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16. Abstract

Safe roadway designs are a critical concern to the motoring public. Escalated costs of providing essential transportation networks and safe driving surfaces have caused funds to be in critically short supply. Therefore, improvements to fixed objects off the roadway must be judiciously examined to determine their relative contribution to the overall safety of the motorist.

Investigation into the magnitude of the problem concerning improved design of roadway culverts has been approached through accident analysis and theoretical computations involving societal costs and probability of impacts.

Findings of this study indicate that culvert related accidents are of minor significance in terms of overall accident occurences as well as expected benefits to be derived from enhancements to existing culvert designs. Ongoing research is investigating proposed culvert design modifications through full-scale crash tests which are scheduled to be concluded during the 1979-80 fiscal year. Until ongoing research has established the relative significance of roadside culvert design relationships and optimized improvements, a list of recommendations concerning design of culverts is provided.

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cross drain culvert, driveway culvert, societal cost, benefit/cost comparison	No Restrictions

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An Analysis of Safety Benefits Expected Through Drainage Structure Design Modifications

By

John F. Nixon
David Hustace

Transportation Planning Division
State Department of Highways and Public Transportation

August 1979

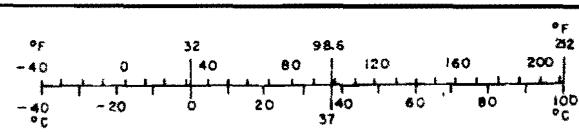
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation and policy of the Texas State Department of Highways and Public Transportation.

LIST OF EXHIBITS

IMPLEMENTATION STATEMENT

Implementation of the findings of this study can be immediately instituted and should be combined with the findings of the ongoing research scheduled for conclusion in the 1979-80 fiscal year. The findings recommended for implementation are as follows:

1. Defer any major design modifications to culvert end treatments not verified by research testing, other than removal of concrete headwalls, until scheduled research has been concluded. It is recommended that any design modification be based upon safety, traffic densities, costs, and hydraulic performance.*
2. Concentrate primary emphasis on providing optimum driving surfaces, shoulders and flat sideslopes to minimize accidental departures from the roadway.
3. Grates should not be required on cross drain culverts through 42" in diameter.
4. Locate driveway culverts as far from the travel way as practical.
5. Minimize cover on driveway culverts to reduce overall height of the obstacle to the motorist.
6. Recommend use of ditchline paved driveways without pipes whenever possible.

* see addendum for interim research findings

AN ANALYSIS OF SAFETY BENEFITS
EXPECTED THROUGH DRAINAGE STRUCTURE DESIGN MODIFICATIONS

PREFACE

Safety on highways is of critical concern to the motorist as well as to the Department. The design engineer must assess the abilities of the driver and provide a safe roadway environment while providing for the basic transportation needs of the community. The discharge of these obligations is frequently obscured by the many facets involved in planning, construction, and maintaining of 72,000 + miles of roadways on the Texas Highway System. Budgetary limitations have caused severe shortages of funds for needed transportation improvements; therefore, all programs must be judiciously compared and selected to achieve and maximize overall betterment and safety to these highways.

Ohio reports (Reference 2) that almost two-thirds of the single vehicle accidents did not involve a fixed object. In a comparison of injury producing accidents, it was found that non-fixed objects were responsible for approximately the same percentage (of accidents) as those caused by fixed objects. Terrain or the basic roadway design (or lack of it) represented the greatest hazard to the single vehicle leaving the road on a rural two-lane highway system. Further, it was estimated that any fixed object improvement program would affect less than 10% of the accidents. Therefore, it was concluded that in Ohio, any improvement directed at roadside obstacles, was judged to be not economically feasible when compared to a program in which primary emphasis is placed on improvements to the shoulder and/or roadways.

Similarly, a tabulation of accidents by type occurring in Texas by the Texas Department of Public Safety (Reference 3) indicates that accidents statewide involving non-fixed objects, amounted to 76.1% and 77.1% of the fatalities occurring during 1977 and 1978, respectively. The largest single category of fatal accidents in Texas is the multi-vehicle collision. In 1977 and 1978, these accidents represented 38.6% and 38%, respectively, of all accidents. Although high speeds are frequently associated with this type accident, since the opportunity exists for both drivers to exercise evasive action, pavement condition is an important factor which directly affects accident frequency and severity. Similarly, single vehicle accidents which occur both on and off the roadway frequently also initially involve similiar pavement conditions to which the driver has not successfully accommodated. Therefore, the importance of focusing primary effort on safe design and maintenance of the travel way is apparent.

Fixed objects off the roadway are another area of concern to the safety engineer. Optimization of design necessitates an intensive examination of each fixed object with respect to the overall safety of the facility. Basically in order to select an optimum design, two questions should be answered when considering treatment of fixed objects off the roadway:

1. Does a problem exist?
2. If a problem exists, what is the optimum method of treating the problem?

INVESTIGATION

Driveway culverts and crossroad culverts represent two types of the many fixed objects adjacent to the roadway. This report shall attempt to examine this class of fixed object to develop a procedure for a systematic evaluation of benefits to be derived from any proposed program for enhancement of these structures.

Four primary factors are involved in considering the relative hazard potential of any fixed object off the roadway: 1). Distance of the object from the roadway, 2). Frequency of occurrence of the object along the roadway, 3). Obstacle size and, 4). Traffic Volume.

Distance of the obstacle from the roadway will affect hazard potential of an impact in two ways. Not only is the probability of an impact greatly reduced by distance from the roadway, but a markedly reduced severity of impact should be possible through driver corrective action in steering or vehicle braking and deceleration.

Frequency of occurrence of a hazard directly influences the probability of impact with that hazard and probabilistic models have been developed to estimate this occurrence. When impacts with intermittently occurring obstacles are compared to those which are continuous; however, such as guardfence, pavement edge dropoffs, or poor driving surface friction resistance, their comparative exposure frequency is slight.

Obstacle size influences both potential impact frequency as well as impact severity. Fewer and less severe impacts are expected with objects which offer a small low "target" value.

Finally, traffic volume must be considered when a comparison is made of roadway appurtenances needing improvement. Higher volume facilities, with a proportional increase in frequency of exposures to a hazard, should receive priority in improvement scheduling over the comparable low volume facility.

Two approaches were used to investigate the problem: An analysis of historical accident data was used to determine the dimensions of the problem and an estimate of the frequency of impact using a probabilistic model was used to compute a benefit/cost comparison for treated and untreated installations.

ACCIDENT STATISTICS

Accident statistics (Reference 4) comparing culvert accidents to total accidents on Texas Highways is illustrated in Exhibit I. Comparison between culvert accidents of all types indicates that culvert accidents represent only 0.7% of the total roadway accidents occurring on state maintained roadways in Texas and only 1.5% of the fatalities, 1.4% of the injuries and 0.4% of the property damage. Although any computed percentage will vary from year to year, it is apparent that culvert accidents represent a very low frequency incident. Further, to yield an indication of the frequency which vehicles departing the road impact culverts, the FHWA reports (Reference 5) that these impacts represent 3.1% of roadside objects most commonly hit and 5.8% of total impacts when secondary hits are considered.

EXHIBIT I

A comparison of

Culvert Accidents to Total Accidents
on Texas Highways
1978

Culvert Accidents*

Fatalities	Fatal Accidents	Number Injured	Injury Accidents	PDO Accidents	Total Accidents
44	37	1217	862	570	1469

Total Accidents - Statewide

Fatalities	Fatal Accidents	Number Injured	Injury Accidents	PDO Accidents	Total Accidents
2987	2538	94,545	59,609	140,135	202,282

Percent Culvert Accidents to All Accidents $= \frac{1469}{202,282} = 0.7\%$

Percent Culvert Fatal Accidents to Total Fatal Accidents $= \frac{37}{2,538} = 1.5\%$

Percent Culvert Injury Accidents to All Injury Accidents $= \frac{862}{59,609} = 1.4\%$

Percent Culvert Property Damage Accidents to All Property Damage Accidents $= \frac{570}{140,135} = 0.4\%$

*Special Data Tabulation by State Department of Highways and Public Transportation

To evaluate the relative significance of the fixed object collision, Exhibit II illustrates a ranking of fixed objects based upon societal costs. Since rates of fatalities, injuries, and property damages for collisions with a given fixture will vary, by weighting these rates, with an estimate of the cost to society associated with each type accident, a comparison between severities of each type object can be made. Societal costs reported by the FHWA (Reference 6) were $287,175 per fatality, $3,185 per injury, and $520 for property damage. A tabulation of societal costs for the ten most frequently impacted fixed objects are compared to the single vehicle accident and total accident costs. By this comparison all culvert accidents represent only 1.9% of the cost of total accidents. Although these percentages cannot be used to infer a relative hazard to other fixed objects unless total numbers of fixed objects are known, they do reflect the low significance of total culvert accidents to all accidents. Also, since a "culvert" accident can be interpreted to include accident with large drainage structures, (structures up to 20 feet long in Texas are classified as culverts) as well as the small diameter pipe culverts, these percentages are apt to be conservative when minimum size driveway and cross drain culverts are being considered.

PROBABILITY MODEL

Therefore, to establish a measure of the hazard potential of the individual culvert and to further complement the historical data, a probability model was next used. The AASHTO Guide (Reference 7) provides a procedure for estimating accidental departures from the roadway, expected impacts with a given fixed object, and a method for analysis with an improved design to achieve a benefit/cost comparison. (See the appendix of this report for sample computations)

EXHIBIT II

Societal Cost Comparisons of Ten
Single Vehicle Fixed Object Accidents
On Texas Highways

($1000)

1977

	Fatalities Costs	Injuries Costs	Property Damage Costs	Total Societal Costs	Percent Cost All Types Accident
Guard Posts Rail	102 $ 29,292	3339 $ 10,635	6490 $ 3,375	$ 43,302	3.8%
Tree or Shrub	95 27,282	1067 3,398	1559 811	31,491	2.7%
Culverts, Headwall	62 17,805	1018 3,242	1339 696	21,743	1.9%
End of Bridge	72 20,677	194 618	371 193	21,488	1.9%
Fence	43 12,349	1278 4,070	2757 1,434	17,853	1.5%
Highway Sign	42 12,061	1099 3,500	3560 1,851	17,412	1.5%
Side of Bridge	29 8,328	1155 3,679	2051 1,067	13,074	1.1%
Utility Pole	20 5,744	1482 4,720	2300 1,196	11,660	1.0%
Pier or Support	36 10,338	230 733	351 183	11,254	1.0%
Luminaire Pole	13 3,733	778 2,478	1434 746	6,957	0.6%
All Accidents State Wide	2671 $ 767,044	84,386 $268,769	227,855 $118,485	$1,154,298	

Basically, the procedure used first estimates the expected frequency of accidental departure from the roadway based on average daily traffic of the facility. Next, utilizing a nomograph (Exhibits III and IV) for a fixed object of known width, length, distance from the roadway, and an estimated departure frequency, a collision frequency, C_F, is determined for various roadway densities with cross drain and driveway culverts, respectively.

A comparison of the benefits of an "improved" design is then made with the existing design to enable a benefit/cost determination. By means of estimates of the expected severities associated with an impact with existing and improved designs and a computation of the societal cost of the accident, a dollar value can be assigned to each installation. The Severity Index used was based upon a scale of 0 to 10. Exhibit V illustrates a graph which was revised from the AASHTO report to reflect the previously cited societal costs for fatalities, injuries, and property damage.

The following equations were used to compute the "R" or benefit/cost value of the existing installation.

$$C_{TU} = C_I + C_D (C_F) (K_T) + C_M (K_T) + C_{OVD} (C_F) (K_T) - C_S (K_F) \quad (1)$$

$$C_{TP} = C_I + C_D (C_F) (K_T) + C_M (K_T) + C_{OVD} (C_F) (K_T) - C_S (K_F) \quad (2)$$

$$C_{TD} = C_I + C_D (C_F) (K_T) + C_M (K_T) - C_S (K_F) \quad (3)$$

$$R = \frac{C_{TU} - C_{TP}}{C_{TD}} \quad (4)$$

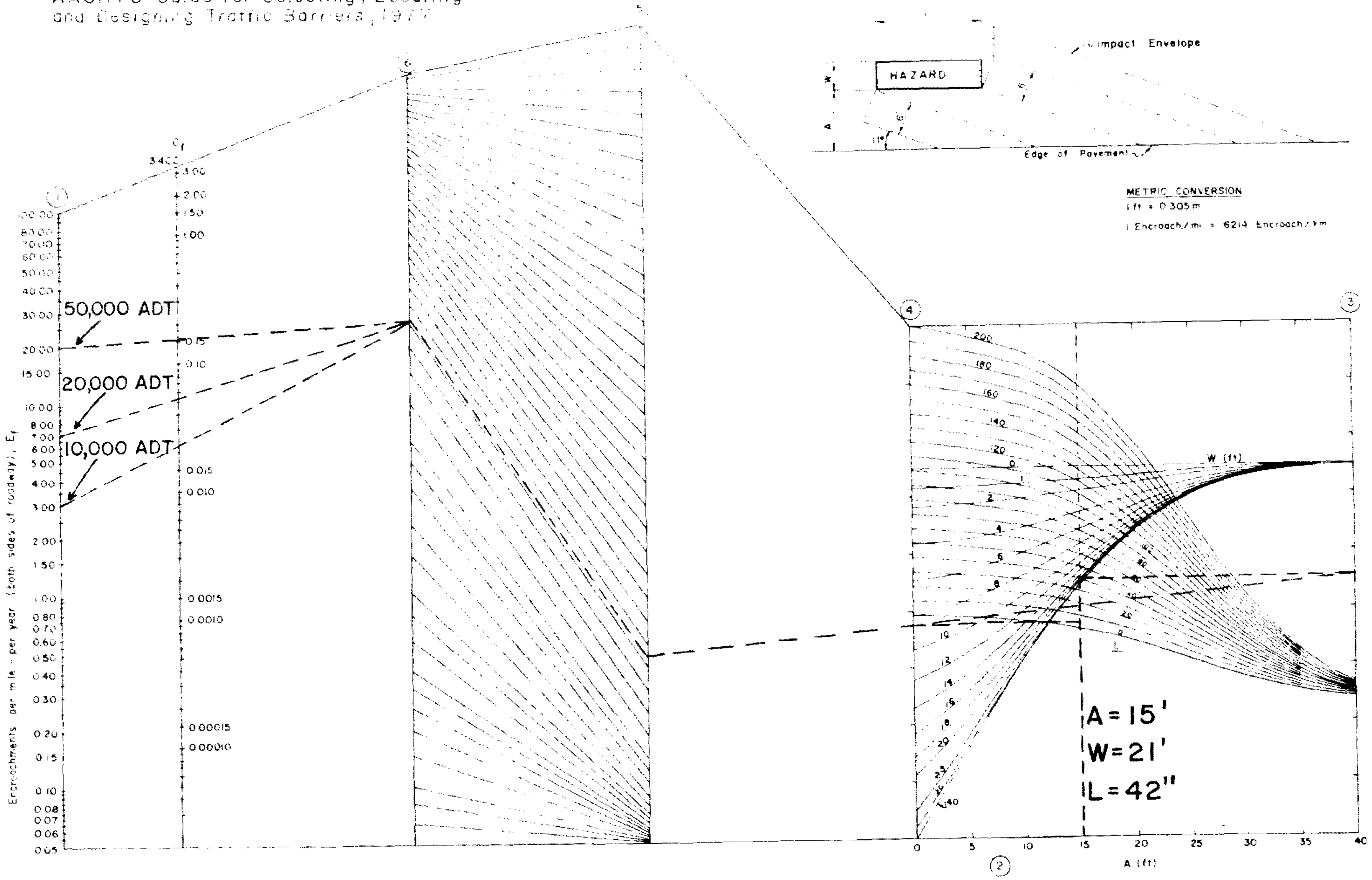
C_{TU} = Cost of unprotected fixed object

C_{TP} = Cost of protected fixed object

C_{TD} = Cost of installation of protected fixed object

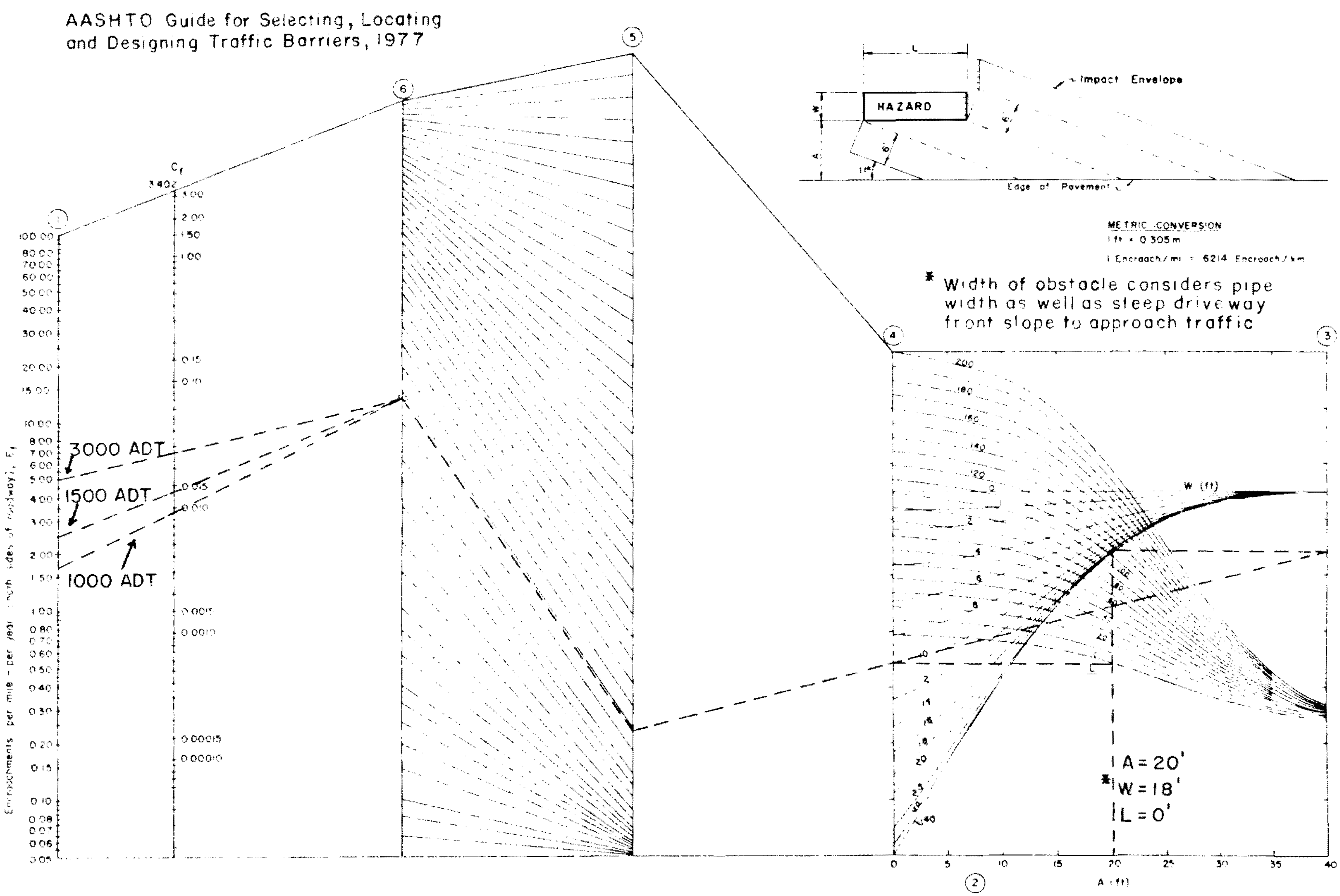
R = Benefit/cost ratio

AASHTO Guide for Selecting, Locating
and Designing Traffic Barriers, 1977



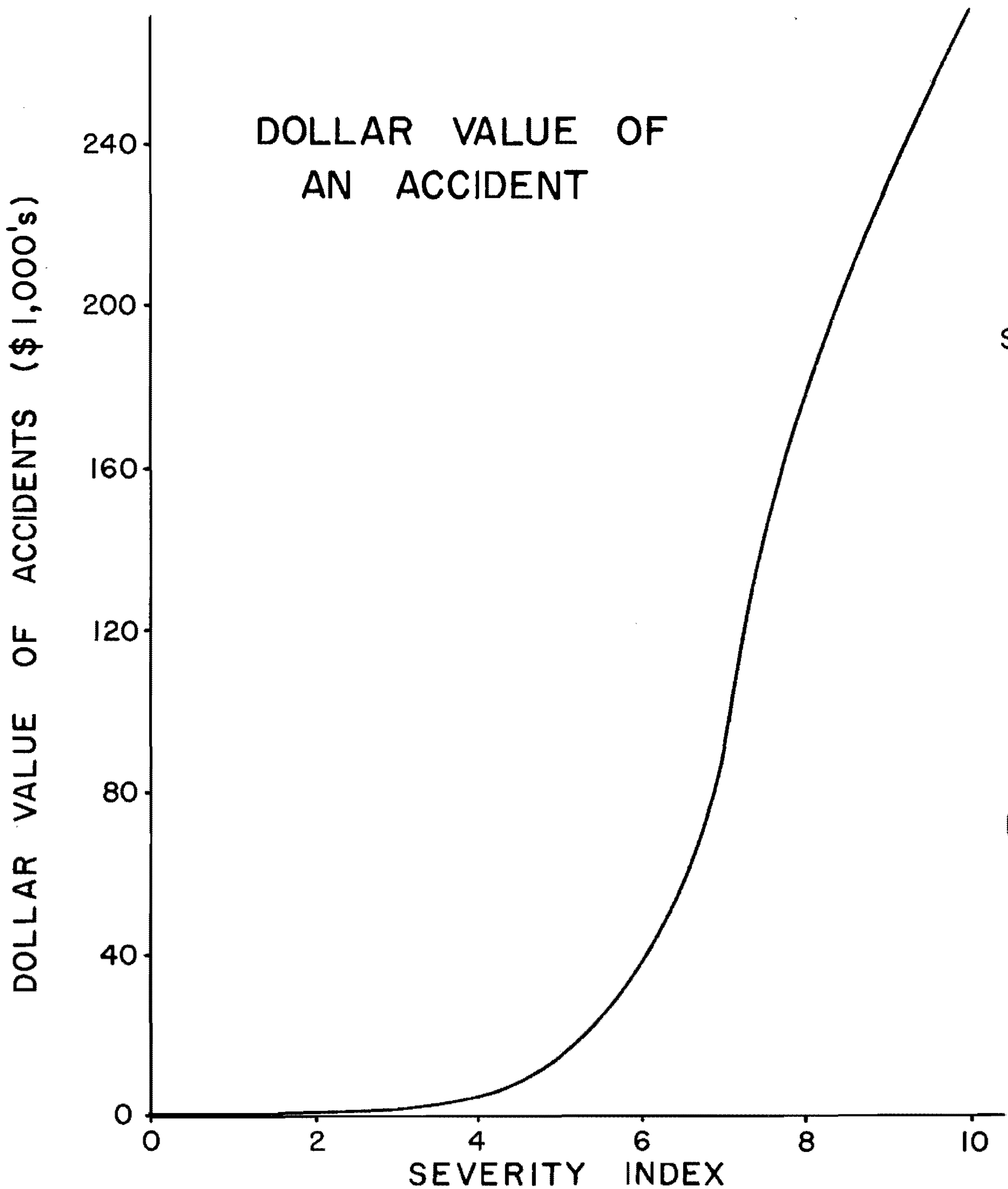
Collision Frequency Nomograph, Lengths from 0-200 Feet
Protected vs. Unprotected Cross-Drain Culvert
42" Diameter Pipe

EXHIBIT IV



Collision Frequency Nomograph, Lengths from 0 - 200 Feet
Driveway Culverts Collision Frequency
18" Diameter Pipe

EXHIBIT V



S.I.	ACCIDENT COST
0	$520
1	920
2	1,320
3	1,719
4	4,959
5	16,585
6	36,731
7	88,116
8	173,579
9	227,537
10	272,975

C_I = Initial cost of fixed object

C_D = Cost of damage through use

C_M = Cost of maintenance through use

C_{OVD} = Cost of accidents

C_S = Salvage value (cost)

C_F = Collision Frequency

K_T, K_F = Interest rates based on 20 year life @ 8%

FINDINGS

Cross Drain Culvert: Exhibit VI illustrates benefit/cost (B/C) values calculated for culvert sizes up to 60" in diameter for traffic densities through 50,000 vehicles per day. An interpretation of the B/C ratio is that a negative value and values less than "1" implies that no benefit is expected for the proposed enhancement. It is only when a B/C ratio of "1" is attained or exceeded that a "net" benefit is realized. For this analysis "unprotected" culvert installations assumed cross drain culverts without head walls and which are sloped to coincide with the side slope of the roadway. The "protected" culvert design assumed the same culvert with the addition of a bar grate.

B/C ratios for cross drain culverts indicated that no benefit is expected for a culvert protected by grates for culvert sizes through 42" in diameter on roads with traffic densities of 20,000 vehicles or less per day.

Driveway Culvert: Exhibit VII illustrates B/C values calculated for 18", 24" and 30" diameter driveway culverts for roadways having traffic densities between 1,000 and 3,000 vehicles per day. "Unprotected" culverts were considered to be circular corrugated metal pipes which do not have headwalls and have

EXHIBIT VI

CROSS-DRAIN CULVERT BENEFIT/COST COMPARISON TO ADT

WITH VS WITHOUT GRATES

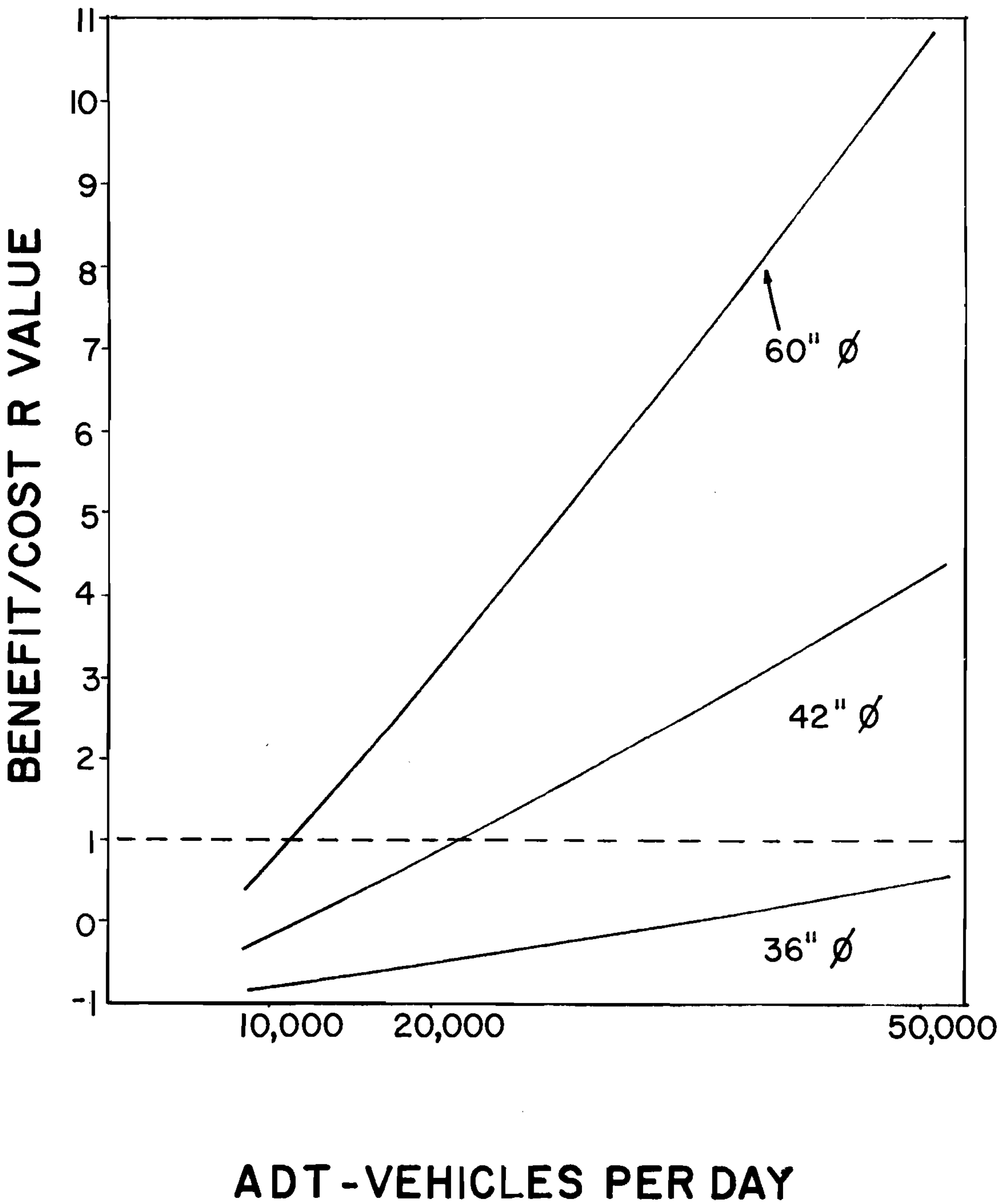
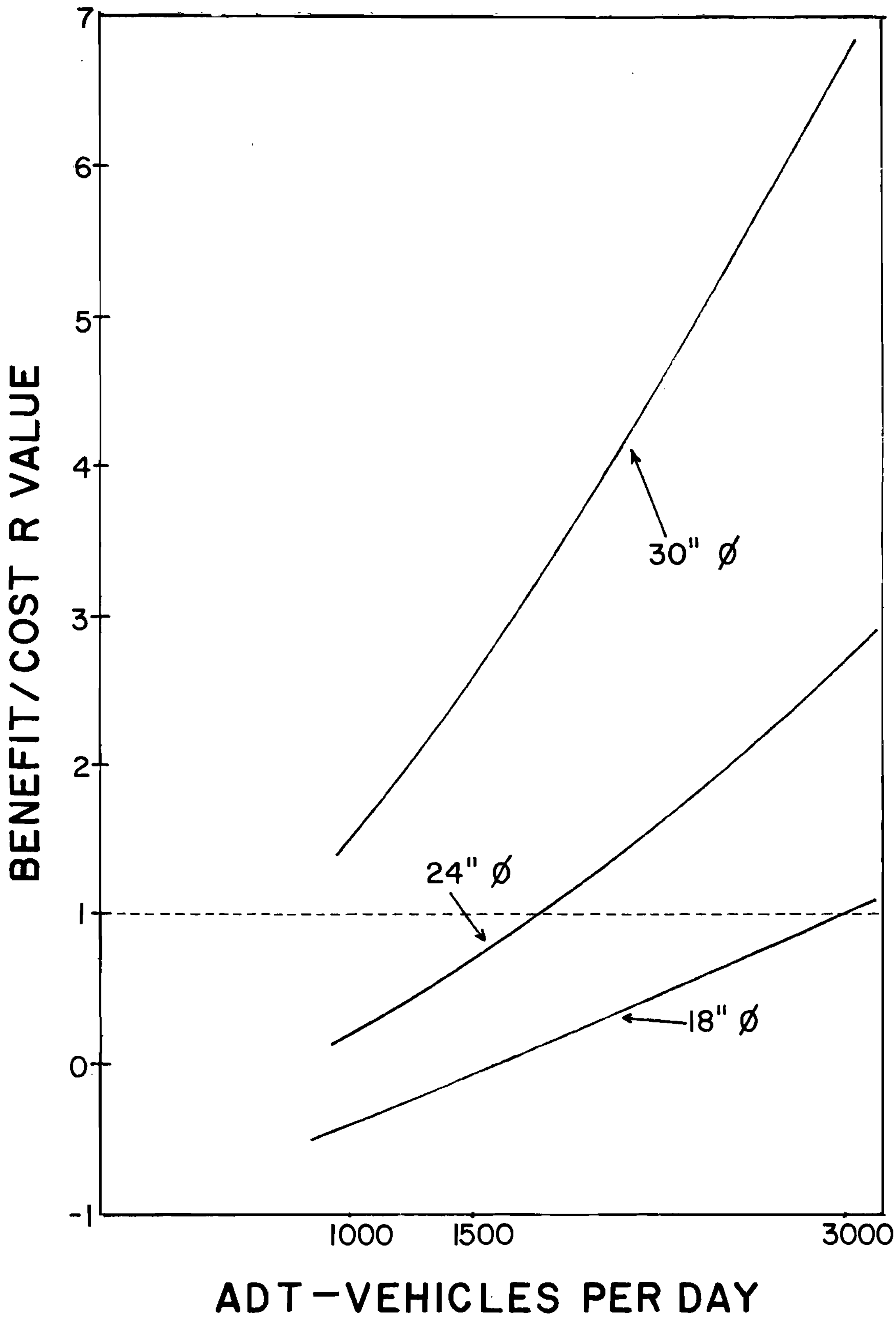


EXHIBIT VII

DRIVEWAY CULVERT BENEFIT/COST COMPARISON TO ADT

SLOPED VS VERTICAL ENDS



no special end treatments to the pipe. "Protected" culverts assumed a pipe which has a 6 to 1 tapered end which has been stabilized with concrete riprap. Neither corrugated arch pipe or concrete pipe were considered in this analysis due to their higher cost of modification compared to the circular pipe.

B/C ratios for the designs considered, indicate that for an 18" diameter pipe culvert a modified design is not cost effective through traffic densities of 3,000 vehicles per day. Similarly a 24" diameter culvert is cost effective only after 1,800 vehicles per day densities are reached. "A 30" culvert shows a B/C ratio of greater than "1" for all traffic densities."

Exhibit VIII illustrates a table of "Safety Benefit Counter Measures" as an example of some B/C ratios for roadway and roadside improvements on actual construction projects. It is noted with interest that many of the highest B/C ratio items are concerned with treatment to the driving surface or adjacent areas. It should be also emphasized that when improvements are being considered, that a B/C ratio is one of the several tools available to the designer to establish a priority of needed improvements to a facility. Crucial elements in any proposed improvement program must also be: (1) a consideration of available funds to achieve the needed program without curtailing essential roadway improvements elsewhere, and (2) the effect that such improvements will produce with respect to increased maintenance of a facility.

ONGOING RESEARCH

Research by the Department has been initiated into the relative hazards of culverts on highway design. A cooperative research study (Reference 8) is presently underway and is directed at producing answers to some of the fundamental questions concerning cross drain and driveway culvert installations. A full scale vehicle crash test program is presently

EXHIBIT VIII

SAFETY BENEFITS OF COUNTERMEASURES

Rank	Code	Improvement	Service Life	Number of Projects	Average Annual Accident Experience						Annual Percent Accident Reduction Expected			Benefit $ 1/	Cost/ Project	Benefit/Cost Ratio
					BEFORE			AFTER								
					Accidents	Injuries	Fatalities	Accidents	Injuries	Fatalities	Accidents	Injuries	Fatalities			
1	23	Shoulder widening or improvement	20	46	1,917	585	35	1,353	465	21	29	20	41	4,754,088	35,200	28.83
2	64	Installation of striping and/or delineators	4	2,000	5,849	3,351	113	5,060	2,599	60	13	20	46	17,493,150	1,094	26.49
3	25	Skid treatment/grooving	20	96	1,117	395	27	580	275	7	48	30	74	6,372,399	32,385	20.12
4	60	Installation or upgrading of traffic signs	4	775	3,727	1,538	80	2,879	1,038	23	23	33	27	8,031,275	2,278	15.03
5	57	Signing and/or marking	10	3,046	191	142	34	192	82	22	0	42	35	3,638,462	536	14.94
6	63	Installation or improvement of median barrier	10	23	962	479	48	994	449	4	-3	6	91	12,712,361	270,070	13.73
7	65	Roadway lighting installation	10	115	1,119	546	20	1,022	499	6	9	9	73	4,393,559	19,363	13.24
8	62	Installation or improvement of road edge guardrail	10	1,651	2,077	844	69	1,716	719	29	13	15	59	12,273,743	4,546	10.97
9	50	Flashing lights replacing signs only—railroad crossing	10	56	36	17	7	2	1	.06	94	93	99	2,014,682	25,655	9.41
10	60/64	Signs/striping combination	4	465	5,858	2,844	90	4,464	2,108	65	24	26	27	9,982,024	8,270	8.60
11	61	Breakaway signs or lighting supports	4	527	195	41	2	127	23	0	35	44	100	656,538	569	7.25
12	11	Traffic signals, installed or improved	10	699	9,408	4,181	87	7,698	2,840	43	18	32	49	17,688,205	26,650	6.36
13	26	Skid treatment/overlay	20	126	3,071	1,627	37	2,552	1,194	26	17	27	30	4,747,692	60,796	6.09
14	55	Automatic gates replacing signs only	10	101	43	17	11	0.2	0.03	0.2	99	99	100	3,100,704	37,872	5.44
15	10	Channelization, including left turn bays	10	612	5,815	2,618	83	4,481	1,860	30	23	29	65	17,982,781	50,091	3.94
16	20	Pavement widening, no lanes added	20	241	951	489	26	715	301	4	25	38	87	7,238,024	80,188	3.68
17	13	Sight distance improved	10	142	338	205	6	234	127	4	31	38	36	859,826	13,696	2.97
18	12	Combination of 10 and 11	10	36	887	333	1	609	215	0.5	31	35	50	620,449	64,846	1.78
19	56	Automatic gates replacing active devices	10	166	28	11	3	5	3	0.1	81	75	96	948,528	33,921	1.13
20	42	Combination of 40 and 41	20	69	423	219	6	332	150	2	21	32	69	1,350,900	211,055	0.91
21	31	Replacement of bridge or other major structures	30	163	113	84	5	63	33	0	44	60	47	1,548,658	118,475	0.90
22	21	Lanes added, without new median	20	96	1,482	595	7	1,224	531	5	17	11	31	900,544	114,987	0.80
23	30	Widening existing bridge or other major structures	20	354	565	291	3	198	76	2	65	74	33	1,103,632	75,440	0.41

1/ Computed according to Metric 7A.

*Evaluation of highway safety program standards within the purview of the Federal Highway Administration Final Report, 1977.

investigating the maximum spacing of bars on culvert grates to provide safety and minimum hydraulic disruption to the systems. Also scheduled for the 1979-80 fiscal year is a determination of safe and economical slopes to driveway culverts. The culmination of this research activity should enable the engineer a greater degree of confidence in the design of all future culvert installations.

SUMMARY AND CONCLUSION

Fundamental in any roadside design safety consideration, is that primary emphasis must be placed not on the roadside, but on the driving surface itself. Roadways should be constructed so that the motorist can achieve his transportation needs in safety and with confidence. Features off the travelway must assume a decidedly subordinate importance to those on roadway which features confront each and every motorist. The greater the distance the fixed object is from the travel way, the infrequency of its occurrence, and its small physical size, the less of a hazard that object becomes.

Investigations into the enhancement of culvert designs has first considered historical accident data on culvert accidents of all types. In a survey of six states and over 8000 accidents, accident rate involving culverts is reported to be 3.1% of roadside objects most commonly hit. In Texas, culvert accidents for 1978 of all types were 0.7% of total roadway accidents, 1.5% of the fatalities, 1.4% of the injuries, and 0.4% of the property damage. Historical accident data therefore, has indicated that the incidence of culvert related accidents of all types is a low frequency item.

Next, a societal cost comparison which weights each accident by the cost involved with fatalities, injuries and property damage, has indicated that for 1977, that culvert accidents represents 1.9% of the cost of all accidents occurring on Texas Highways. This theoretical cost also indicates that culvert accidents of all types to be a low cost item compared to all types of accidents.

Finally, a computation of the probable frequency of impact with cross drains and driveway culvert installations on typical roadways was made. Benefit/Cost comparisons indicate that cross drain culverts up to 42" in diameter would not exceed "1" for less than 20,000 vehicles per day. Similarly, driveway culverts do not exceed a B/C ratio of "1" for:

Culvert Size	Traffic Densities Vehicles per day
18"	through 3,000
24"	through 1,500

Therefore, due to the severe shortages of funds available for needed construction and maintenance, a program to slope ends of driveway culverts and to require grates on many cross drain culverts does not appear to be in the best interest of the traveling public. From the monetary as well as most importantly, functional standpoints, until ongoing research has established the relative significance of roadside culvert safety design relationships and has optimized safety improvements, it is suggested that the following recommendations concerning the design of culverts be utilized:

1. Defer any major design modifications to culvert end treatments not verified by research testing, other than removal of concrete headwalls, until scheduled research has been concluded. It is recommended that any design modification be based upon safety, traffic densities, costs, and hydraulic performance.*
2. Concentrate primary emphasis on providing optimum driving surfaces, shoulders and flat sideslopes to minimize accidental departures from the roadway.
3. Grates should not be required on cross drain culverts through 42" in diameter.

4. Locate driveway culverts as far from the travel way as practical.
5. Minimize cover on driveway culverts to reduce overall height of the obstacle to the motorist.
6. Recommend use of ditchline paved driveways without pipes wherever possible.

* see addendum for interim research findings

REFERENCES

1. Lynn, C., Attitudes of Virginians Toward Transportation Safety, Final Report, Virginia Highway and Transportation Research Council, 1979.

2. Foody, T. J., and Long, M. D., The Identification of Relationships Between Safety and Roadway Obstructions, Final Report, Ohio Department of Transportation, 1974.

3. Motor Vehicle Traffic Accidents, Texas Department of Public Safety, 1977.

4. Summary of all Reported Accidents in the State of Texas for Calendar Year 1978, Texas Department of Public Safety.

5. Hazardous Effects of Highway Features and Roadside Objects, Vol. 2, Findings, Federal Highway Administration, 1978.

6. Ricker, E. R. , et al, Evaluation of Highway Safety Program Standards Within the Purview of the Federal Highway Administration - Final Report, U. S. DOT, FHWA, March 1977.

7. Guide for Selecting, Locating and Designing Traffic Barriers, American Association of State Highway and Transportation Officials, 1977.

8. Safe End Treatment for Roadside Culverts, Study Number 2-8-79-280, Texas State Department of Highways and Public Transportation.

Appendix

Cross Drain Culverts
Protected vrs Unprotected

		ADT 10,000 VPD $E_f = 3.0$			ADT 20,000 VPD $E_f = 7.0$			ADT 50,000 VPD $E_f = 20.0$		
		36"φ	42"φ	60"φ	36"φ	42"φ	60"φ	36"φ	42"φ	60"φ
C_I	protected	$400	$500	$600	$400	$500	$600	$400	$500	$600
C_f		0.022	0.0225	0.023	0.051	0.053	0.055	0.16	0.165	0.17
SI	unprotected	3.0	4.0	4.5	3.0	4.0	4.5	3.0	4.0	4.5
C_{OVD}	"	1719	4959	10,772	1719	4959	10,772	1719	4959	10772
S.I.	protected	0	0	0	0	0	0	0	0	0
C_{OVD}	protected	520	520	520	520	520	520	520	520	520
C_{TU}	unprotected	371	1095	2432	861	2580	5817	2700	8033	17979
C_{TP}	protected	1280	1384	1486	1450	1562	1673	2087	2215	2345
C_{TD}	"	1168	1269	1369	1190	1291	1392	1270	1373	1677
R		(-0.8)	(-0.2)	0.7	(-0.5)	0.8	3.0	0.5	4.2	10.6

* $C_S(K_f)$ assumed to be an expense at end of useful life

SAMPLE CALCULATIONS:

36"φ 10,000 VPD

UNPROTECTED:

$$C_{TU} = C_I + C_D(C_f)(K_T) + C_M(K_T) + (C_{OVD})(C_f)(K_T) - C_S(K_f)^{*}$$
$$= 0 + 0 + 0 + (1719)(0.022)(9.818) + 0$$
$$= \$371$$

PROTECTED

$$C_{TP} = 400 + (75)(0.022)(9.818) + (75)(9.818) + (520)(0.022)(9.818) + 75(0.2145)$$
$$= 400 + 16 + 736 + 112 + 16$$
$$= \$1280$$

$$C_{TD} = 400 + 16 + 736 + 16$$
$$= \$1168$$

$$R = \frac{371 - 1280}{1168}$$
$$= (-0.8)$$

36"φ 20000 VPD

$$C_{TU} = (1719)(0.051)(9.818)$$
$$= \$861$$

$$C_{TP} = 400 + 75(0.051)(9.818) + 736 + (520)(0.051)(9.818) + (75)(0.2145)$$
$$= 400 + 38 + 736 + 260 + 16$$
$$= \$1450$$

$$C_{TD} = 400 + 38 + 736 + 16$$
$$= \$1190$$

$$R = \frac{861 - 1450}{1190}$$
$$= -0.5$$

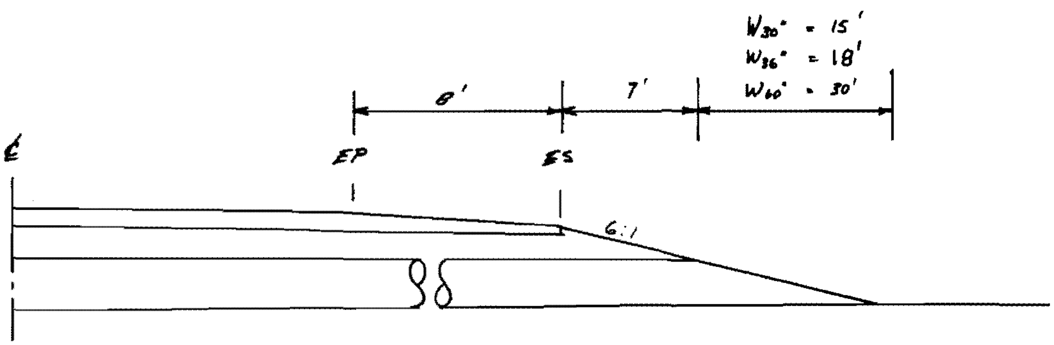
36"φ 50,000 VPD

$$C_{TU} = (1719)(0.16)(9.818)$$
$$= \$2700$$

$$C_{TP} = 400 + (75)(0.16)(9.818) + (75)(9.818) + (520)(0.16)(9.818) + (75)(0.2145)$$
$$= 400 + 118 + 736 + 817 + 16$$
$$= \$2087$$

$$C_{TD} = 400 + 118 + 736 + 16$$
$$= \$1270$$

$$R = \frac{2700 - 2087}{1270}$$
$$= 0.5$$



Driveway Culverts
Protected Vrs. Unprotected
Benefit/Cost Comparison

	ADT 1000 VPD, E_f = 1.6, Culvert Sizes 18"Ø	24"Ø	30"Ø	ADT 1500 VPD, E_f = 2.5, Culvert Sizes 18"Ø	24"Ø	30"Ø	ADT 3000 VPD, E_f = 5.1, Culvert Sizes 18"Ø	24"Ø	30"Ø
C_f		0.009			0.013			0.028	
SI unprotected	4.0	4.5	5.5	4.0	4.5	5.5	4.0	4.5	5.5
C_{OVD} "	4959	10772	26,658	4959	10,772	26,658	4959	10,772	26,658
SI protected	3.0	3.5	4.0	3.0	3.5	4.0	3.0	3.5	4.0
C_{OVD} "	1719	3339	4959	1719	3339	4959	1719	3339	4959
C_{TU} unprotected	438	952	2356	633	1375	3402	1363	2961	7328
C_{TP} protected	593	846	1209	660	977	1404	914	1469	2134
C_{TD}	441	551	771	441	551	771	441	551	771
R	(-0.4)	0.2	1.5	(-0.06)	0.7	2.6	1.0	2.7	6.7

	18"Ø	24"Ø	30"Ø
C_I** protected	$210	$266	$376

** computations assume two treatments, upstream and downstream, at each location.

* $C_S(K_f)$ assumed to be an expense at end of useful life

SAMPLE CALCULATIONS:

18"Ø 1000 VPD

UNPROTECTED:

$$C_{TU} = C_I + C_D(C_f)(K_T) + C_M(K_T) + C_{OVD}(C_f)(K_T) - C_S(K_f)^{*}$$
$$= 0 + 0 + 0 + (4959)(0.009)(9.818) + 0$$
$$= \$438$$

PROTECTED:

$$C_{TP} = \$420 + 0 + 0 + (1719)(0.009)(9.818) + 100(0.2145)$$
$$= 420 + 152 + 21$$
$$= \$593$$

$$C_{TD} = C_I + C_D(C_f)(K_T) + C_M(K_T) - C_S(K_f)$$
$$= 420 + 0 + 0 + 21$$
$$= \$441$$

$$R = \frac{C_{TU} - C_{TP}}{C_{TD}}$$
$$= \frac{438 - 593}{441}$$
$$= (-0.4)$$

18"Ø 1500 VPD

$$C_{TU} = (4959)(0.013)(9.818)$$
$$= \$633$$

$$C_{TP} = 420 + (1719)(0.013)(9.818) + 21$$
$$= \$660$$

$$C_{TD} = 441$$

$$R = \frac{633 - 660}{441}$$
$$= (-0.06)$$

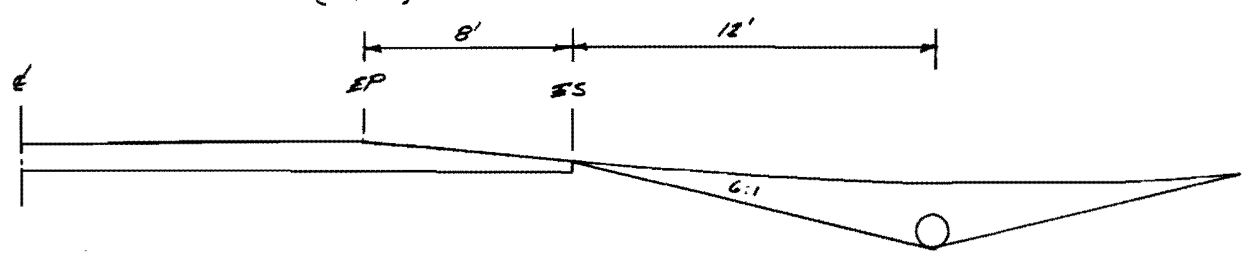
18"Ø 3000 VPD

$$C_{TU} = (4959)(0.028)(9.818)$$
$$= \$1363$$

$$C_{TP} = 420 + (1719)(0.028)(9.818) + 21$$
$$= \$914$$

$$C_{TD} = 441$$

$$R = \frac{1363 - 914}{441}$$
$$= 1.0$$



Addendum

Interum research findings on grate bar spacing on cross drain culverts conducted under the Texas State Department of Highways and Public Transportation cooperative research program 2-8-79-280 has indicated that single pipe cross drain culverts 36" in diameter or less do not require grates and for larger than 36" a grate bar spacing up to 2'6" may be safely used. Implementation of this finding on Texas highways was initiated on November 11, 1979, by the following Administrative Circular No. 77-79:

Texas Highway Department

ADMINISTRATIVE CIRCULAR NO. 77-79

To:	DISTRICT ENGINEERS, DIVISION HEADS, AND ENGINEER-MANAGER	Date:	November 7, 1979
Subject:	Improving Safety of Drainage Facilities	Expires:	
Reference:	Administrative Circular (A.C.) 8-79	File:	D-8, D-5

Gentlemen:

Guidelines for improving safety of drainage facilities were transmitted by Administrative Circular 8-79 dated January 26, 1979. The guidelines addressed the clear zone concept, cross drainage culverts, side ditch configurations, and culverts for parallel drainage.

Crash tests have been performed recently to evaluate the safety aspects of cross drainage culverts, that is, those culverts that handle drainage beneath the travel lanes. Based on the results of these low and high speed tests, that portion of A.C. 8-79 pertaining to cross drainage culverts is revised as follows:

Paragraph 4. - Clear zone requirements do not apply to single cross drainage pipes which are 36 inches or less in diameter; the 24-inch maximum diameter shown in A.C. 8-79 is superseded.

Paragraph 5. - The drawing showing a typical grate for cross drainage has been revised and the attached version replaces the Figure transmitted with A.C. 8-79. The vertical 1'6" drop at the end of the grate has been eliminated, and the maximum spacing of the grate members has been increased from 1'3" to 2'6" center to center.

Other parts of the cross drainage section and the remaining portions of A.C. 8-79 have not been changed.

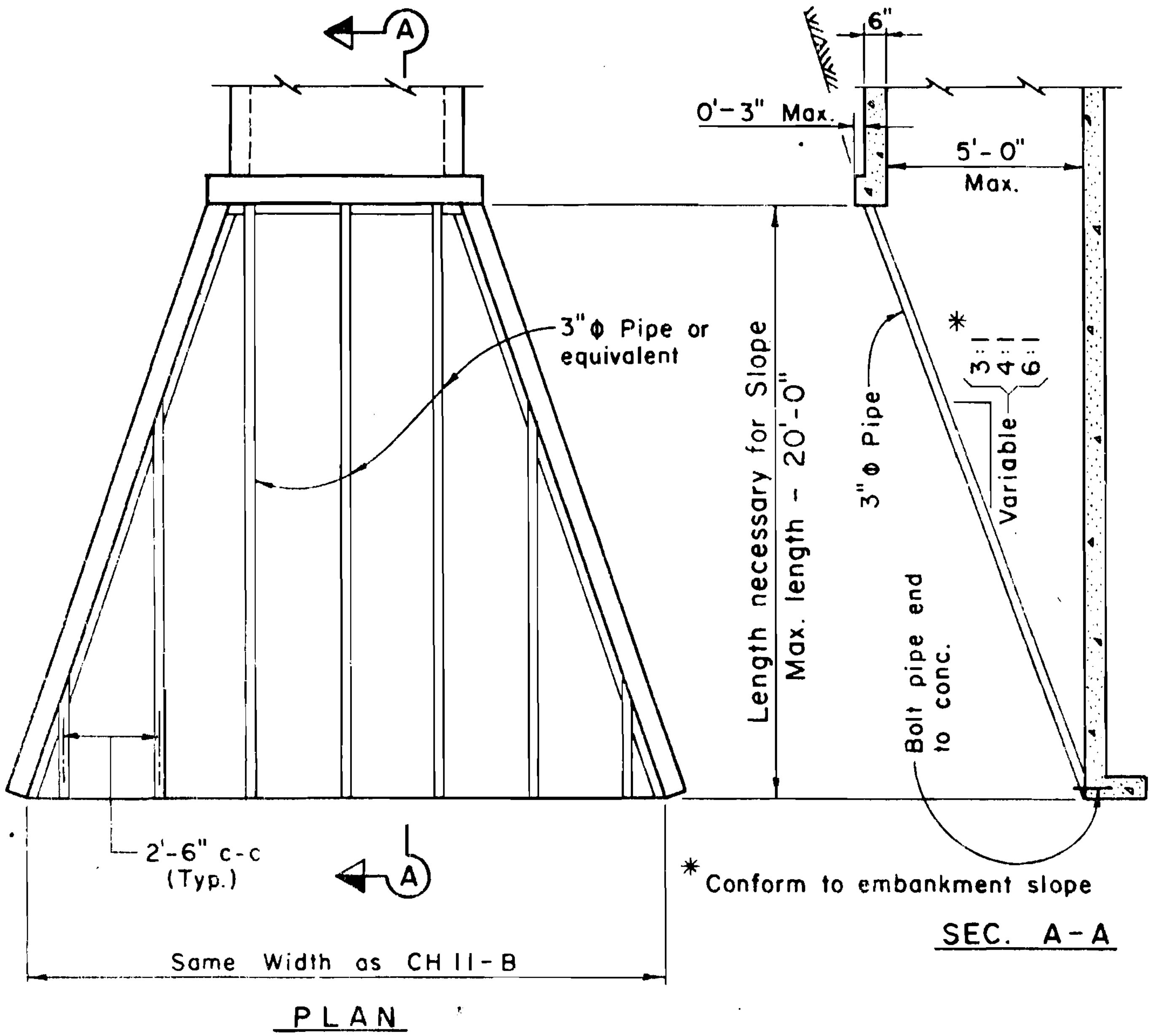
For your information, an analysis of the effect of grates on hydraulic performance and an evaluation of safety treatment for driveway and side road pipes will be performed through the research program. As results become available, further changes in the guidelines transmitted by A.C. 8-79 may become appropriate.

Sincerely yours,

B. L. DeBerry
B. L. DeBerry
Engineer-Director

Attachment

DISTRIBUTION:
District Engineers
Engineer-Manager
Division Heads
Resident Engineers



SAFETY GRATES FOR PIPE AND BOX CULVERTS

CROSS DRAINAGE STRUCTURES ONLY

NOTES:

1. For heights up to 5' use 3" ϕ pipe or equivalent. (Maintain 2'-6" c-c).
2. No cross members are required.
3. Grate members shall be parallel to direction of flow.
4. Do not use grate for pipe or box culvert over 5' in height. Heights of culverts greater than 5' cause the end treatment to be excessively long and costly.
5. Do not use grates when skew exceeds 15°.

Rev: Sept. 1979

STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION

Wilson F
File: AP
AC: F/H.

ADMINISTRATIVE CIRCULAR NO. 8-79

To: DISTRICT ENGINEERS, DIVISION HEADS, AND ENGINEER-MANAGER

Date: January 26, 1979

Subject: Improving Safety of Drainage Facilities

Expires:

Reference:

File: D-8, D-5

Gentlemen:

Departmental design policy has emphasized for several years the desirability and need for providing a roadside area free of fixed objects to reduce the severity of run-off-the-road accidents. As evidence of this emphasis, designs include obstruction clearance zones with width depending on traffic volume. Fixed objects which are impractical to remove or relocate from the clear zone are neutralized with breakaway or crash cushioning devices, shielded with barriers, or otherwise designed so as to be traversable by an errant vehicle. For drainage structures, Administrative Circular No. 51-70, dated May 12, 1970, was issued to provide guidelines for drainage structure design for improved safety.

Field reviews of recently constructed projects indicate that high roadway design standards are being used, and that safety devices and the clear recovery area concept are being applied in the Department's designs. There were instances, however, where minor adjustments in the treatment or location of an appurtenance would provide an even safer roadside. Drainage facilities are common appurtenances which frequently were found improvable in that fine tuning of design would improve safety.

In designing drainage systems, the primary objective, of course, is to properly accommodate surface run-off along and across highway right-of-way through the application of sound hydraulic principles. More consideration must be given to a second, important goal of incorporating safety into the design of drainage appurtenances. The best design would efficiently accommodate drainage and be traversable by an out-of-control vehicle without rollover or abrupt change in speed. The attached guidelines are intended to improve roadside safety with respect to drainage facilities, and generally supplement and expand previously issued material. Where there are conflicts (specifically, Item 4, A.C. No. 51-70), the attached guidelines supersede and replace previously issued guidelines.

All guidelines contained in this Circular are appropriate for immediate design implementation. P.S.& E. should be prepared, or revised where applicable, to reflect these criteria. These guidelines apply to all rural, high speed facilities and other facilities where posted speed limit will be 40 mph or more.

Sincerely yours,

B. L. DeBerry

B. L. DeBerry
Engineer-Director

Attachments

DISTRIBUTION:
District Engineers
Engineer-Manager
Division Heads
Resident Engineers

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IMPROVING SAFETY OF DRAINAGE FACILITIES

The Clear Zone Concept

For major reconstruction and new alignment projects on high speed facilities without full control of access, obstruction clearance zone criteria have been established. Clear zone width varies with traffic volume as shown in Figure 4-15A, page 4-31B, of the Highway Design Division Operations and Procedures Manual and as tabulated below:

Average Daily Design Life Traffic (vpd)	Clear Zone Width (Ft.) Minimum	Clear Zone Width (Ft.) Desirable
0 - 250*	0	7
0 - 750	7	16
750 - 1500	16	30
1500 or more	30	--

* Applies only to Farm and Ranch to Market Roads.

In applying these criteria, "Average Daily Design Life Traffic" is the average of current and design year ADT volumes.

For minor reconstruction projects, i.e., those projects where existing alignment and slopes are fundamentally retained, separate criteria are shown in Figure 4-15B, page 4-31C, of the Manual.

For drainage facilities, the designer's primary goal is to effectively and efficiently accommodate surface run-off along and across highway right-of-way. A second important goal is the incorporation of safety into the design of drainage facilities. To meet safety needs, the designer may (1) design or treat the drainage appurtenance so that it will be traversable by a vehicle without abrupt change in speed or rollover; (2) locate the appurtenances a sufficient distance, consistent with traffic volume, from the travel lanes so as to reduce the likelihood of accidental collision; or (3) protect the driver through installation of guard fence when neither (1) nor (2) is feasible.

To improve the traversable aspects of drainage facility design, the following guidelines are applicable.

Culverts at Median Crossovers, Side Roads, and Driveways

The inlet-outlet points of culverts under median crossovers, side roads, and driveways are common, potential hazards. Flow quantities for these longitudinal drainage situations are generally small with drainage typically accommodated by a single pipe. The following design guidelines apply to these drainage appurtenances:

1. There should be no culvert headwalls or vertical ends (except as described in Item 2 below) on pipes.

2. Pipe ends should be sloped at 6:1 or flatter with riprap added where required to prevent erosion and/or to protect the end of pipe. The sloping end may be terminated and a vertical end introduced when the partial pipe section height is six inches or less (see attached sketch).

3. Median crossover, side road, or driveway embankment slope should be 6:1 maximum, with 8:1 preferred, within the clear zone.

4. Where large (greater than 30 inches in diameter) pipe ends are located within the clear zone, grates should be provided with maximum slope of 6:1 or a preferred slope of 8:1. Grates are not required on single, small (30 inches or less diameter) pipes regardless of end location with respect to clear zone requirements; however, the ends of small pipes should be sloped and rip-rapped as described in Item 2 above.

5. The use of paved dips, instead of pipes, is encouraged, particularly at infrequently used driveways such as those to fields.

6. For unusual situations, such as where driveways are on high fills or where box culverts or multiple pipes are necessary to accommodate side or median ditch drainage, the designer should consider the alternatives available and select an appropriate design.

Cross Drainage Culverts

For culverts handling drainage under the travel lanes, potential hazard lies at or near the inlet-outlet points. For cross drainage structures, design recommendations are as follow:

1. No protruding headwalls should be used.

2. Guard fence protection may be appropriate for large drainage structures, particularly those which are bridge class (length 20 feet or more). For smaller than bridge class drainage structures, guard fence protection is not a desirable method of treatment, and other treatments are preferred where practical.

3. Locating culvert ends to meet clear zone requirements is an acceptable safety treatment for a range of culvert sizes. Desirable, rather than minimum, values for clear zone width should be used where feasible.

4. Clear zone requirements do not apply to single, small (24-inch diameter or less) cross drainage pipes. In such instances, pipe ends may be located inside the clear zone at the side slope-pipe intercept. Riprap should be added to the sloped pipe end to prevent erosion. Pipe end slope should be 3:1 or flatter and typically would match side slope rate.

5. The use of grates as a solution for treating unsafe culvert ends is discouraged for cross-drainage structures. However, special grates as shown on the attached drawing will be allowed under the following guidelines:

    a. A design consideration for the use of grates on cross drainage structures shall include an evaluation of the proposed grate in a completely clogged condition. Grates in this condition shall not be the cause of flooding that would produce significant damage to either the highway or any other property. If the clogged condition causes the highway to be inundated, evaluate the hazards to, and the interruption of, the traveling public based upon the depth, velocity, and duration of flooding, and sight distance. If damage is anticipated to the traveling public, the highway facilities, or other property, grates will not be acceptable.

b. Grates should be considered only where the cross sectional characteristics of the cross drainage channel are such that an out-of-control vehicle can be reasonably expected to safely (without rollover or abrupt stop) traverse the open exposed channel near the culvert end.

c. If, after the above considerations, grates are deemed acceptable, the cross drainage structure to receive the grates shall be increased in area to at least 1.5 times the area required by standard hydraulic design procedures. This is intended to compensate for loss of hydraulic performance by the culvert due to addition of the grate.

d. The configuration of the grate shall conform to the general configuration as shown on the attached drawing. District personnel shall modify existing flared wingwall standards to receive the type of grate shown. The height of the culvert for which grates are to be proposed is limited to five feet and the maximum skew will be 15°.

Research will be initiated to evaluate the safety and the hydraulics of end treatments for cross-drainage structures, whereupon standards will be issued. The Districts are discouraged from developing extensive details based upon these guidelines.

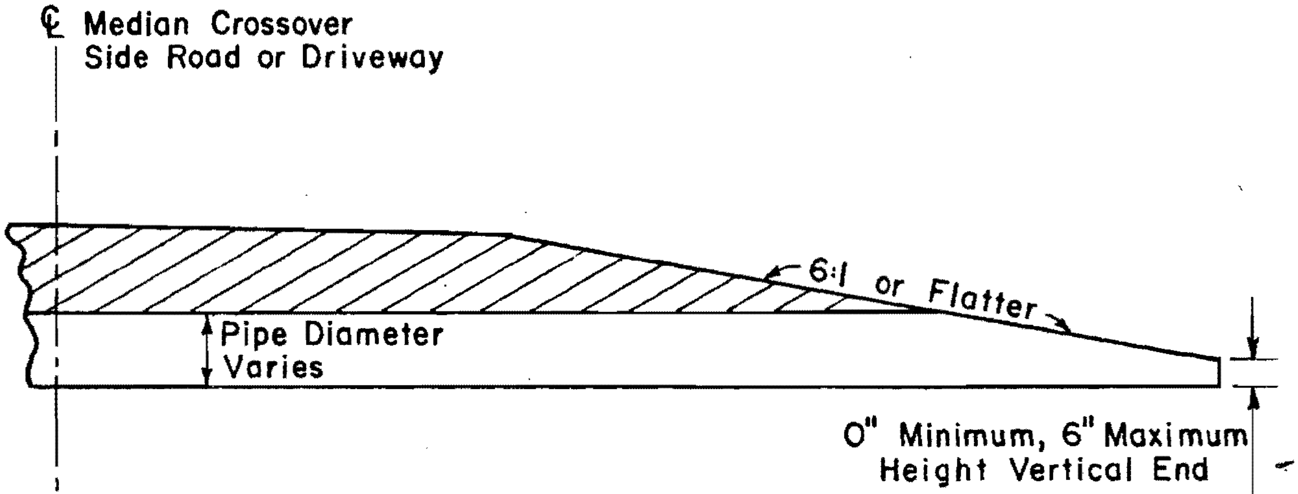
Side Ditches

For side ditches, attention to cross section design can reduce the likelihood of serious injuries during vehicular encroachments. In this regard, ditches with the following cross sectional characteristics are preferred and should especially be sought when ditch location is within the clear zone.

	Preferred Maximum Back Slope*	
Given Front Slope*	Vee-Shaped	Trapezoidal Shaped
8:1	3.5:1	2.5:1
6:1	4:1	3:1
4:1	6:1	4:1
3:1	Level	8:1

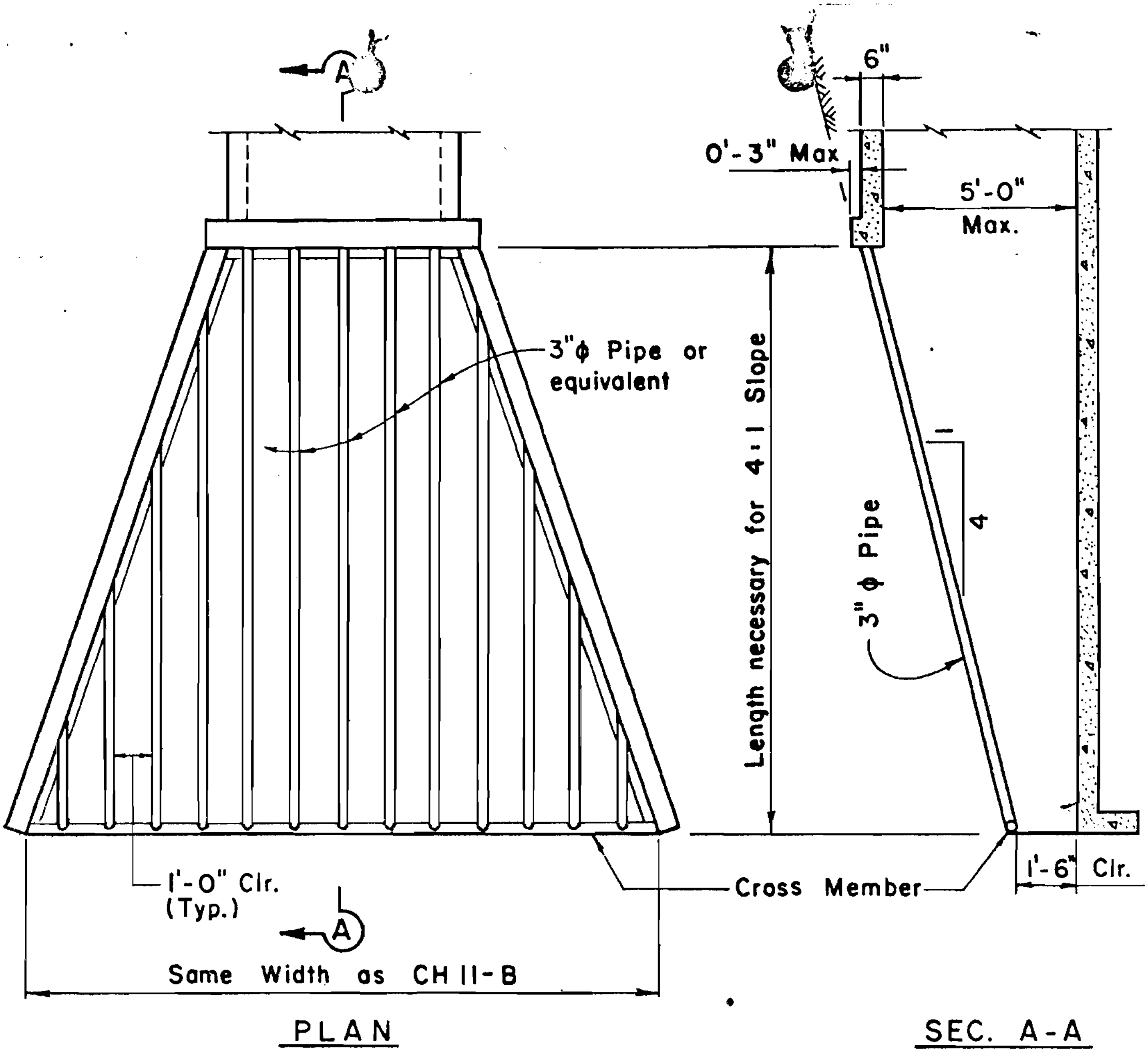
* Horizontal: Vertical

Ditches which include retards to control erosion should be avoided inside the clear zone and should be located as far from the travel lanes as practical. Non-traversable catch or stilling basins should also be located outside the clear zone.



TYPICAL CROSS SECTION

MEDIAN CROSSOVER,
SIDE ROAD, OR DRIVEWAY PIPES



SAFETY GRATES FOR PIPE AND BOX CULVERTS

Notes:

1. For heights up to 5' use 3"ϕ pipe or equivalent (Maintain 1'-0" CLEAR).
2. No cross members are required except for end support.
3. Grate members shall be parallel to direction of flow.
4. Do not use grate for pipe or box culvert over 5' in height.
5. If multiple boxes or pipes are used, add pipe column supports under the end cross member at points opposite the interior walls for boxes and at points midway between each pipe. Do not extend the interior walls of the box.
6. Do not use grates when skew exceeds 15°.