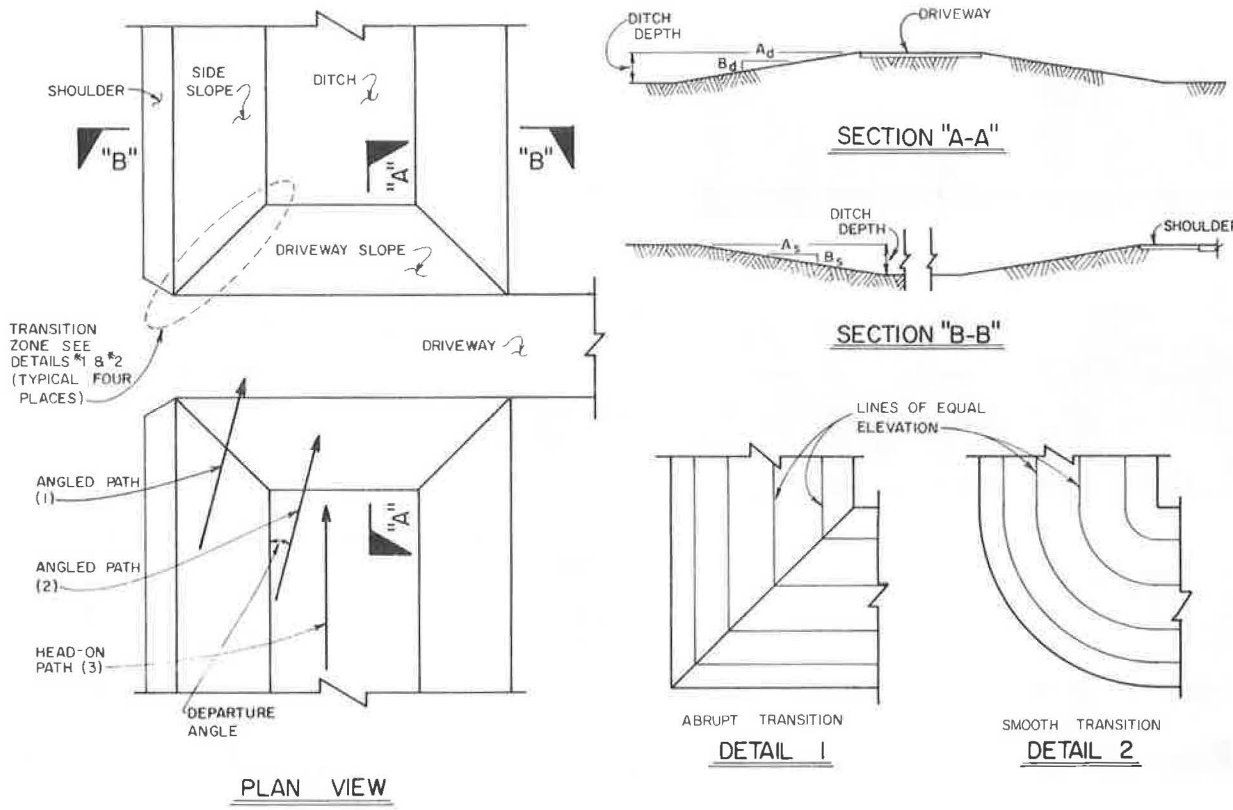


Table 4. Summary of full-scale test results.

Test No.	Vehicle Speed (mph)	Vehicle Path[a]	Driveway Slope	Ditch Slope	Culvert Configuration	Results
1-1	30	3	3.8:1	NA	No culvert	Satisfactory, no rollover
1-2	35	3	3.8:1	NA	No culvert	Satisfactory, no rollover
1-3	40	3	3.8:1	NA	No culvert	Satisfactory, no rollover
1-4	50	3	3.8:1	NA	No culvert	Unsatisfactory, vehicle pitched over
5-1	50	3	6.7:1	NA	No culvert	Satisfactory, no rollover
7-1	50	3	6.7:1	NA	See Figure 10	Unsatisfactory, vehicle rolled over
7-2	50	3	6.7:1	NA	See Figure 10	Unsatisfactory, vehicle rolled over
7-4	20	3	6.7:1	NA	See Figure 10	Satisfactory, no rollover
7-5	50	3	6.7:1	NA	See Figure 10	Unsatisfactory, vehicle rolled over
7-6	50	3	6.7:1	NA	See Figure 10	Satisfactory, no rollover
9-1	40	2	6.5:1	6.8:1	See Figure 13	Satisfactory, no rollover
9-2	50	2	6.5:1	6.8:1	See Figure 13	Satisfactory, no rollover

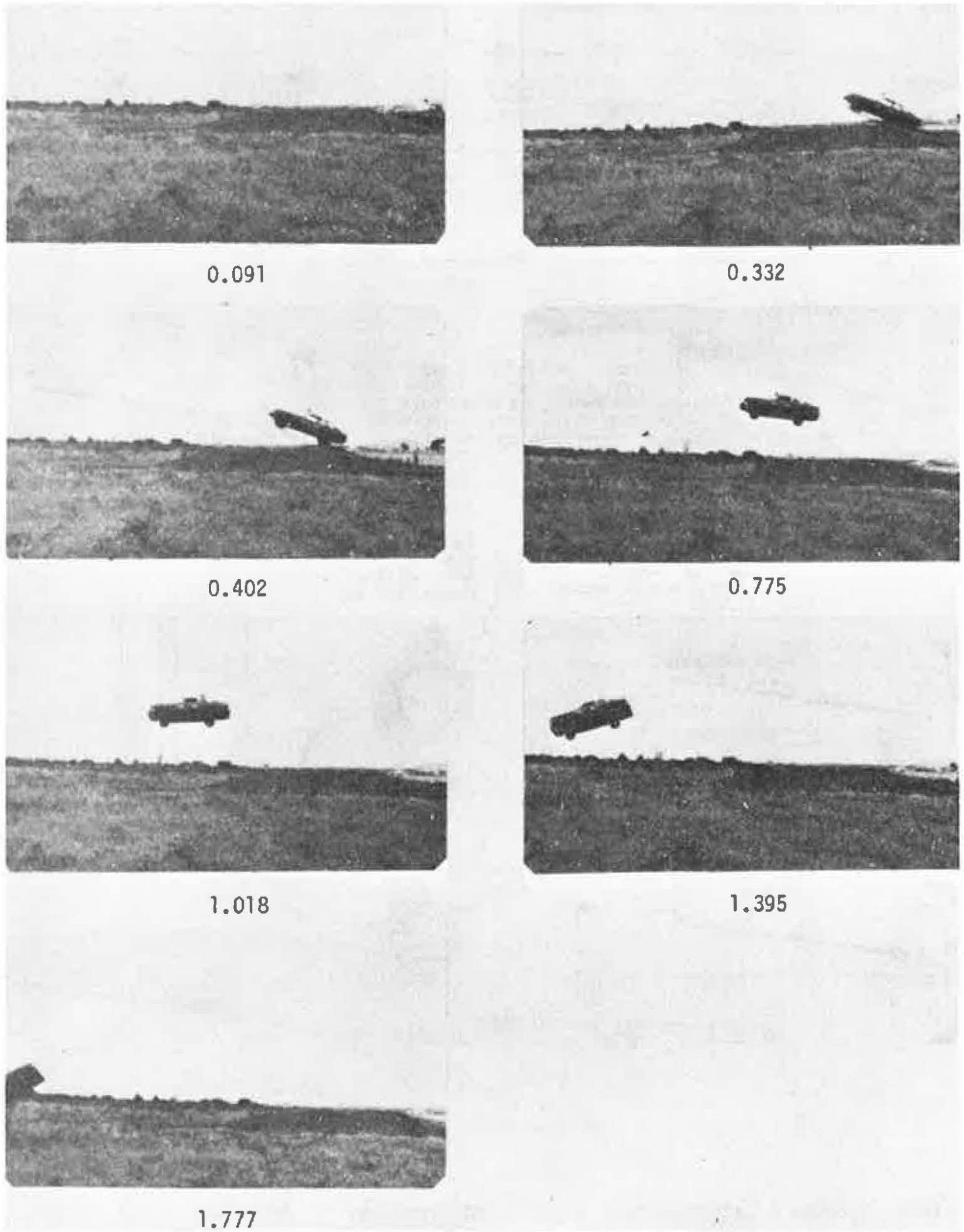
Note: 1 mph = 1.609 km/h; NA = not applicable.
[a]See Figure 1.

culvert end was needed in addition to the sloped end treatment. The 6.7:1 driveway slope was used in each test. It was assumed that a head-on path into the driveway culvert would be as critical as, 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 upper part of Figure 12. This culvert size was selected because the diameter of most driveway culverts in Texas are equal to or less than 24 in. The 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 shown in Figure 12. Test 7-1 was conducted at 50 mph with an open culvert, i.e., no grate members. Photographs of the installation are given in Figure 13 and sequential photographs of the test are given in Figure 14. 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 12. 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 were 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 12. Grate members consisted of 2-lb/ft (2.98-kg/m) steel flanged channel sections. The channel section was chosen because it is widely used as a delineator post by TSDHPT and would therefore be readily avail-

Figure 11. Sequential photographs, test 1-4.



able. The first test on this treatment (test 7-4) was conducted at 20 mph and the results were acceptable. Test 7-5 was conducted at 50 mph and rollover occurred due to structural failure of the grates.

In test 7-6, 2.5-in (6.35-cm) ID standard steel pipe (schedule 40) was used as a grate member. Details 7 through 10 of Figure 12 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

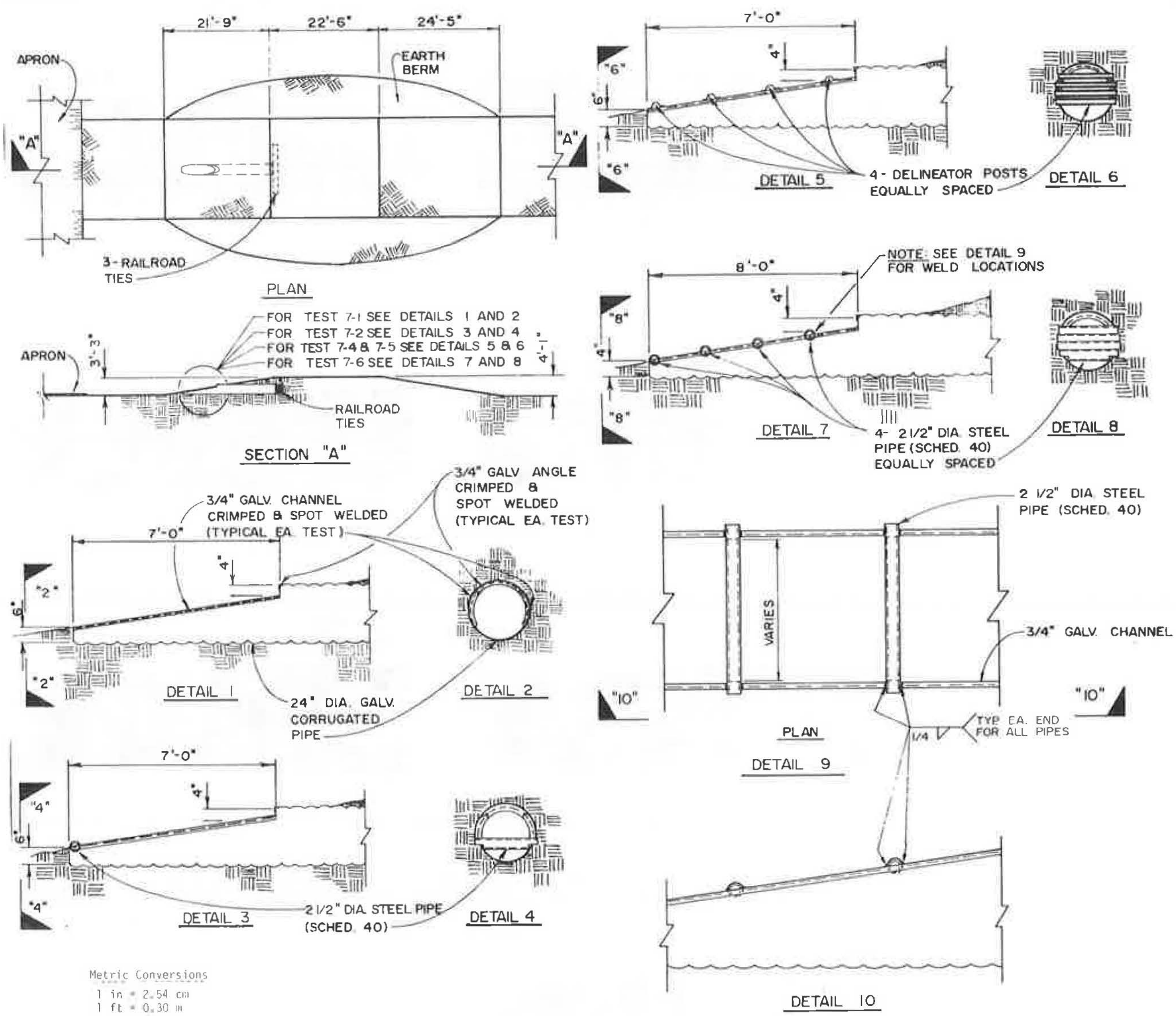
The final two tests (tests 9-1 and 9-2) were selected to verify the tentative conclusions reached as a result of the simulation work and the full-scale slope and culvert testing. A full-scale prototype of a ditch and driveway configuration was constructed as shown in Figure 15 and the photographs of Figure 16. Test 9-1 was conducted at 40 mph (64.4 km/h) and the approach path into the driveway was as shown in Figure 15, 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 that the speed was increased to 50 mph. Sequential photographs of the test are shown in Figure 17. The vehicle remained upright and sustained only minor damage. The culvert was only slightly damaged and could have been used without repair.

Cost/Benefit Analysis

A cost/benefit analysis was made to develop warrants for safety treatment of parallel-drainage structures and adjoining roadside slopes. The analysis was conducted by assuming that (a) the roadway side slope was 6:1, (b) the roadway had a 12-ft (3.66-m) shoulder, and (c) the centerline of the culvert was 25 ft (7.62 m) from the edge of the travelway.

Figure 12. Berm and culvert details, tests 5-1 through 7-6.



Safety treatment alternatives considered included (a) 1.5:1 driveway slope and no culvert safety treatment (this is considered the untreated condition), (b) 6:1 driveway slope and culvert end cut to match the 6:1 slope, and (c) 6:1 driveway slope, culvert end cut to match slope, and a safety grate treatment as recommended herein.

With the three options above and the assumed roadside geometry, a cost/benefit analysis was conducted. A description of the cost/benefit analysis procedure used is given in Kohutek and Ross (10). Input required to perform the analysis included cost of treatment, accident or societal cost, traffic volume, hazard size and location, discount rate, and severity index of the hazard being evaluated.

Costs of safety treatment of each culvert are given in Table 5. Severity indices and construction costs were estimated by TTI and TSDHPT engineers.

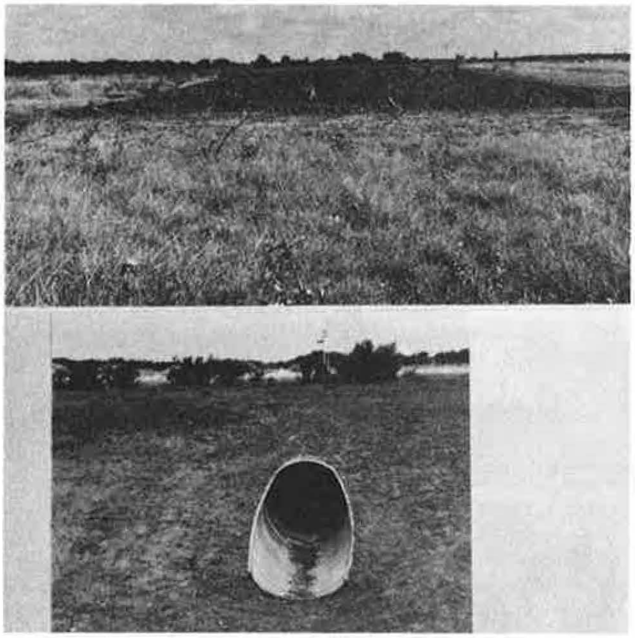
Figure 18 shows the warrants developed for parallel-drainage culverts. Because the warrants shown in this figure were based in part on judgment and the analysis was conducted for only one highway cross section, discretion must be used in their application.

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 30-36 in, it was shown that grates spaced on 30-in centers would provide satisfactory safety treatment. These findings were in fact borne out through six full-scale prototype tests. Tests of a 30-in-diameter corrugated steel-pipe culvert end, cut to match a 5:1 side slope, were successfully conducted. The culvert opening was readily traversed by both a full- and mini-sized automobile at 20 mph. Tests of a relatively large box culvert constructed to match the existing 5:1 side slope also verified that grates spaced on 30-in centers provide a satisfactory safety treatment. Tests of this treatment at 20 mph and 60 mph (96.5 km/h) by both full- and mini-sized automobiles were conducted. It was also shown that

Figure 13. Test installation before test 7-1.



the grates should be extended and anchored at the flow line to avoid any appreciable drop-off 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) ID schedule-40 steel-pipe grates were of sufficient strength to support a full-sized 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 (1 ft = 0.30 m; 1 in = 2.54 cm):

Span Length (ft)	Suggested Standard Schedule-40 Pipe Size ID (in)
Up to 12	3.0
12-16	3.5
16-20	4.0

If midspan vertical supports are used, 3.0-in ID standard schedule-40 pipe can be used for spans up to 20 ft (6.1 m). Other sections that have equivalent strengths could of course be used. Reference may also be made to a Federal Highway Administration

Figure 14. Sequential photographs, test 7-1.

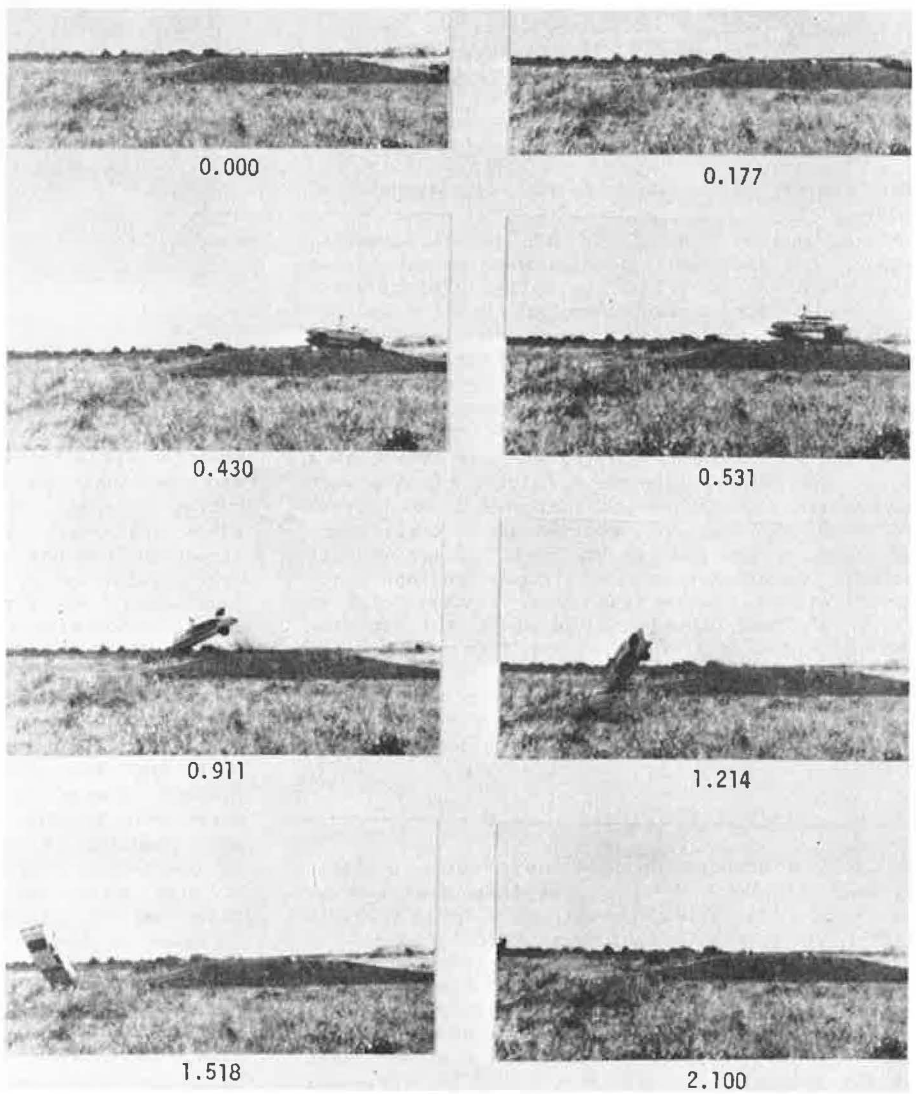


Figure 15. Test site conditions, tests 9-1 and 9-2.

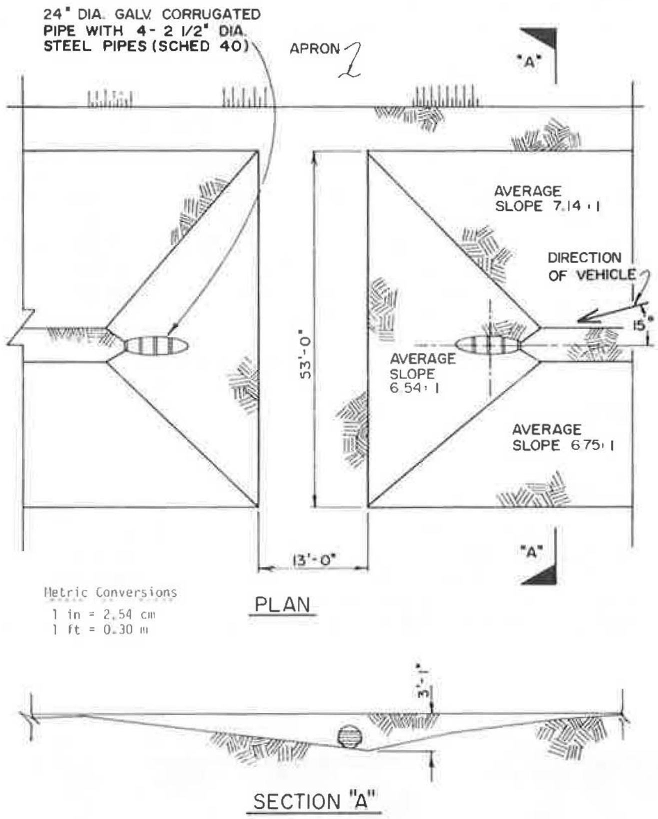


Figure 16. Test site, tests 9-1 and 9-2.

(FHWA) report (4) for strength requirements of grates.

A cost/benefit analysis of six typical culvert, roadway, and side-slope combinations revealed that safety treatment of 36 in or smaller pipe culverts is generally not warranted unless traffic volumes exceed 20 000 vehicles/day. Treatment of larger box culverts is generally warranted for traffic volumes greater than approximately 750 vehicles/day. More specific guidelines for safety treatment of culverts are available in Ross and others (6).

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 6:1 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 6:1 or flatter. Even at these relatively flat slopes, a vehicle traveling at 50 mph will become airborne for approximately 65 ft (19.8 m). The computer simulations also indicated that the potential for rollover could be minimized by a smooth rounded transition zone between the ditch side slope and the driveway slope.

Preliminary tests were conducted on various degrees of safety treatment of the culvert end. The vehicle approached the culvert head on in each test, and the right-side wheels crossed the center of the culvert opening. The baseline test involved an open 24-in (61.0-cm) diameter corrugated steel pipe sloped at the end to match the 6:1 driveway slope. Considerable wheel drop occurred, especially the rear wheel, which caused large vertical and longitudinal forces on the vehicle and subsequently produced rollover. The initial treatment involved a single grate member placed at the end of the culvert. This provided little improvement. Results indicated that grates would have to be placed approximately every 2 ft (0.61 m) to prevent significant wheel drop. The next two tests evaluated steel flanged channel grate members on 2-ft centers. Structural failure of the grates during the 50-mph test resulted in vehicle rollover. The final test in the series involved 2.5-in (6.4-cm) ID schedule-40 pipe grates on 2-ft centers. The test vehicle traversed the treatment at 50 mph without rollover.

Based on the preliminary studies, a prototype of a typical ditch, driveway, and culvert configuration was constructed and tested. Slopes of the ditch and the driveway were approximately 6:1 and the culvert end was safety treated with 2.5-in ID schedule-40 pipe. Tests at 40 mph (64.4 km/h) and 50 mph verified the tentative conclusions reached in the pre-

Figure 17. Sequential photographs, test 9-2.

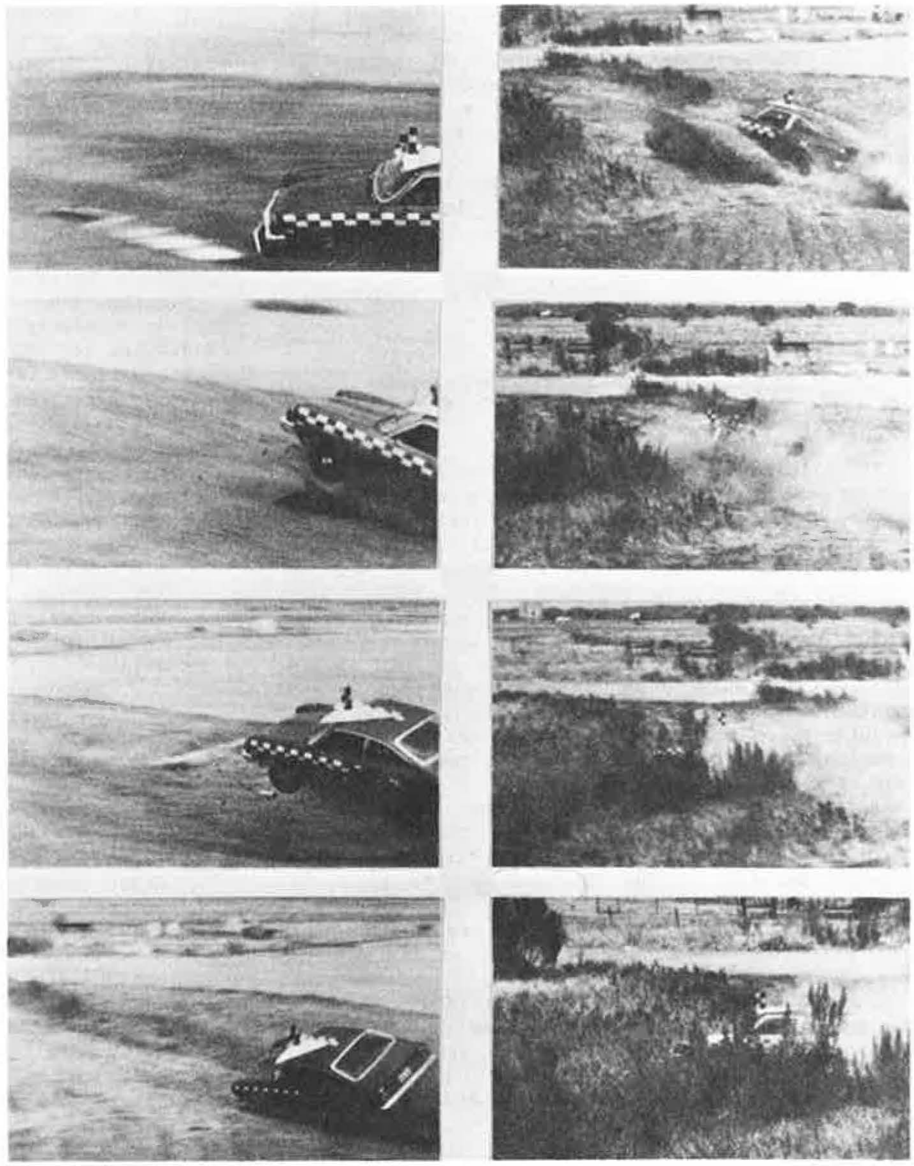
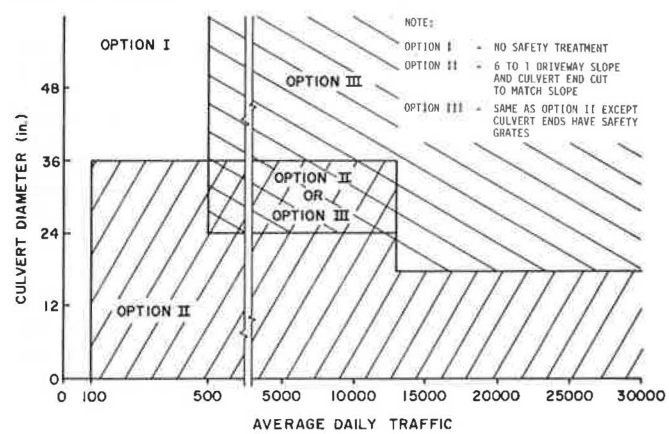


Table 5. Incremental cost of treatments.

Culvert Diameter (in)	Cost to Upgrade from Option I to II ($)	Cost to Upgrade from Option II to III	
		Construction ($)	Maintenance ($/year)
18	375	225	150
24	378	300	150
36	475	600	150
48	835	900	150

Note: 1 in = 2.54 cm.

Figure 18. Warrants for safety treatment of parallel-drainage culverts.



liminary studies. Results of the 12 full-scale tests are summarized in Table 4.

Analysis of the crash tests and the computer simulations showed that the dynamic wheel load on a driveway grate member is about 10 000 lbf (44 480 N) when impacted by a 4500-lb (2043-kg) automobile at 50 mph, assuming the culvert is on a 6:1 slope. It is therefore suggested that a 10 000-lbf concentrated load applied at midspan be used in designing a driveway cross member, its attachment to the culvert and/or riprap, and any reinforcing that may be necessary to the culvert and/or riprap. It is noted that the 2.5-in schedule-40 steel pipe used in the test program, while structurally adequate for a 2250-lb (1022-kg) automobile and a 24-in-diameter culvert, would probably not have supported a 4500-lb automobile. Calculations show that a 3-in (7.6-cm) ID schedule-40 pipe would have been needed for the larger automobile.

Warrants for recommended safety treatments of parallel drainage culverts were developed by using cost/benefit techniques, and they are shown in Figure 18.

CONCLUSIONS

Cross-Drainage Structures

The conclusions for traffic-safe cross-drainage structures are as follows:

1. All culvert ends not shielded by a traffic barrier should be made to match the existing side slope if they terminate within the clear zone. Protrusions of the culvert and adjoining wing walls and head wall above the terrain in excess of 3-4 in (7.6-10.3 cm) should be avoided.
2. Round culverts with diameters of 30 in (76.2 cm) or less need no end treatment other than what was mentioned in 1 above. Elliptic or oval-shaped culverts with major axes 30 in or less need no end treatment other than as mentioned in 1 above. Rectangular-shaped culverts with a horizontal clear distance 30 in or less need no end treatment other than as mentioned in 1 above.
3. Culverts that have dimensions greater than those given in 2 above can be made traffic-safe by grate members placed on 30-in centers that are oriented parallel to the flow and in the plane of the surface of the side slope.
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-sized automobile, the following sizes or their equivalent are adequate (1 ft = 0.3 m, 1 in = 2.54 cm):

Span Length (ft)	Suggested Standard Schedule-40 Pipe Size ID (in)
Up to 12	3.0
12-16	3.5
16-20	4.0

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

6. Safety treatment of large cross-drainage structures is warranted on most highways that have traffic volumes in excess of 750 vehicles/day. Guidelines for application of the cross-drainage culvert safety treatments are available in Ross and others (6).

Parallel-Drainage Structures

The conclusions for traffic-safe parallel-drainage structures (for driveways, median crossovers, ramps, etc.) are as follows:

1. The roadway side slope (or ditch slope) in the vicinity of the driveway slope should be 6:1 or flatter.
2. The driveway slope should be 6:1 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 lbf (44 480 N) applied at midspan.
6. Warrants for safety treatment of parallel-drainage structures are shown in Figure 18.

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